Migration-velocity analysis using image-space generalized wavefields

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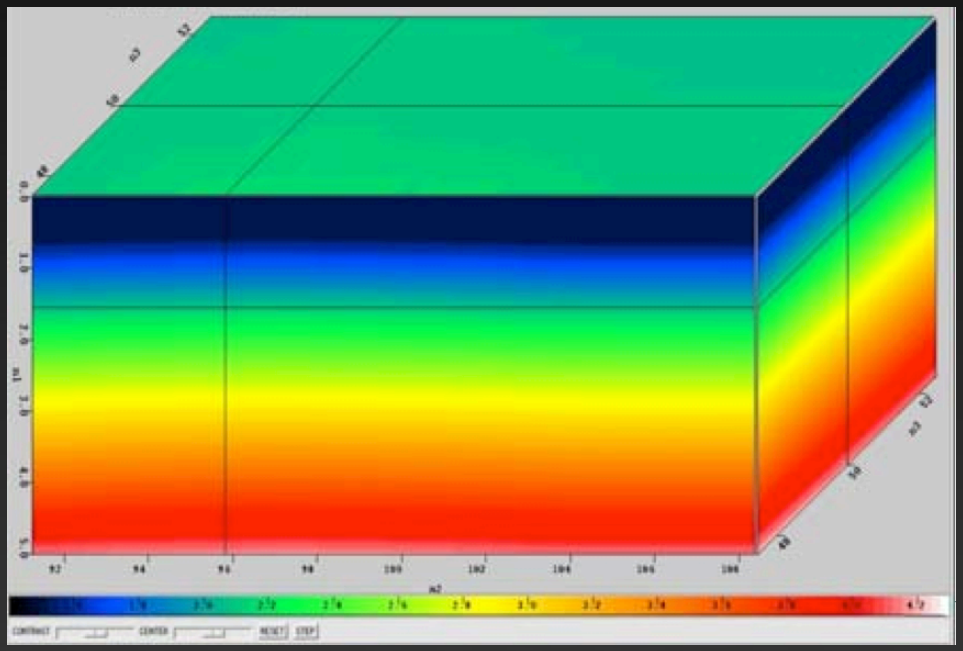
Research Review
Jun 2010

For complex geology ...

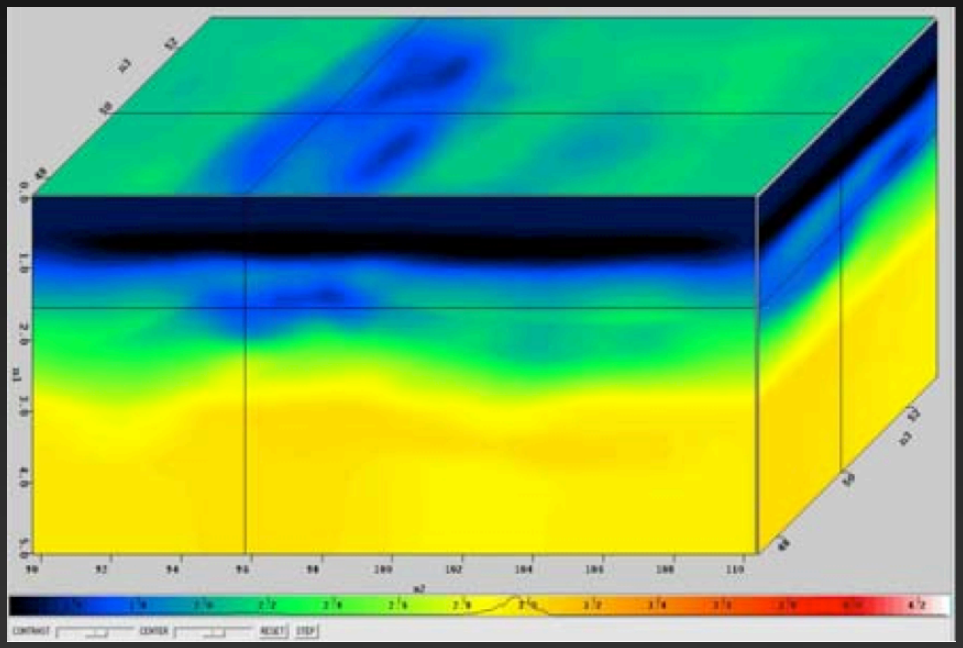
Image-space wave-equation tomography (ISWET) is theoretically more robust than ray-based methods

However ...

- **ISWET has rarely been applied in 3D**
  - **High cost and lower flexibility than ray-based methods**



Initial velocity

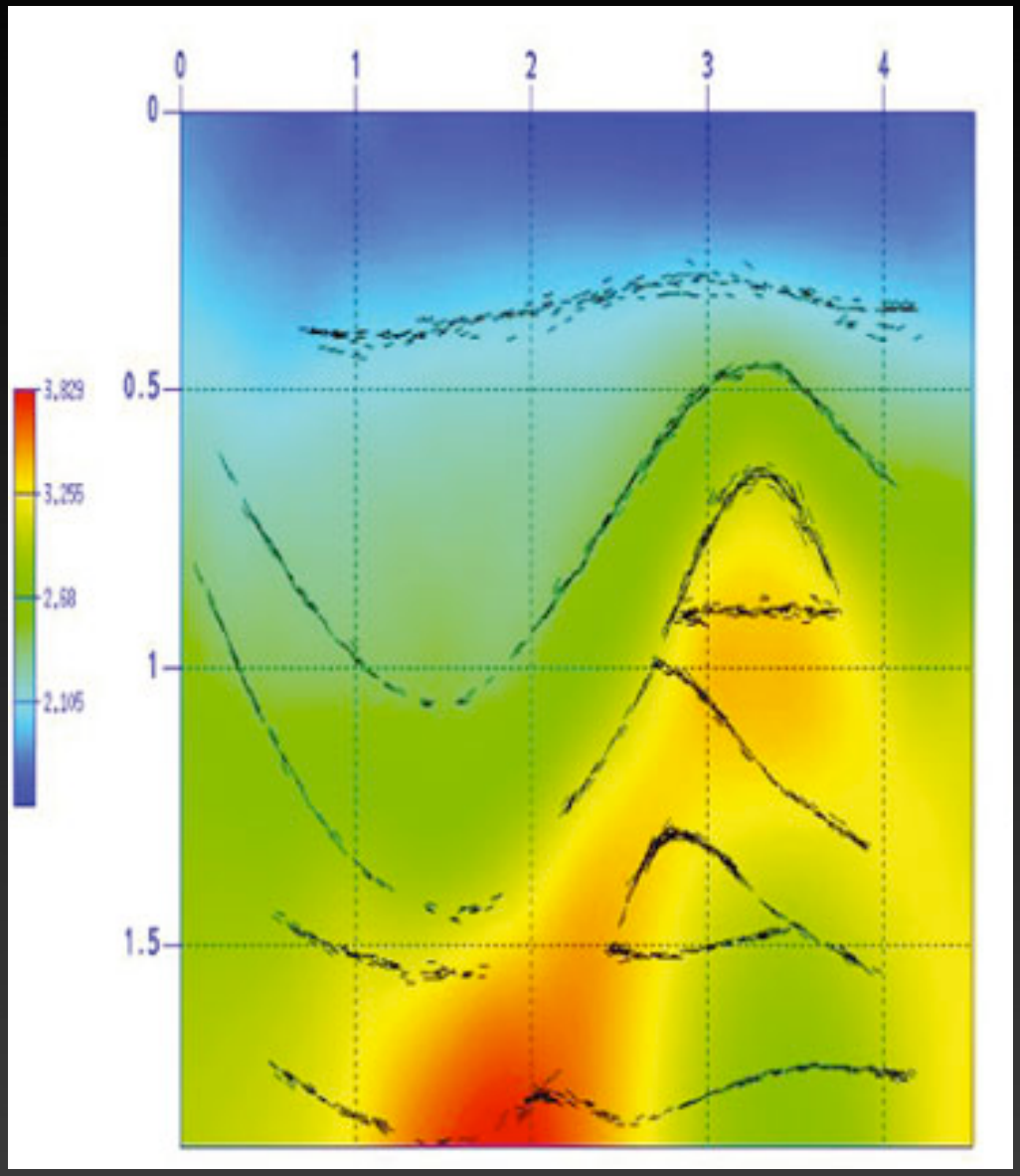


Final velocity

Fei et al., 2009

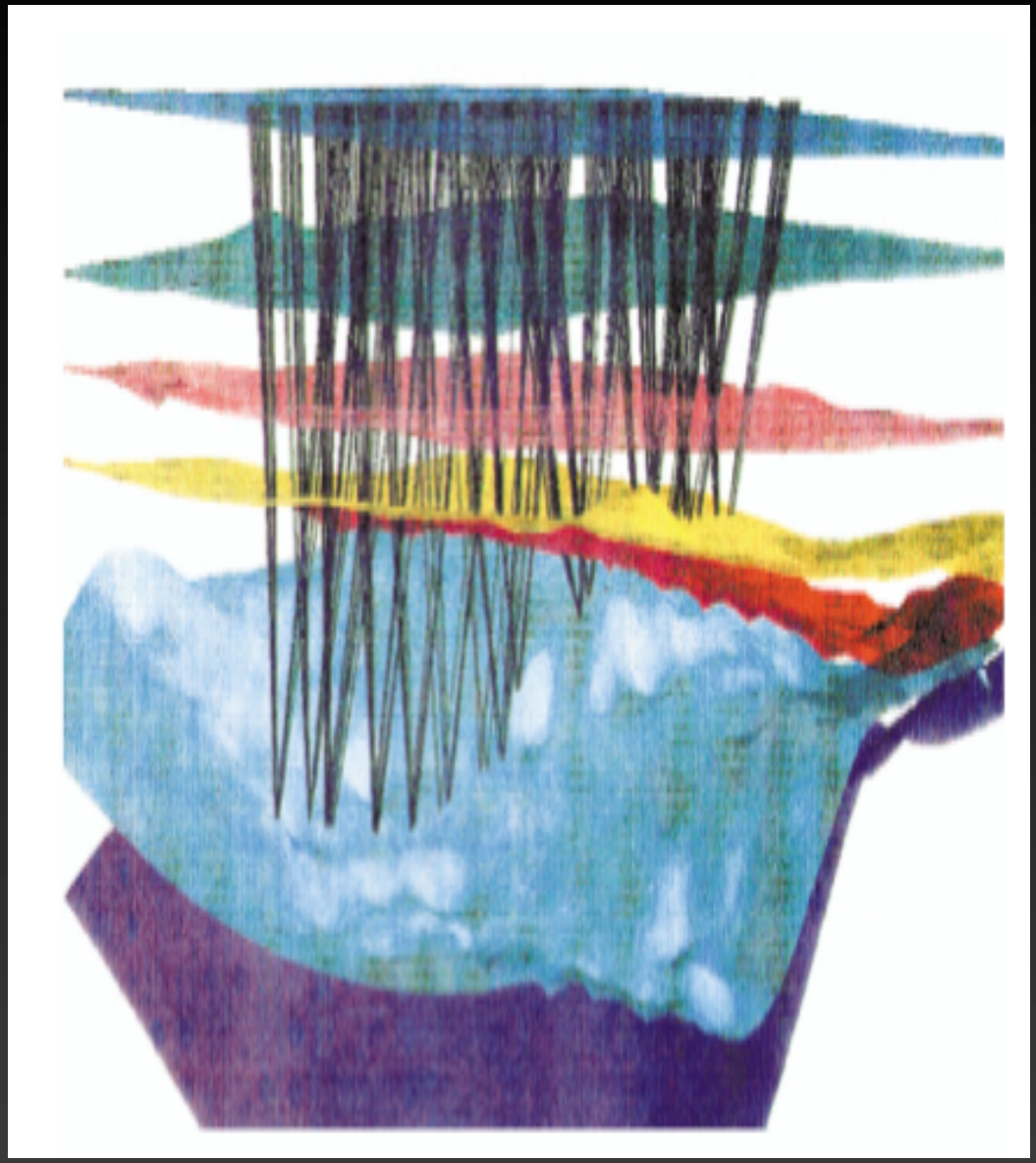
Ray-based strategies

Grid-based



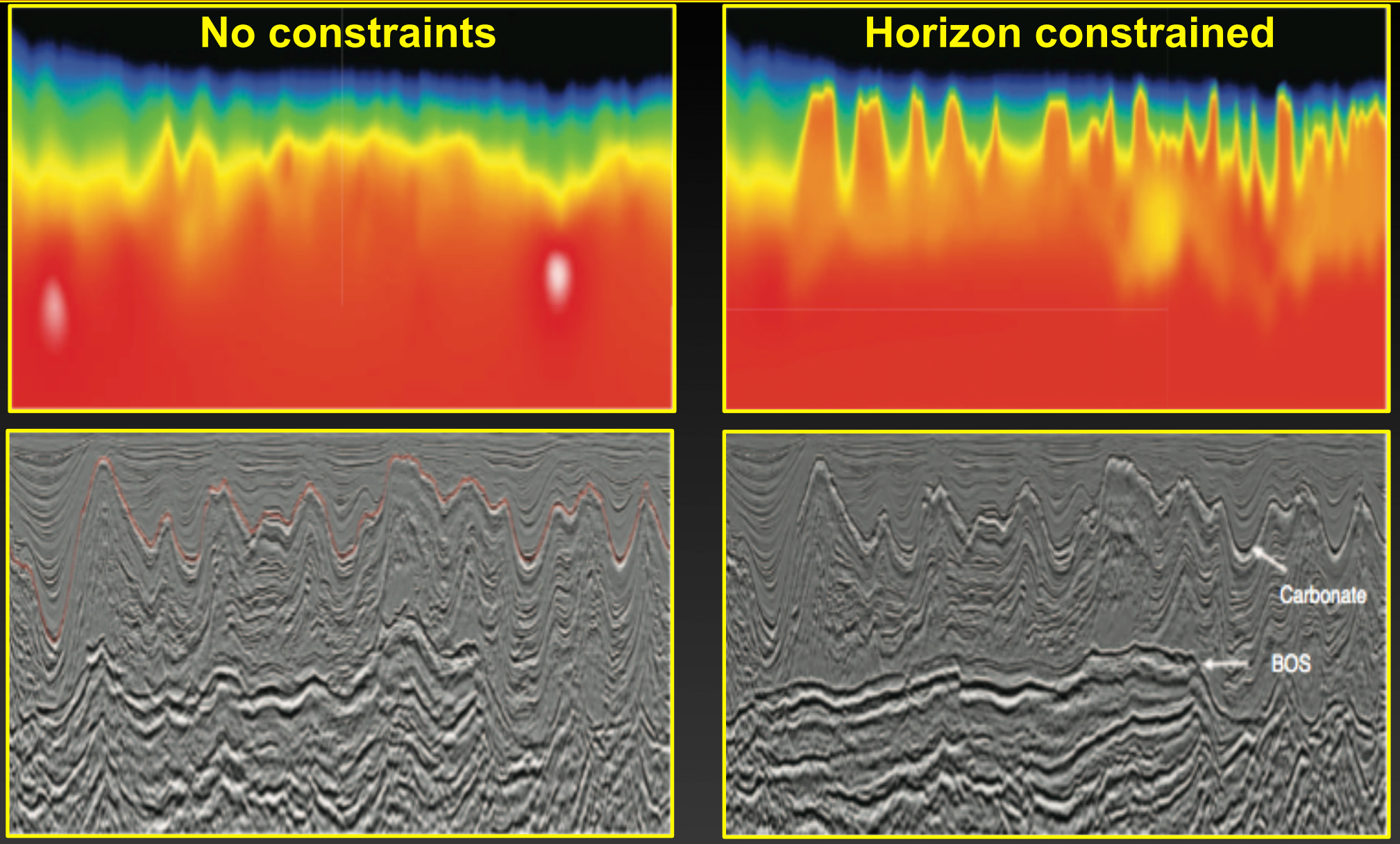
www.sintef.no

Horizon-based



Jones et al., 1998

Hybrid tomography



Wang et al., 2008

3D-ISWET as routine processing

- **Reduce cost**

3D-ISWET as routine processing

- **Reduce cost**
- **Improve flexibility**

3D-ISWET as routine processing

- **Reduce cost**
- **Improve flexibility**
- **Keep robustness**

Reducing 3D-ISWET cost

- **Decrease data size**

Reducing 3D-ISWET cost

- **Decrease data size**

- **Solve in a target-oriented manner**
  - **Wavefield propagation restricted to the inaccurate velocity region**

Improving 3D-ISWET flexibility

- **Incorporate strategies from ray-based methods into ISWET**

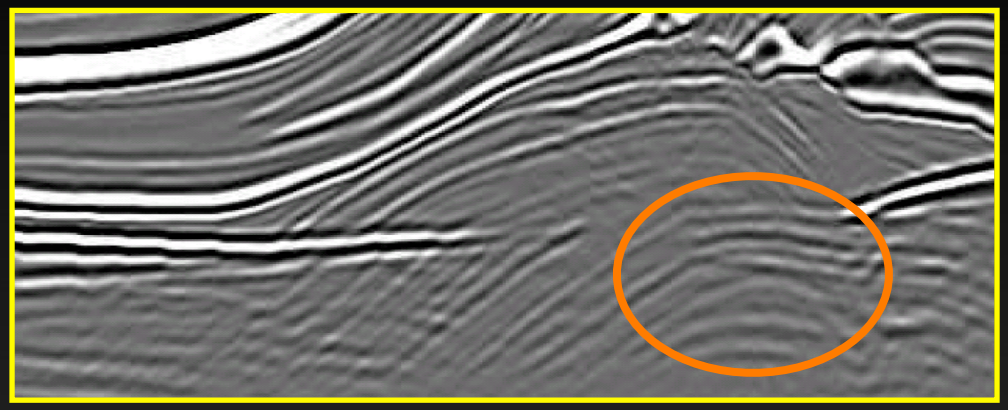
Improving 3D-ISWET flexibility

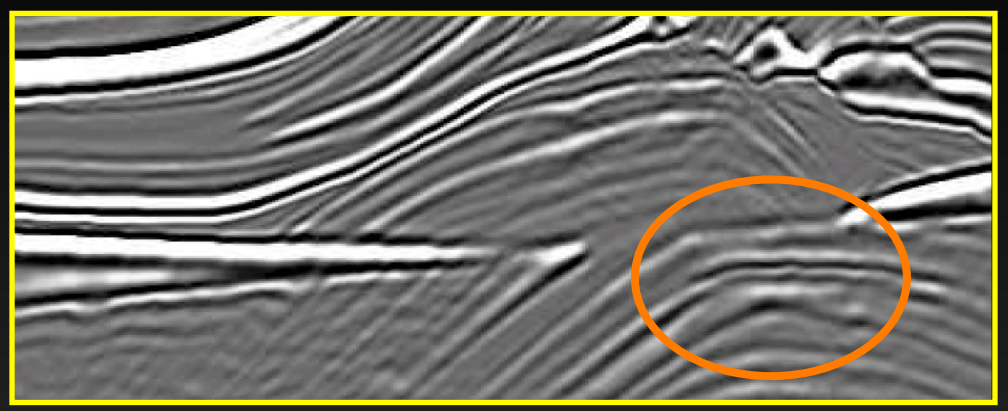
- **Incorporate strategies from ray-based methods into ISWET**
  - **Use image-space generalized wavefields**

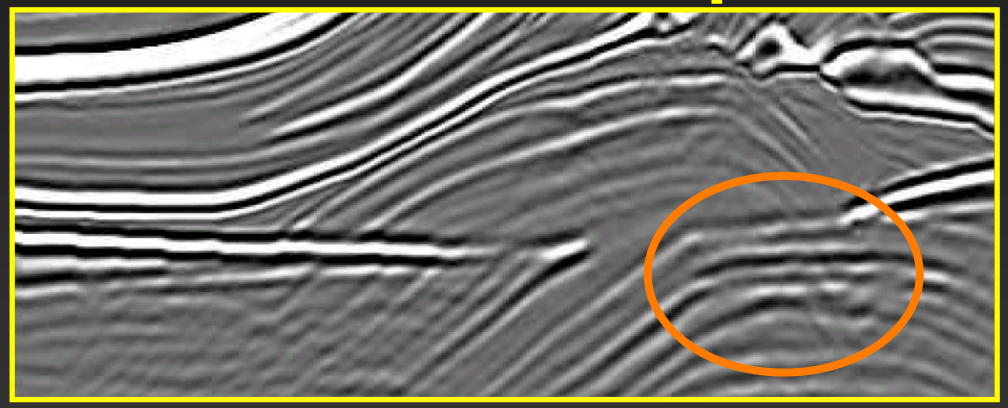
Keeping 3D-ISWET robustness

- **Guarantee correct kinematics and reasonable amplitudes**

2D example







20x faster

Outline

- **Image-space generalized source domain**
- **Research proposal**
- **Where we are**
- **Final remarks**

Image-space generalized-source domain

Generalized-source domain

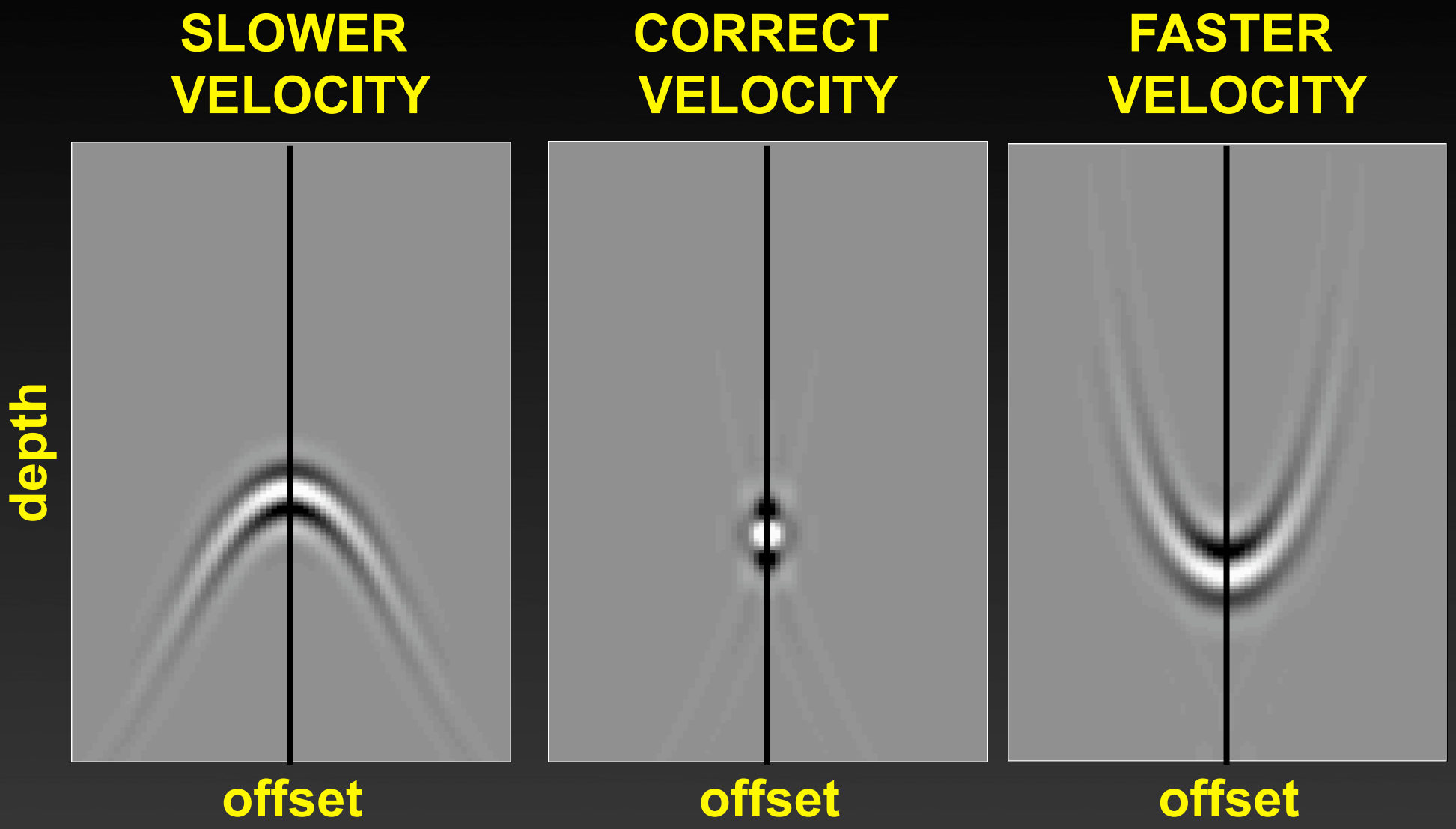
Data space
- plane waves
- random phases
- controlled illumination

Image space
- PERM wavefields
- ISPEW

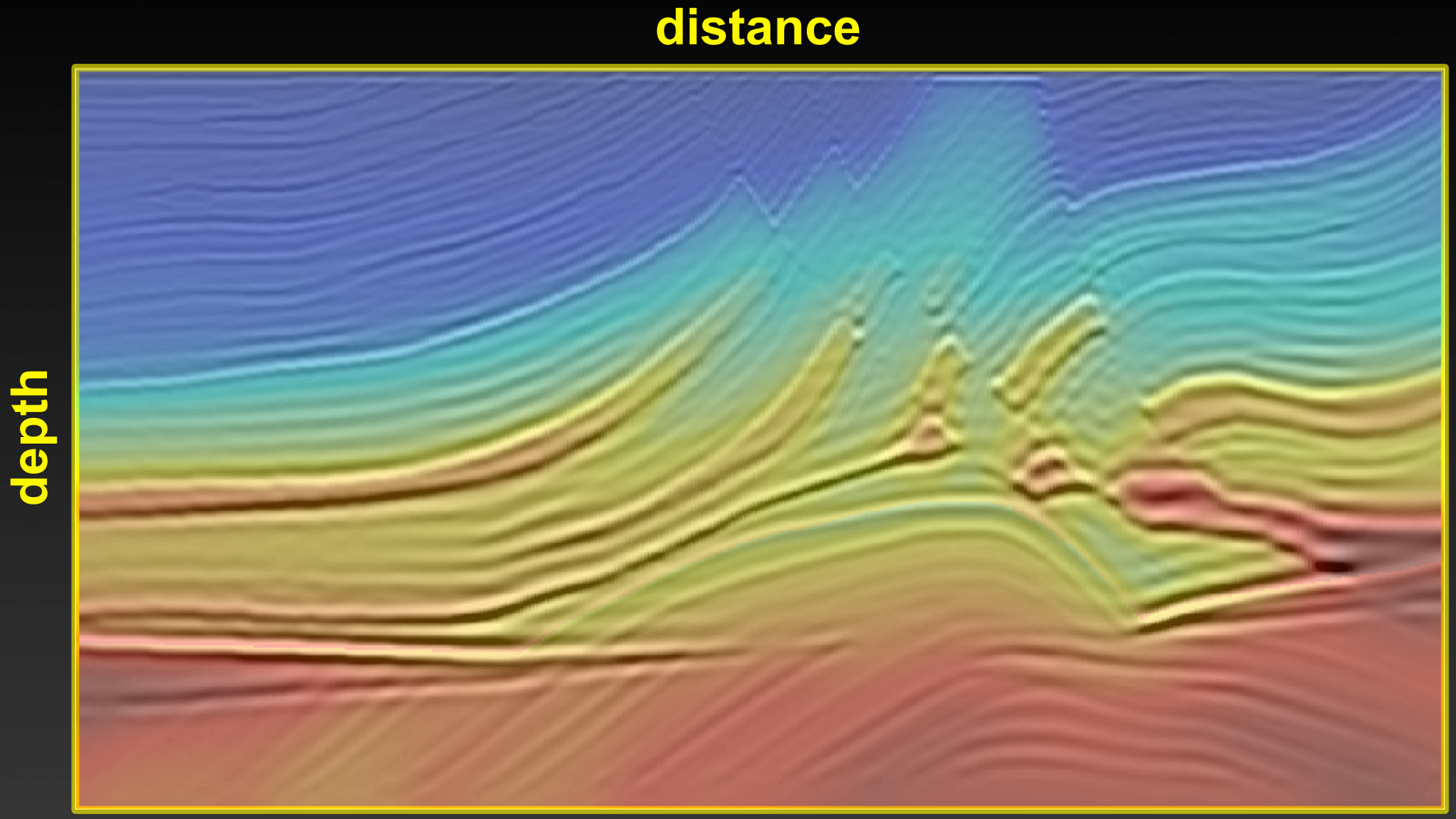
Pre-stack exploding reflector

- **Generalizes the exploding-reflector model**
  - **Subsurface-offset gathers are used to model source and receiver wavefields**

