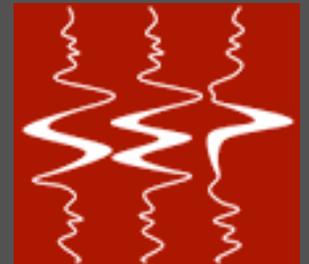


Extended image space separation of continuously recorded seismic data

SEP149 - 171

Chris Leader
SEP Sponsor Meeting
June 19th 2013



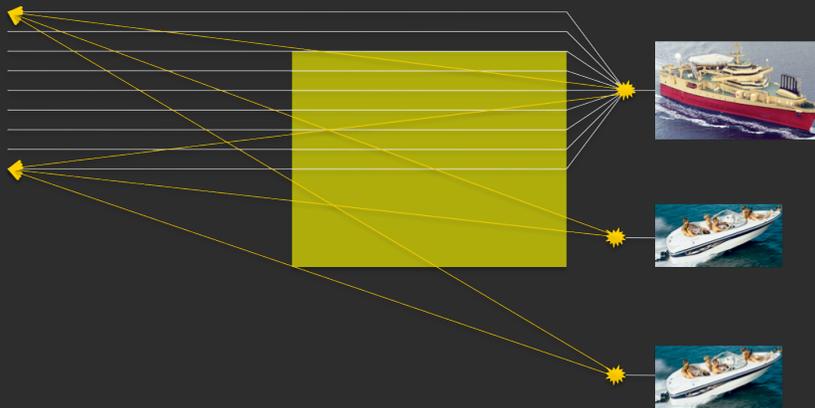
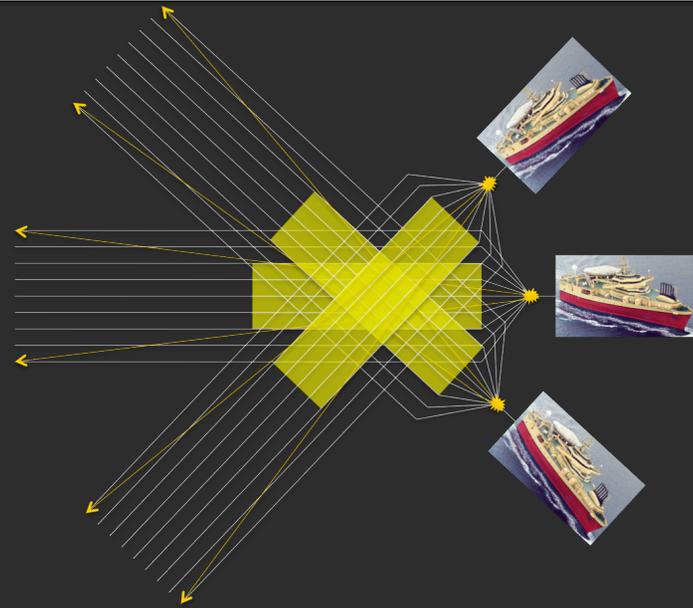
Today's outline

- Continuously recorded data
- Existing processing methods
- Image space separation
- Discussion

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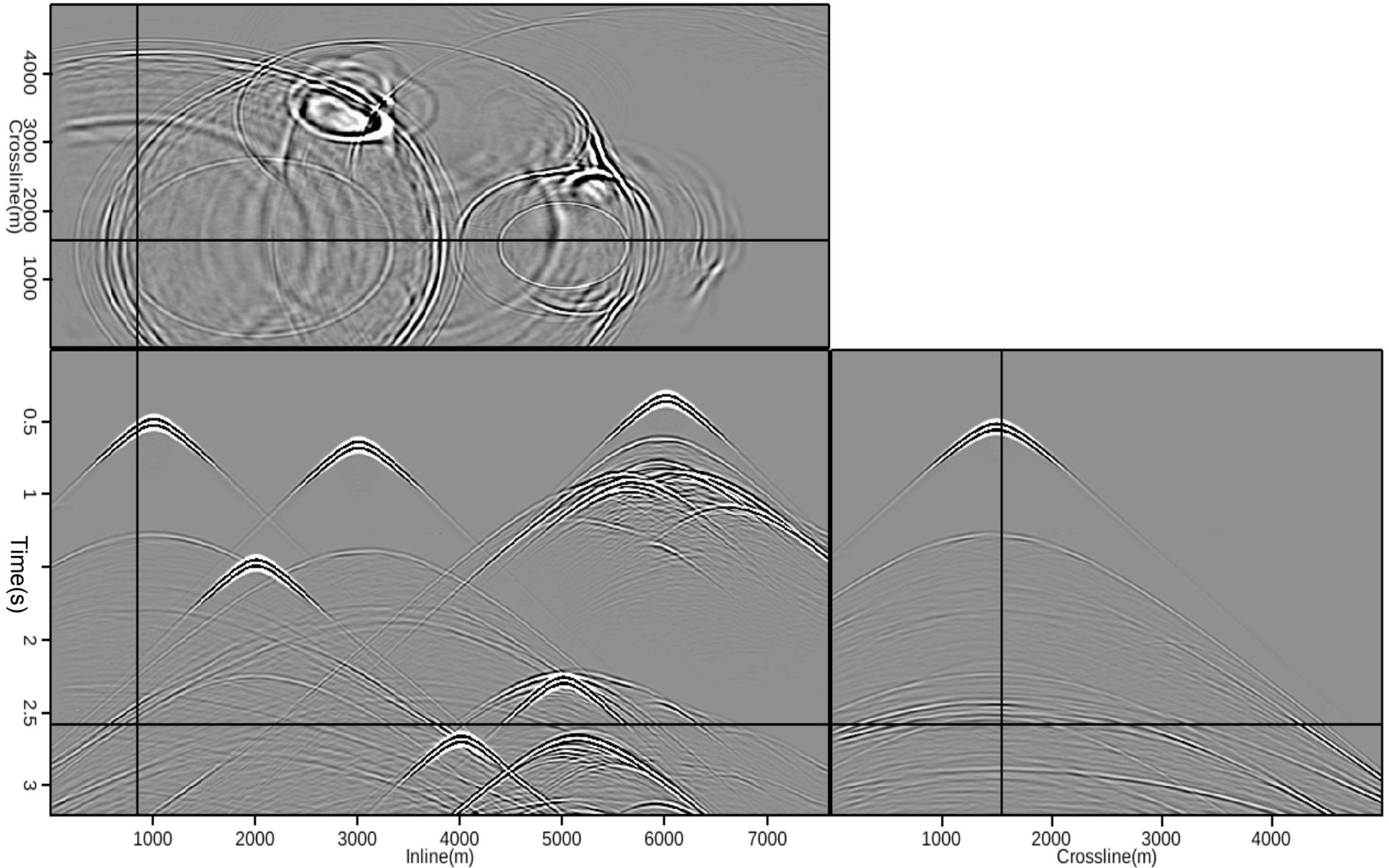
Acquisition