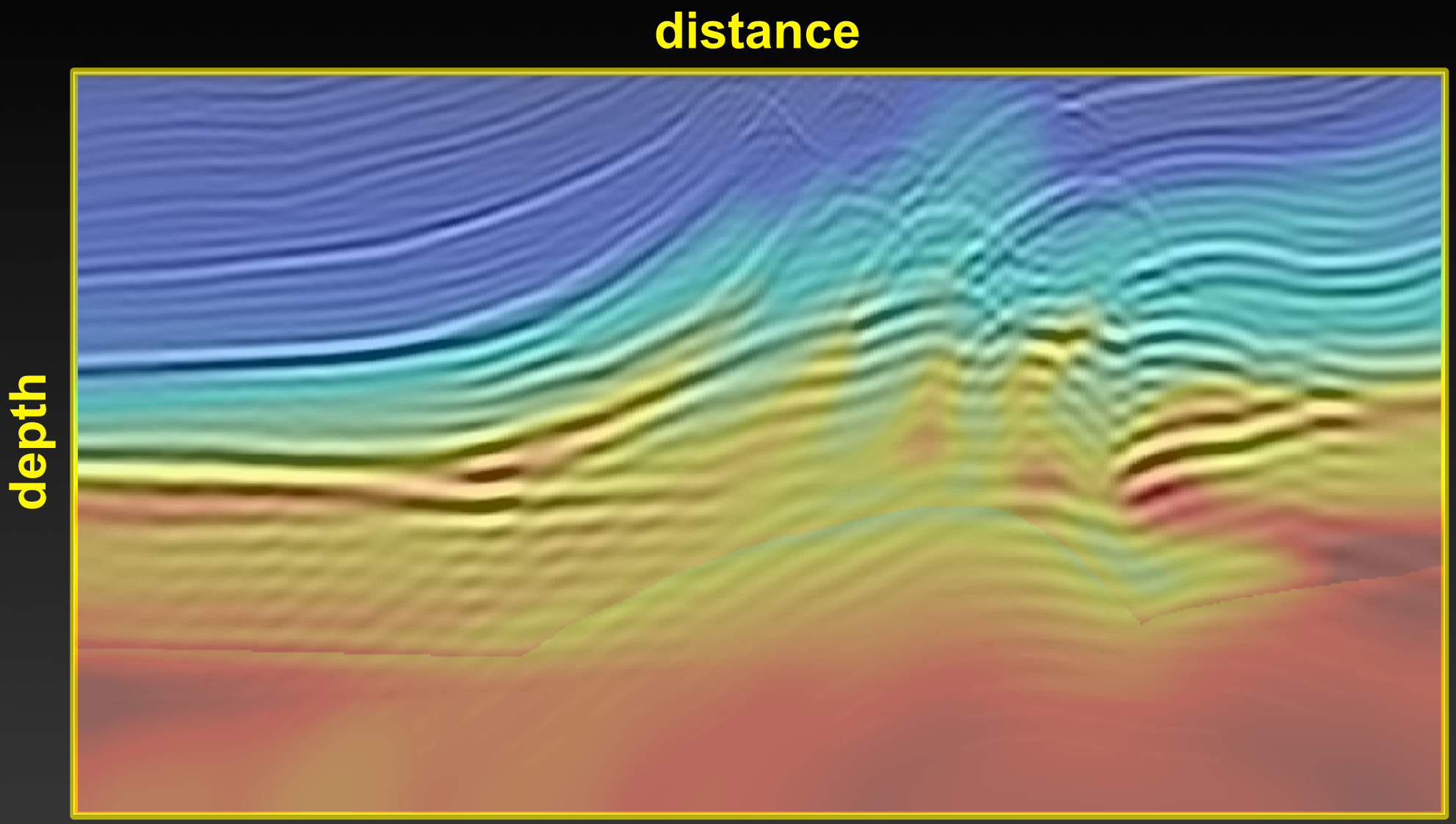
Subsurface-offset gathers



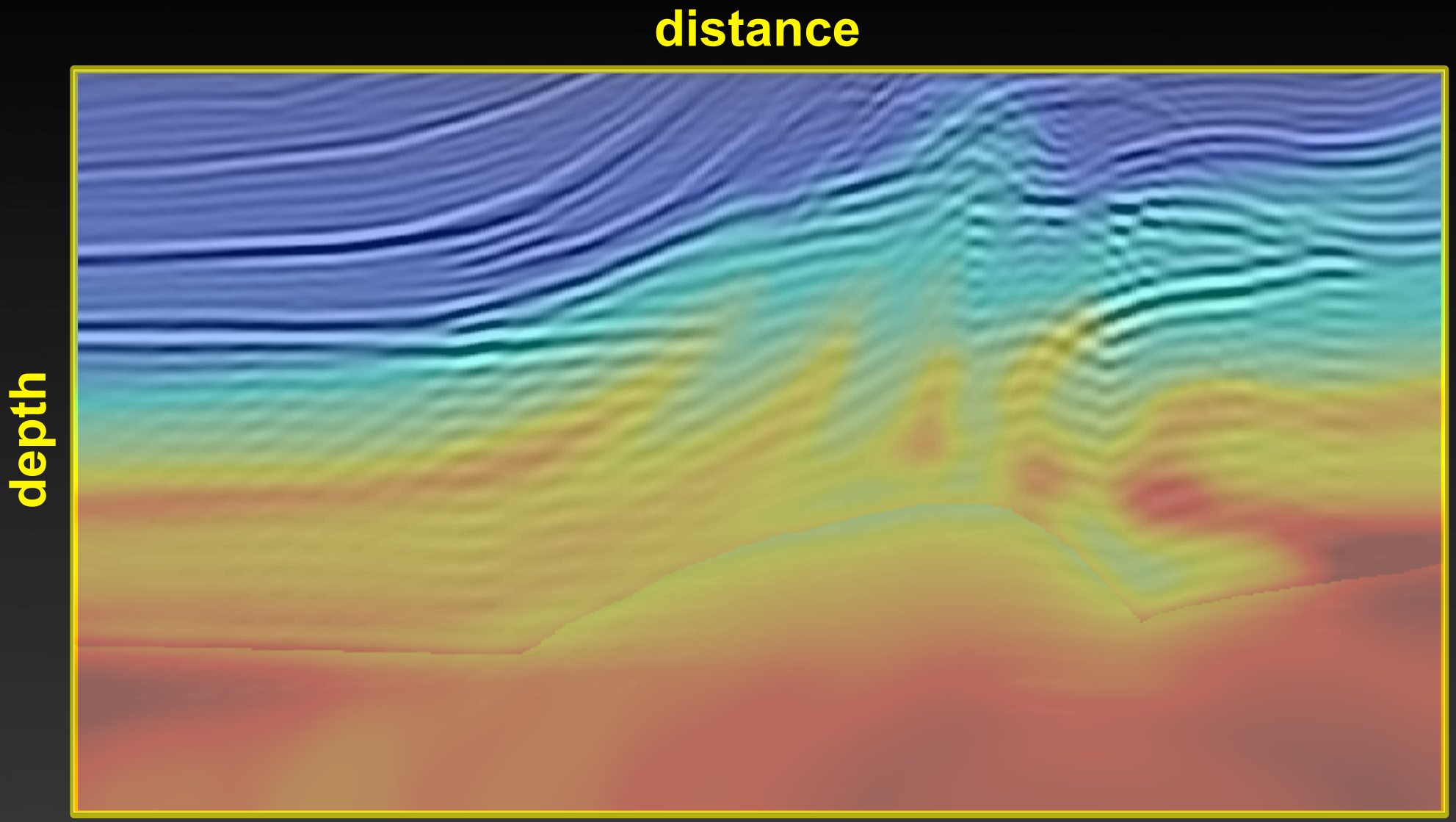
Exploding reflectors



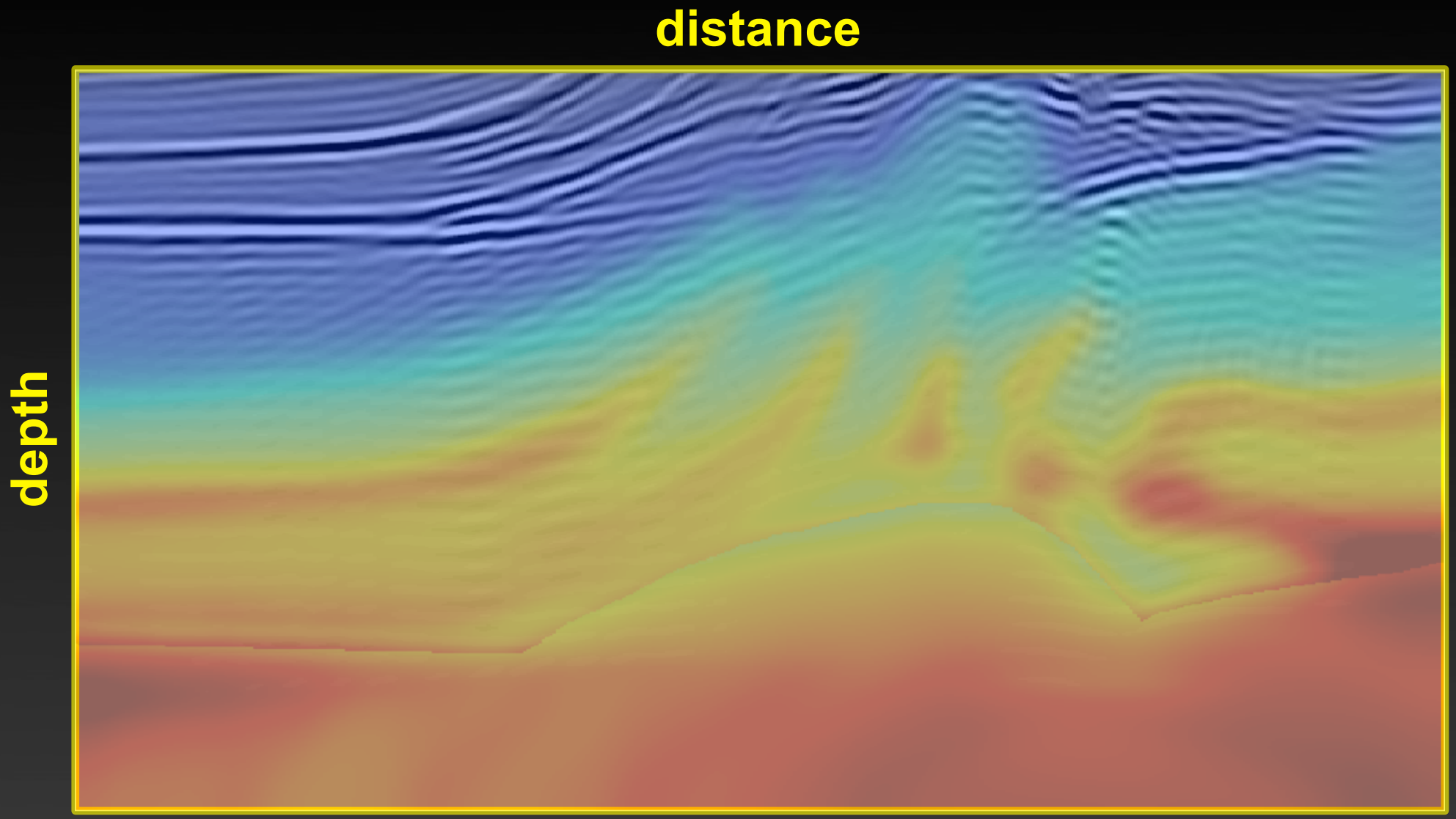
Exploding reflectors



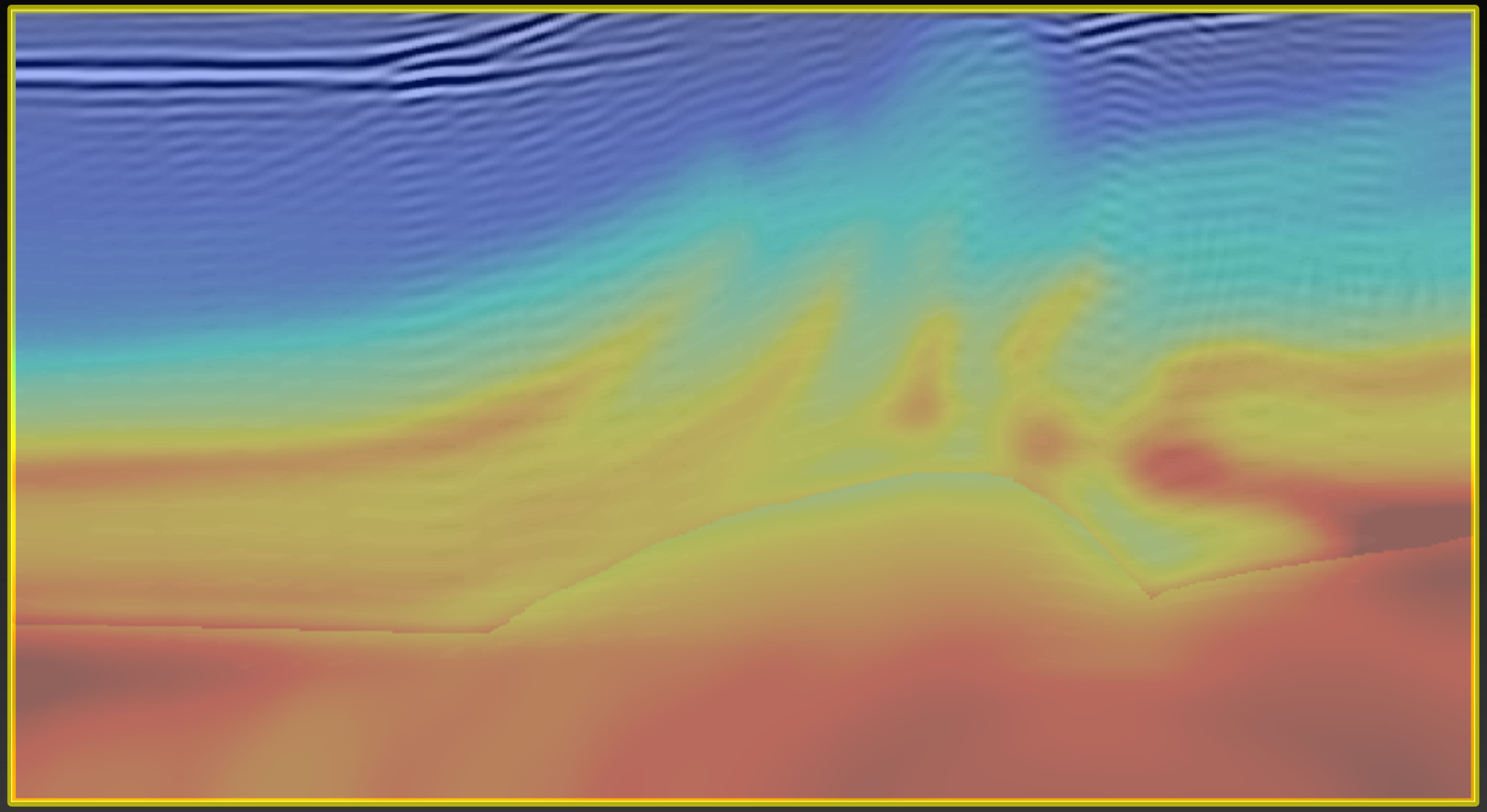
Exploding reflectors



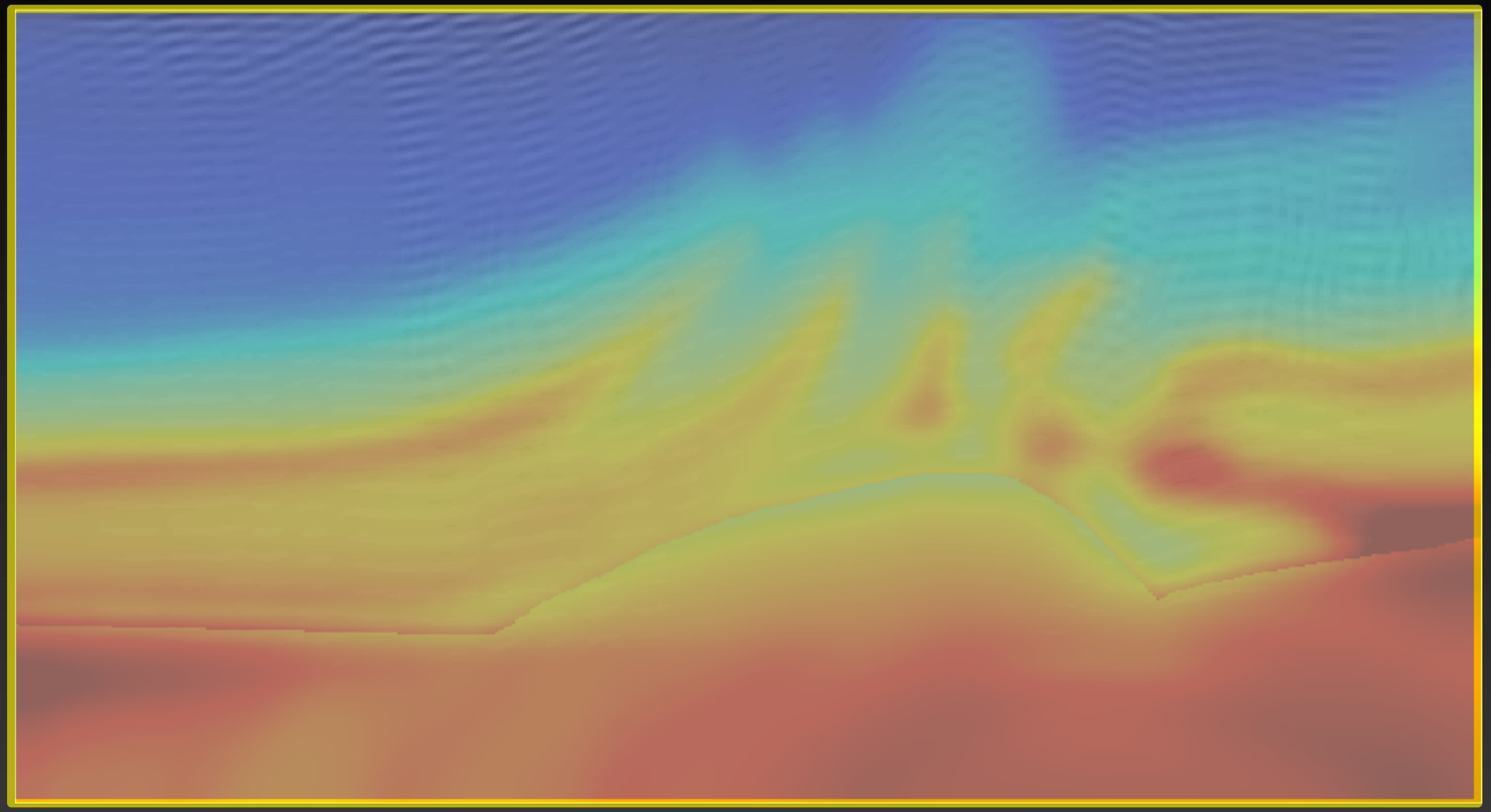
Exploding reflectors



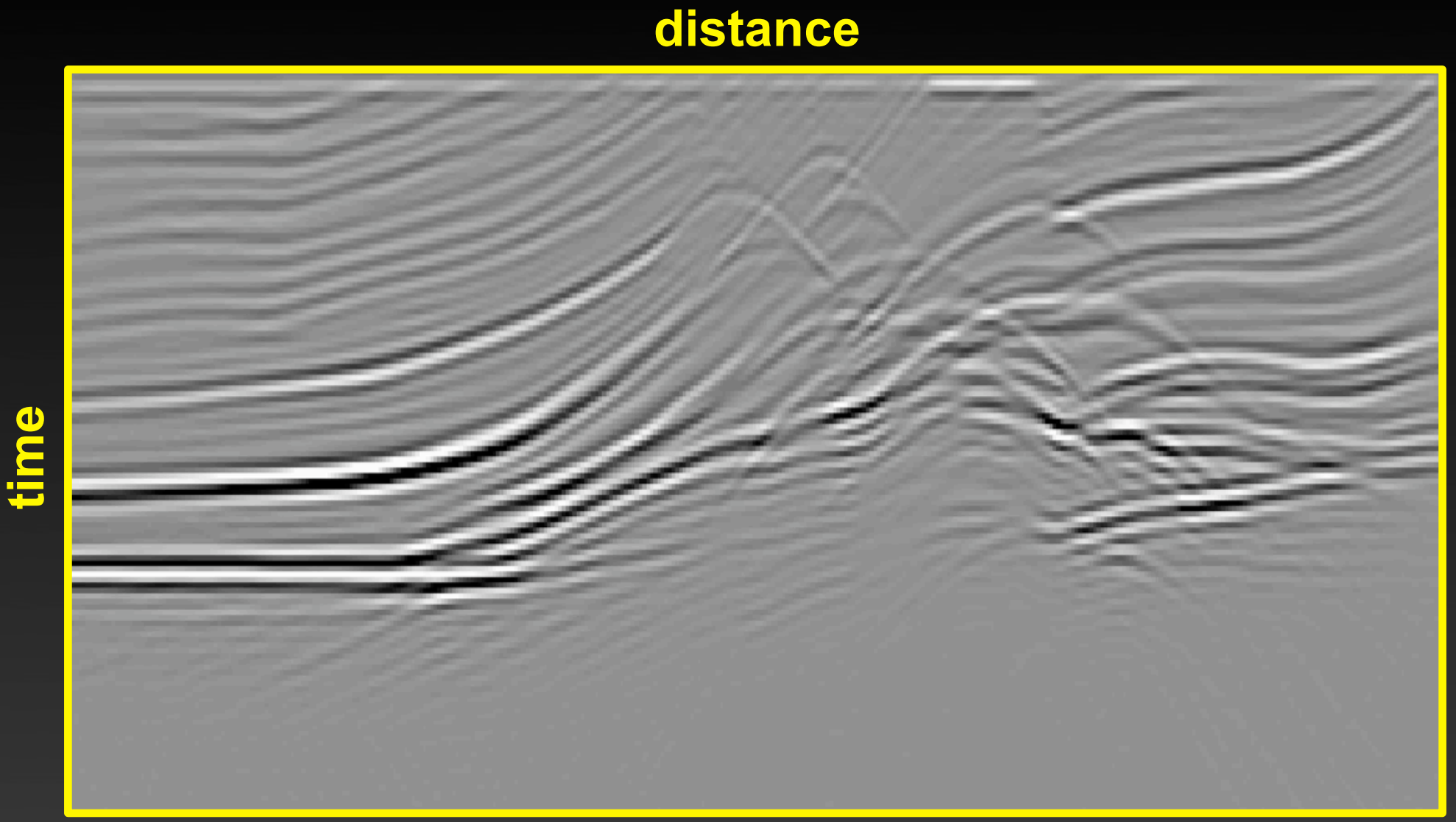
Exploding reflectors



Exploding reflectors



Zero-offset section

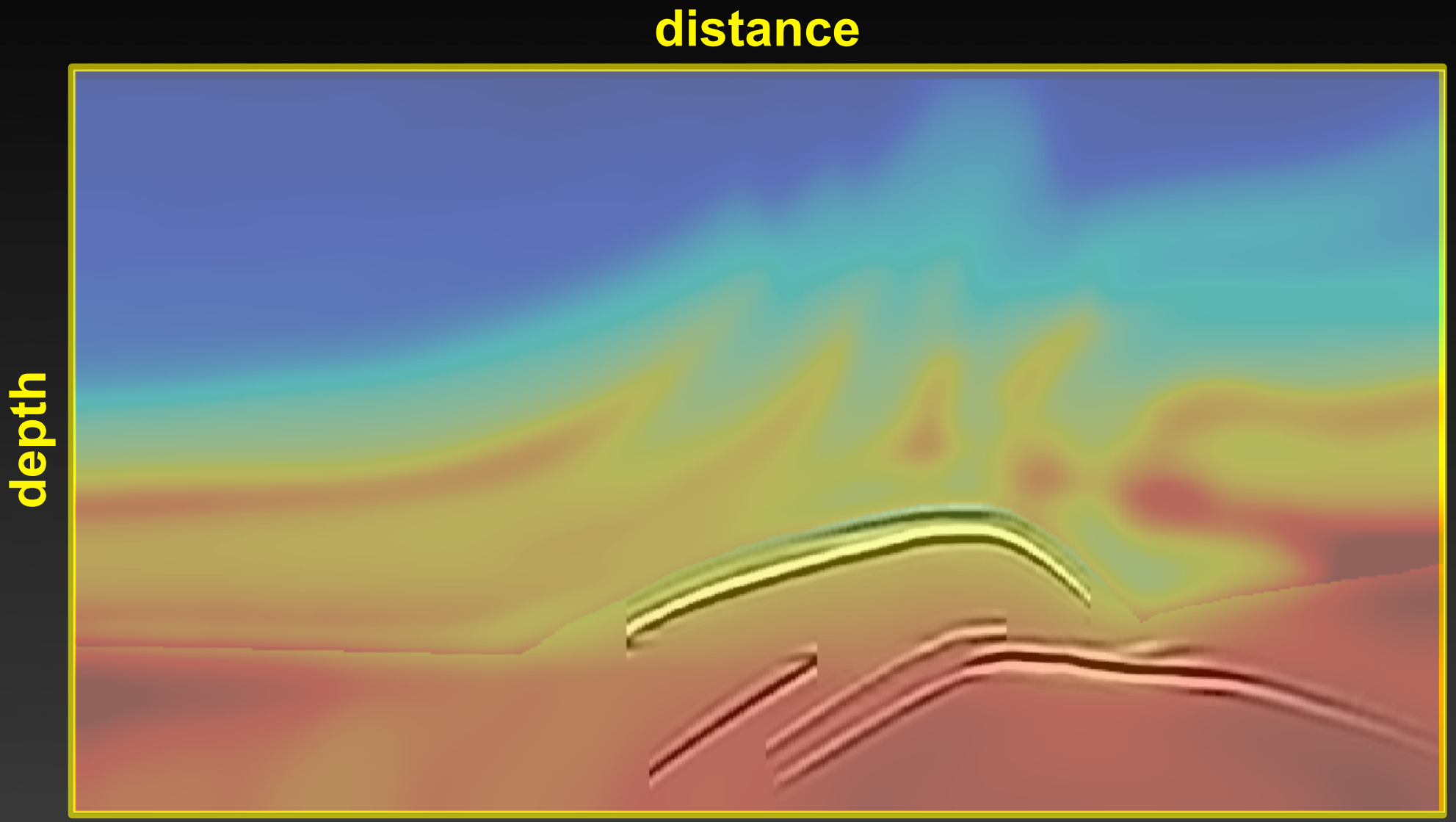


PERM

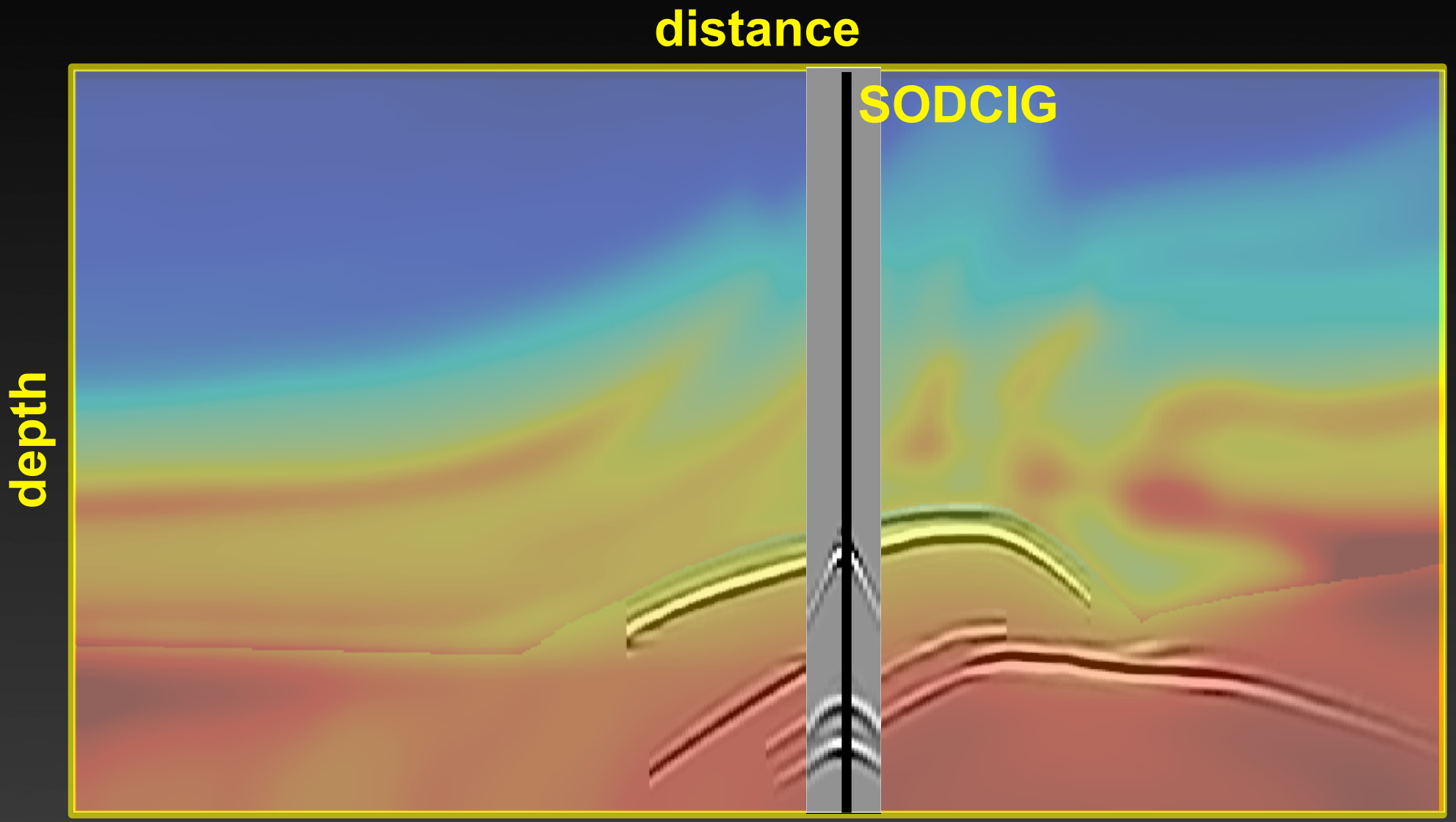
- **Generalizes the exploding-reflector model**
  - **Subsurface-offset gathers are used to model source and receiver wavefields**

- **Uses selected reflectors as the initial conditions**
  - **Naturally incorporates a horizon-based tomography strategy into wave-extrapolation methods**

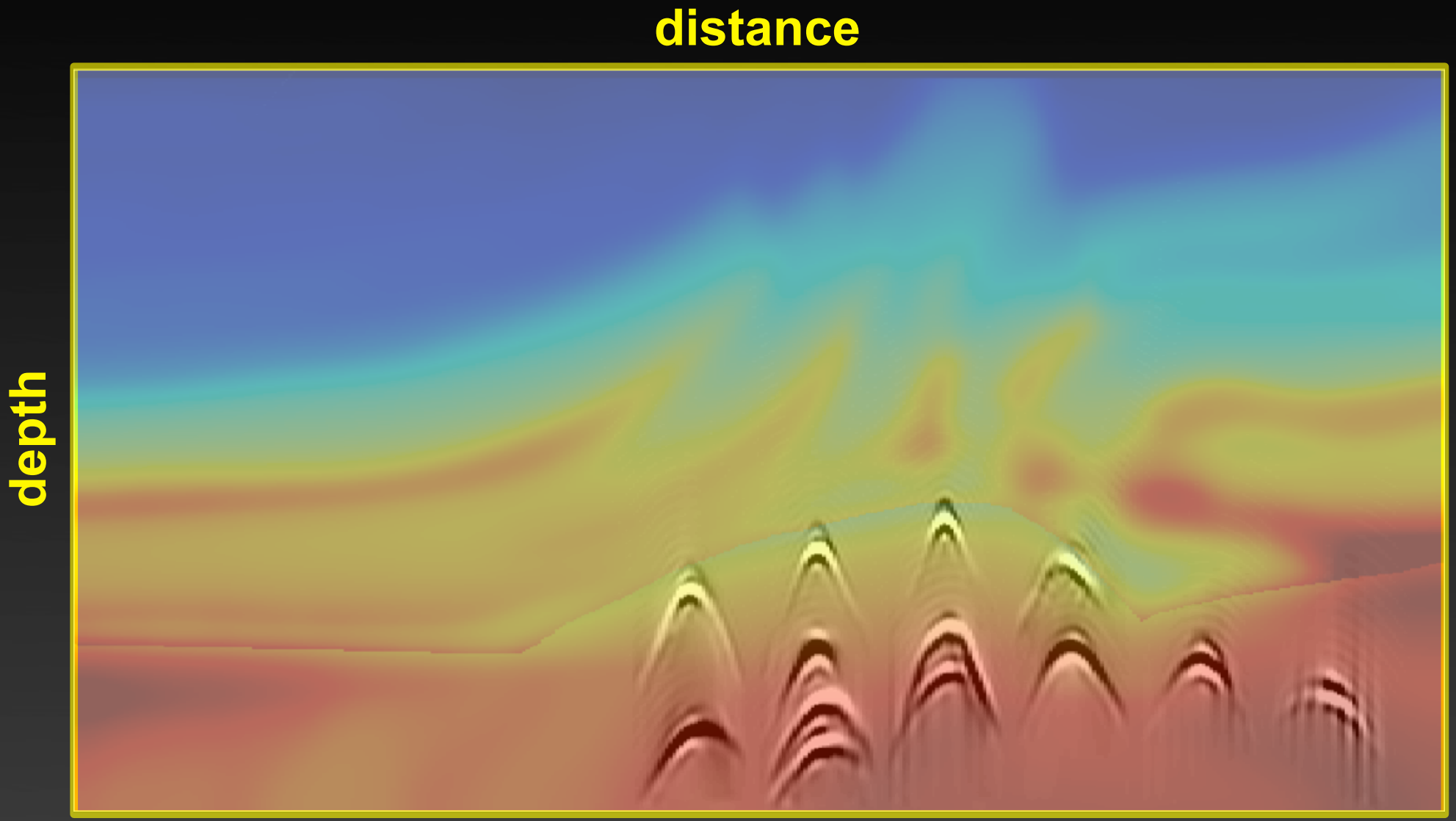
Modeling receiver wavefield



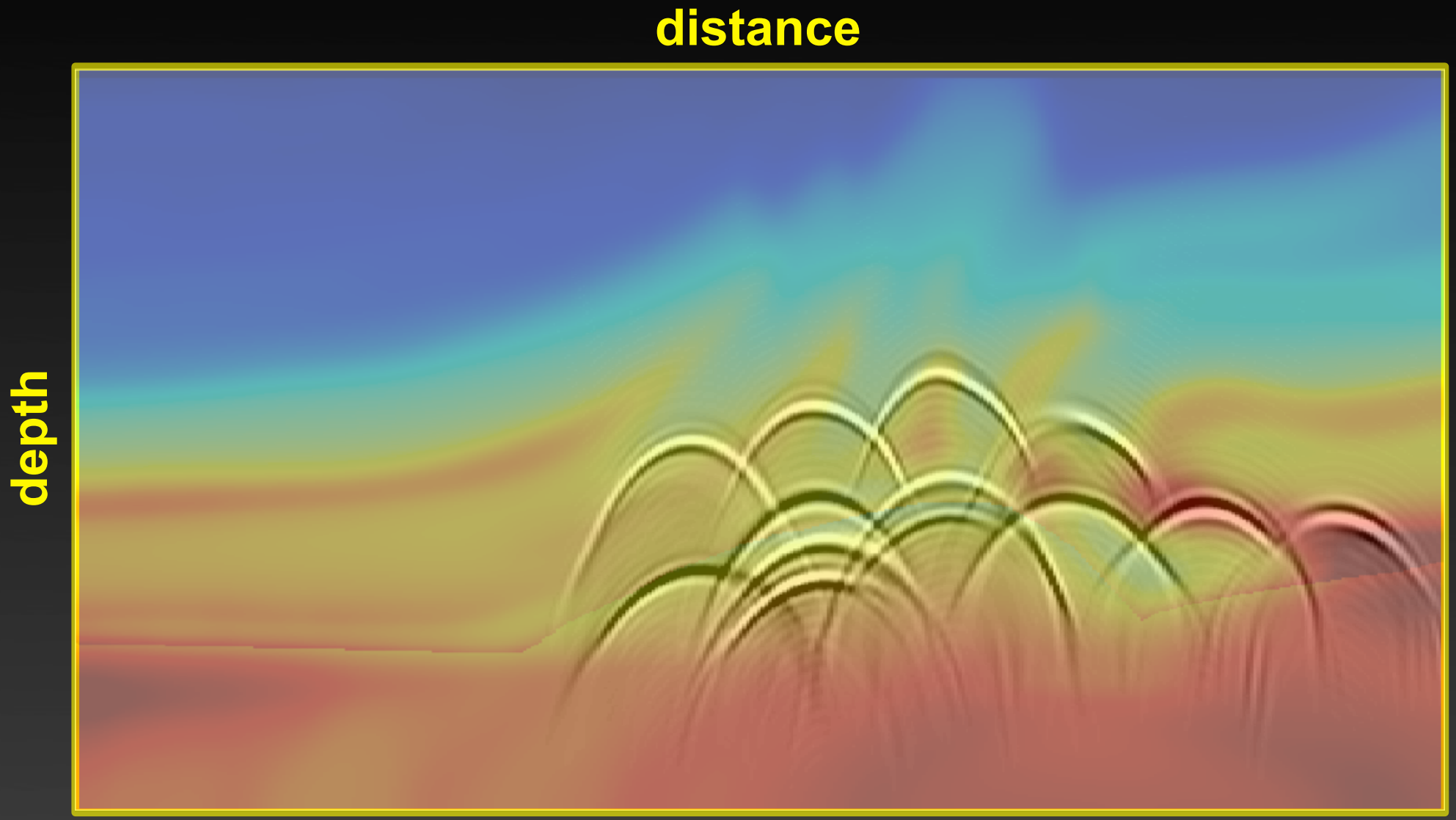
Modeling receiver wavefield



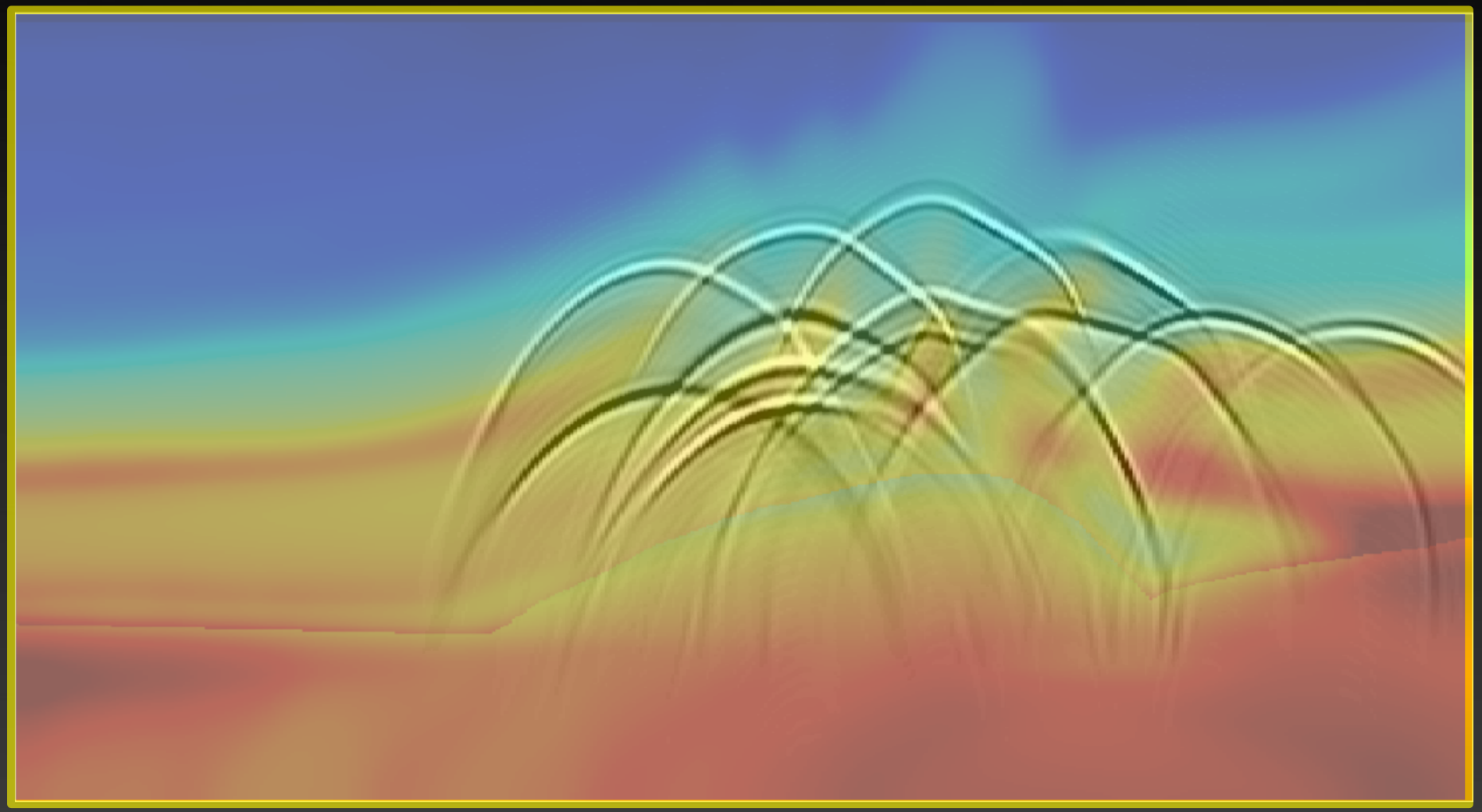
Modeling receiver wavefield



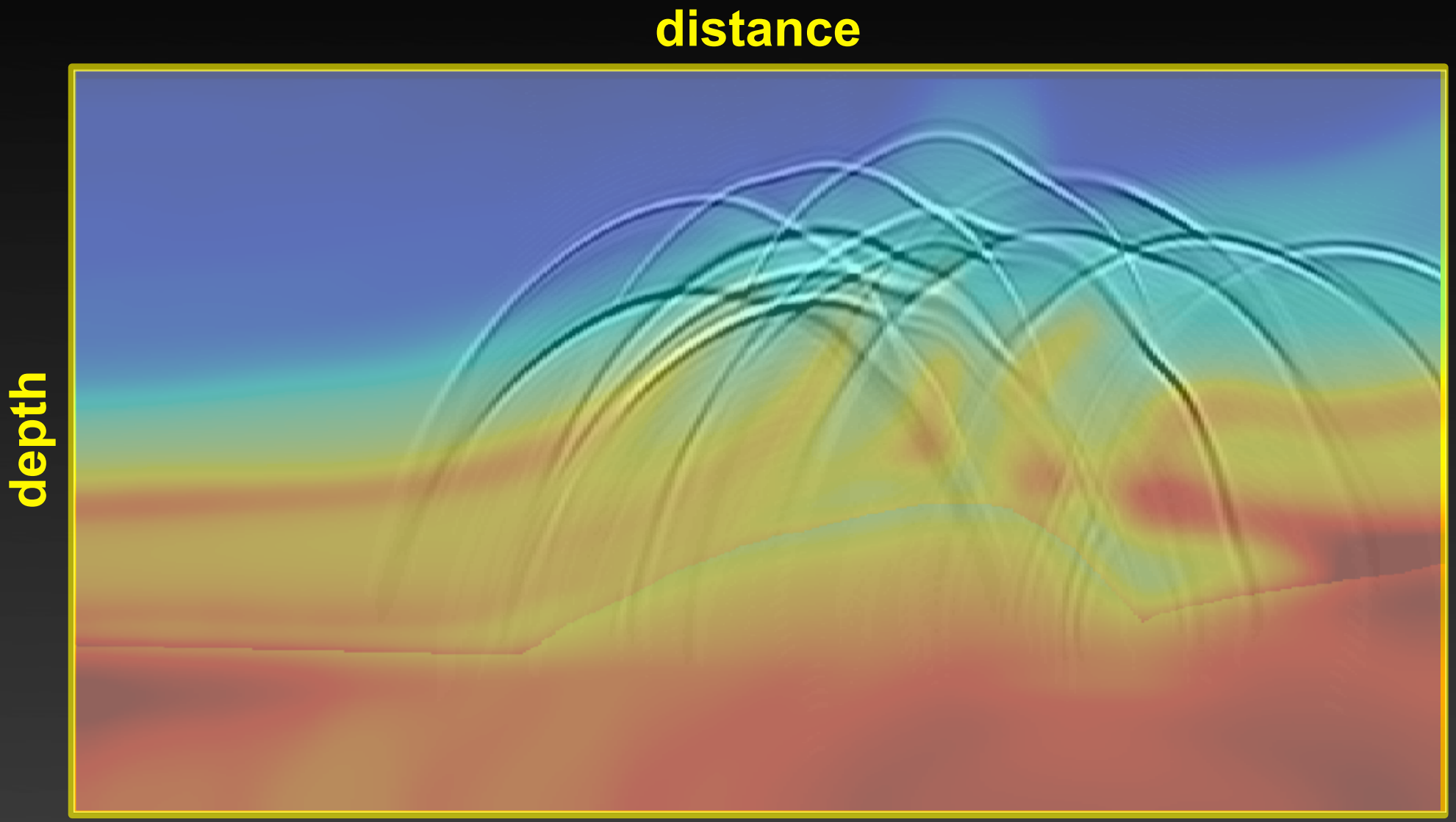
Modeling receiver wavefield



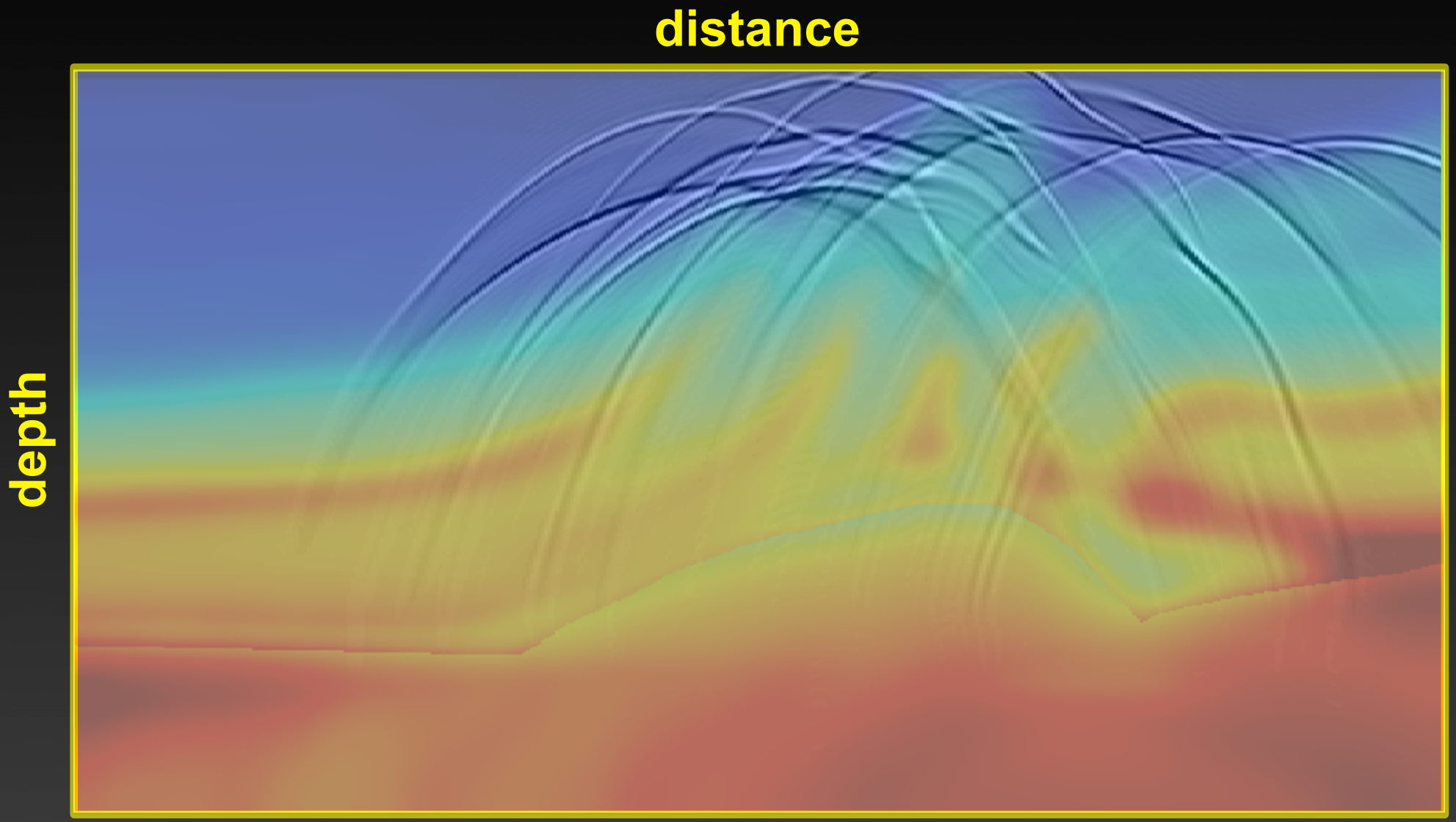
Modeling receiver wavefield



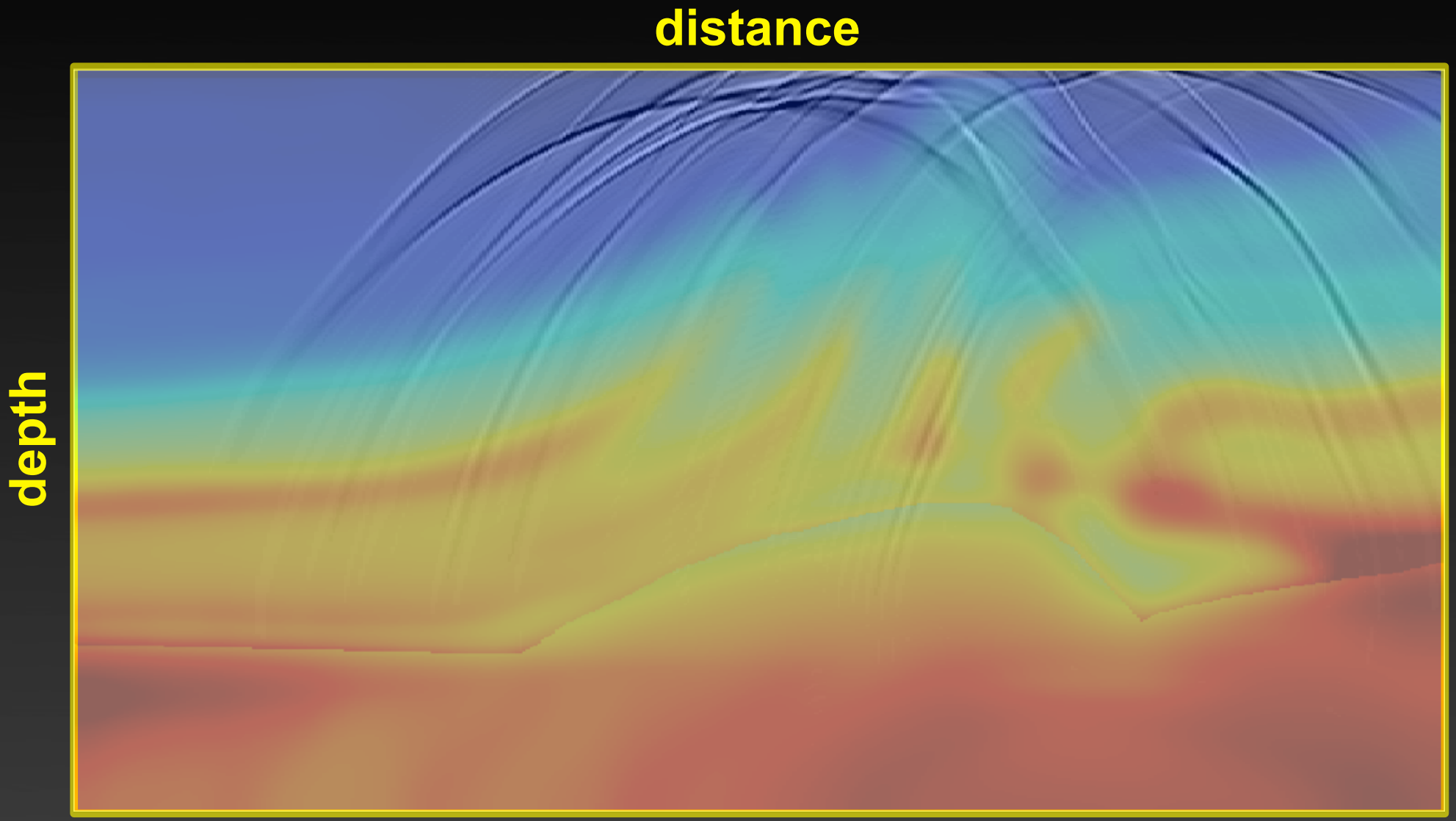
Modeling receiver wavefield



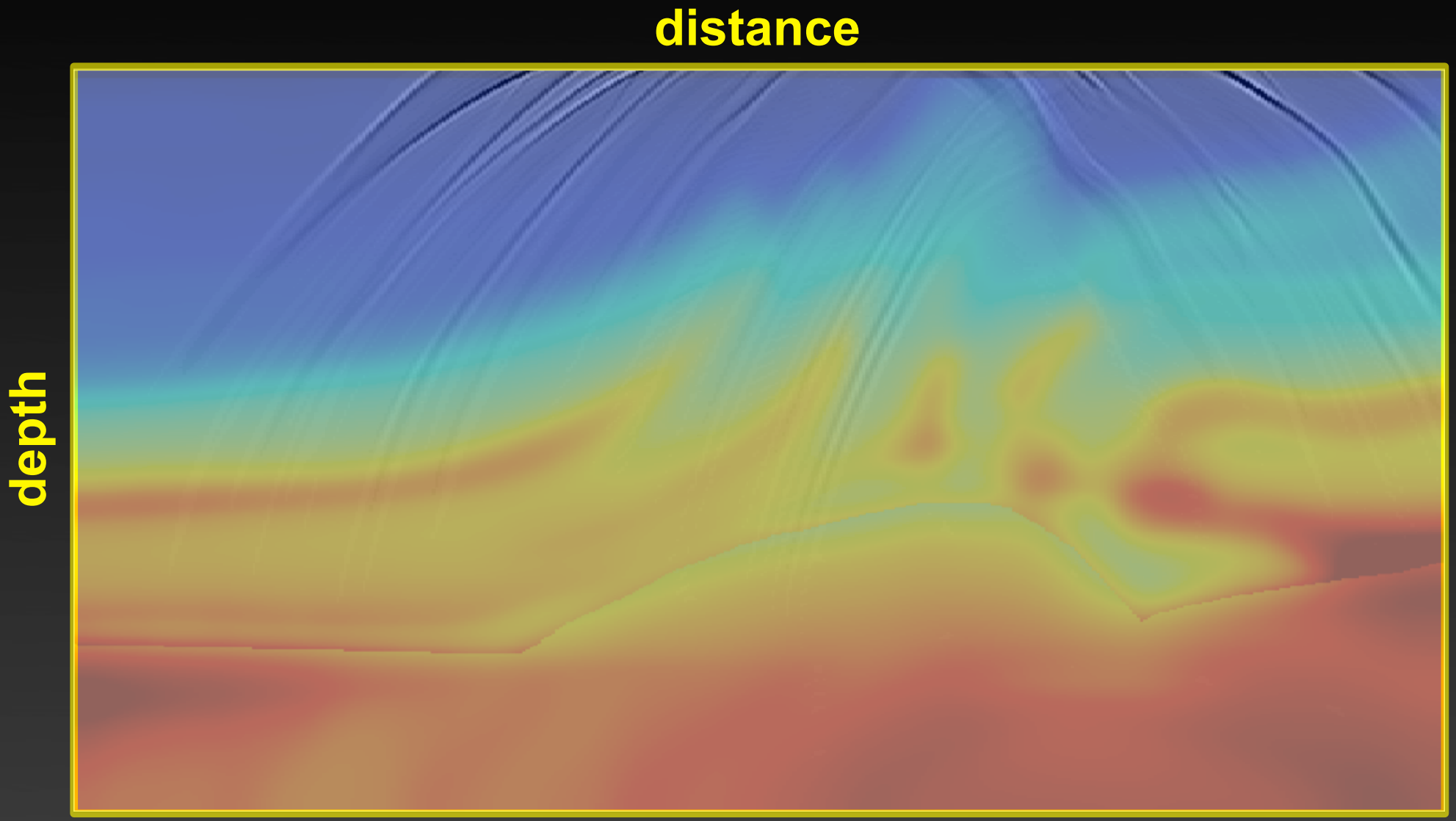
Modeling receiver wavefield



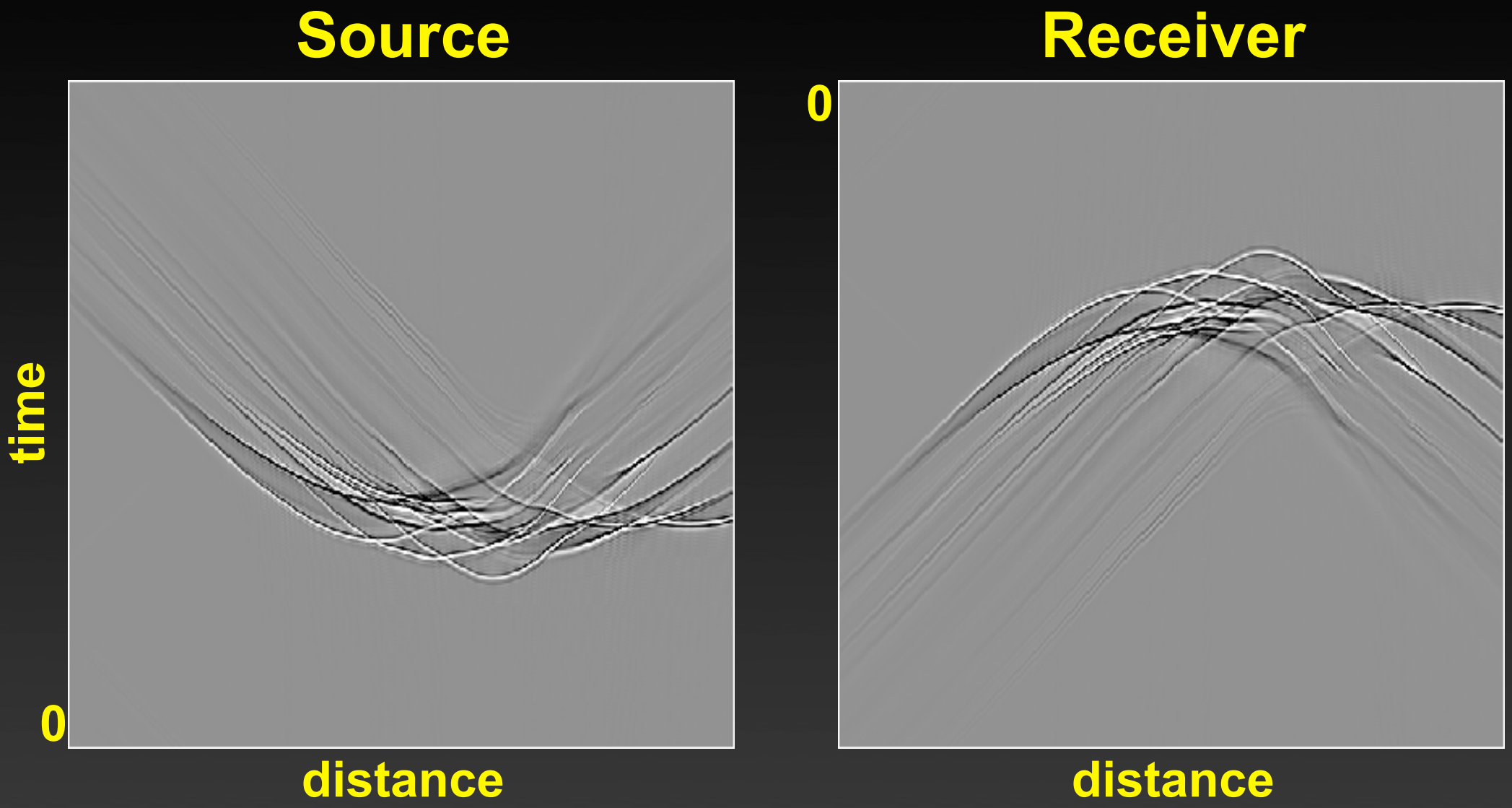
Modeling receiver wavefield



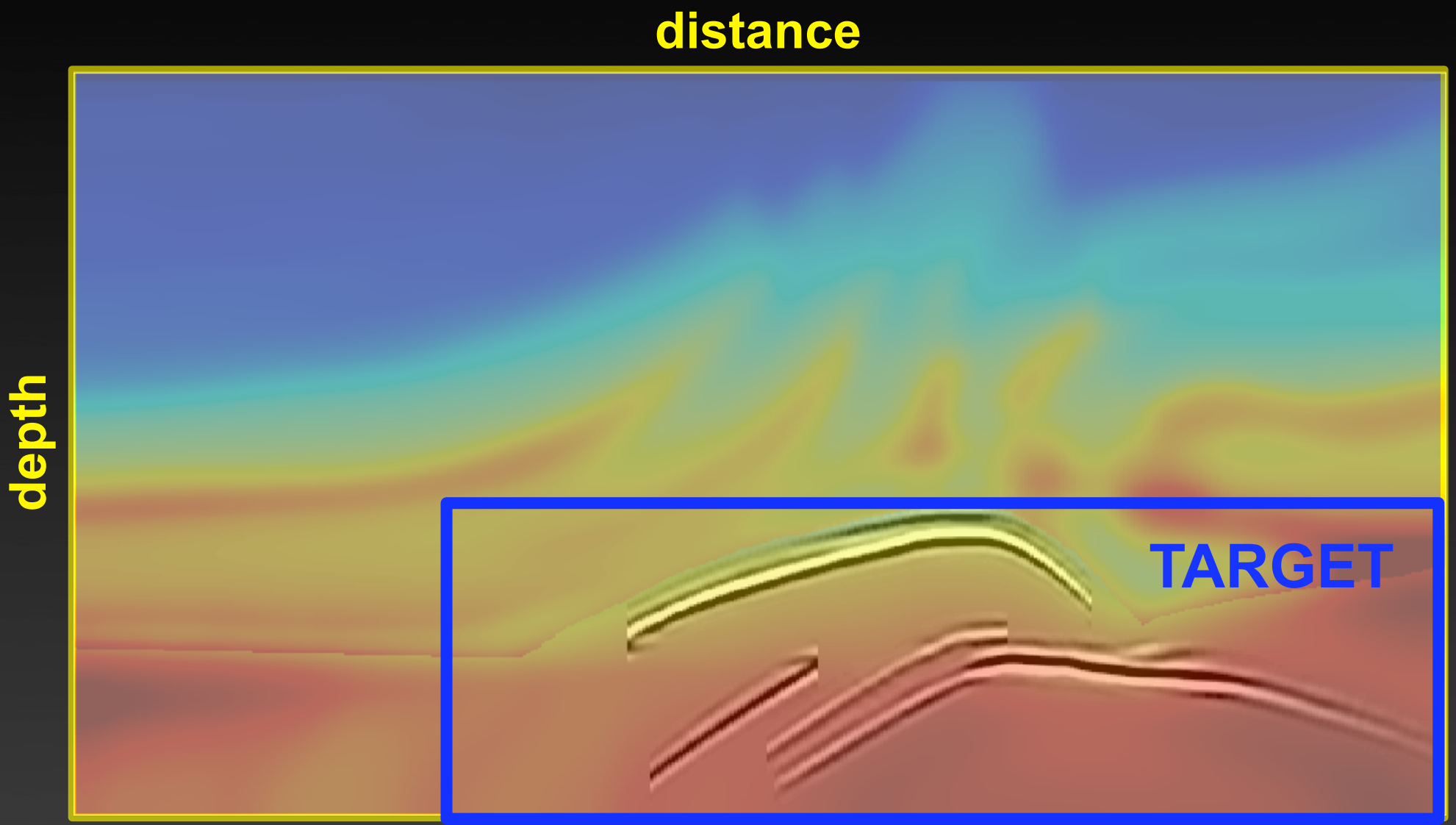
Modeling receiver wavefield



PERM data

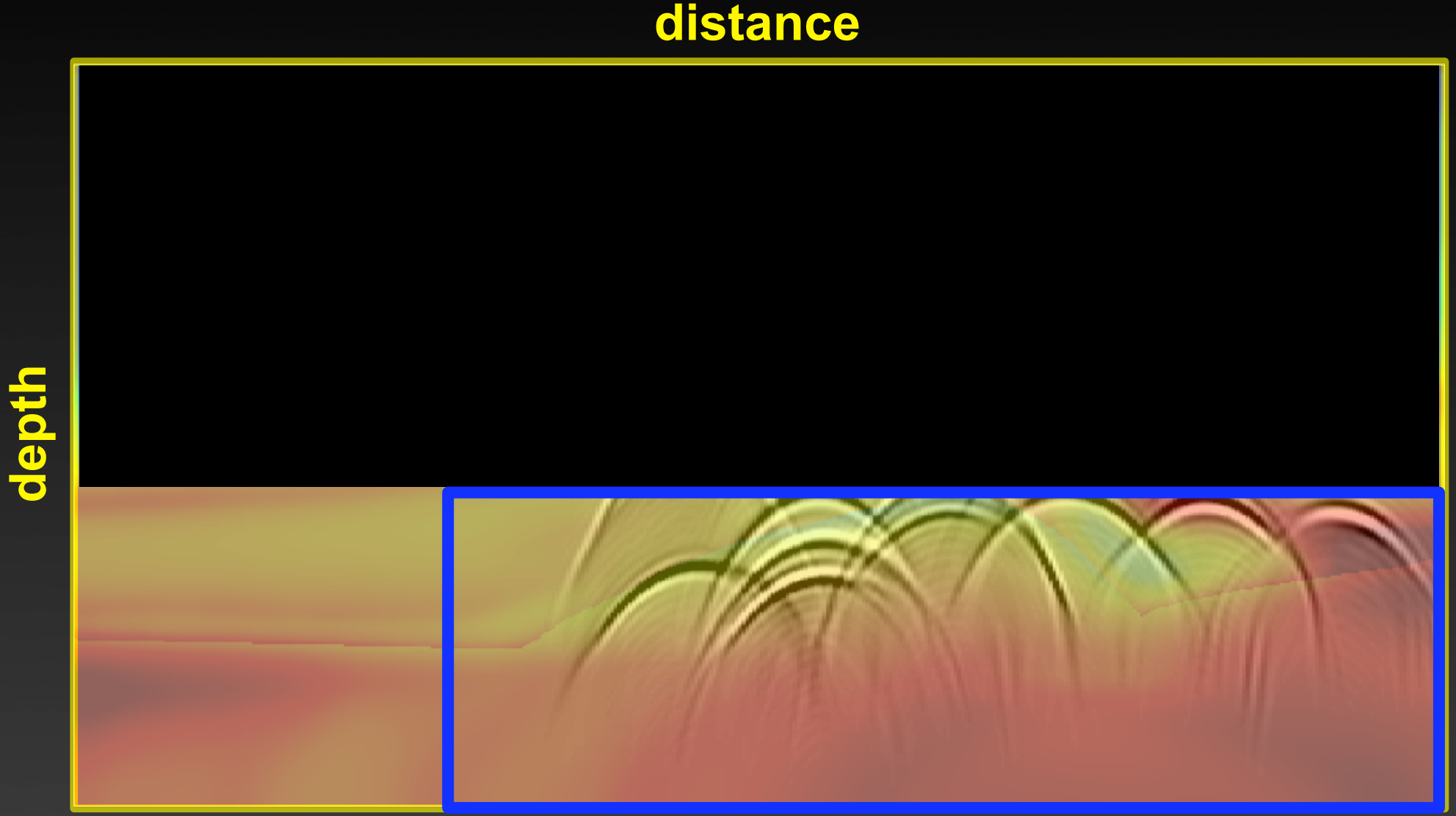


Target-oriented strategy



Target-oriented strategy

Wavefields collected at the top of the target



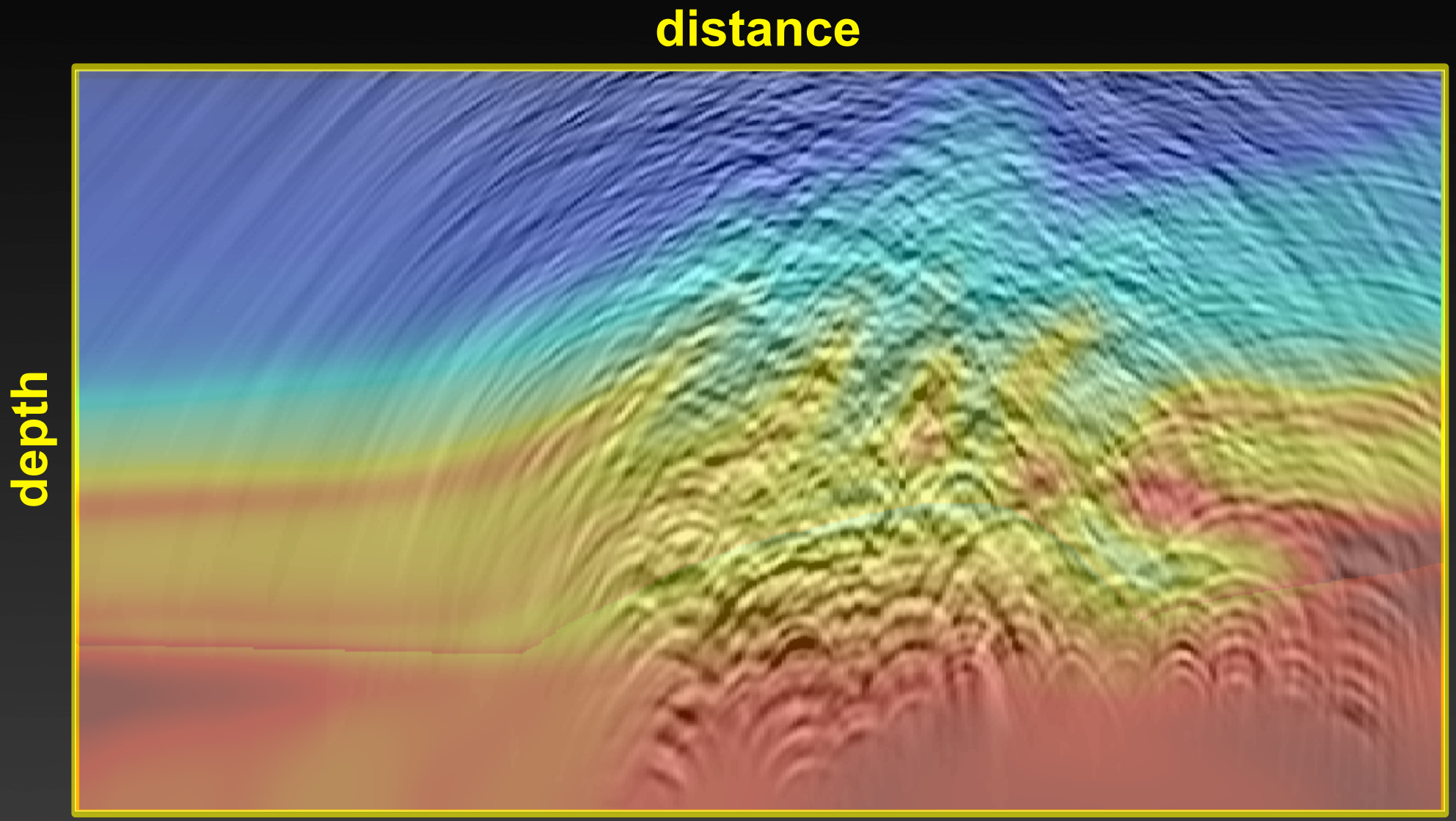
In 3D

- **~ 1,000 PERM wavefields**
  - **Using inline and crossline offsets**

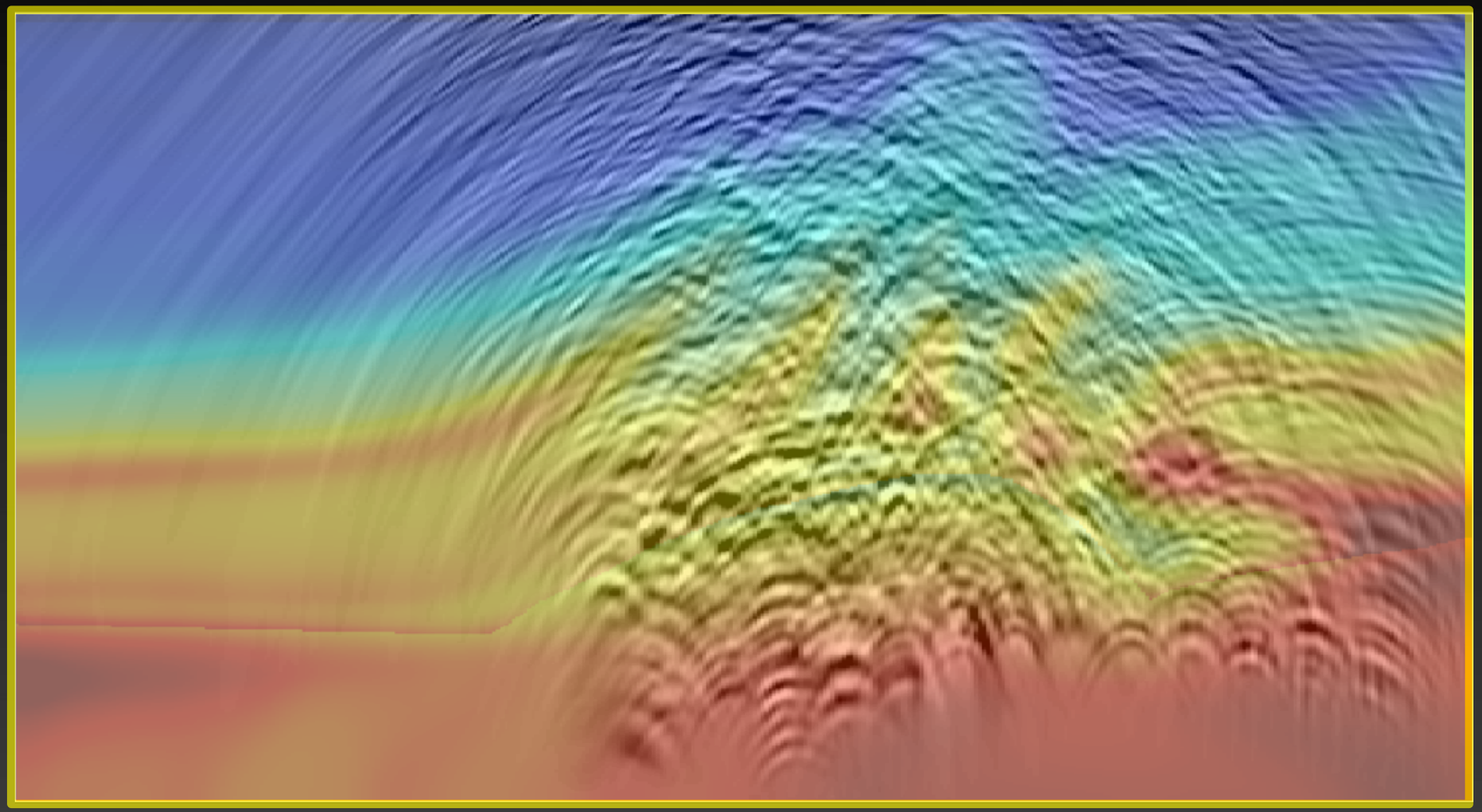
- **< 100 PERM wavefields**
  - **Using only inline subsurface-offsets**