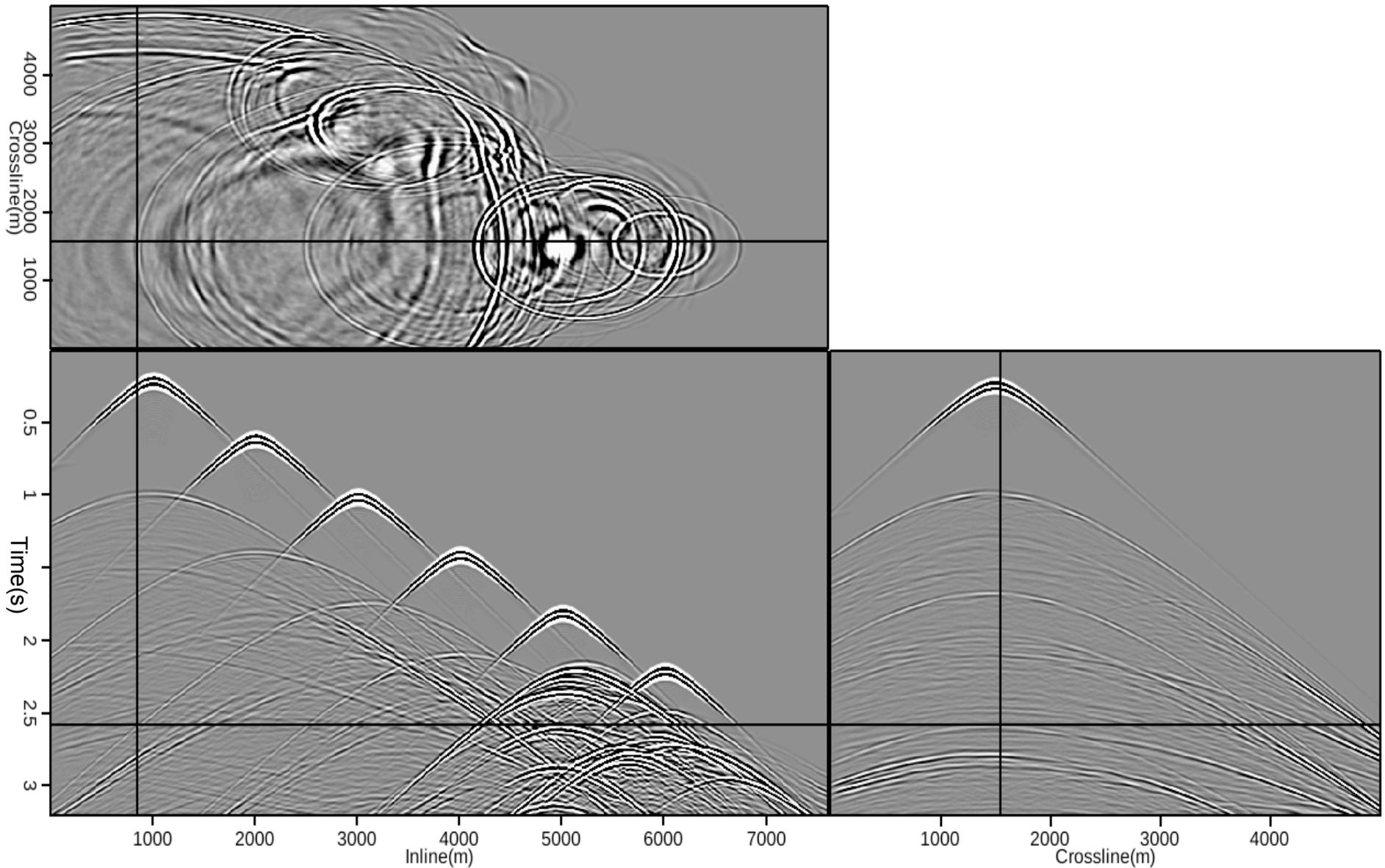
Continuously recorded data

- Blended / simultaneous / continuously recorded
- More data can be recorded per unit time
 - Large surveys more economical
 - Less waiting time in WATS surveys
- Assumption: extra computation time is cheaper than acquisition

Randomly blended



Linearly blended



Today's outline

- Continuously recorded data
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- Discussion

How can we process these data?

- Direct imaging
 - Migration
 - Inversion
- Create unblended data
 - Data space filtering
 - Data space inversion
 - Image space inversion

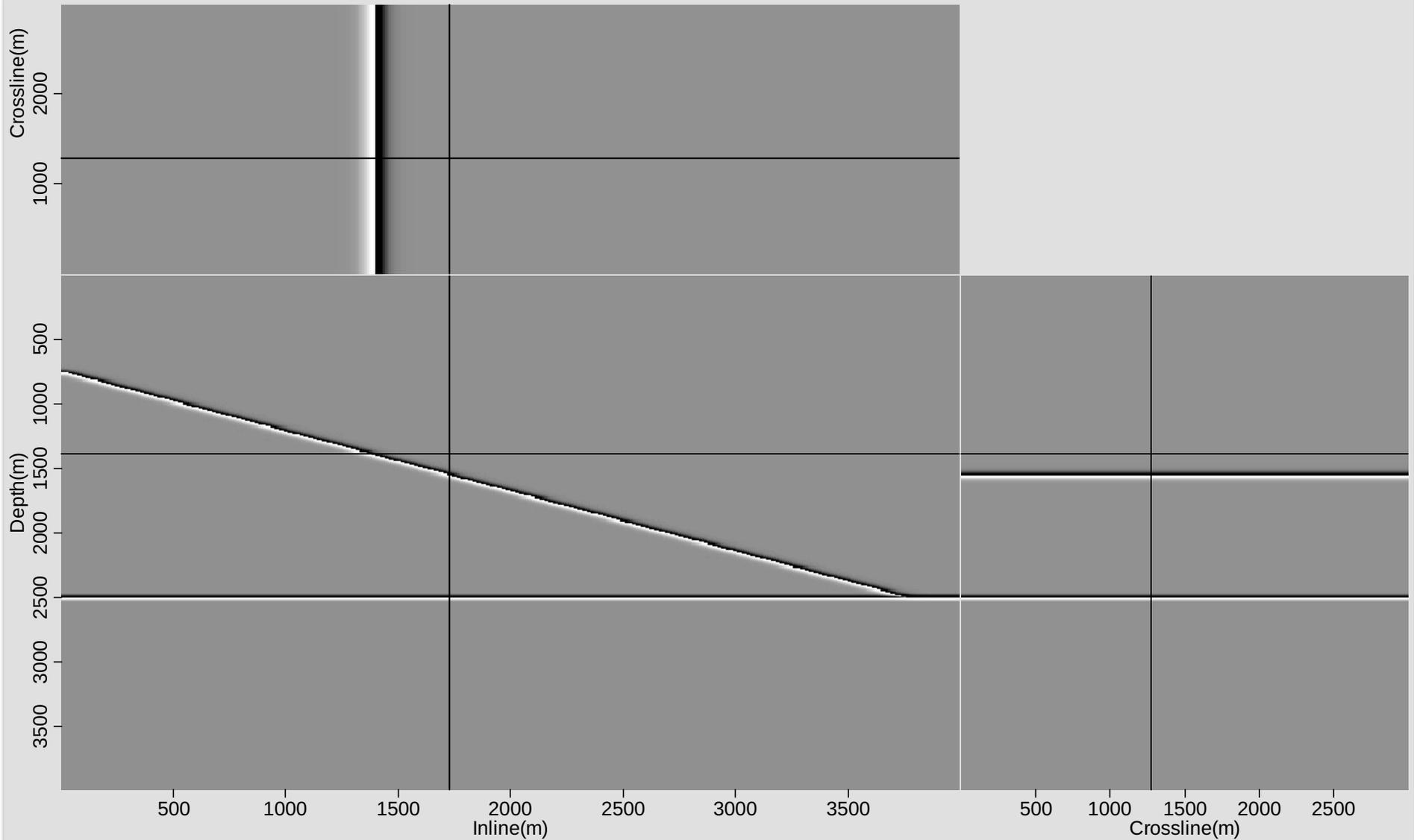
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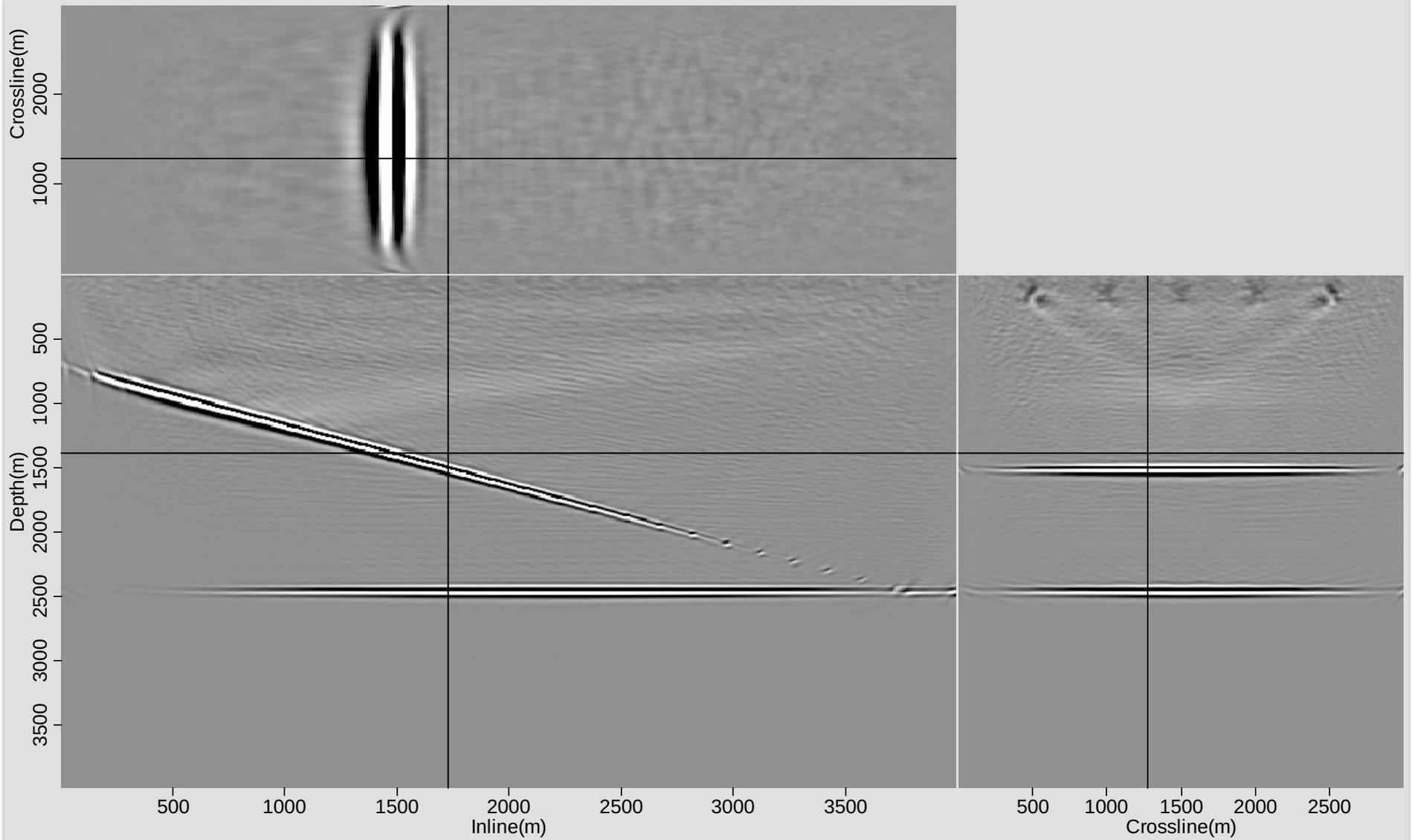
'Passive' imaging