Further data reduction by phase-encoding the modeling experiments

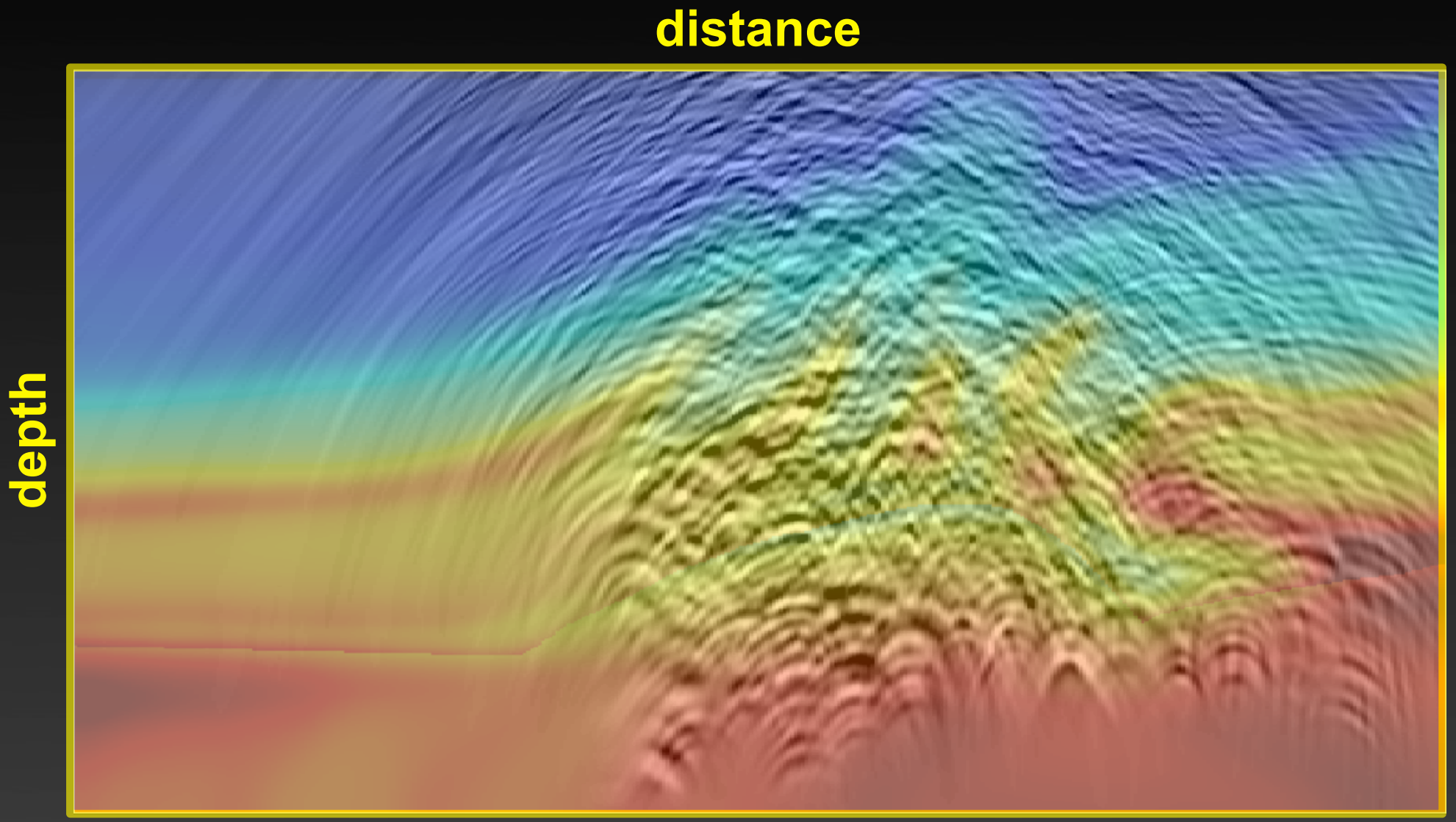
Phase-encoded receiver wavefield



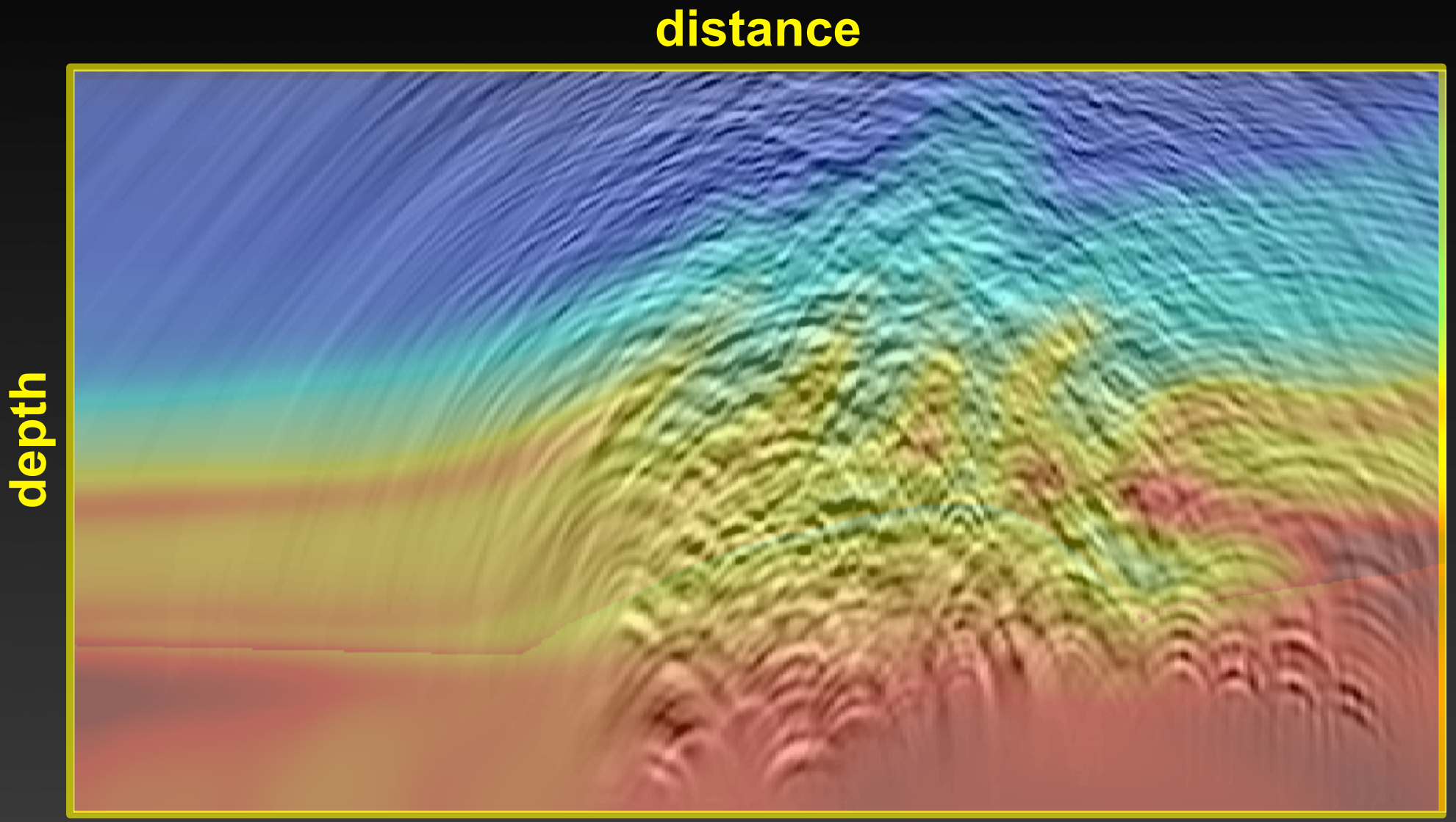
Phase-encoded receiver wavefield



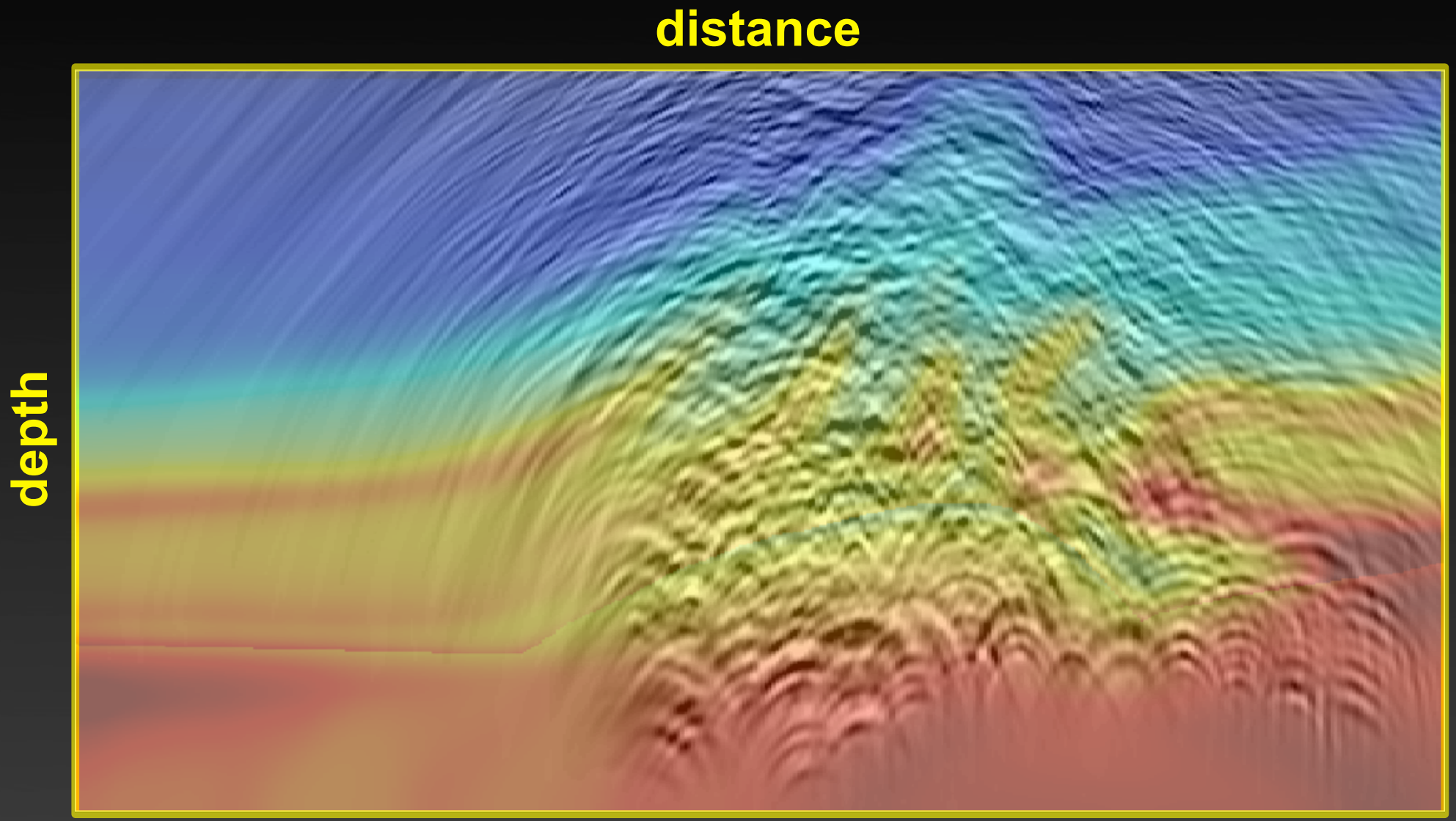
Phase-encoded receiver wavefield



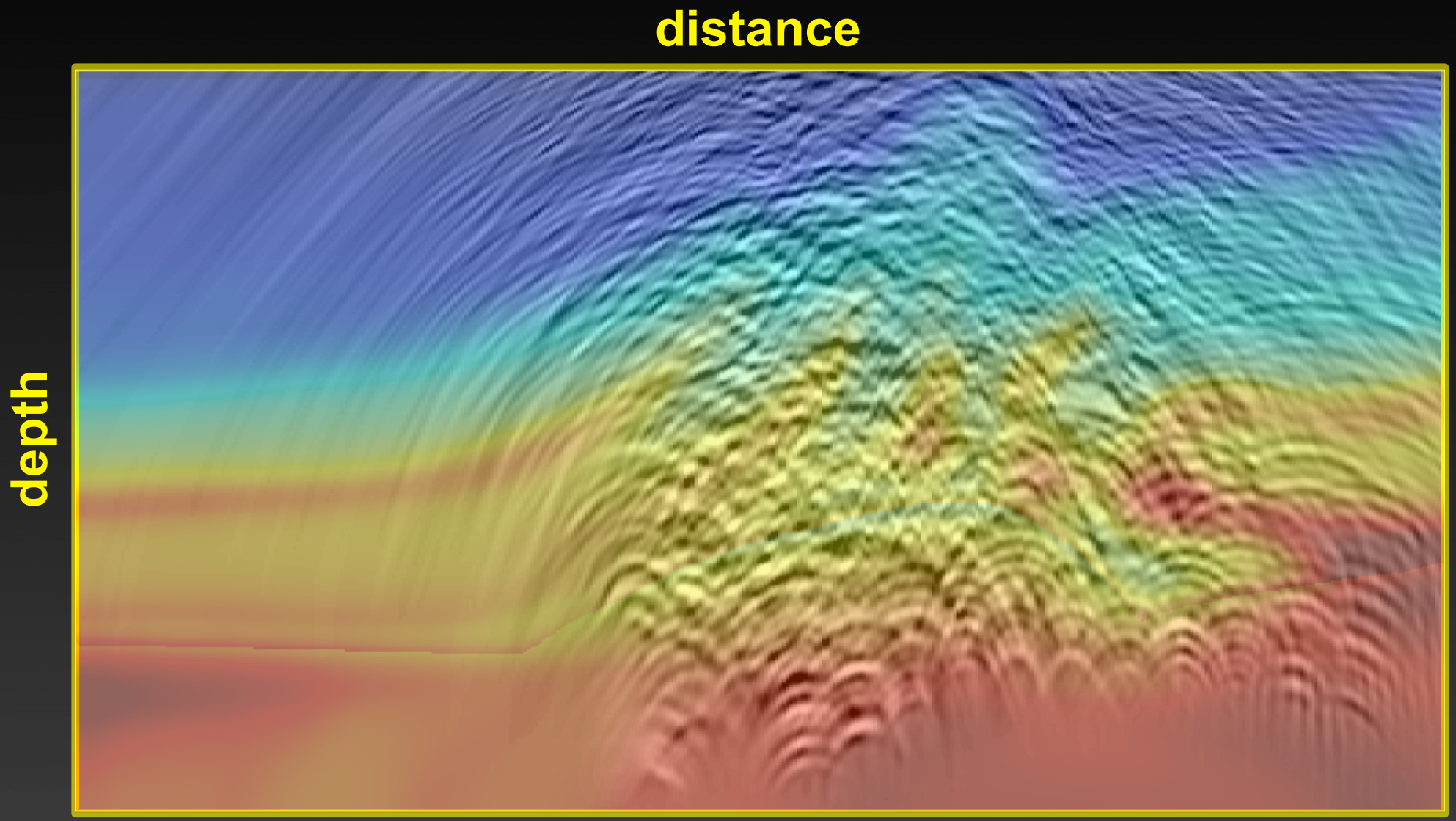
Phase-encoded receiver wavefield



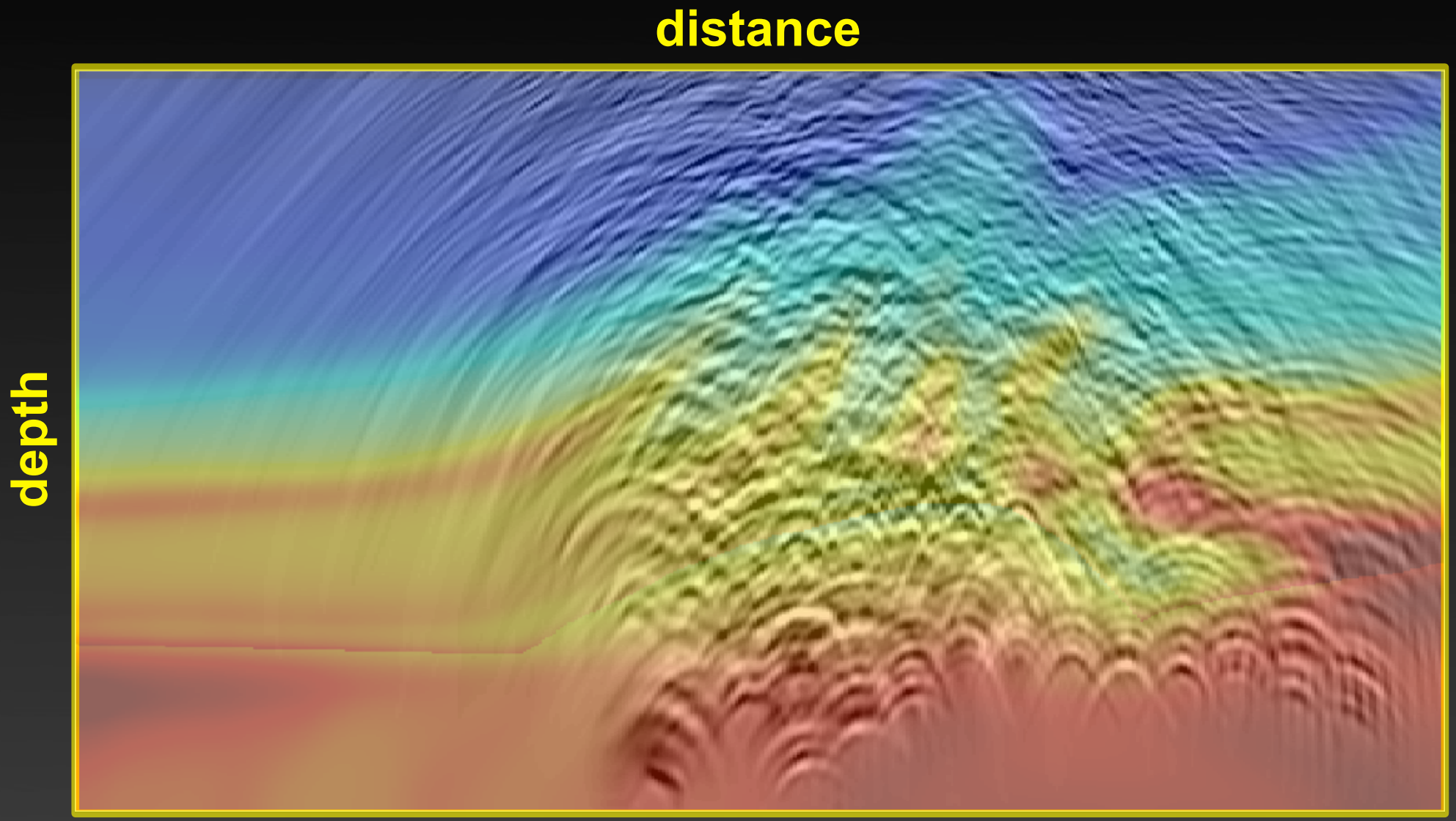
Phase-encoded receiver wavefield



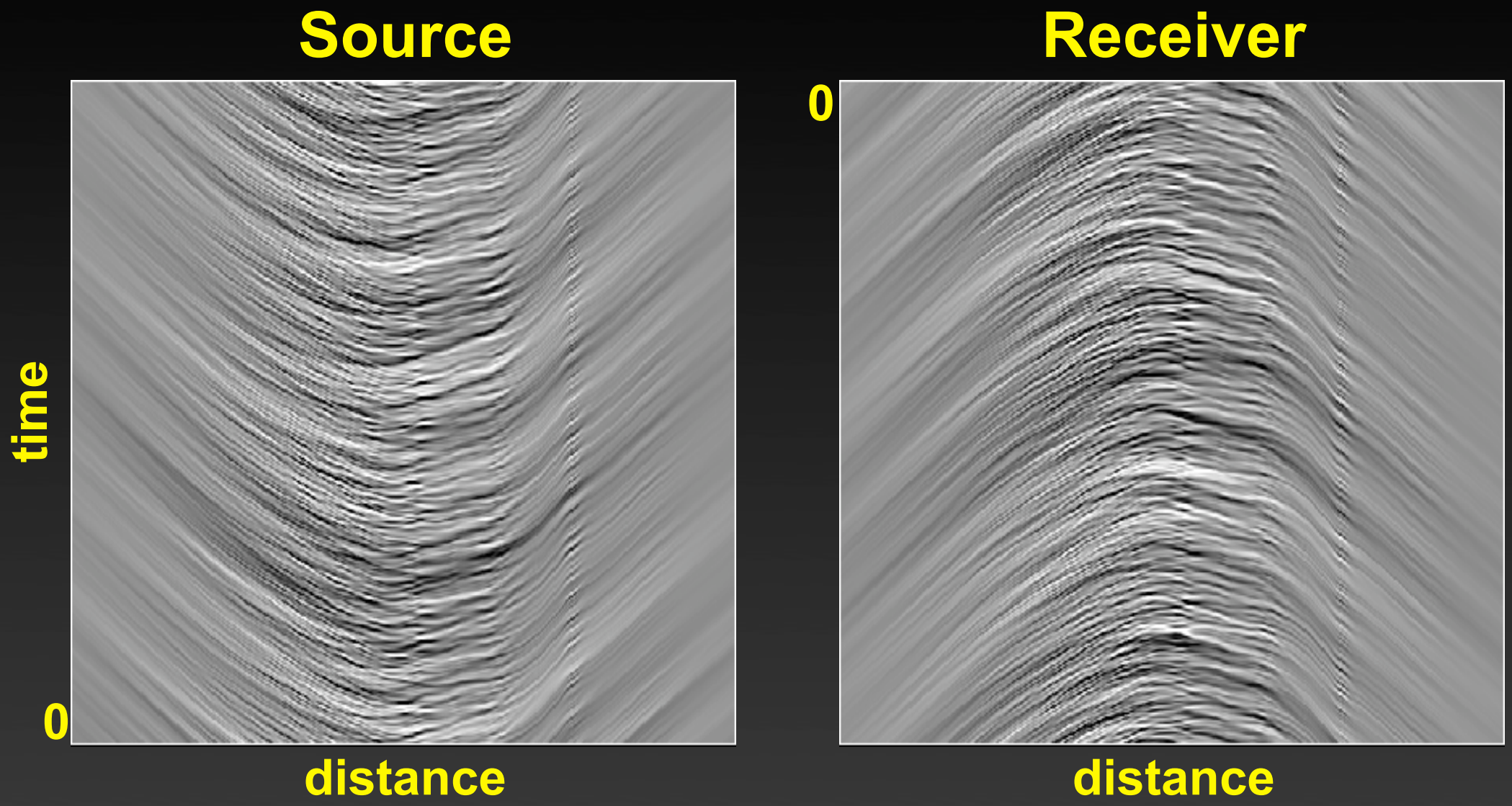
Phase-encoded receiver wavefield



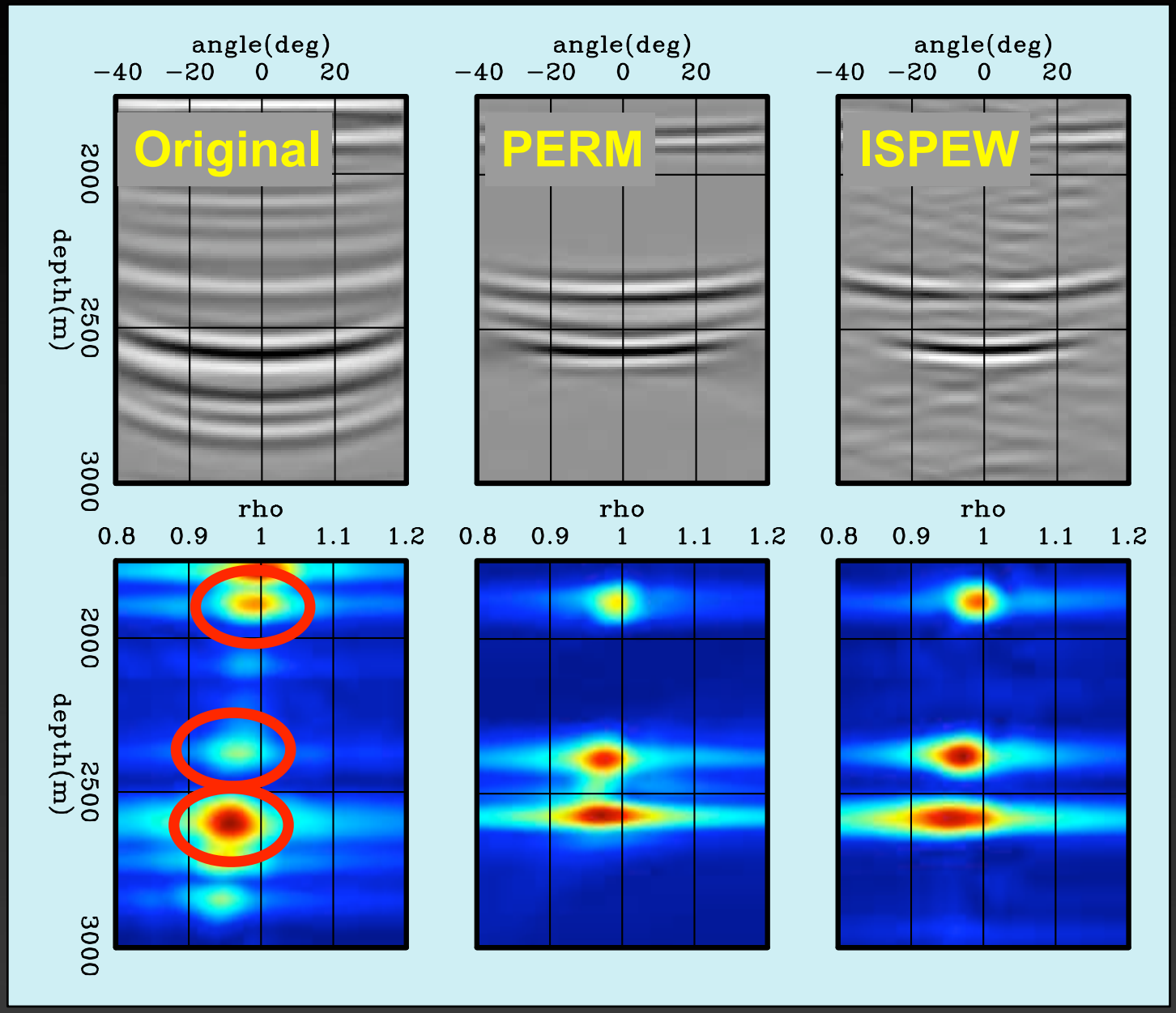
Phase-encoded receiver wavefield



ISPEW data



Moveout information



rho - curvature parameter

By the time of the research proposal ...

Goal

- Velocity model definition for depth migration under the framework of the horizon-based pre-stack exploding-reflector model

Why horizons?

- Reduces the crosstalk problem
  - making the pre-stack exploding-reflector model applicable to field data

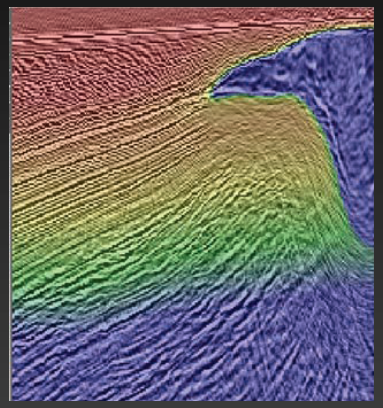
Why horizons?

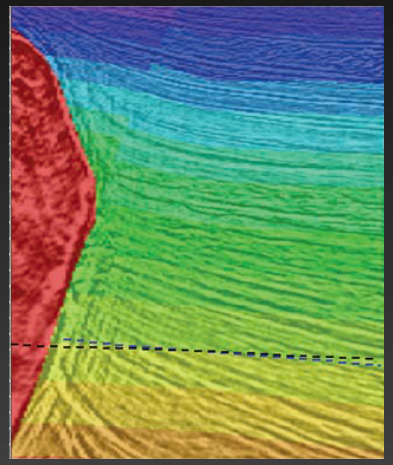
- Reduces the crosstalk problem
- Enables us selecting key reflectors
  - yielding potentially more stable velocity updates

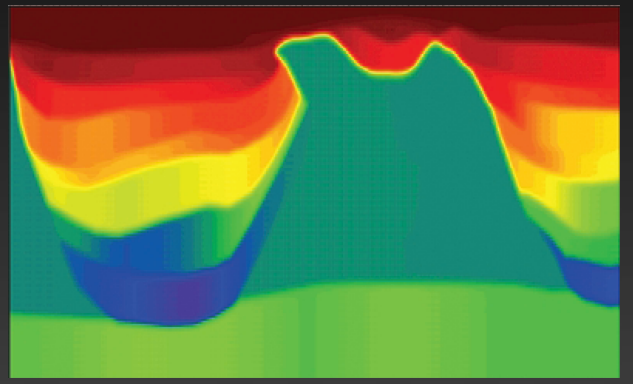
Why horizons?

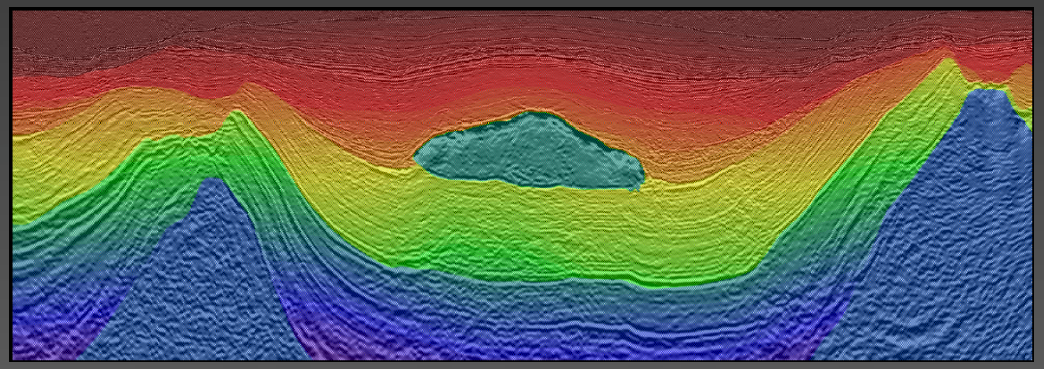
- Reduces the crosstalk problem
- Enables us selecting key reflectors
- Layered-model parameterization
  - geologically constraining the null space of MVA

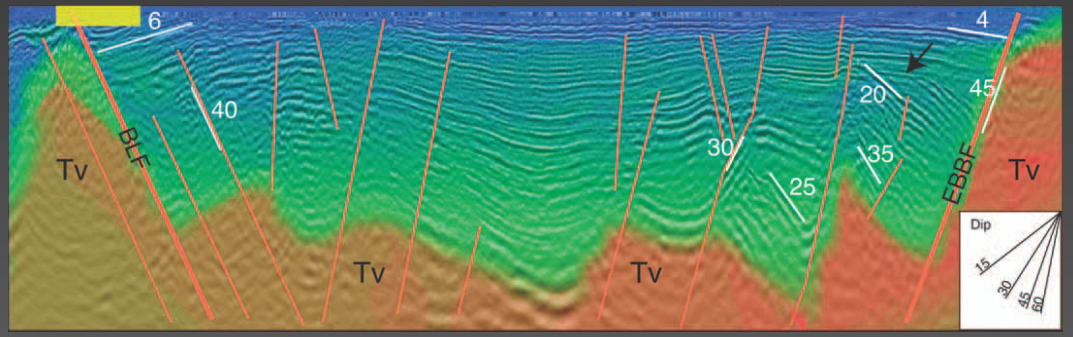
Using a few key reflectors reduces the velocity resolution ...

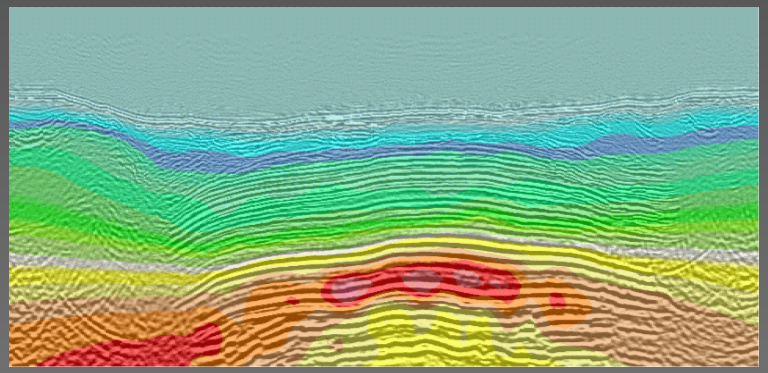












Problems and challenges

- Picking 3D/5D volumes
- Picking in complex geology

Problems and challenges

- Picking 3D/5D volumes
- Picking in complex geology

Time line

- **Deadline: March 2009**
  - 3.5y time constraint
  - Got 6 months extension → Sept 2010

Suggestions from the committee ...