- Just image the data as if there are no overlapping shots
- We need truly random delays
- Higher shot density -> cleaner images

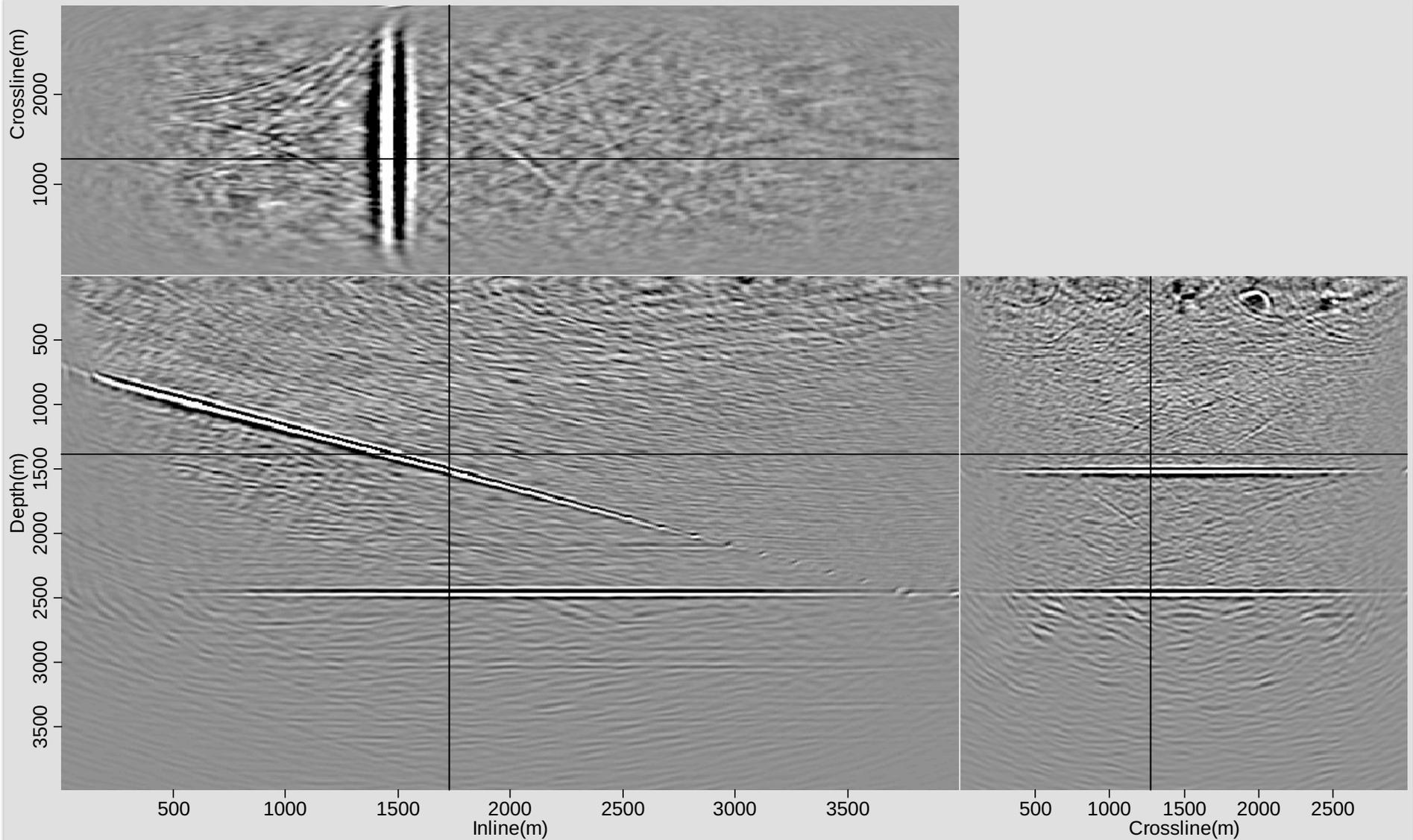
Some complex 'reflectivity'



Conventional image



'Passive' blended image



Invert for model

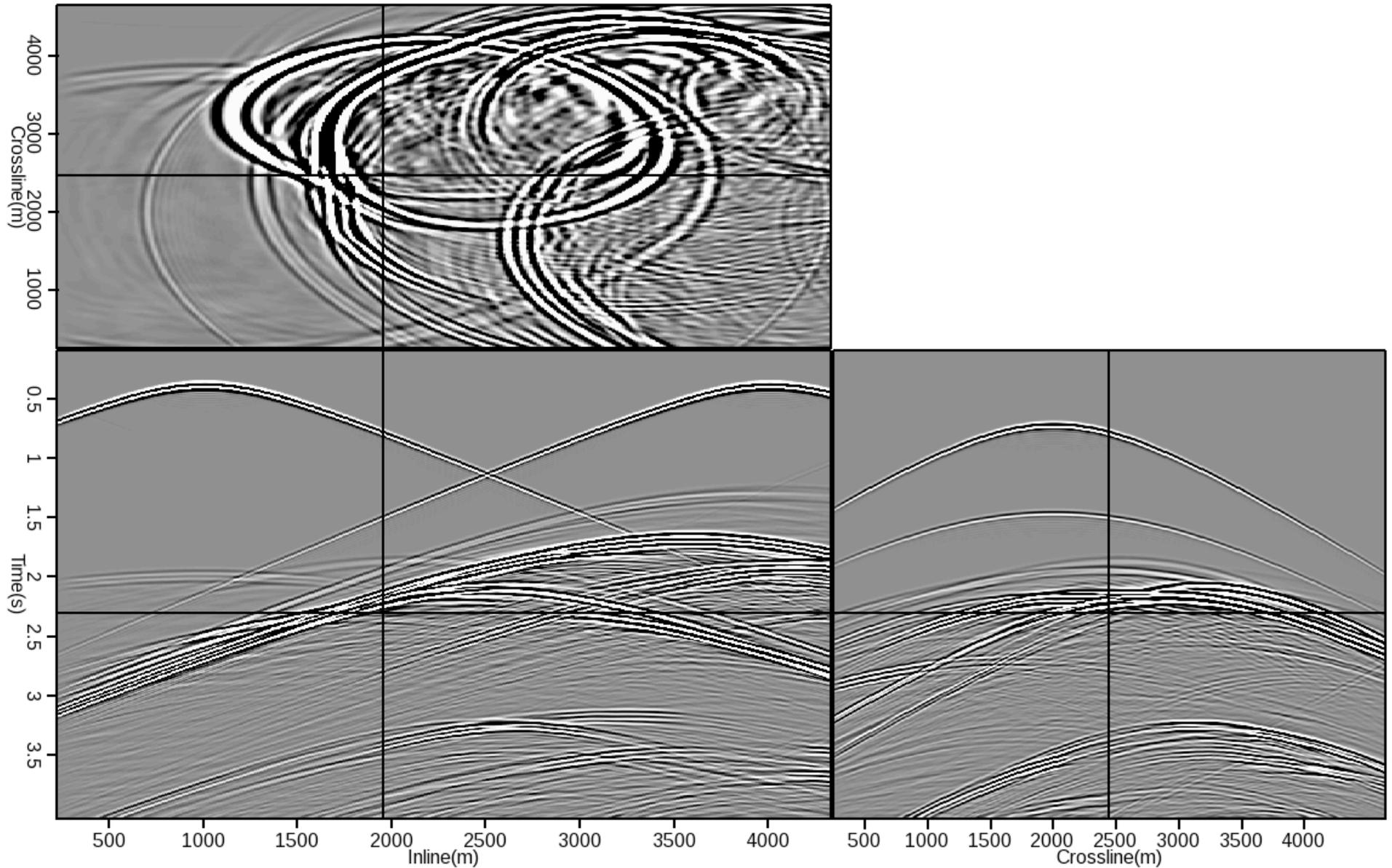
$$J(\mathbf{m}) = \|\tilde{\mathbf{L}}\mathbf{m} - \tilde{\mathbf{d}}\|_2^2 + \varepsilon\|\mathbf{A}\mathbf{m}\|_2^2$$

- Can give very clean images
- Assumes we know the velocity model
 - We are arguing partly for exploration surveys
 - Do not want strong model knowledge assumption

How can we process these data?

- Direct imaging
 - Migration
 - Inversion
- Create unblended data
 - Data space filtering
 - Data space inversion
 - Image space inversion

Filter overlapping shots



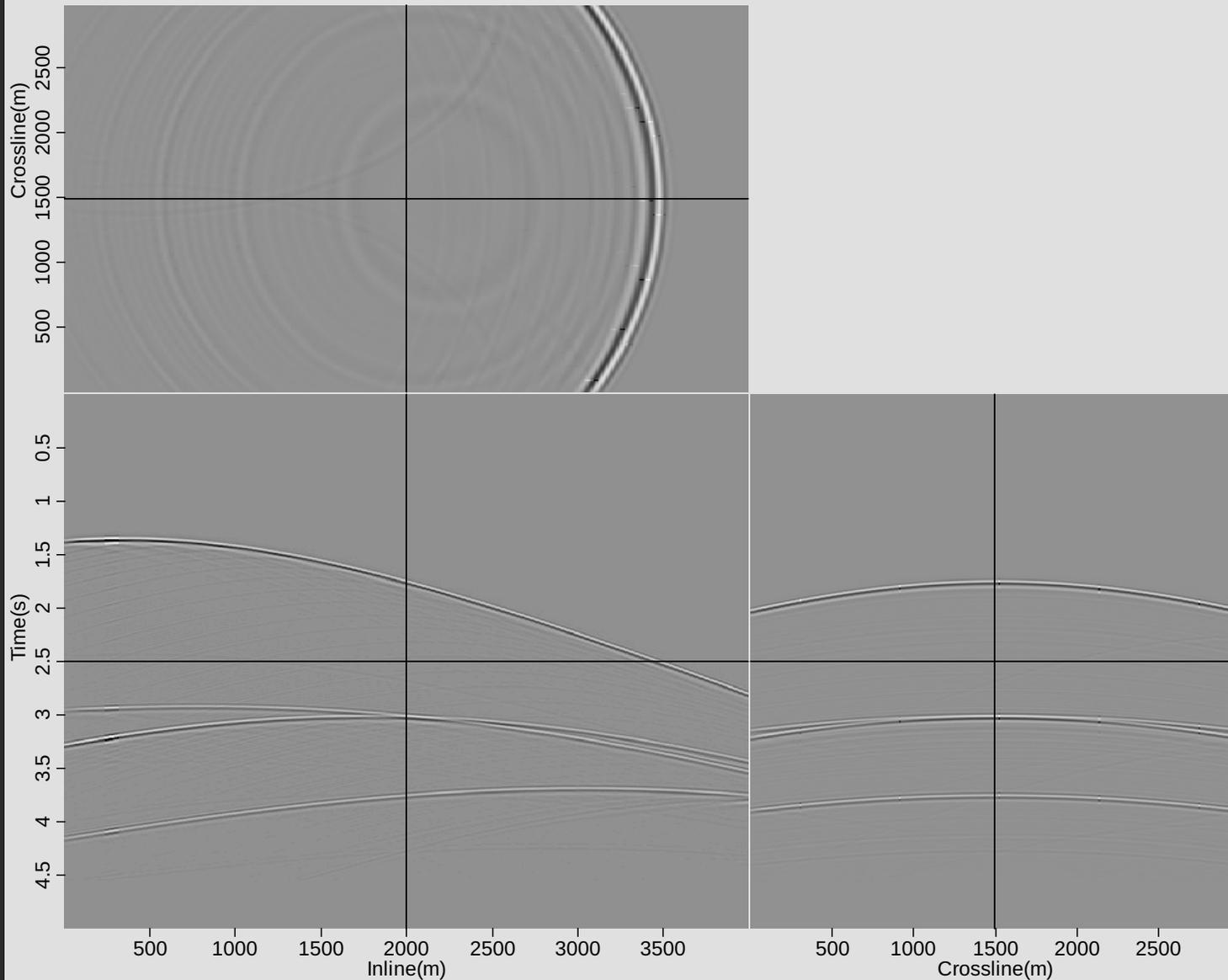
How can we process these data?

- Direct imaging
 - Migration
 - Inversion
- Create unblended data
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 - Image space inversion

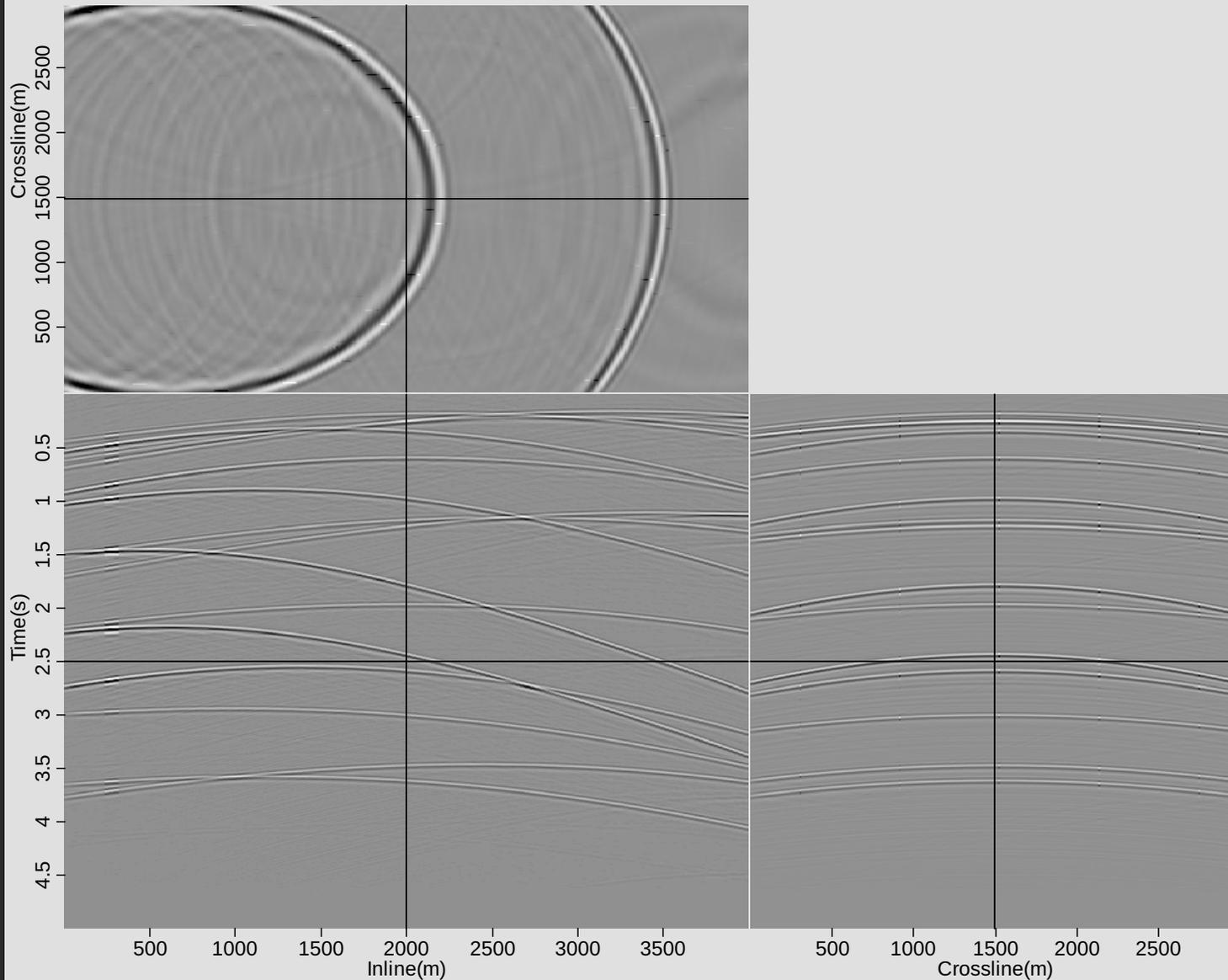
Invert for separated data

- Multiple existing methods
 - Thresholding/coherency pass methods (Abma 2012; Doulgeris 2011; Ayeni and Biondi 2011)
 - Compressive sensing / inversion (Haneet and Herrman 2011)
 - Decoding transforms (Ikelle 2007)
- All require random sampling along source axes
 - Or model / overlap assumptions