- 2D wave-equation migration-velocity analysis
- 3D ray-based migration-velocity analysis

And what I’m doing

- 2D wave-equation migration-velocity analysis
- 3D wave-equation migration-velocity analysis

Where we are

- Thesis chapters
  - Pre-stack exploding-reflector model
  - Image-space phase-encoded wavefields
  - Migration-velocity analysis using ISPEW
    - running 2D synthetic examples
  - 3D field-data example

3D-North Sea data example

- **Dimensions: 12 x 4 km**

3D-North Sea data example

- **Dimensions: 12 x 4 km**

- **20 ISPEW**
  - **Target region: 600-3200 m depth range**

3D-North Sea data example

- **Dimensions: 12 x 4 km**

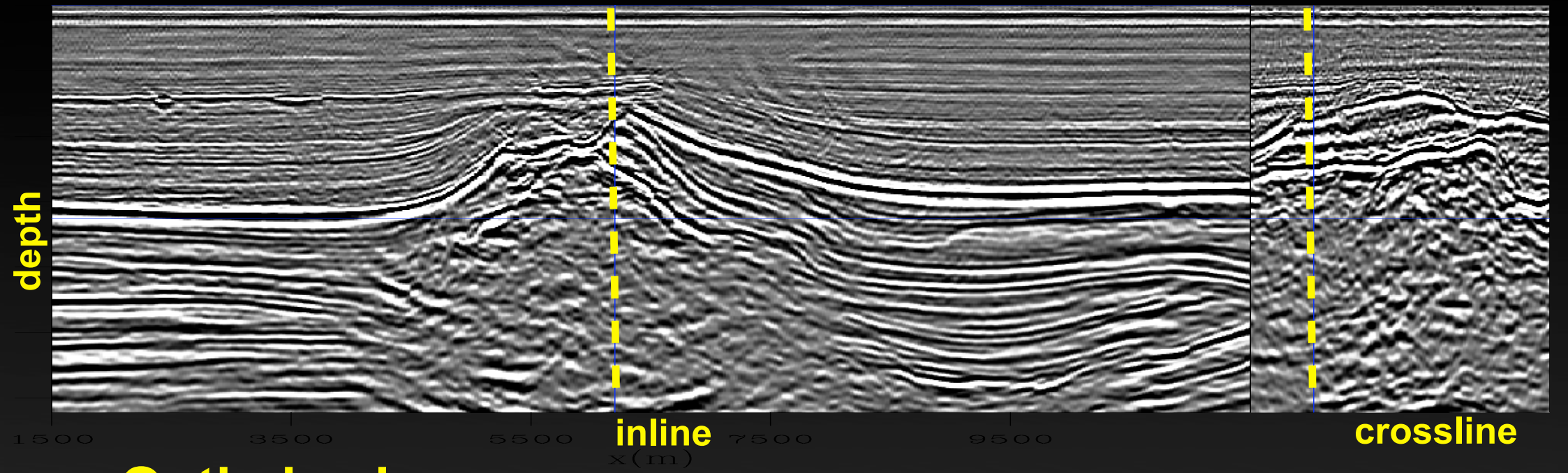
- **20 ISPEW**
  - **Target region: 600-3200 m depth range**

- **CEES: 20 Dual Nehalem 5520, 24Gb RAM**
  - **Perturbed image: 20 min**
  - **Gradient: 40 min**

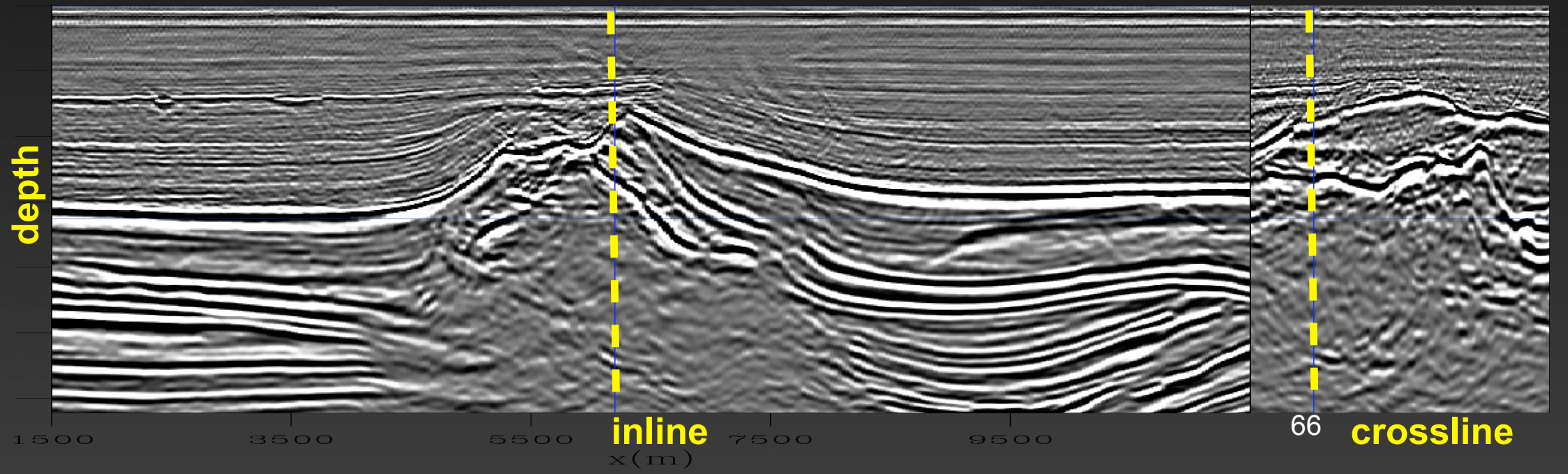
3D-North Sea data example

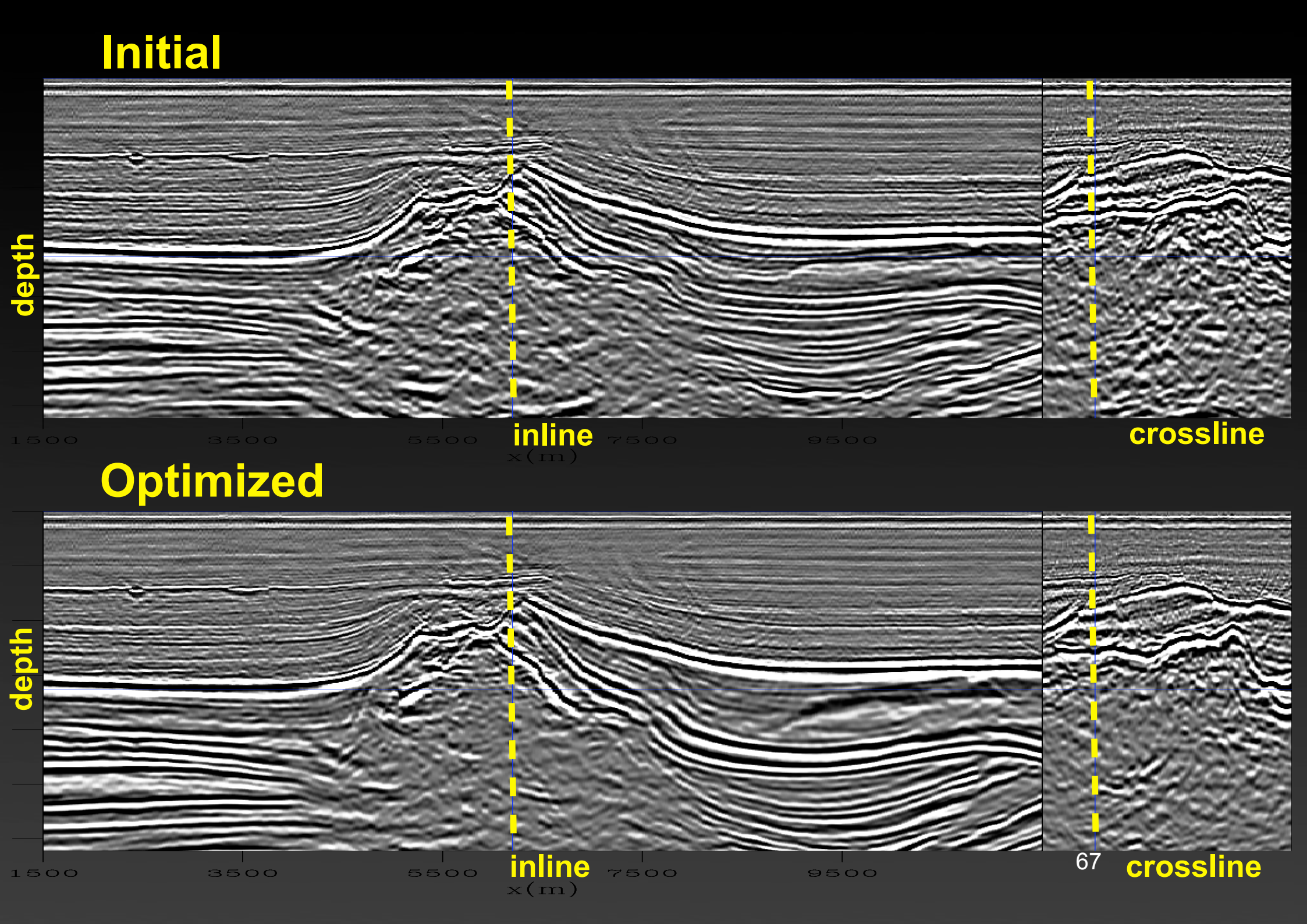
- **First ISWET run for the base of chalk**
  - **Image improved compared to the initial**
- **Second ISWET run for the base of chalk**
  - **Improvements, but still with some residual moveout**

Initial

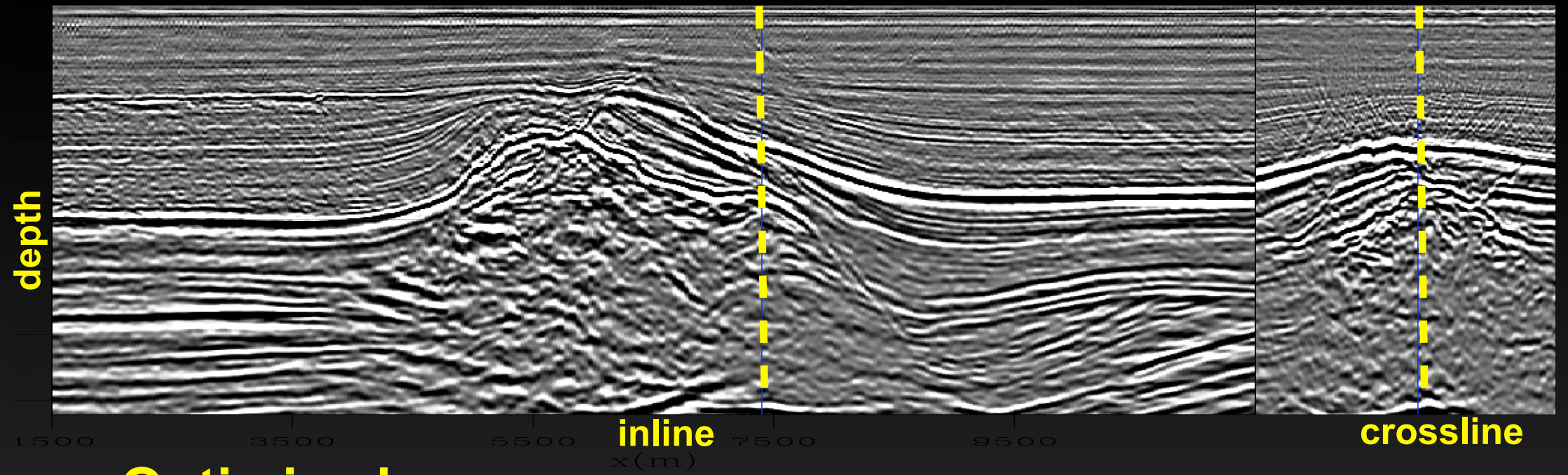


Optimized

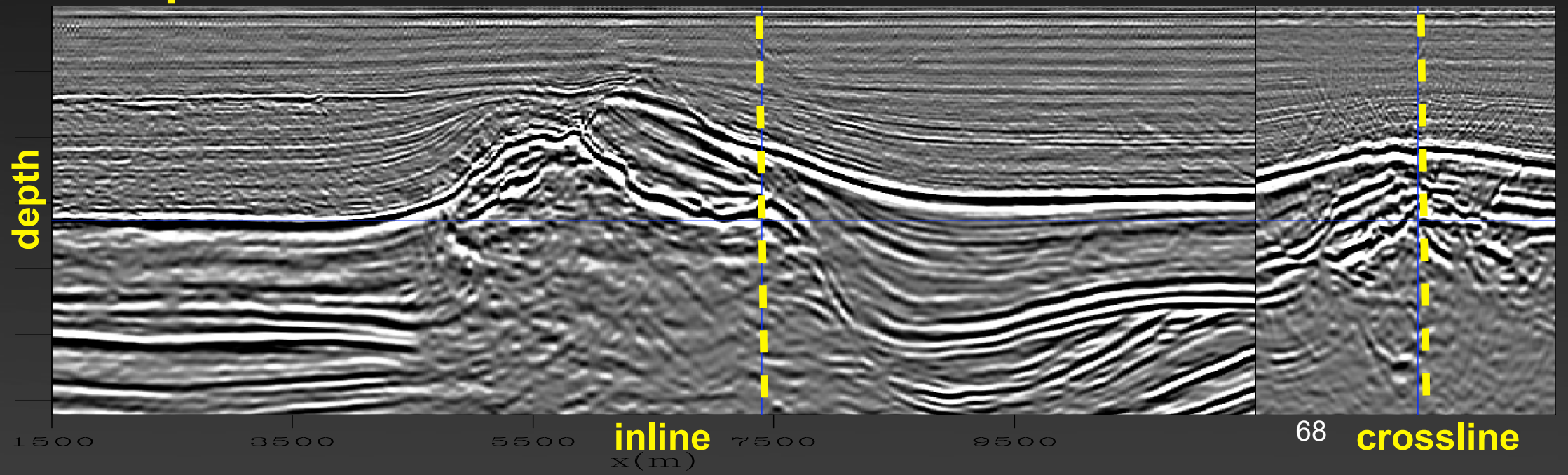



Initial
depth
1500
3500
5500
inline
7500
9500
x(m)
crossline
Optimized
depth
1500
3500
5500
inline
7500
9500
x(m)
67
crossline

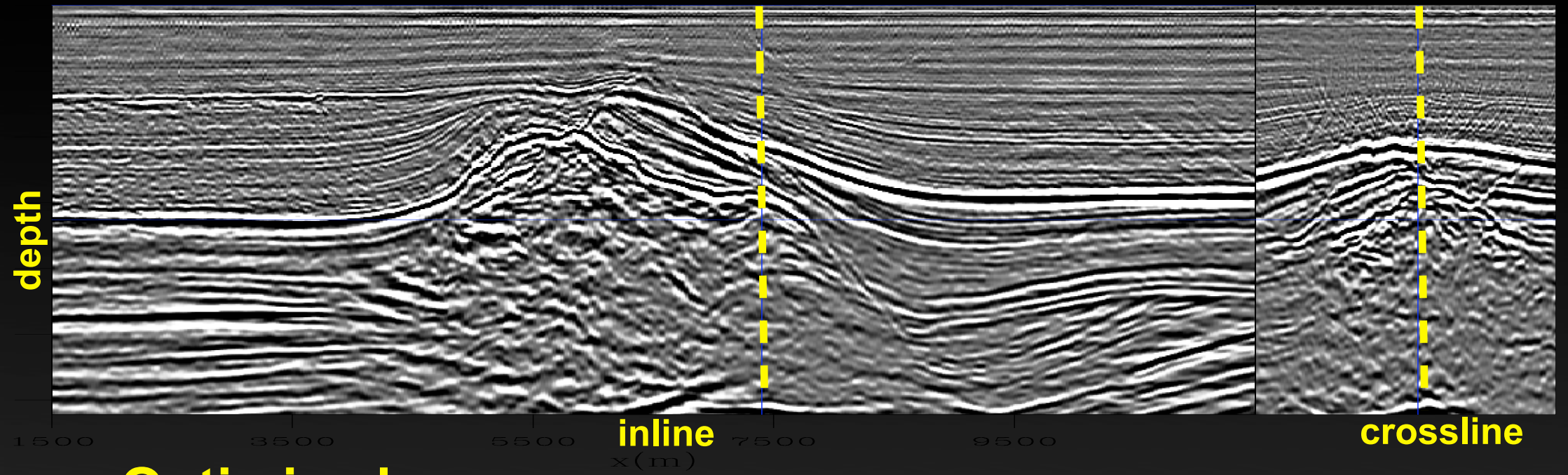
Initial



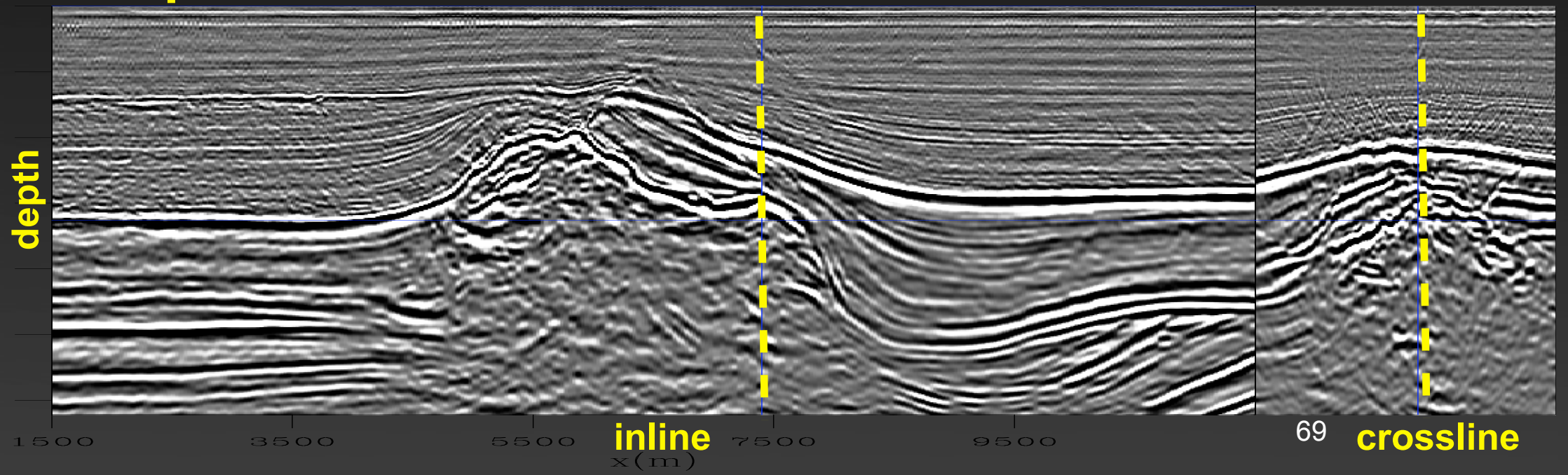
Optimized



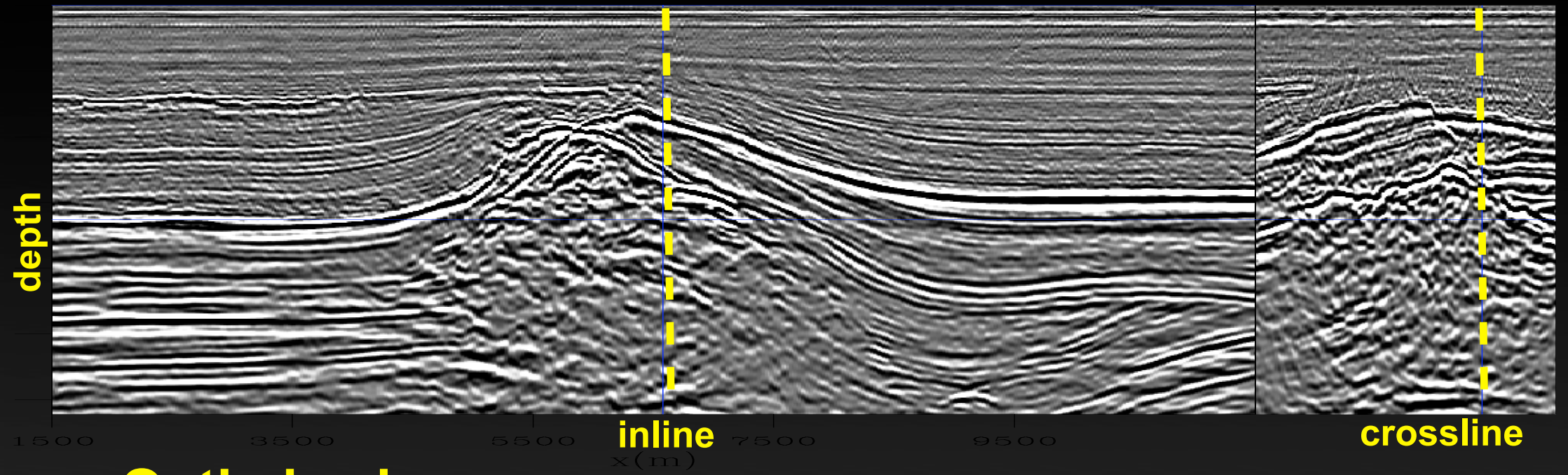
Initial



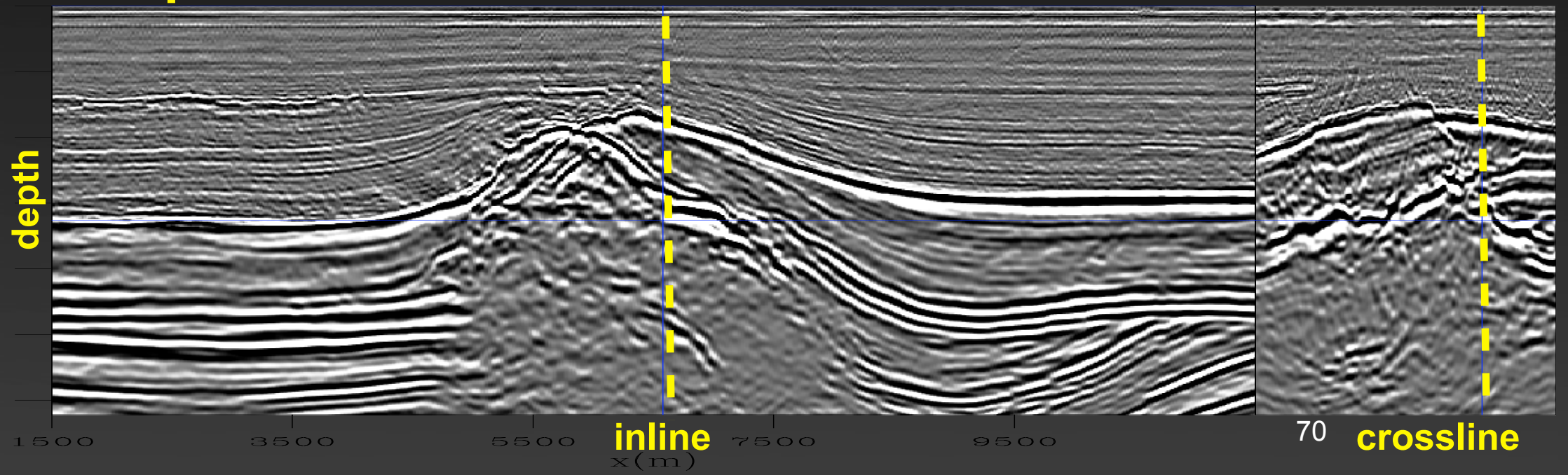
Optimized



Initial



Optimized



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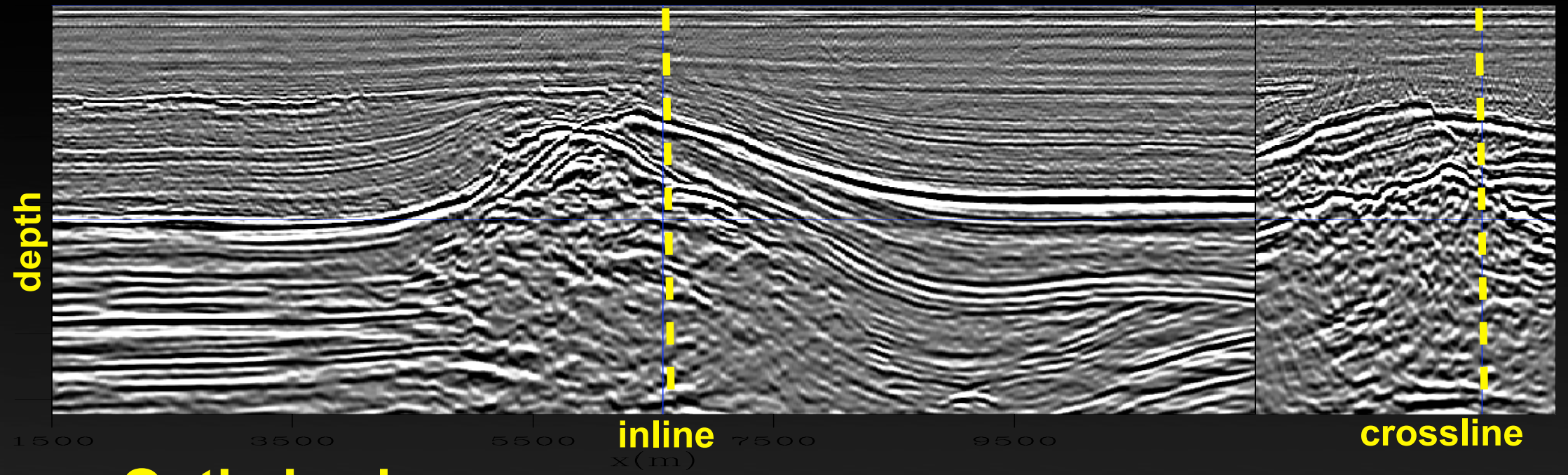

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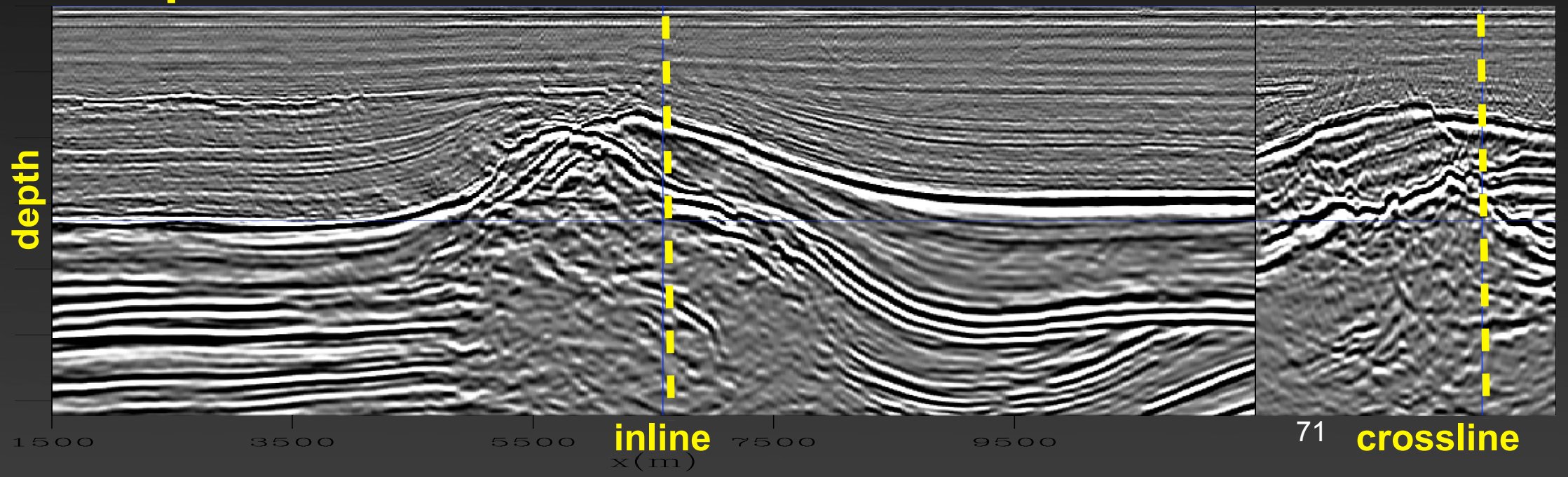