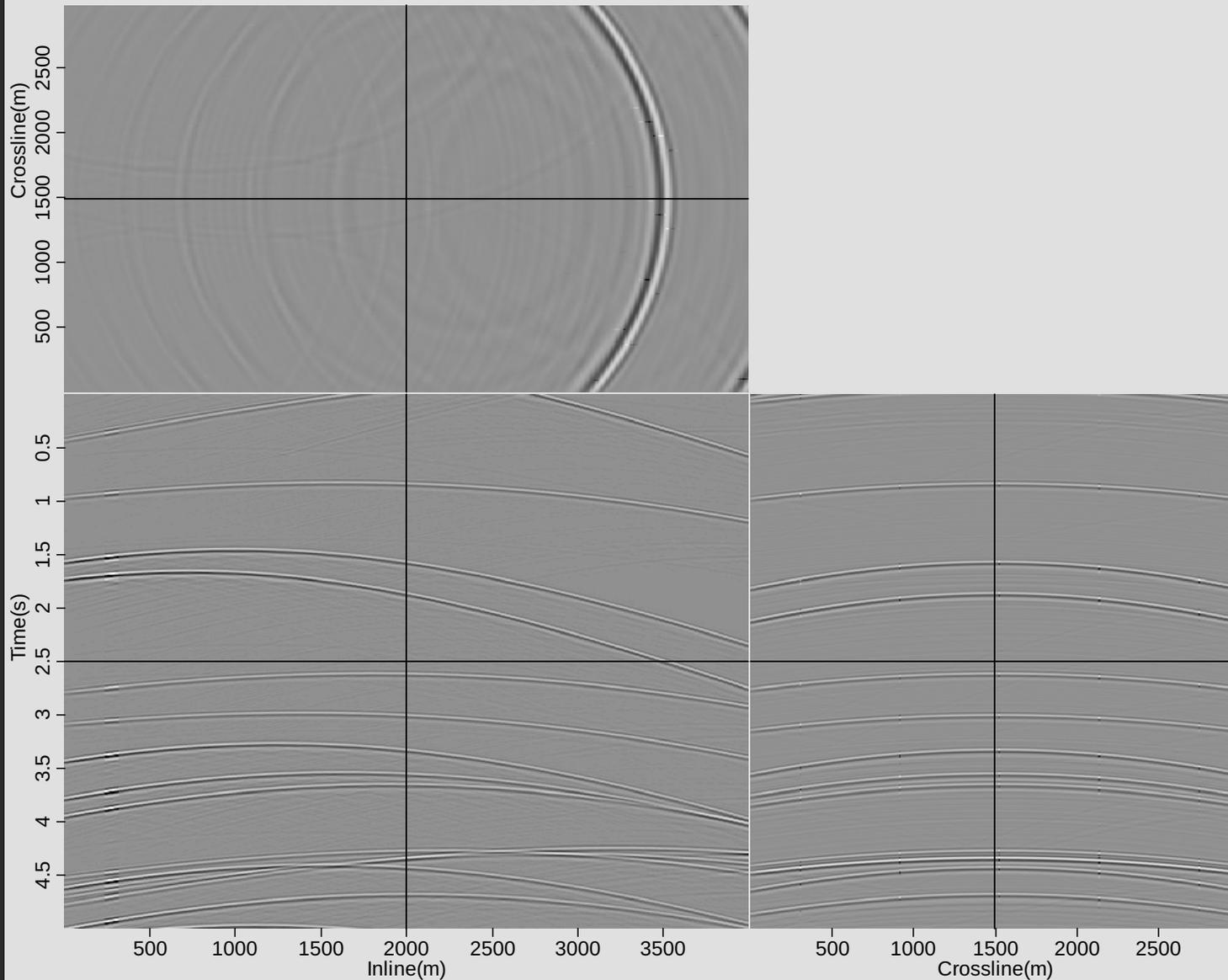
Randomly delayed data (1/5)



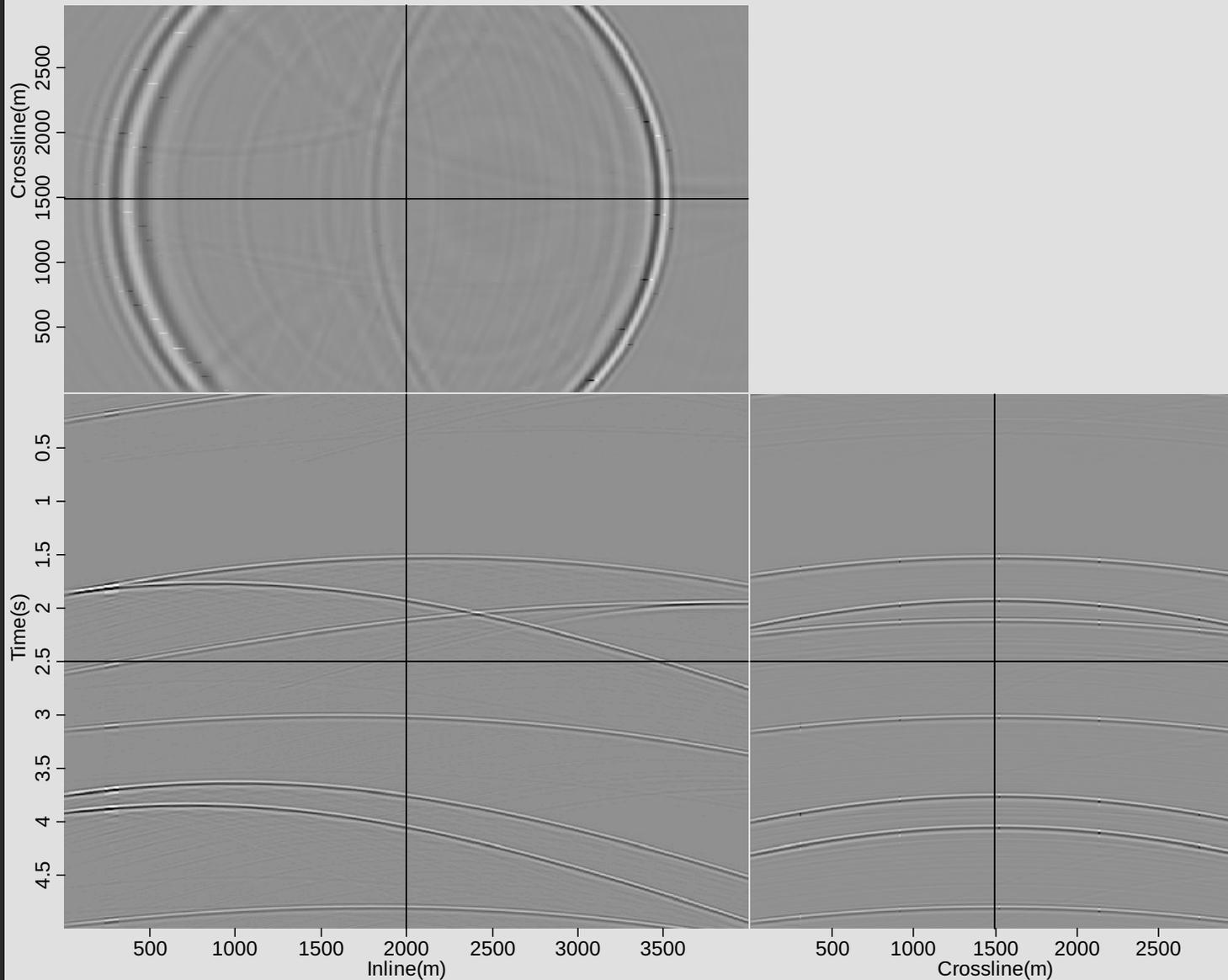
Randomly delayed data (2/5)



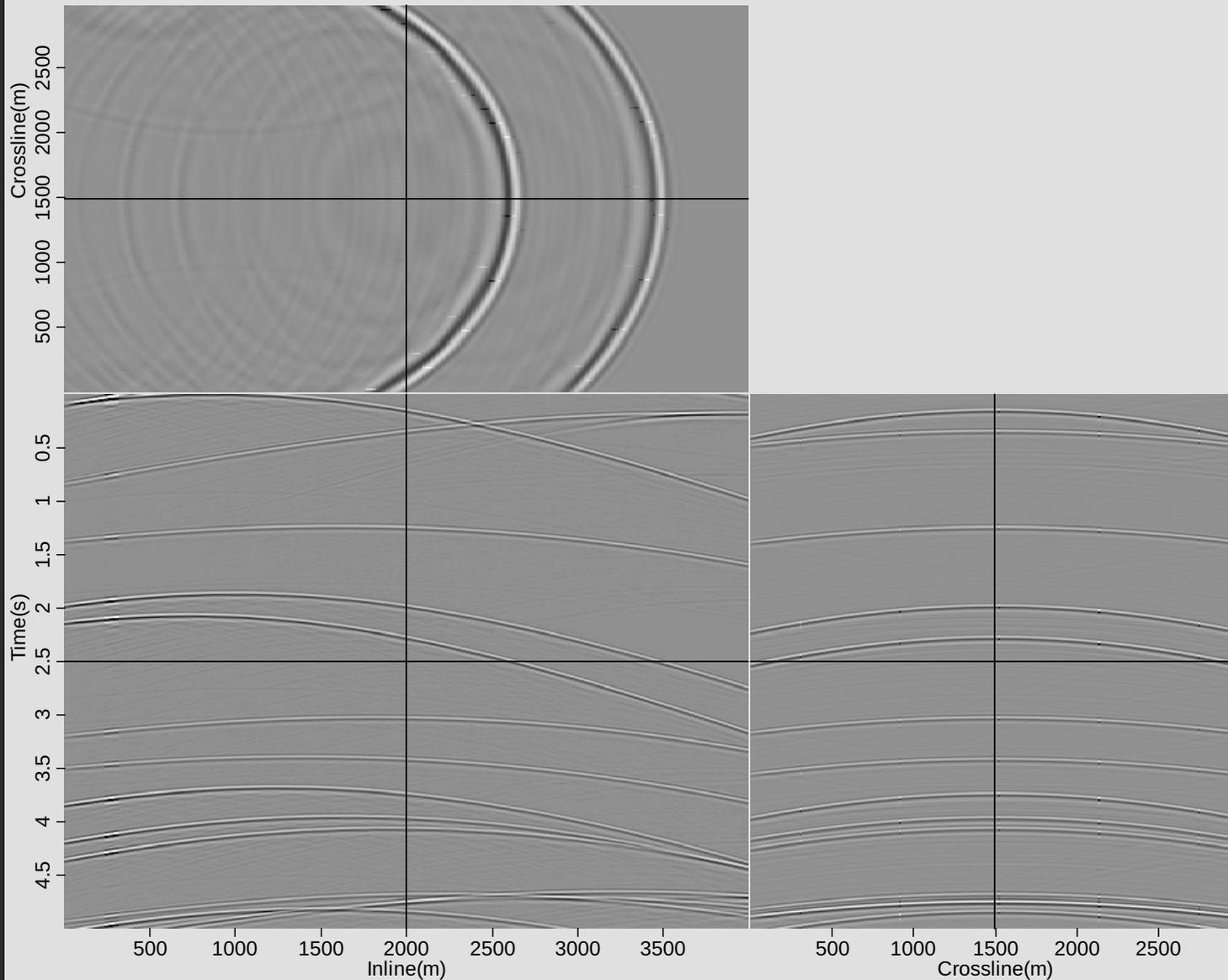
Randomly delayed data (3/5)



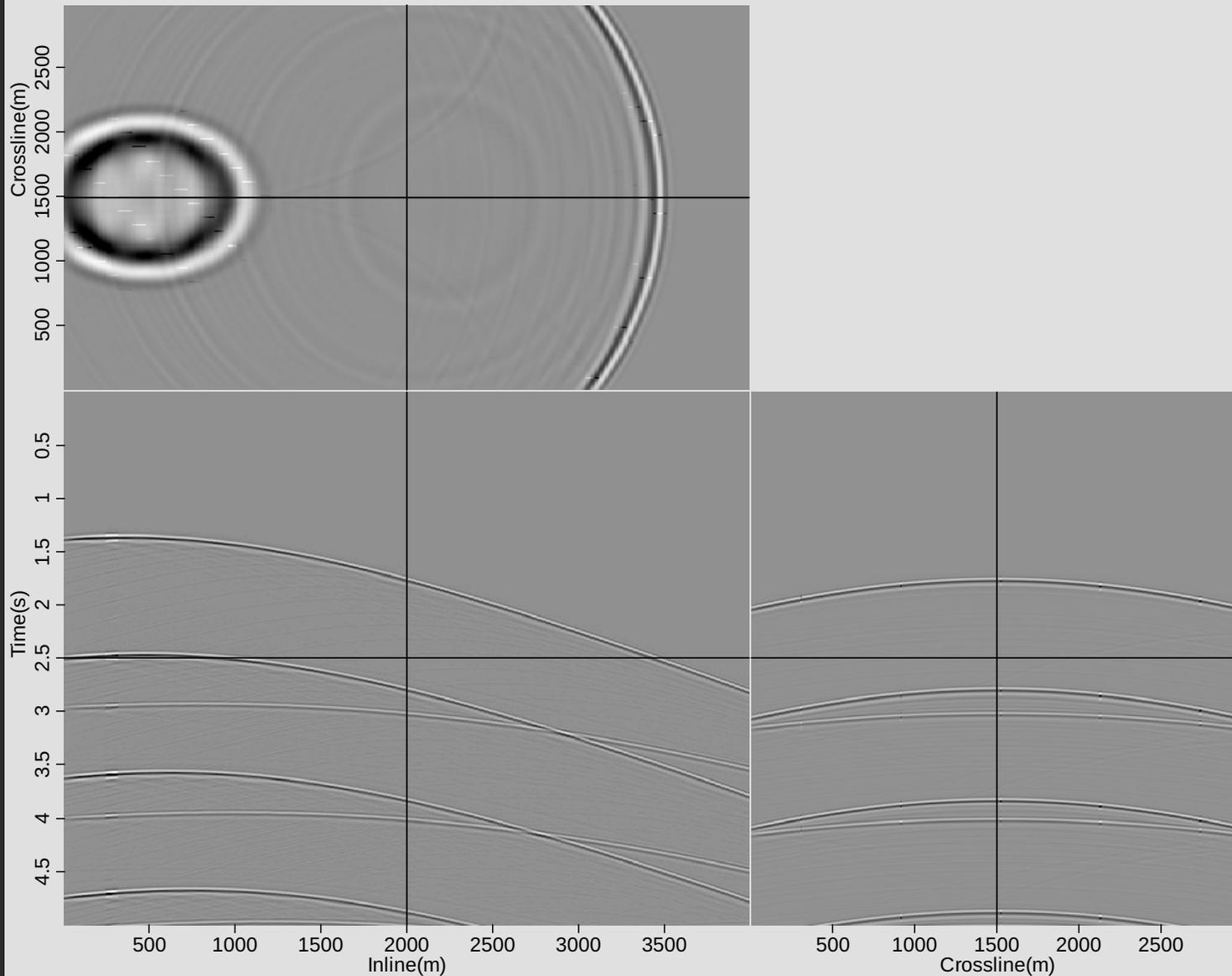
Randomly delayed data (4/5)



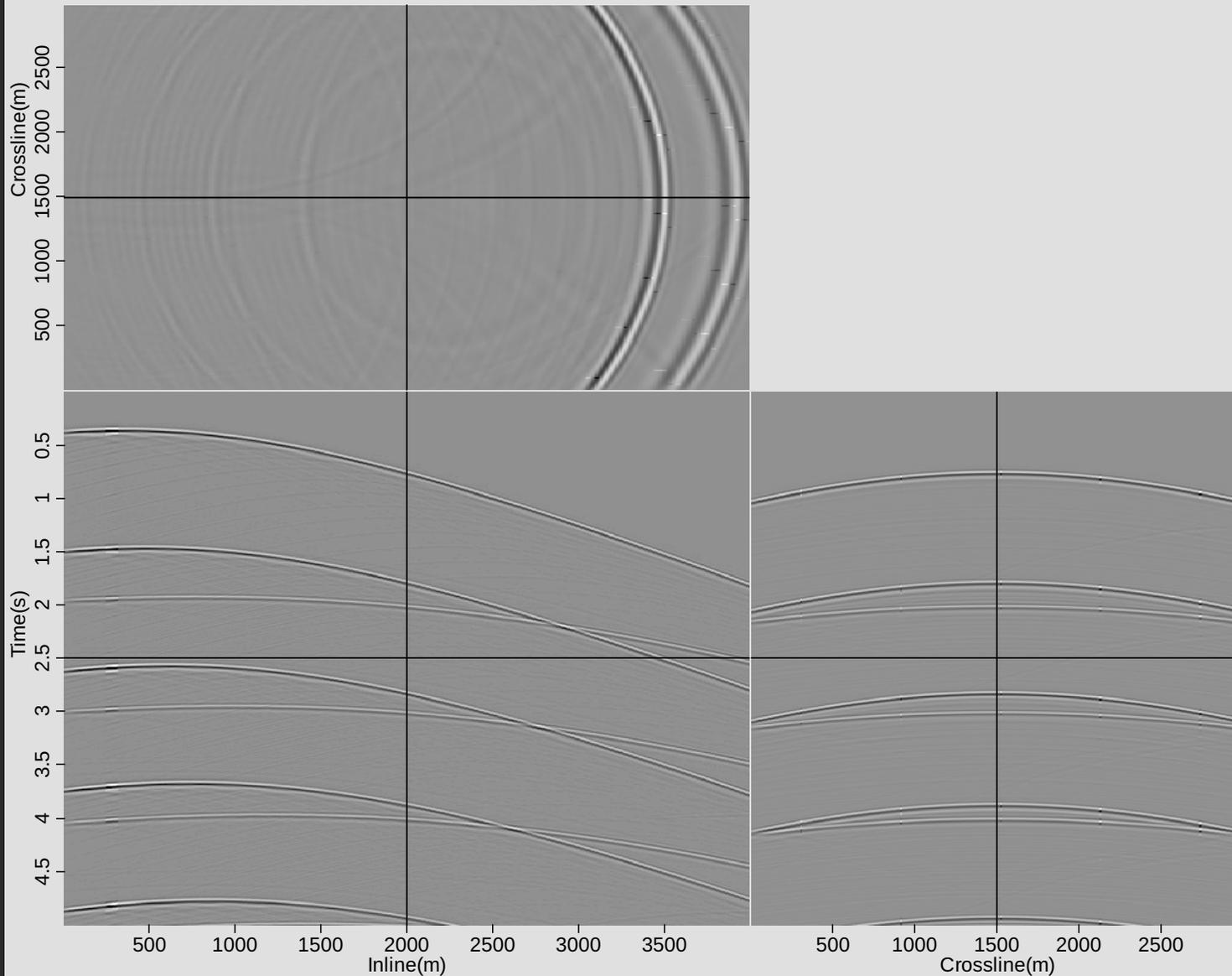
Randomly delayed data (5/5)