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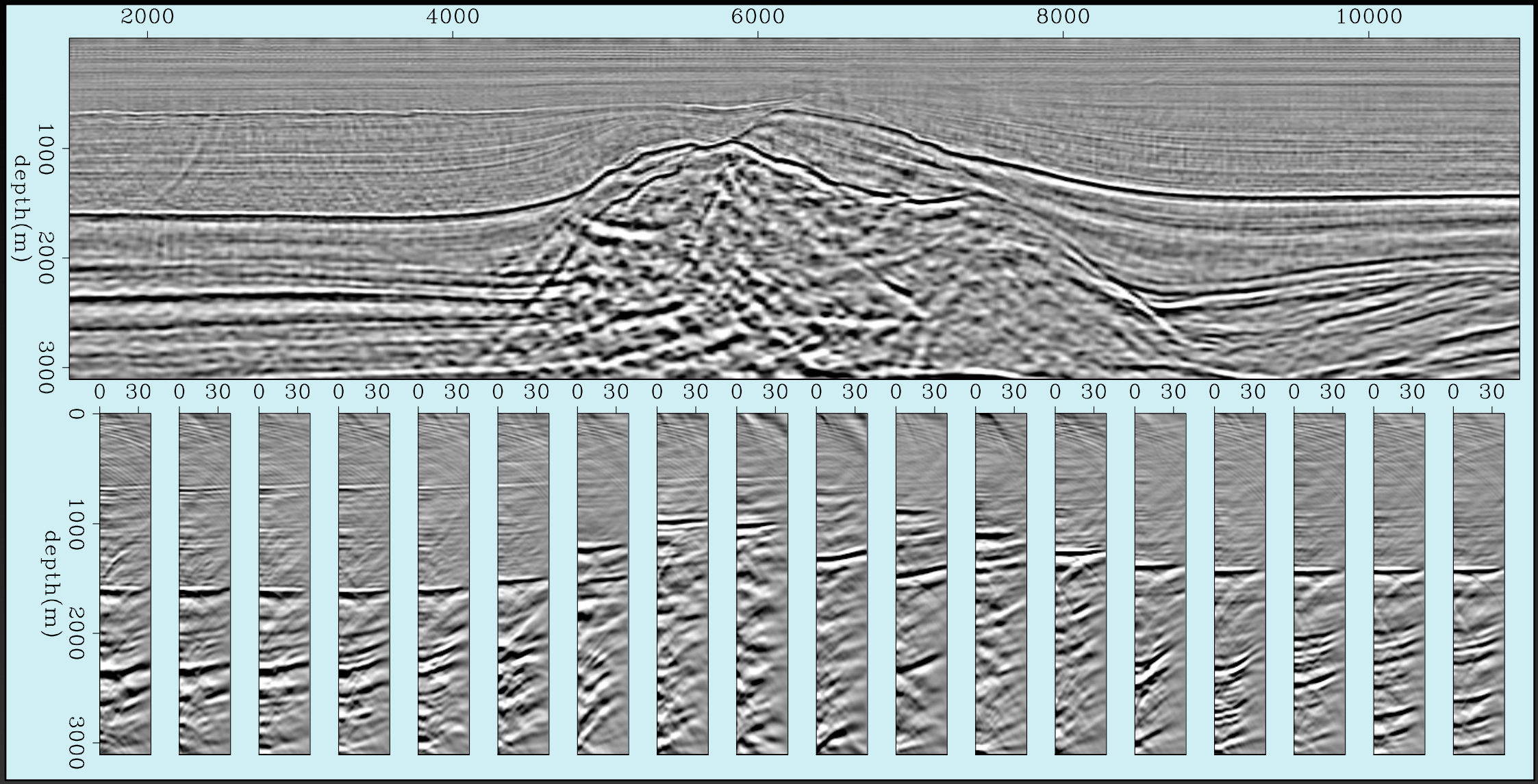
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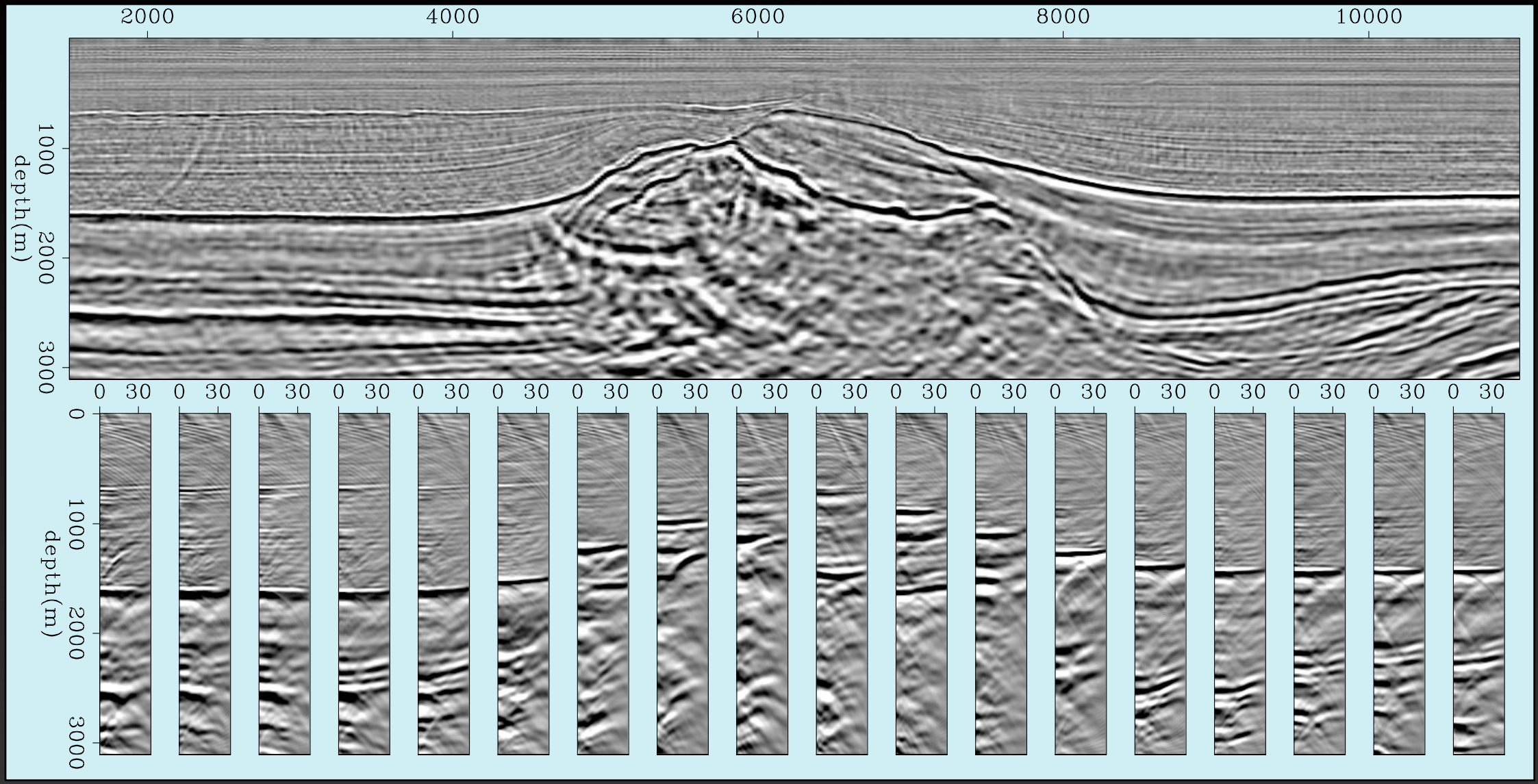
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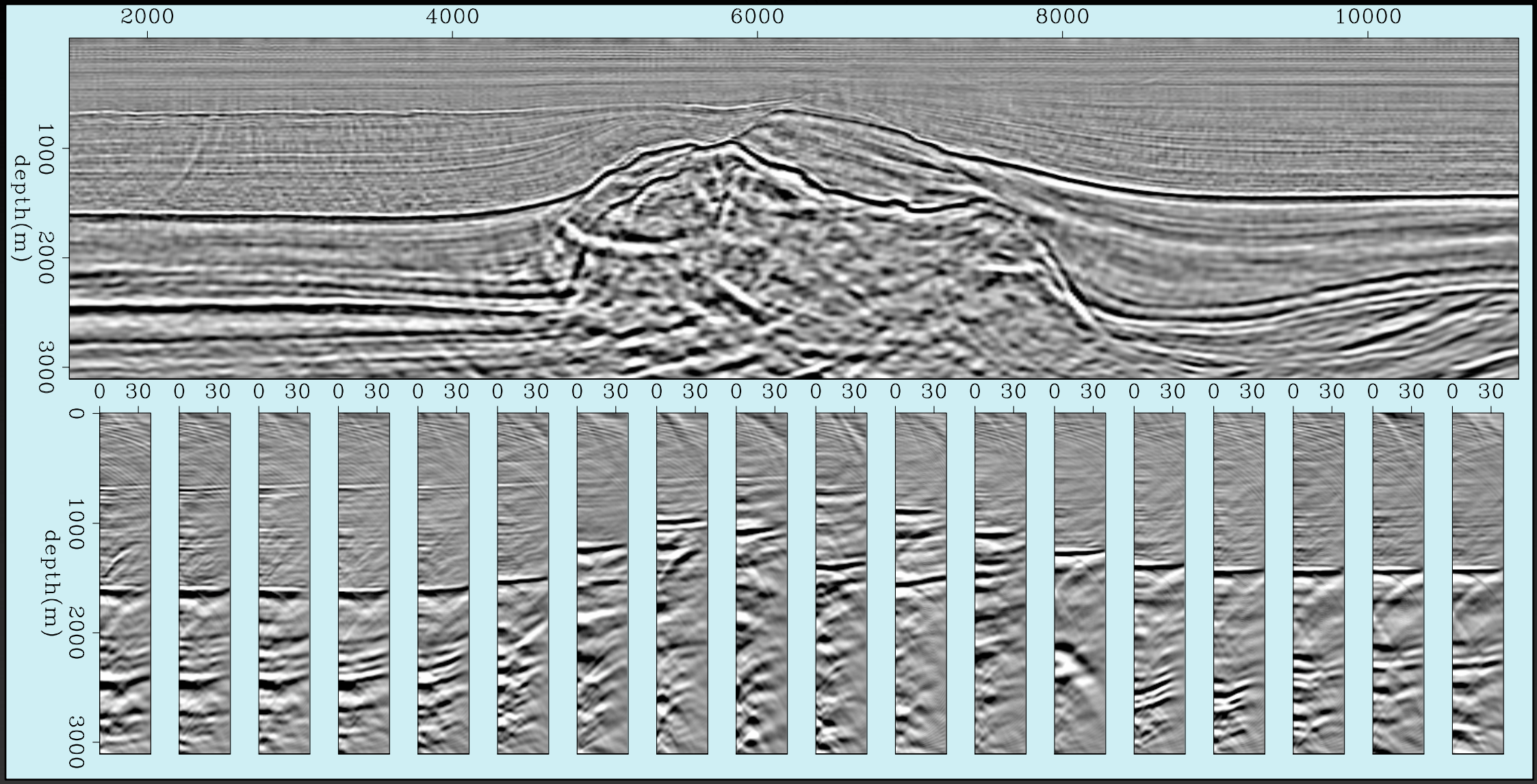
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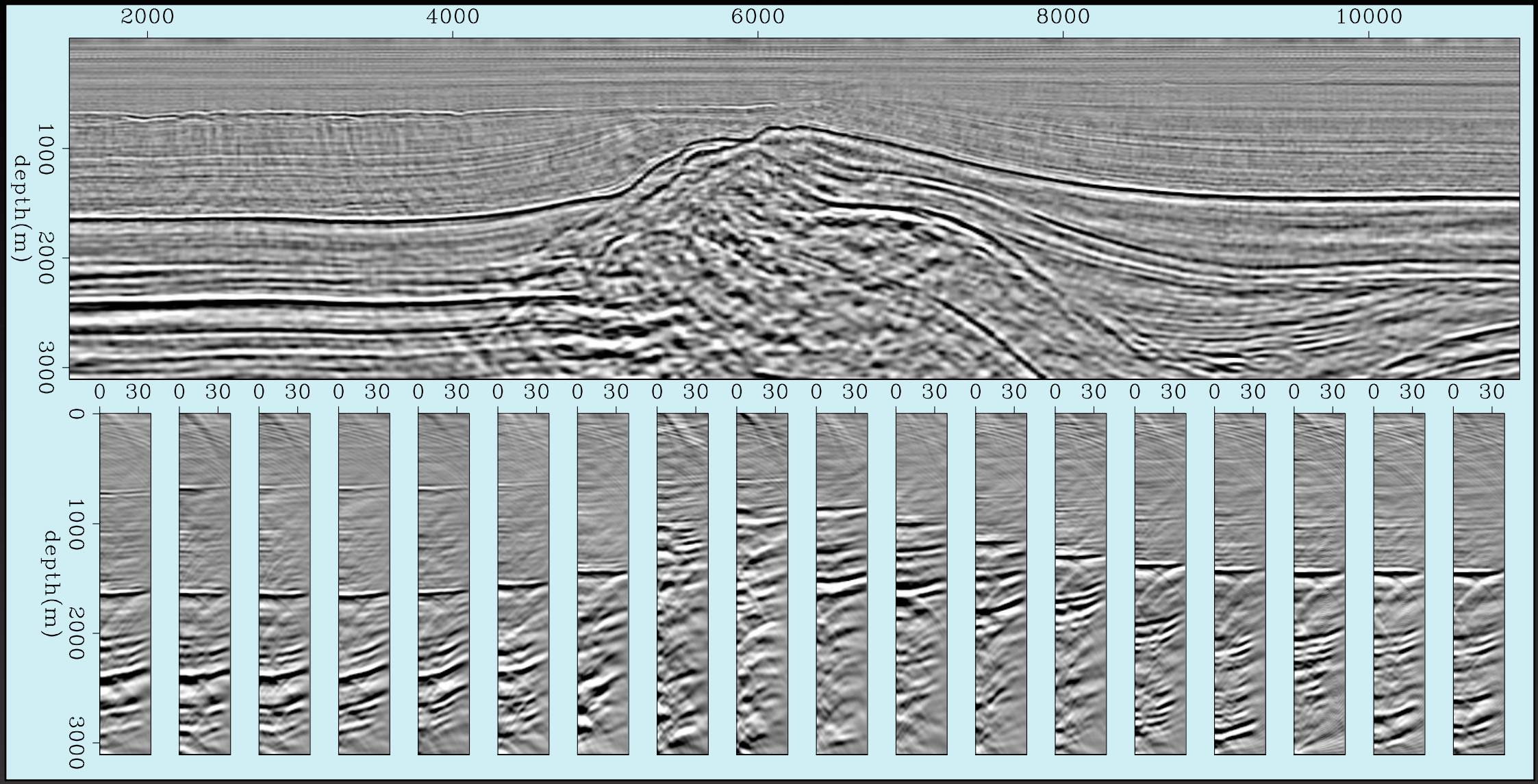
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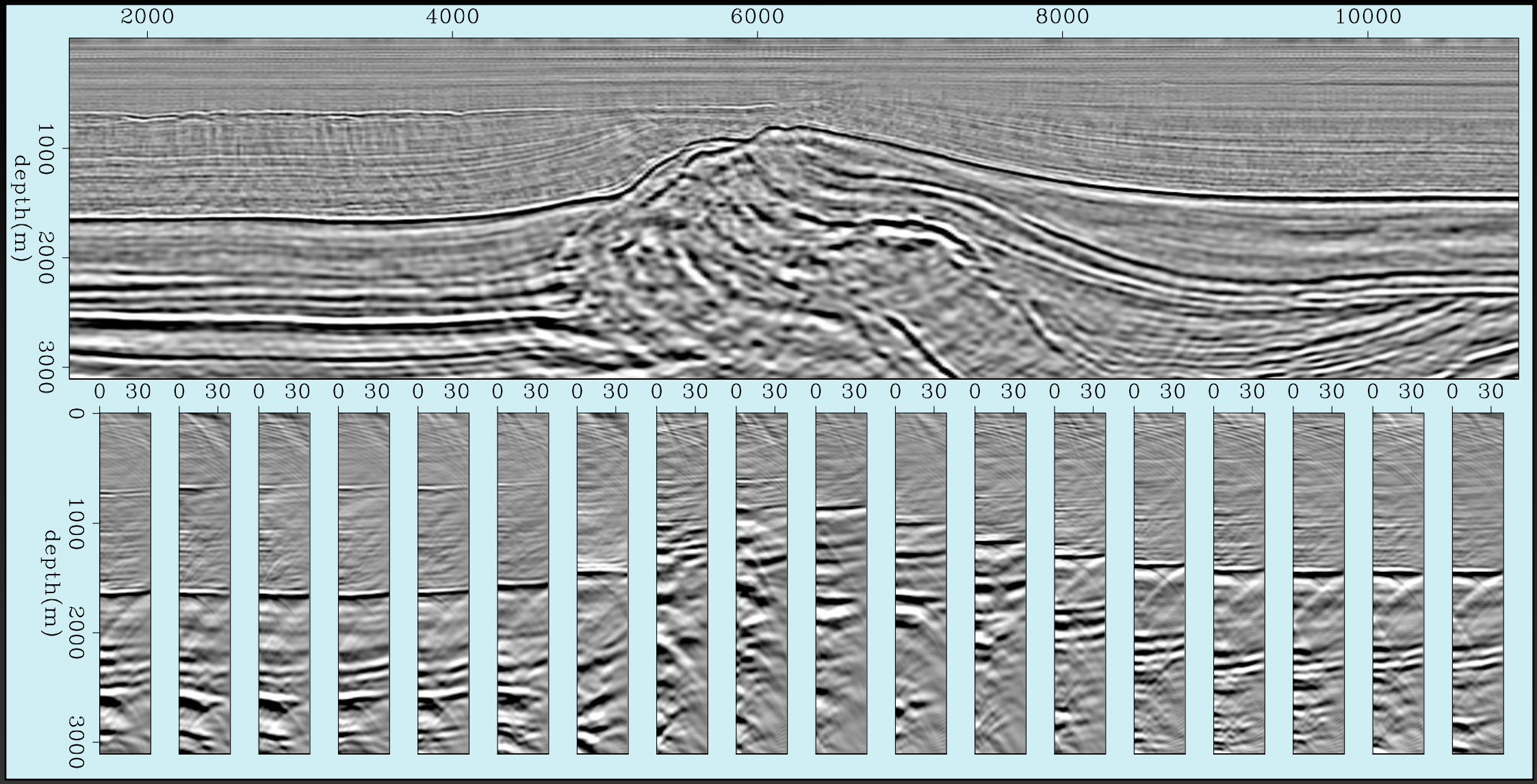
Optimized 1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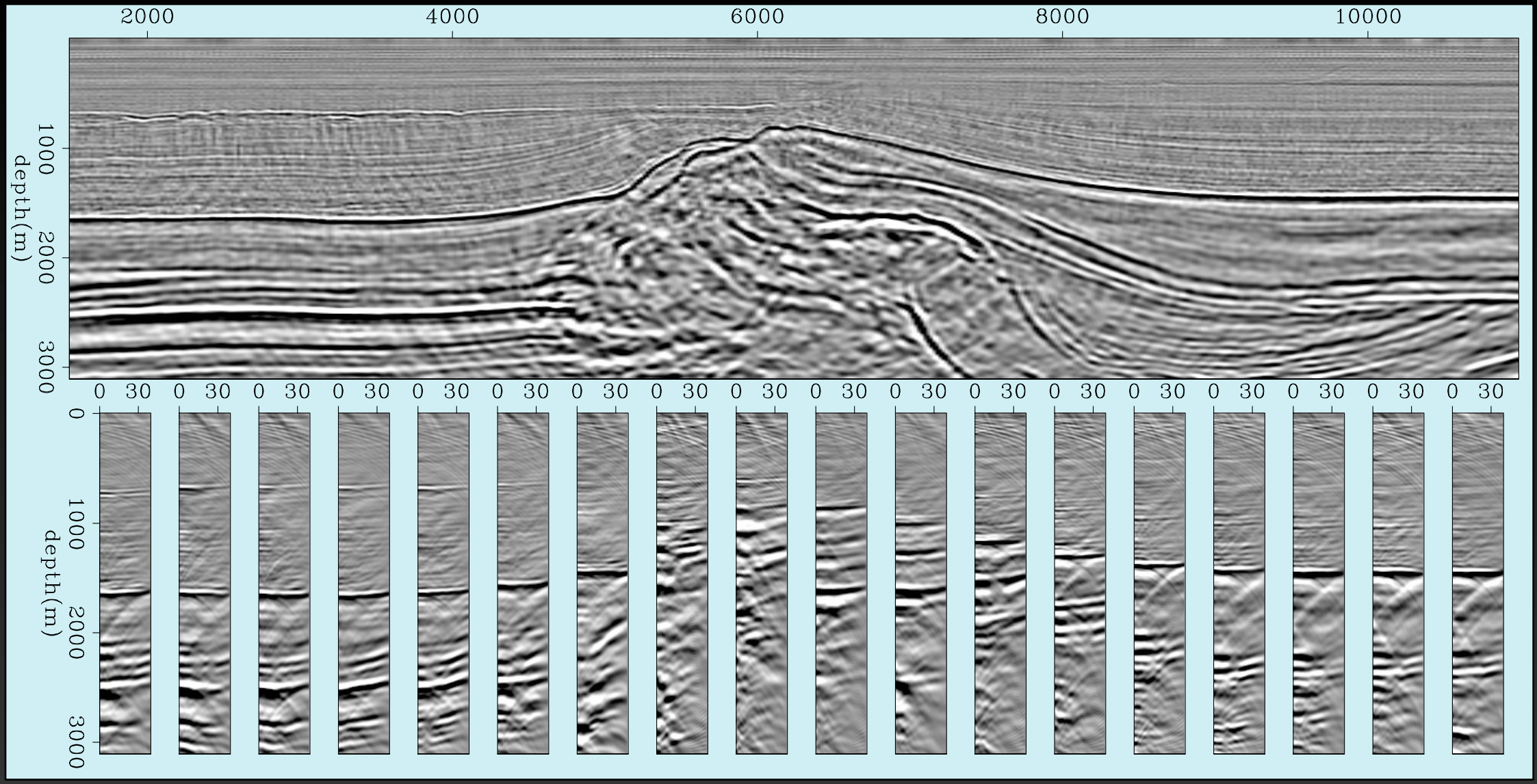
Optimized 2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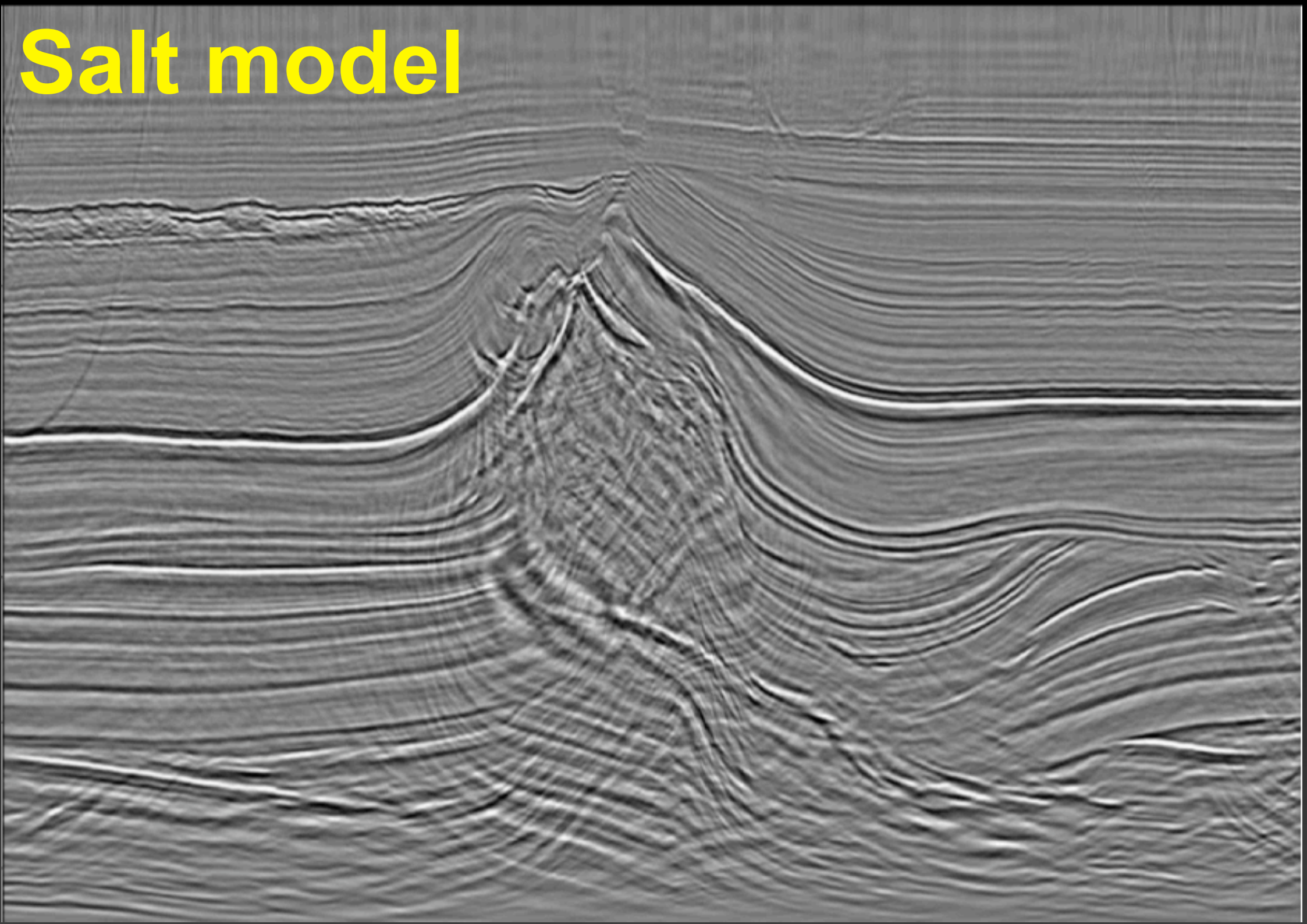
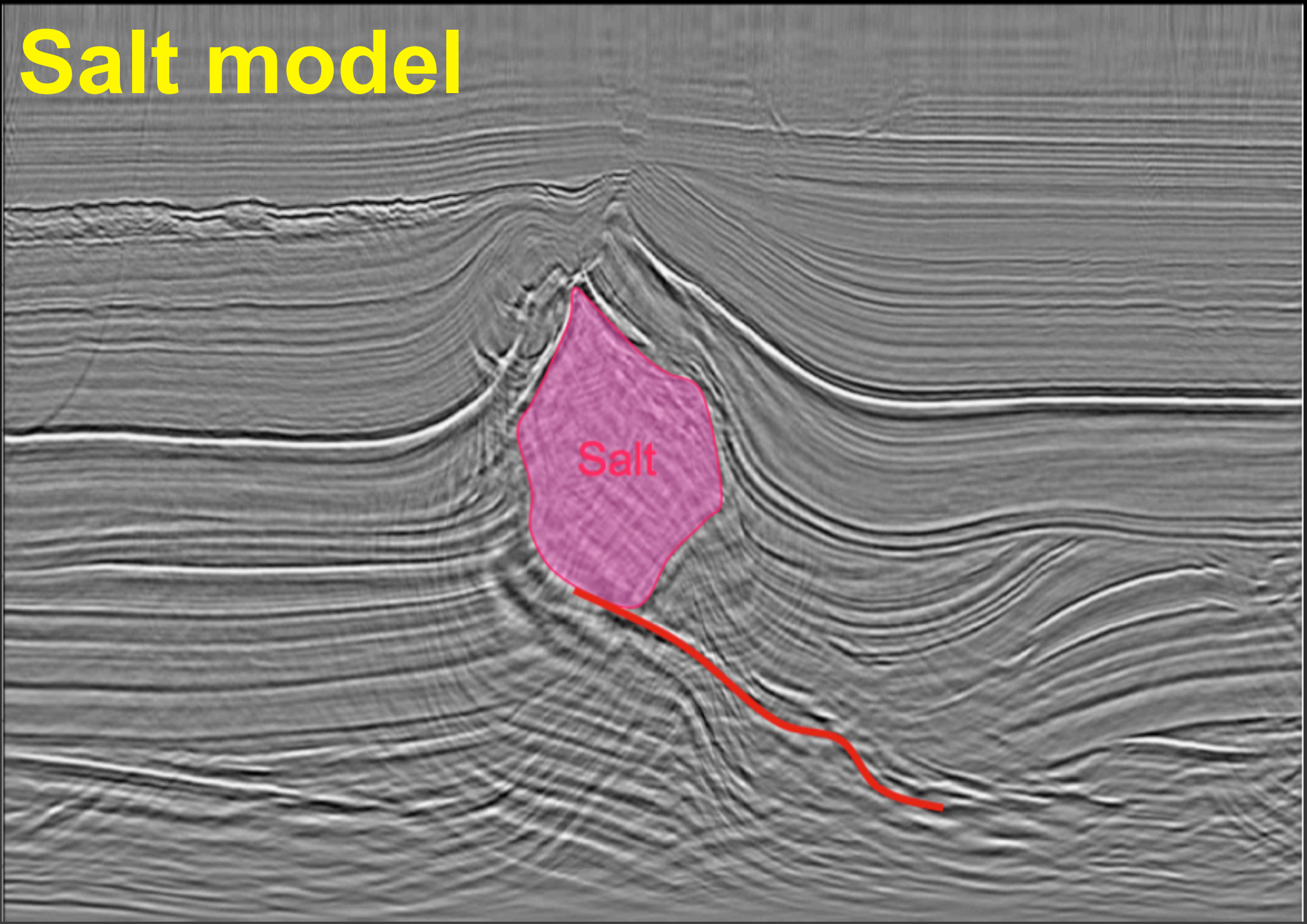

Salt model


Salt model
Salt

Salt Model

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3D-North Sea: Next steps

Final Remarks

- **Image-space generalized wavefields accelerate ISWET**
  - **reduced data size**
  - **target-oriented strategy**
  - **2 h per iteration**

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  - **reduced data size**
  - **target-oriented strategy**
  - **2 h per iteration**

- **Image-space generalized wavefields naturally incorporate a horizon-based strategy**

Final Remarks

Suggestions are highly appreciated

Acknowledgements

- Pierre Jousselin, from Total, for discussing about velocity model building in the North Sea
- Bob Clapp for continuously improving SEP's visualization/interpretation capability
- Dennis Michael, from CEES, for his continuous support
- TotalFinaElf for providing the North Sea dataset

Thanks

Fast 3D velocity updates using the pre-stack exploding-reflector model

Claudio Guerra and Biondo Biondi

SEP 140, pp 1-10
May 2010

Generalized-source domain

- **Wavefields combined using linearity of wavefield propagation**

Generalized-source domain

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  - **Smaller number of seismic experiments**

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  - **Simultaneous-sources**

- **Seismic processing**
  - **plane-wave encoding (Whitmore, 1995)**
  - **random-phase encoding (Romero et al., 2000)**
  - **controlled illumination (Rietveld et al., 1992)**

Generalized-source domain

- **Data-space generalized sources**
  - **plane-wave encoding**
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Generalized-source domain

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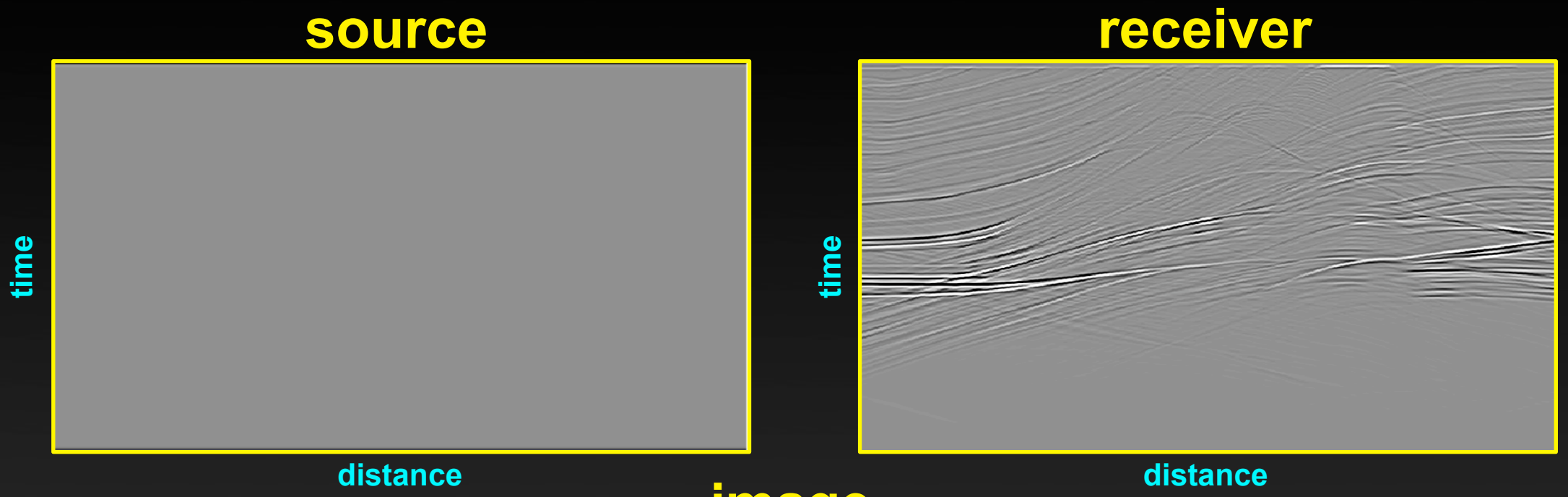
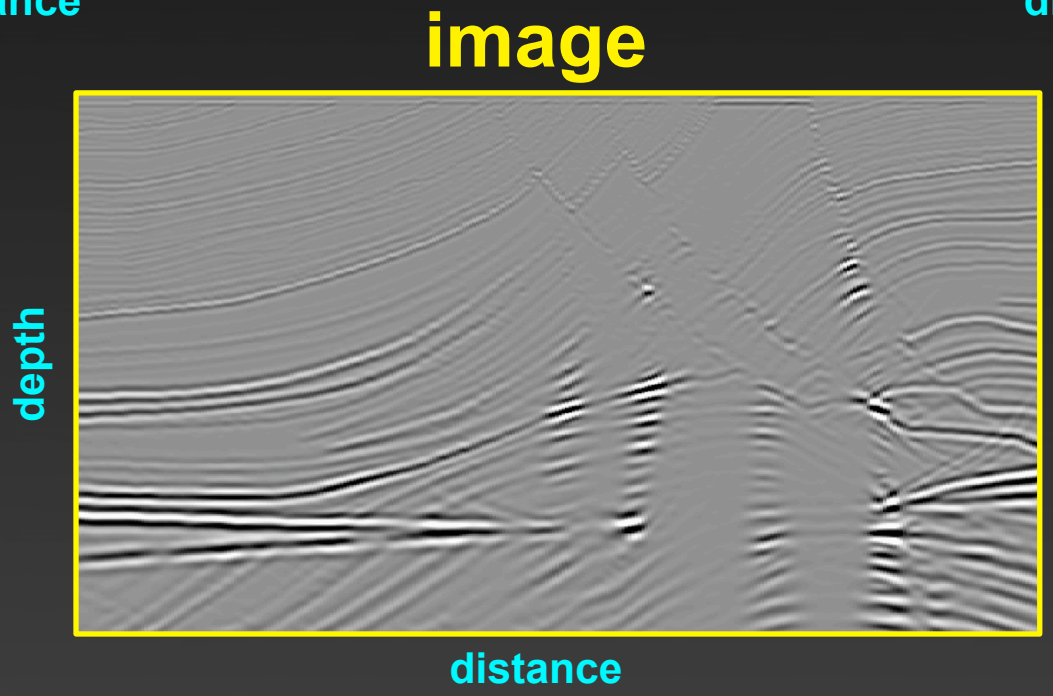
  - **plane-wave encoding**
  - **random-phase encoding**
  - **controlled illumination**

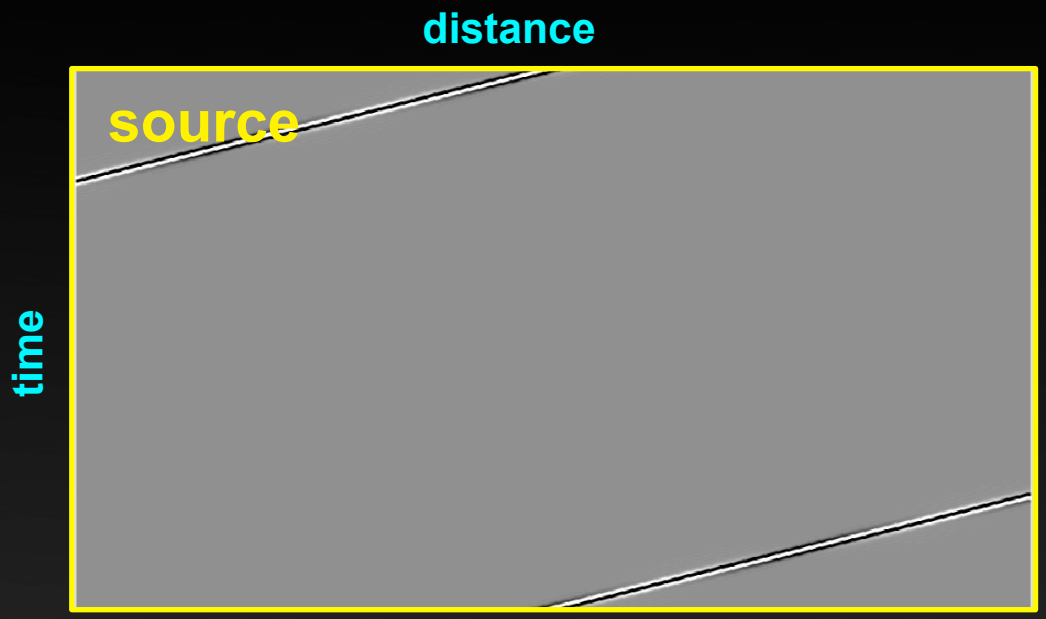
- **Image-space generalized sources**
  - **Pre-stack exploding-reflector modeling - PERM (Biondi, 2006)**
  - **Image-space phase-encoded wavefields - ISPEW (Guerra and Biondi, 2008)**