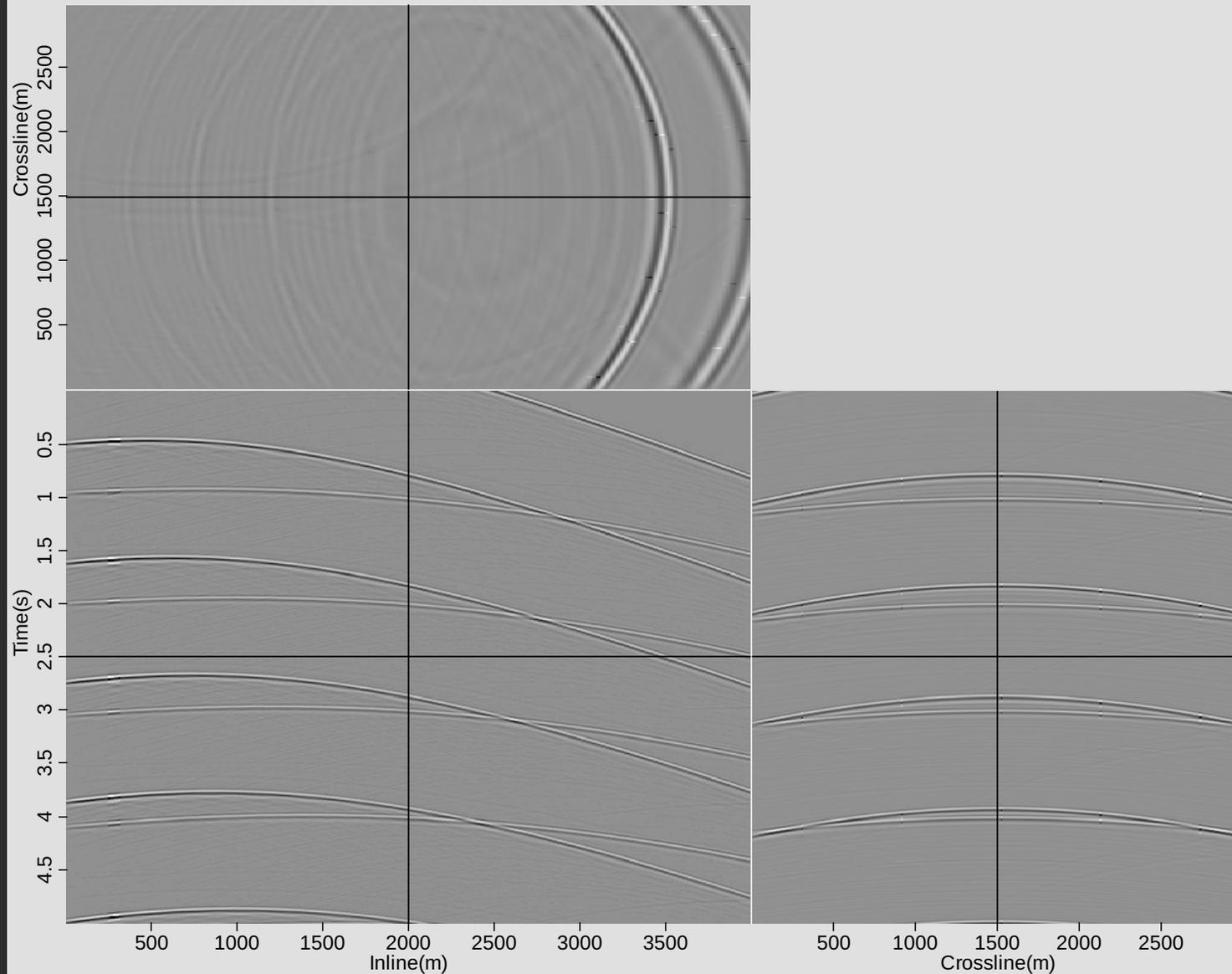
Linearly delayed data (1/5)



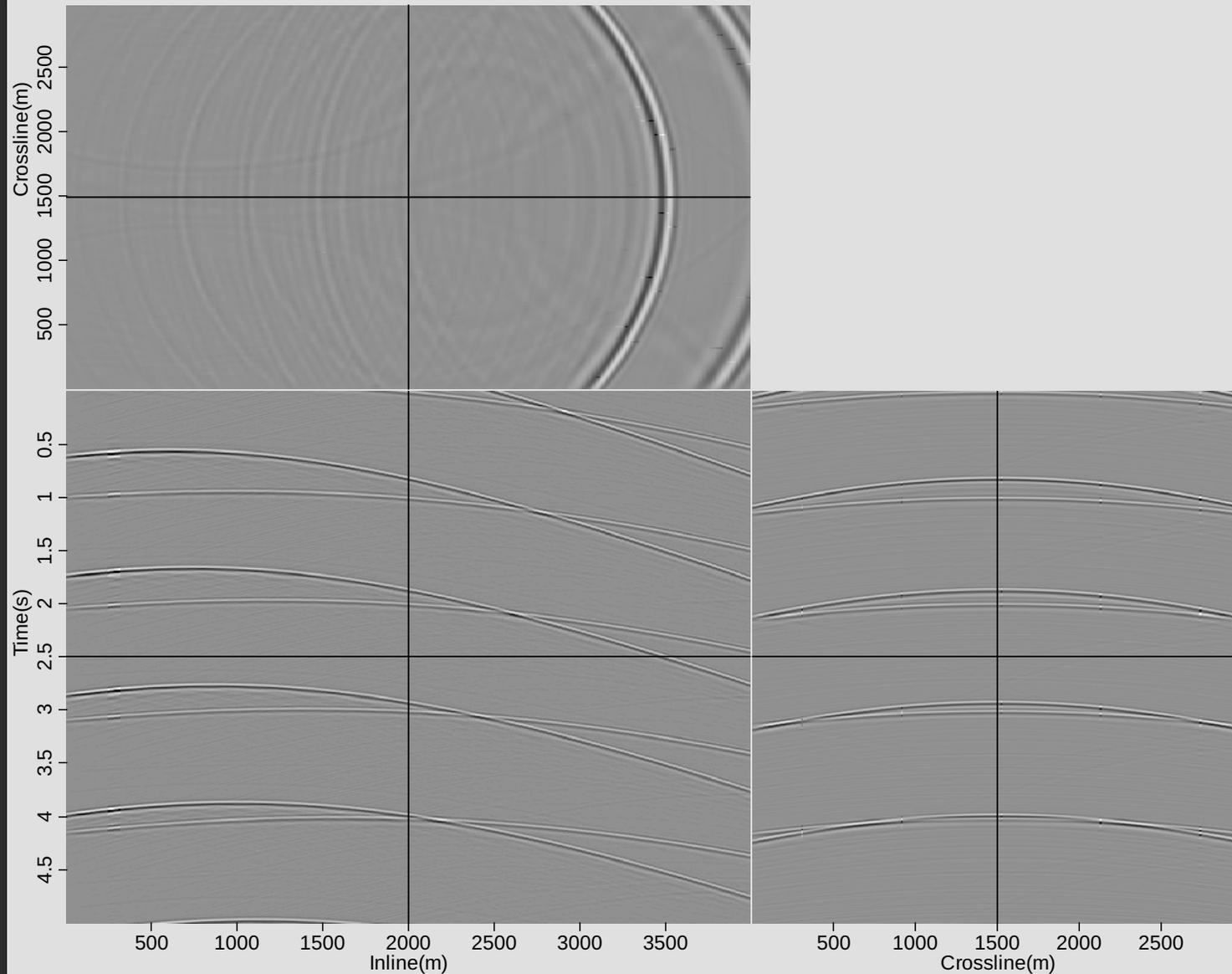
Linearly delayed data (2/5)