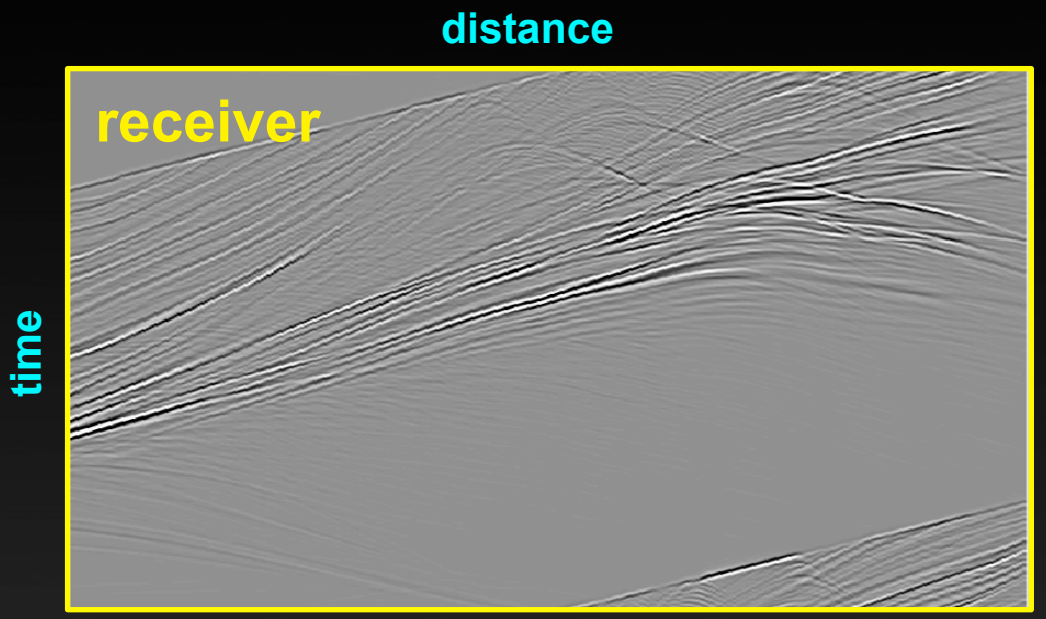
Data-space: 0° plane wave

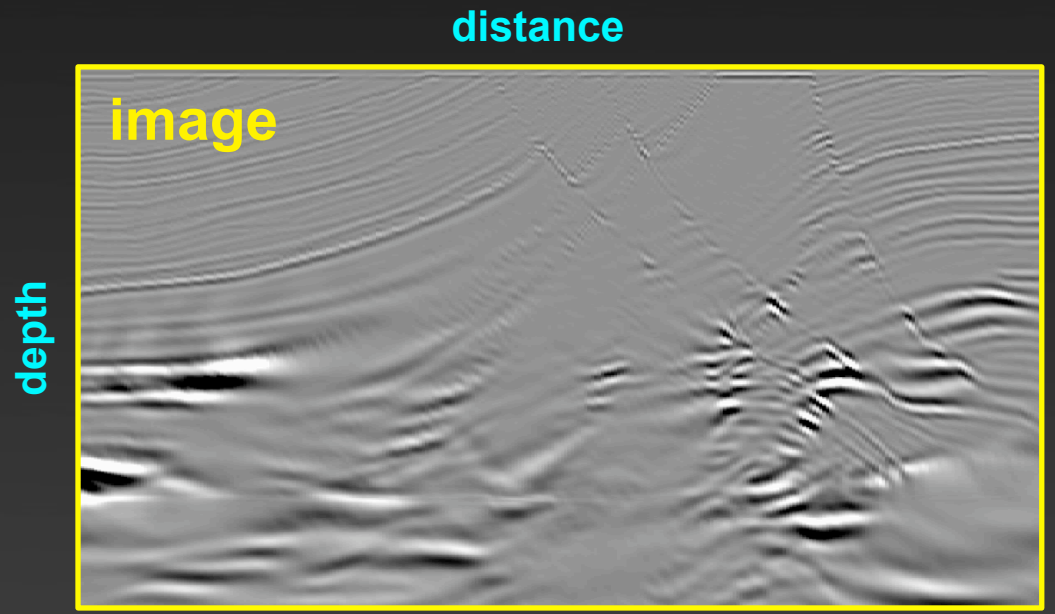




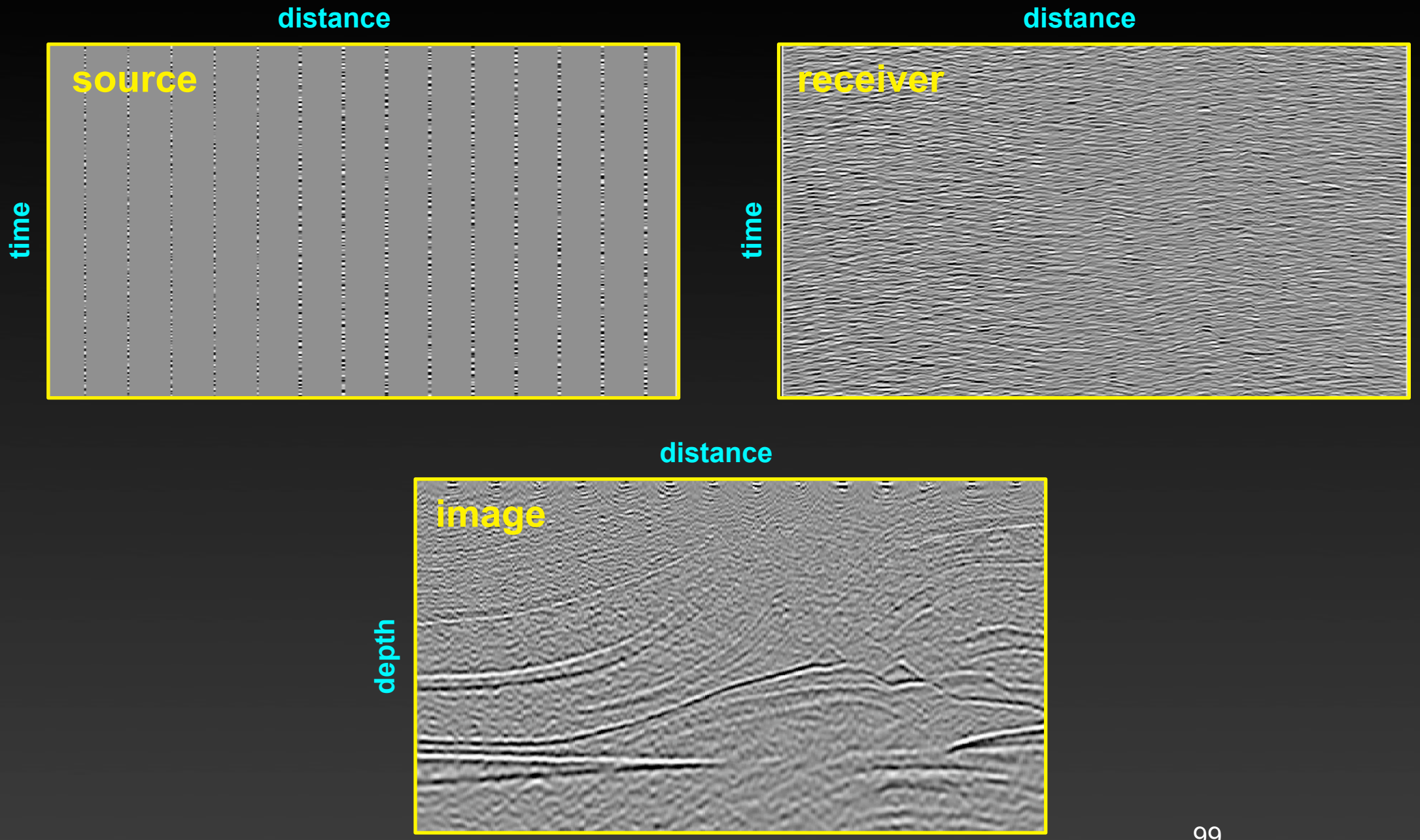
Data-space: plane waves



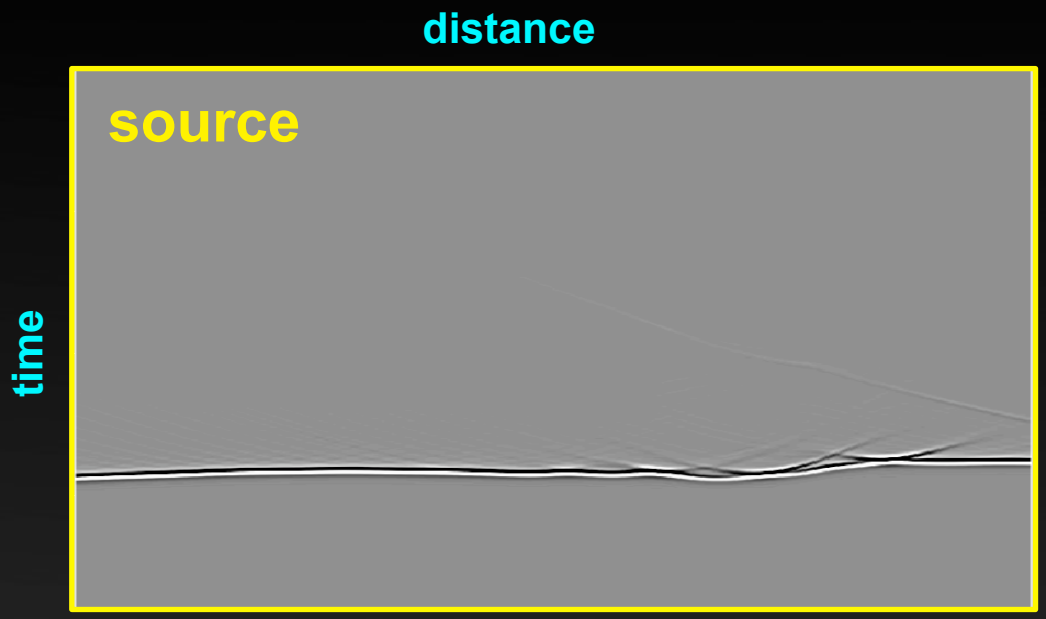


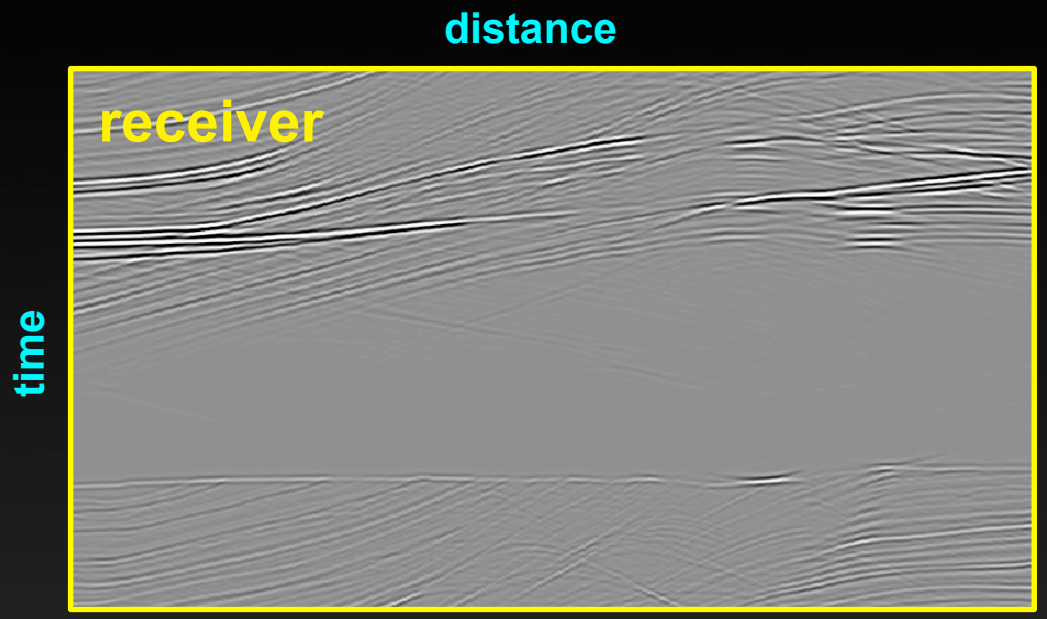


Data-space: random phases



Data-space: controlled illumination





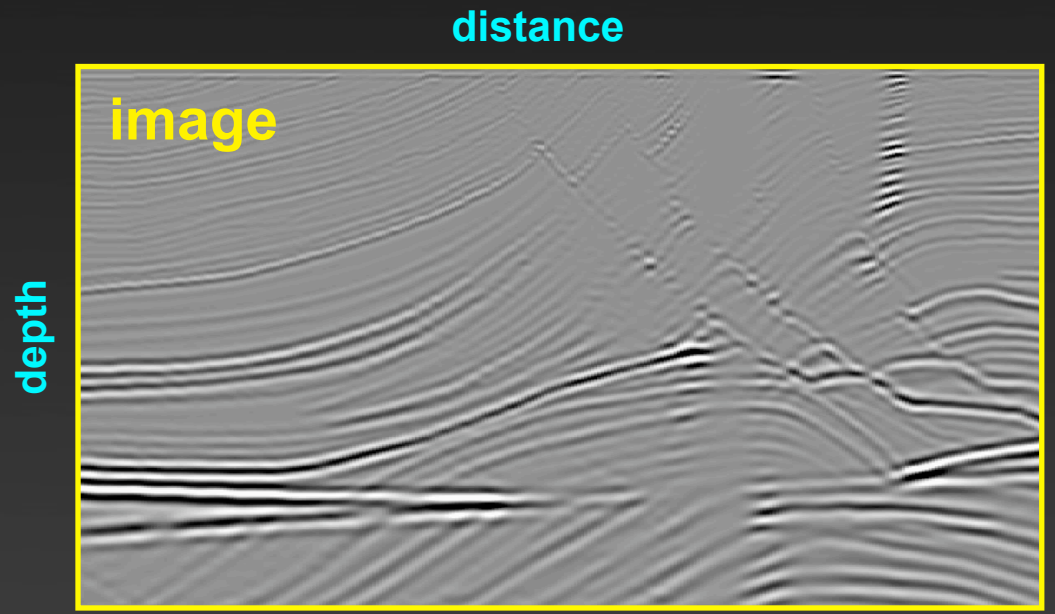


Image-space: prestack-exploding reflector

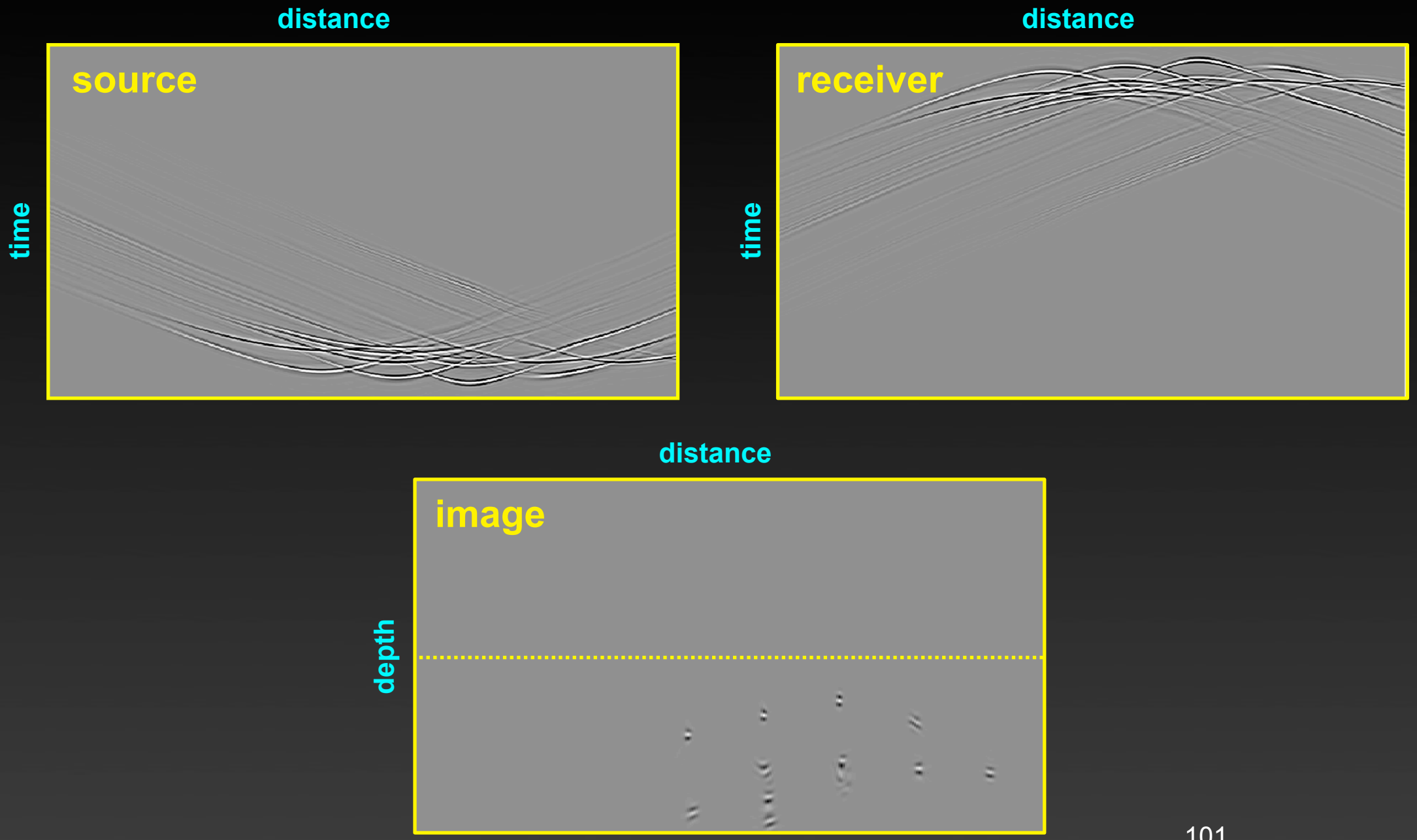
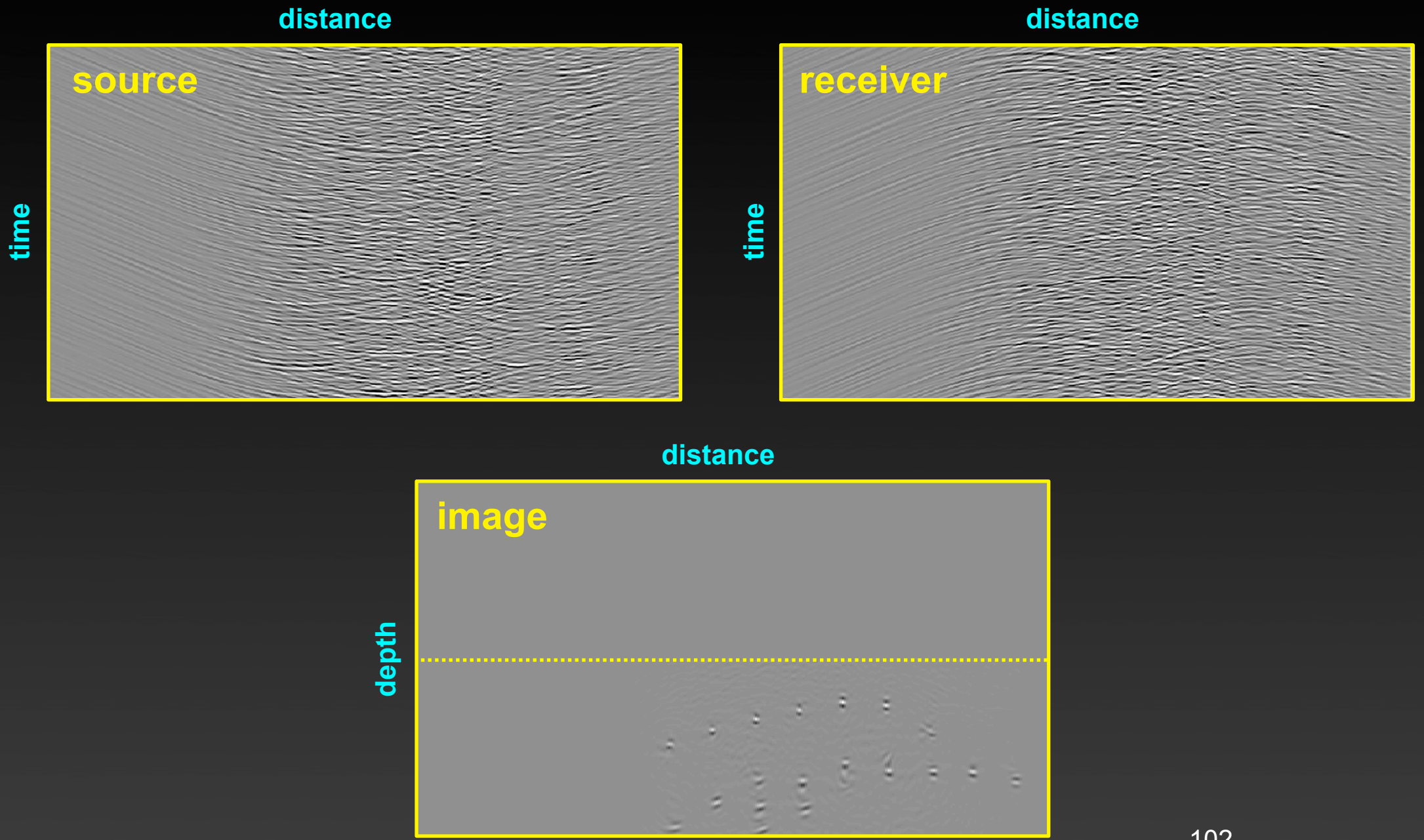
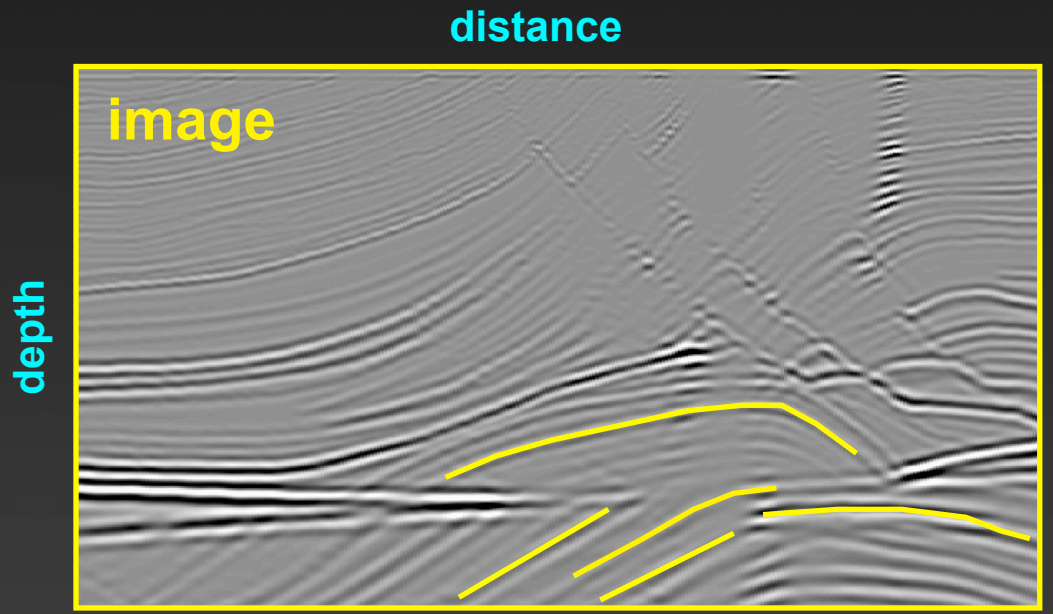
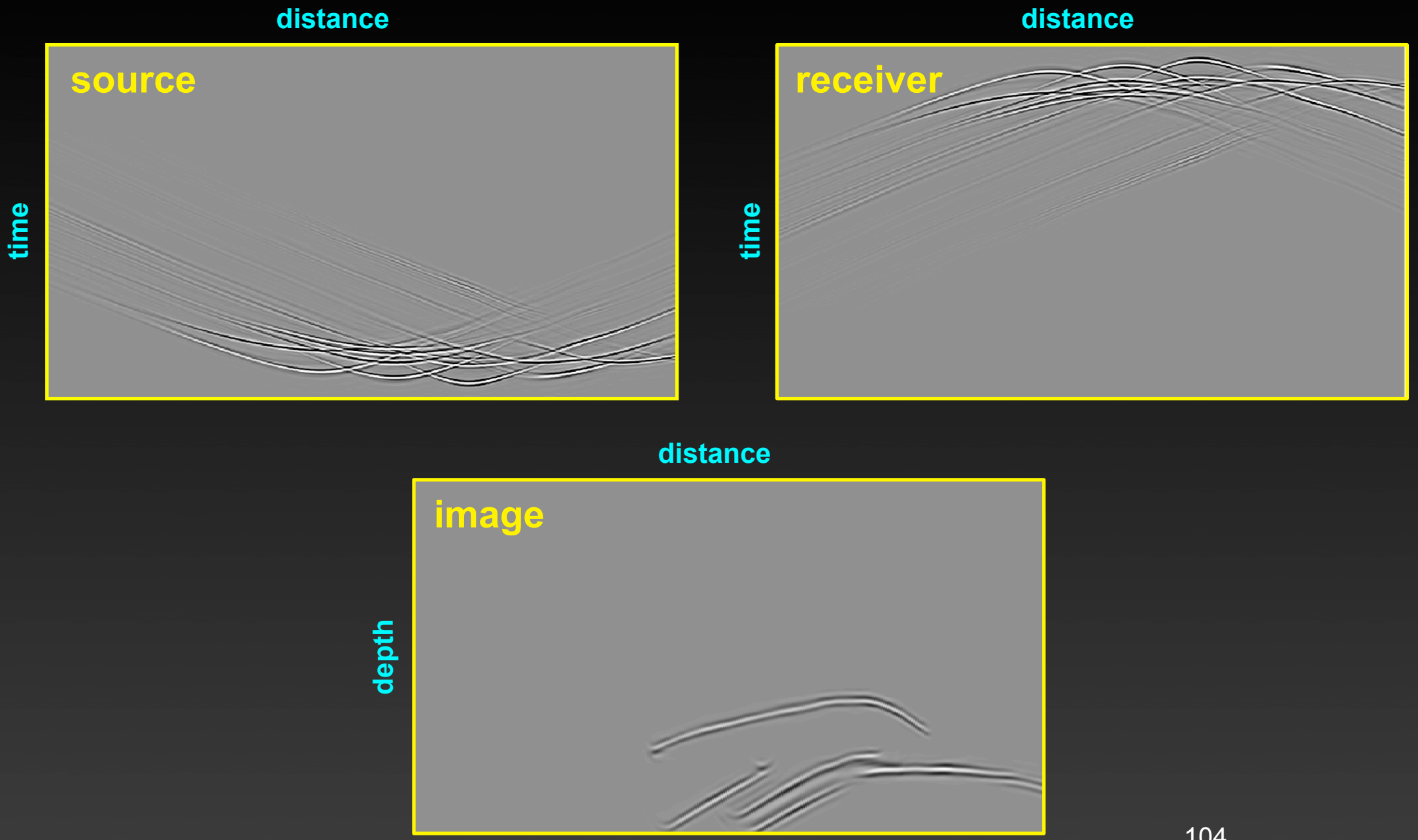


Image-space: random phases (ISPEW)



- **Models wavefields from selected reflectors**

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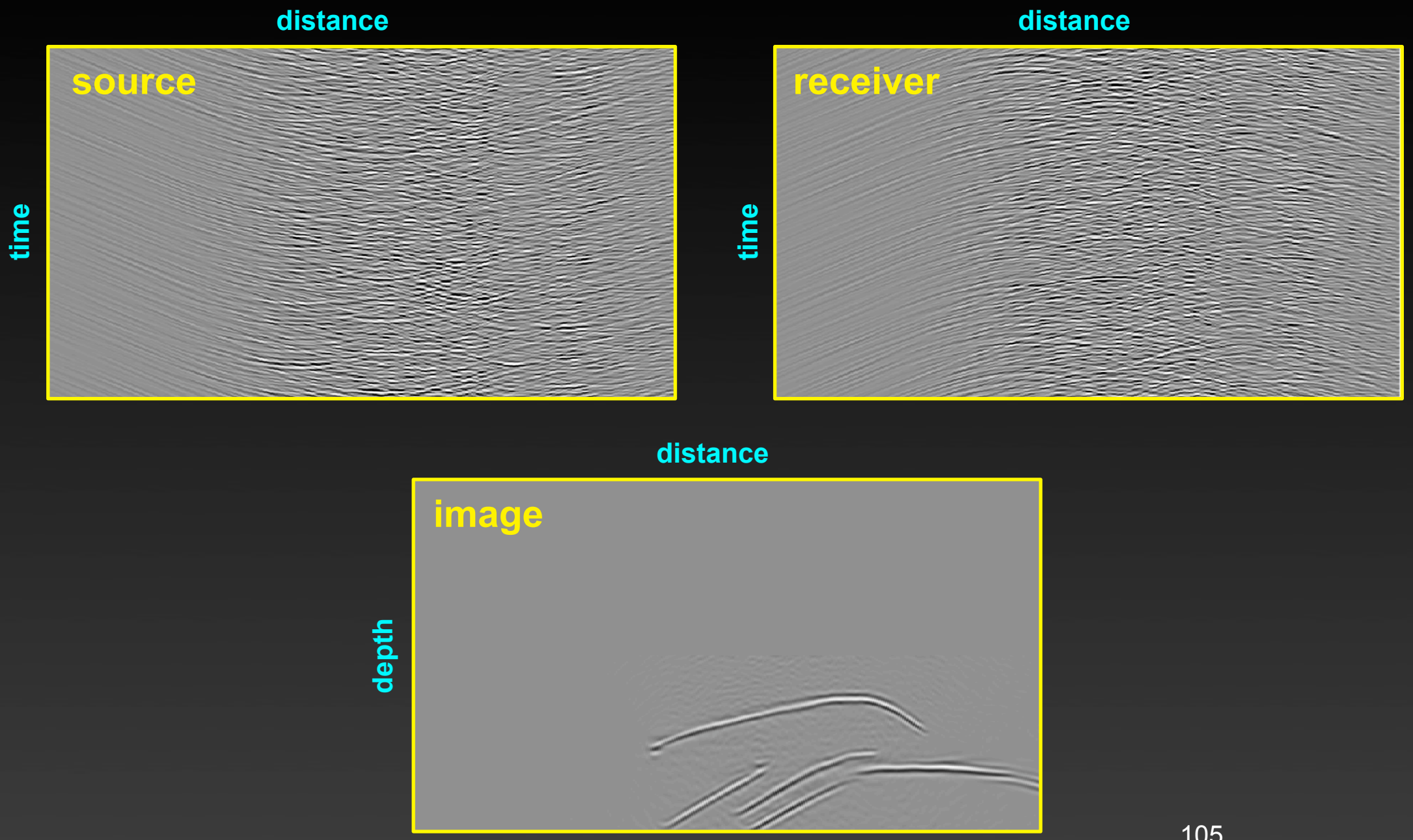
distance
source
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image
depth

Work that had to be done

- Test phase-encoding schemes from different communities
- Alternative imaging conditions
- 3D algorithms

GS-ISWET Objective function

$$J(s) = \frac{1}{2} \left\| \Delta \widetilde{I}(s) \right\|_2$$

Residual pre-stack depth migration (Sava, 2004)

Differential semblance optimization (DSO) operator (Symes and Carazzone, 1991)

$J(s) = \text{objective function} \quad \Delta \widetilde{I}(s) = \text{perturbed image}$

Differential-semblance objective function

$$J(s) = \frac{1}{2} \left\| \mathbf{h} \widetilde{I}(s) \right\|_2$$

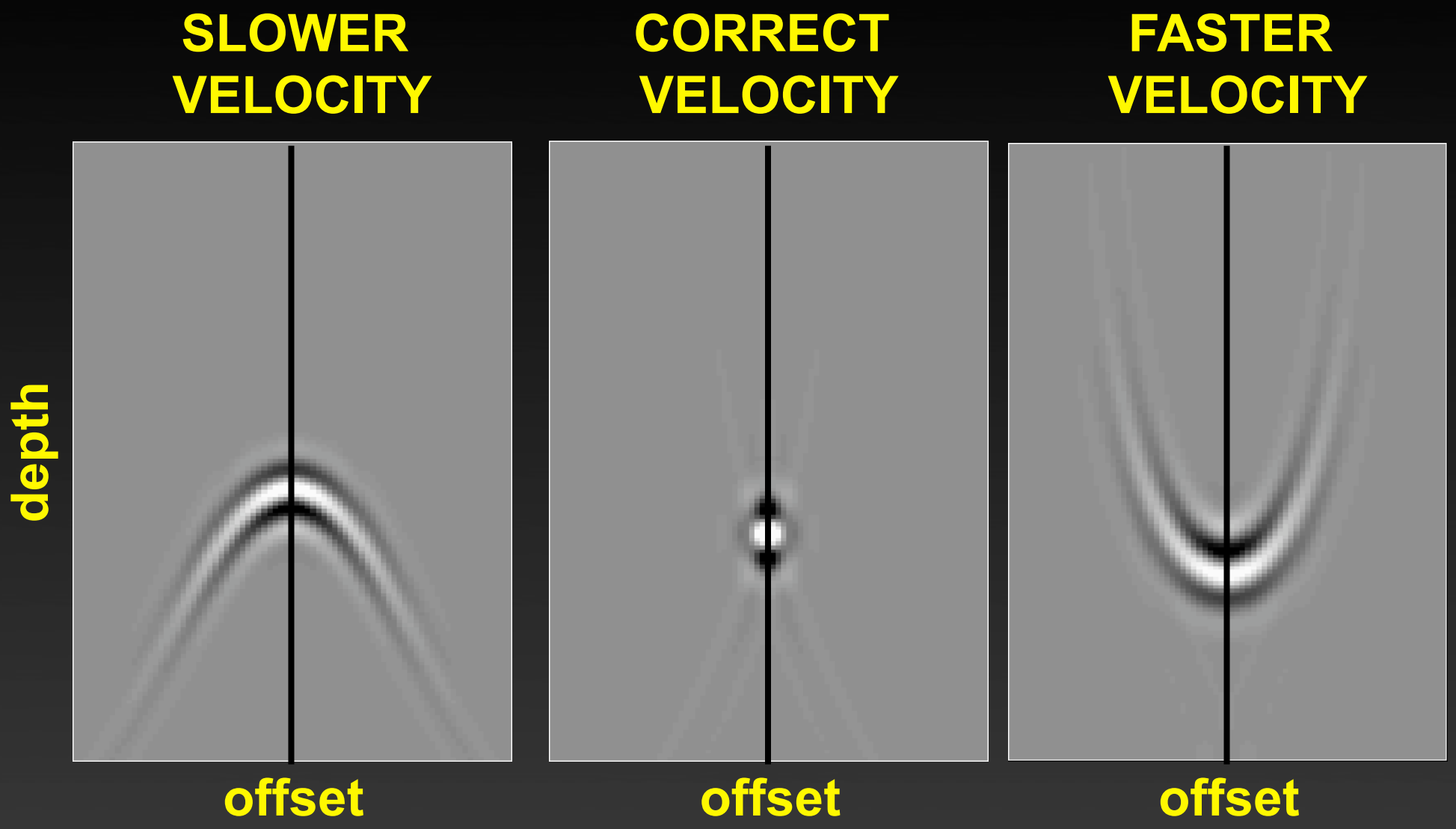
$J(s) =$ objective function

$\mathbf{h} =$ DSO operator

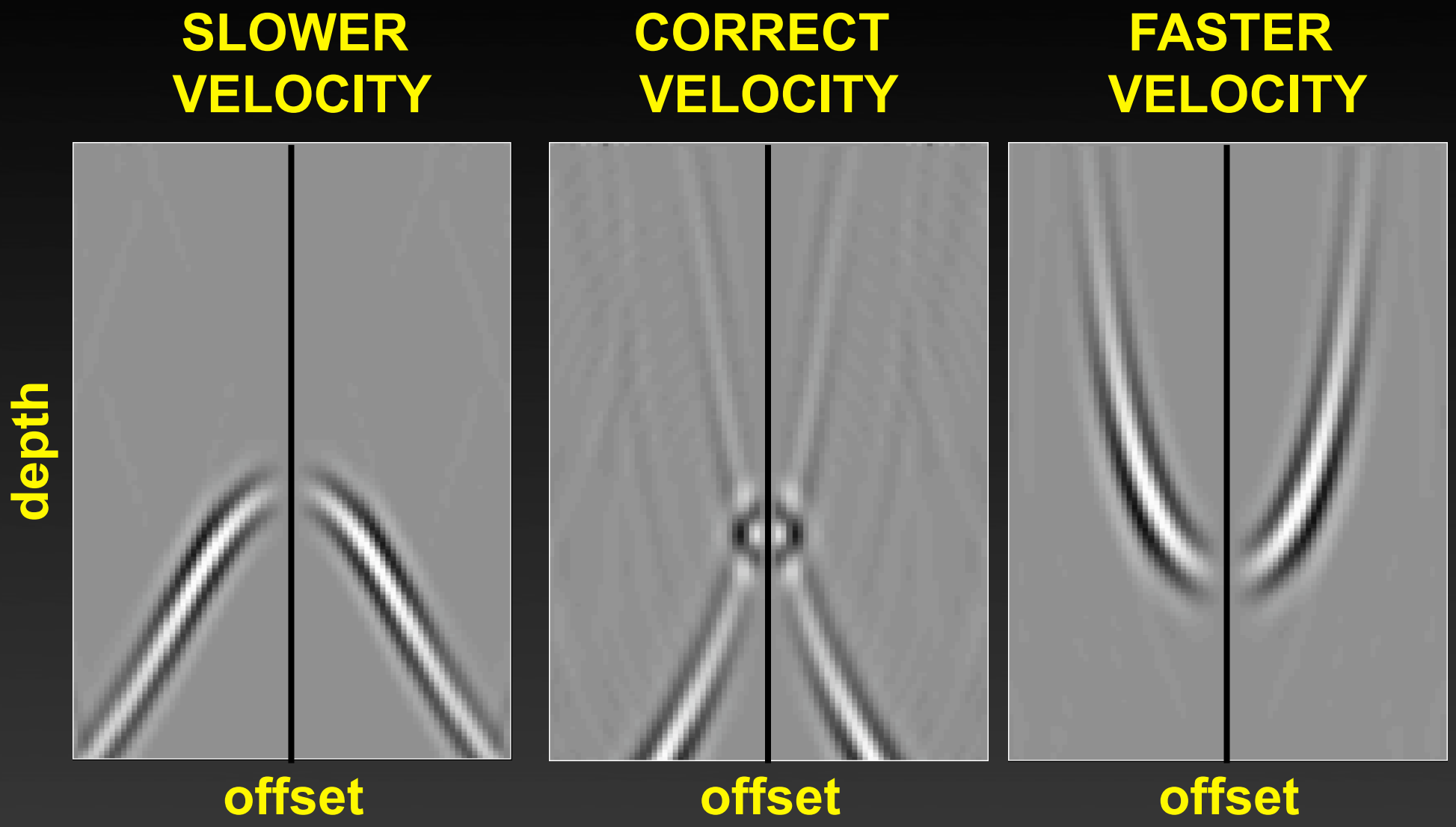
$\Delta \widetilde{I}(s) =$ perturbed image

$\widetilde{I}(s) =$ current image

DSO operator



DSO operator



DSO gradient

$$J(s) = \frac{1}{2}\left\|\mathbf{h}\tilde{I}(s)\right\|_2$$

$$\nabla J(s) = \left(\frac{\partial \tilde{I}}{\partial s}\right)' \mathbf{h}^2 \tilde{I}\Big|_{s=s_o}$$

$J(s)$ = objective function

$\mathbf{h}$ = DSO operator

s_o = current velocity

$\Delta\tilde{I}(s)$ = perturbed image

$\tilde{I}(s)$ = current image

Source wavefield

$$\begin{cases} \left(\frac{\partial}{\partial z} - i\Lambda\right) \widetilde{P}_d(\mathbf{x}, \mathbf{r}_m, \omega) &= \widetilde{I}_d(\mathbf{x}, \mathbf{h}, \mathbf{r}_m, \omega) \\ \widetilde{P}_d(x, y, z = z_{\max}, \mathbf{r}_m, \omega) &= 0 \end{cases}$$

Receiver wavefield

$$\begin{cases} \left(\frac{\partial}{\partial z} + i\Lambda\right) \widetilde{P}_u(\mathbf{x}, \mathbf{r}_m, \omega) &= \widetilde{I}_u(\mathbf{x}, \mathbf{h}, \mathbf{r}_m, \omega) \\ \widetilde{P}_u(x, y, z = z_{\max}, \mathbf{r}_m, \omega) &= 0 \end{cases}$$

$\Lambda =$ SSR operator

$\widetilde{P}_d =$ phase encoded source wavefield

$\widetilde{I}_d =$ source wavefield initial condition

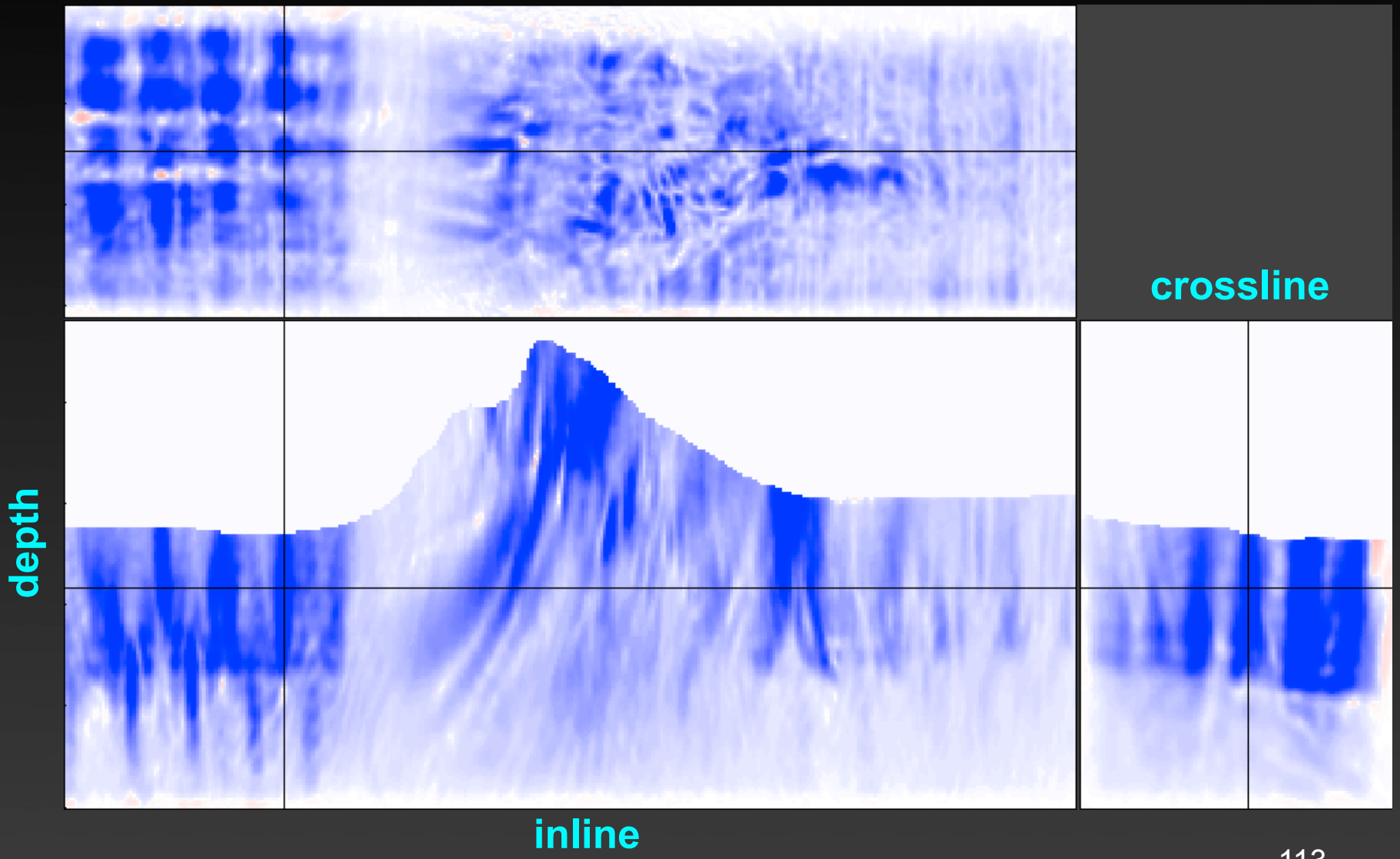
$\mathbf{r}_m =$ index of random realizations

$\widetilde{P}_u =$ phase encoded receiver wavefield

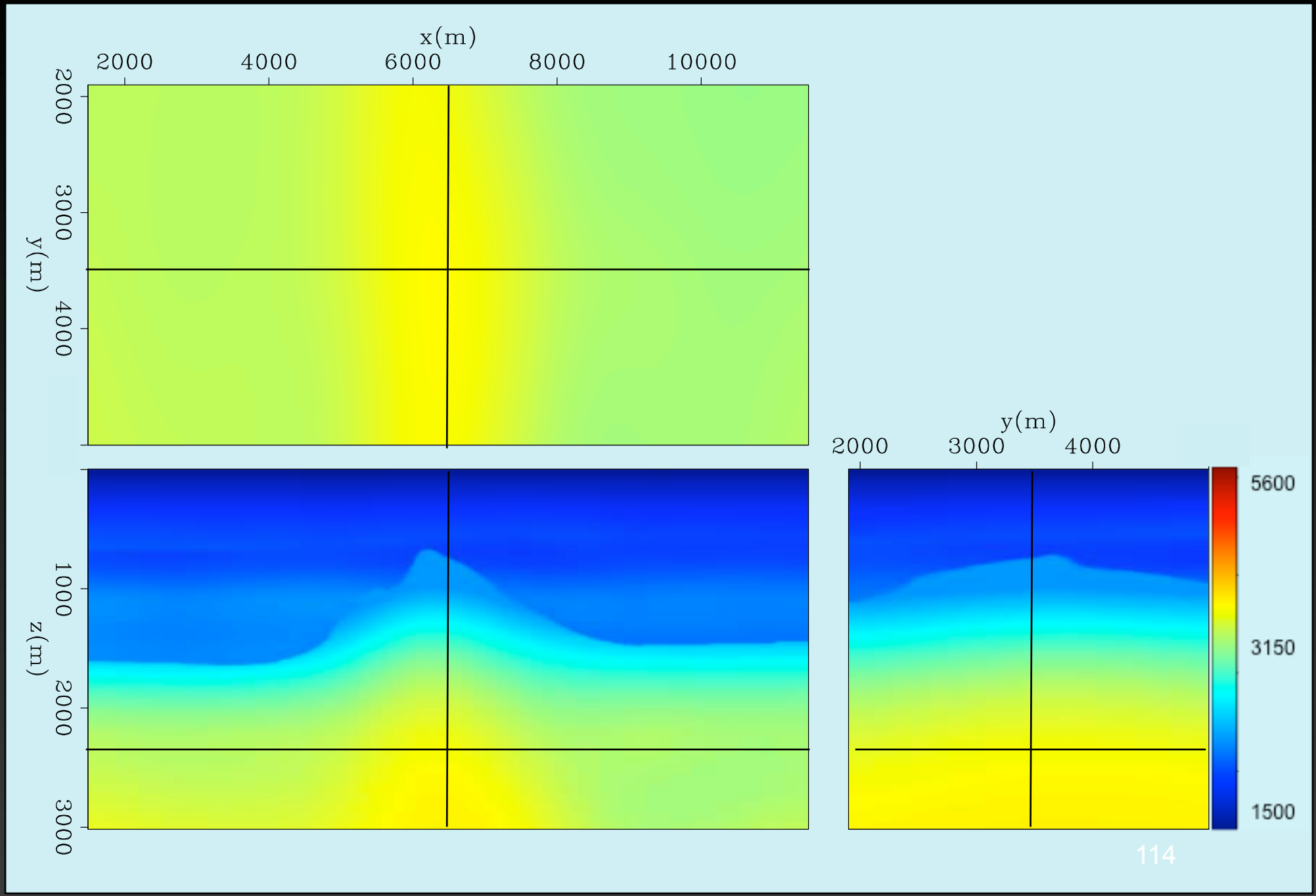
$\widetilde{I}_u =$ receiver wavefield initial condition

Potential for grid-tomography

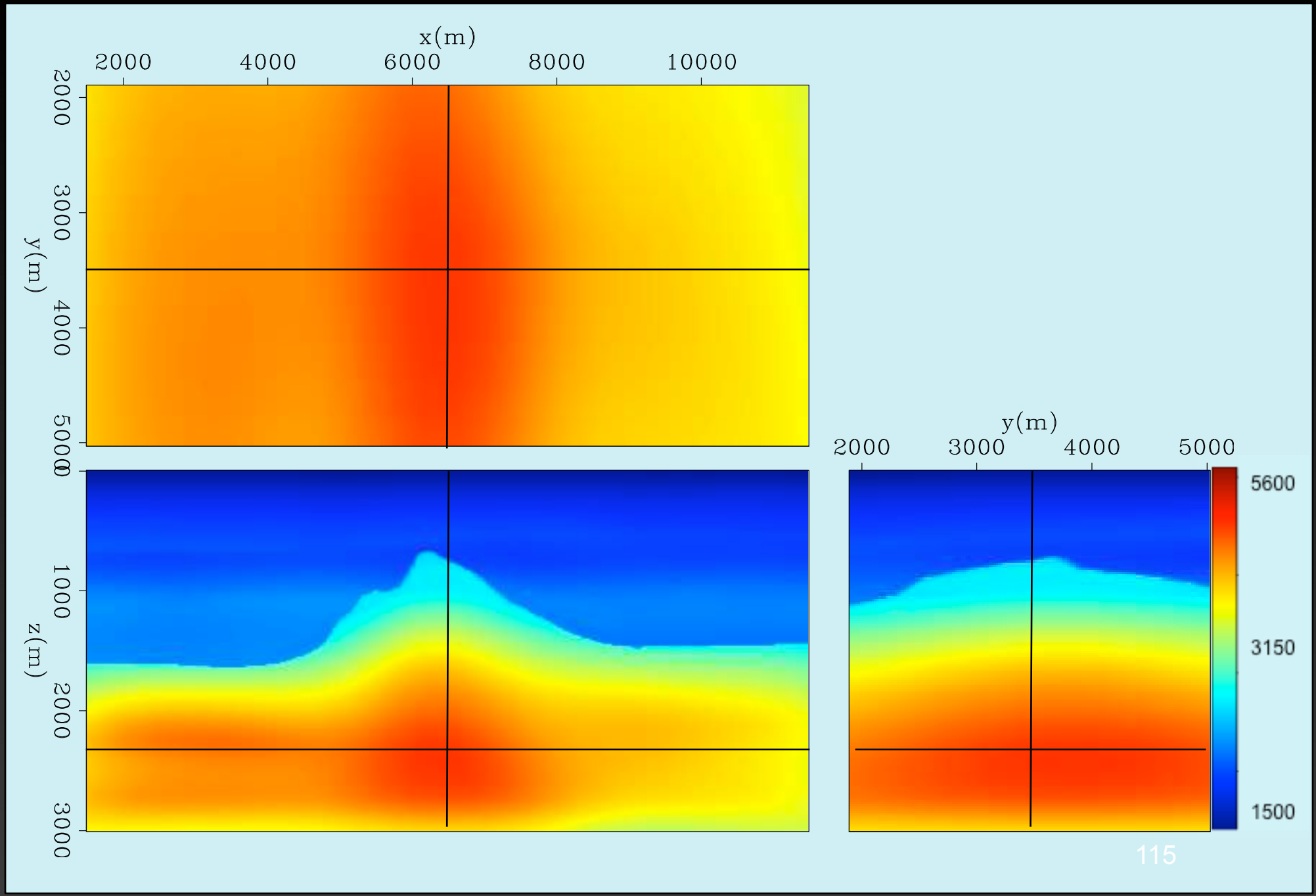
Gradient with 1 pair of ISPEW



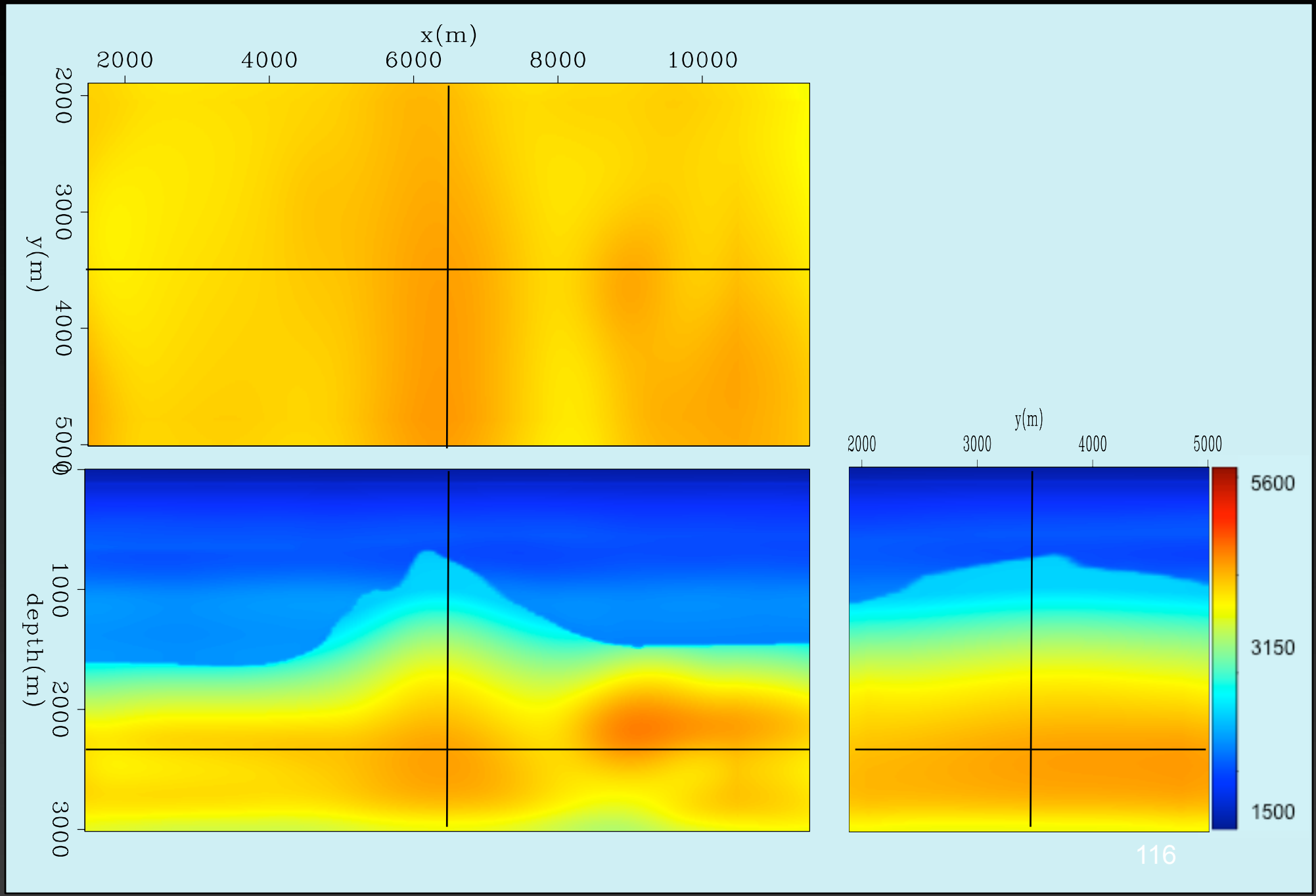
Initial velocity model



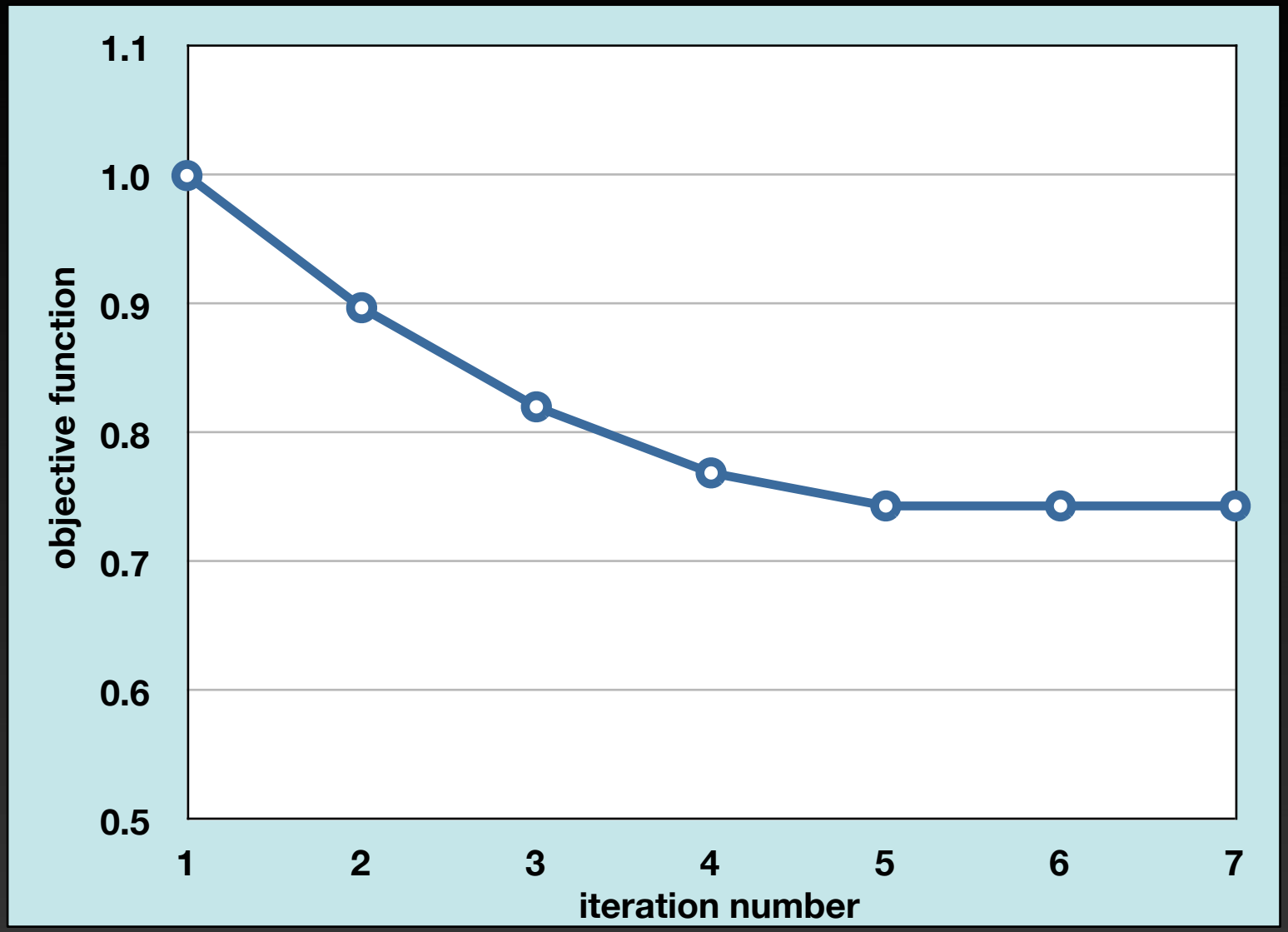
Optimized #1 (7 iterations)



Optimization #2



Objective function #1



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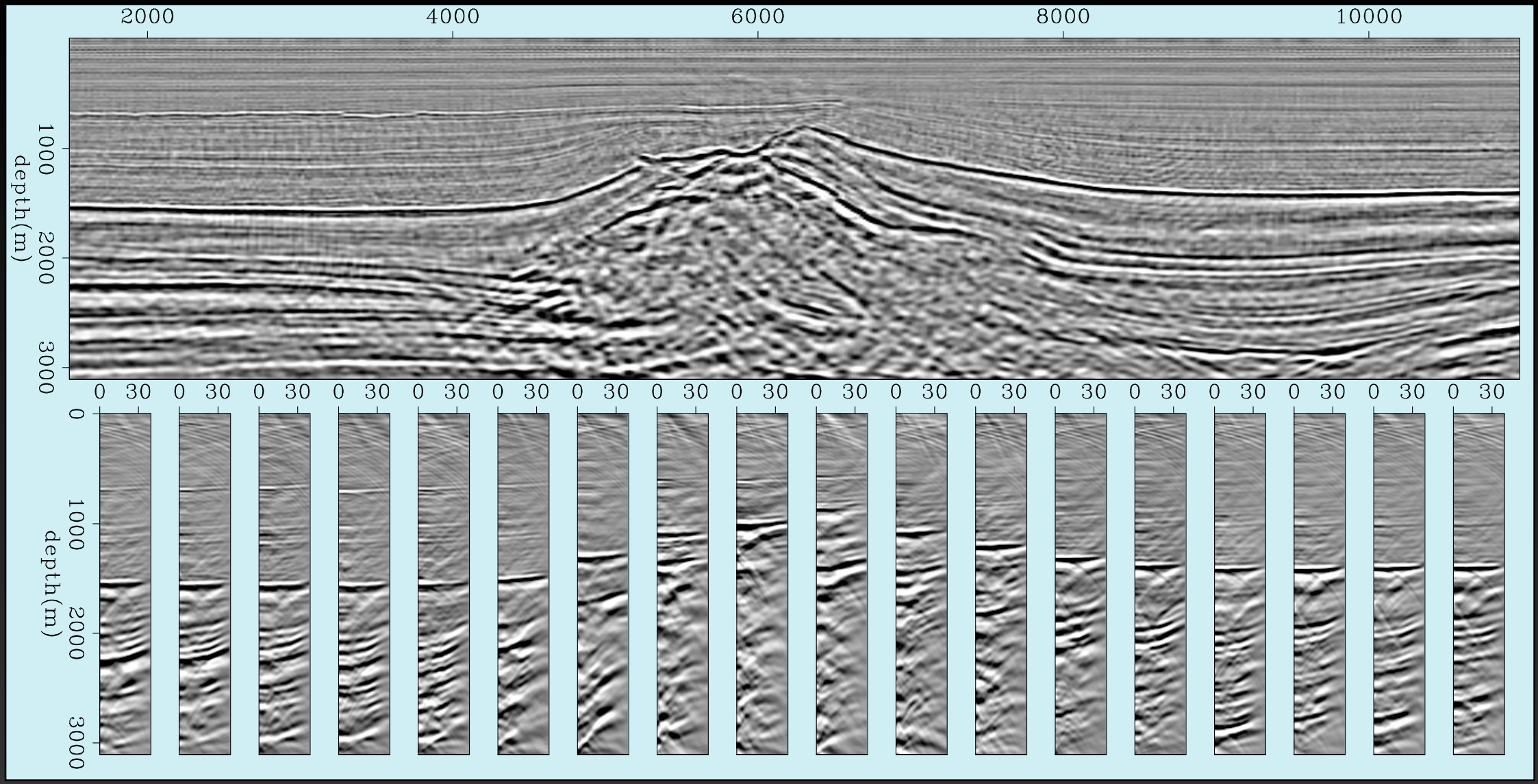
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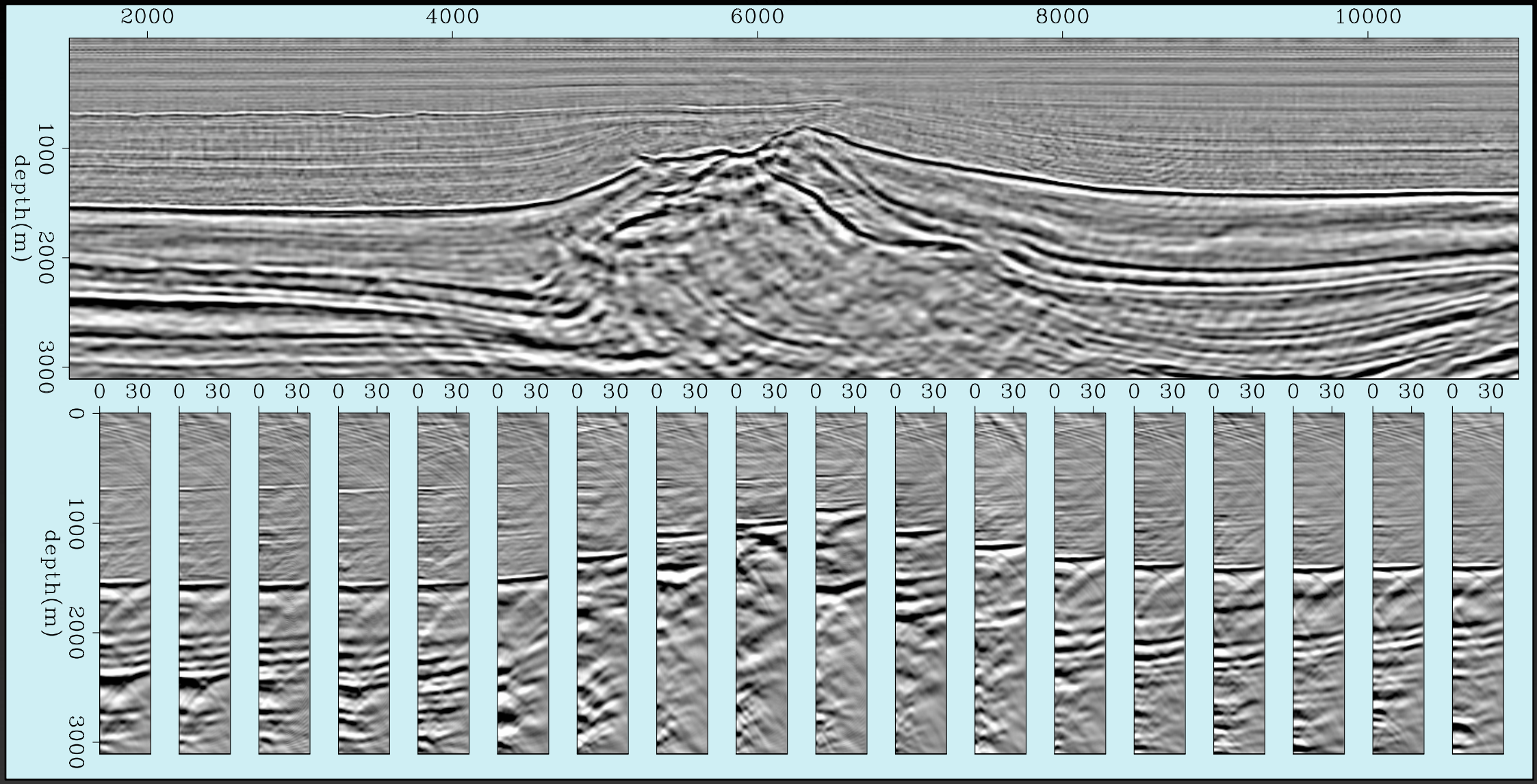
Optimized 1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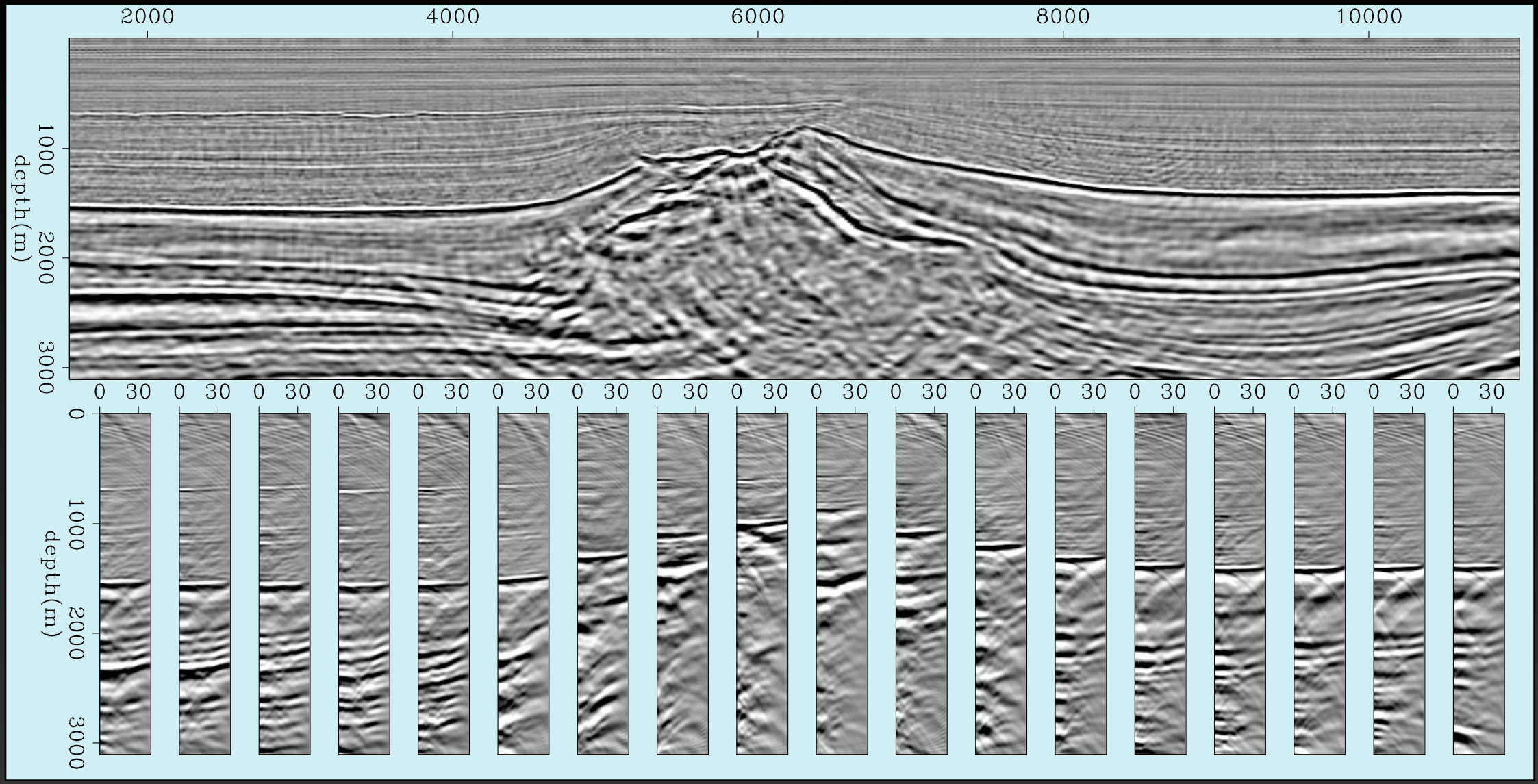
Optimized 2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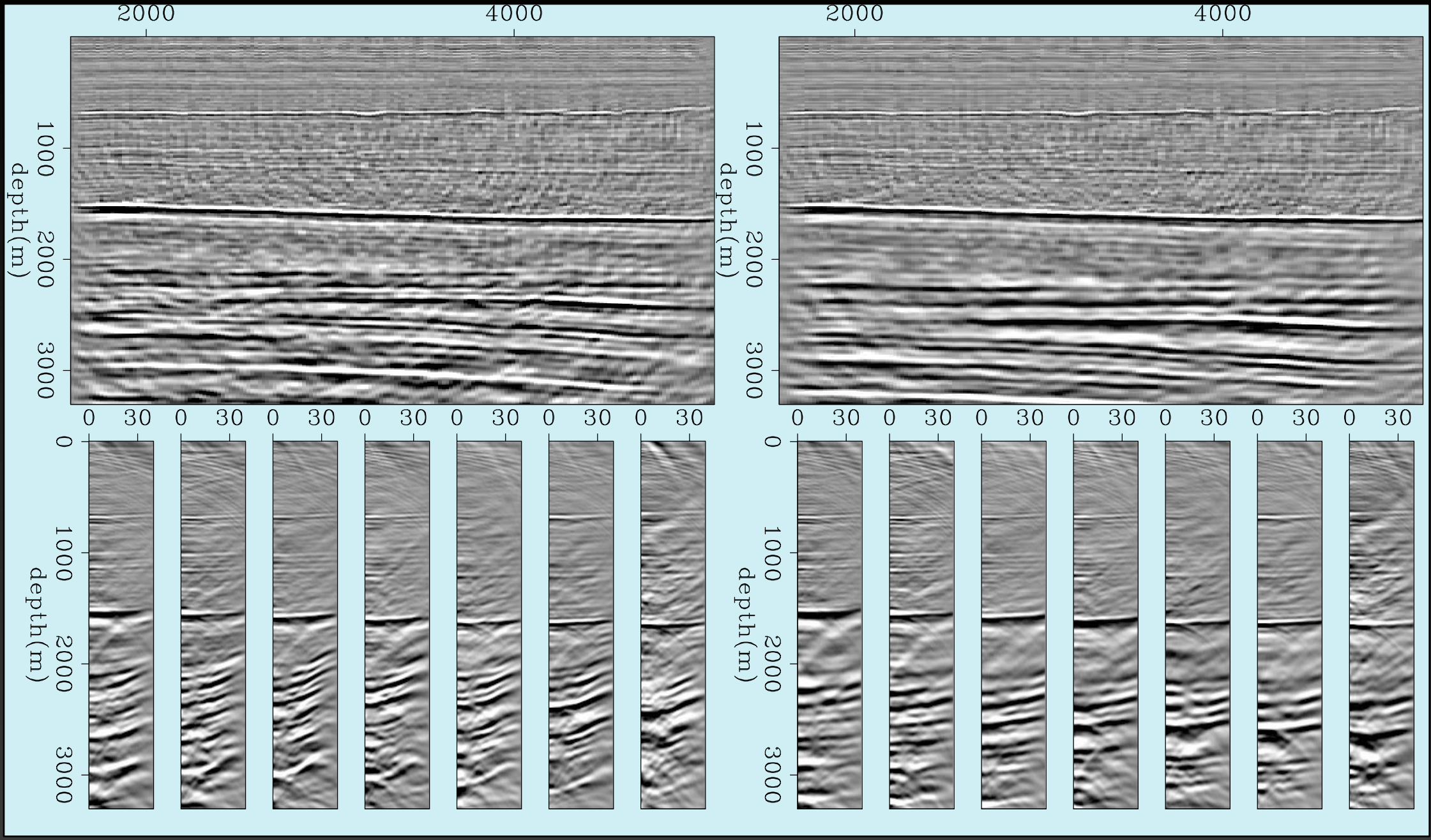
depth(m)

Initial

Optimized



Initial

Optimized