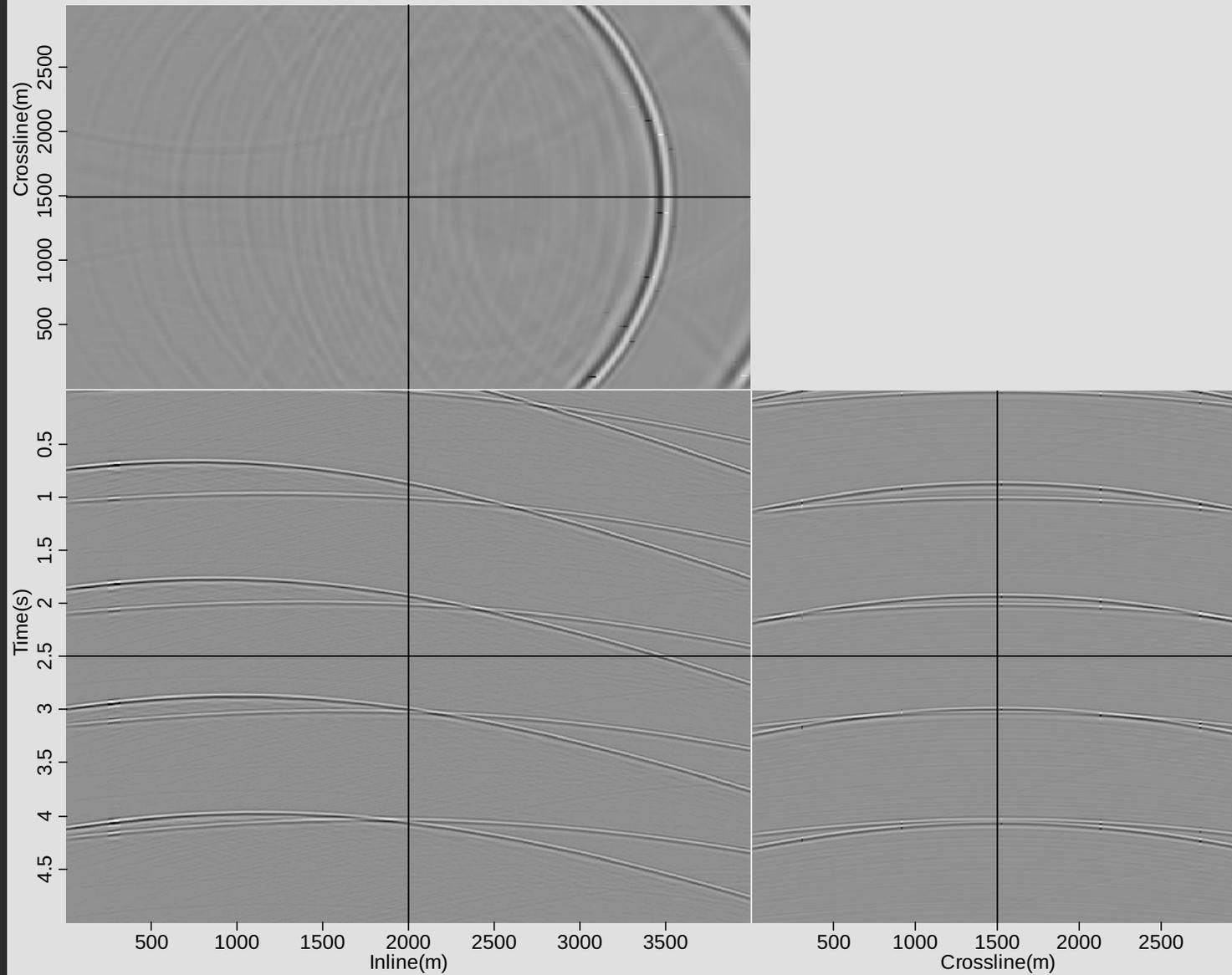
Linearly delayed data (3/5)



Linearly delayed data (4/5)



Linearly delayed data (5/5)



Why are linear delays so difficult?

- Can't rely on overlapping shots stacking out incoherently
- In Fourier space, tau-p etc secondary data is still coherent and focused
- Can create notches in the spectra

Today's outline

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Conventional imaging

- Typical imaging condition:

$$I(x, y, z) = \sum_{shots} \sum_t P^r(x, y, z, t; \mathbf{s}_i) P^s(x, y, z, t; \mathbf{s}_i)$$

- 'Zero-order cross correlation' of the receiver and source wavefields
 - We can extend this beyond zero order
 - Shift wavefields in x , y or z and multiply

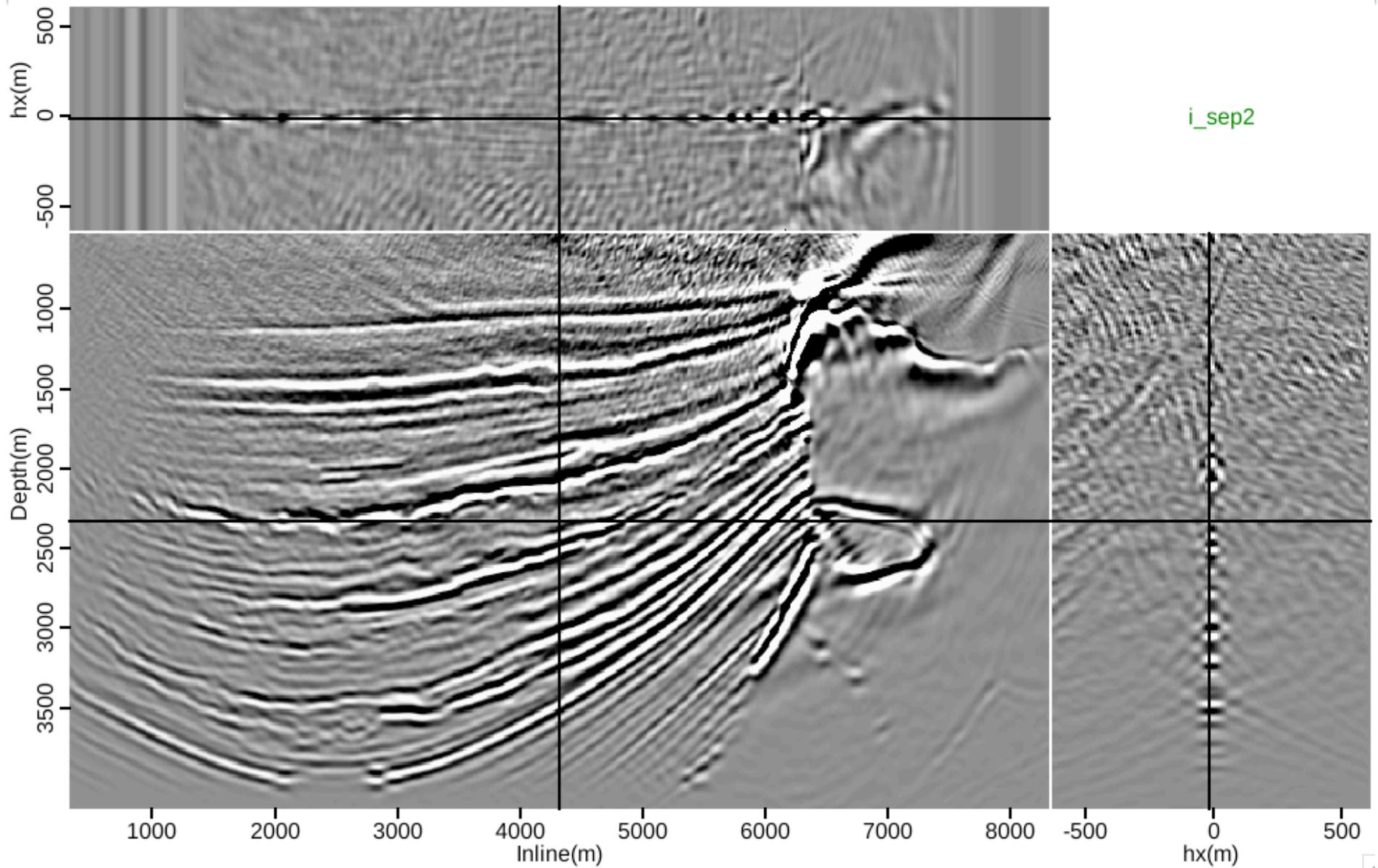
Extended imaging

- Extended imaging condition:

$$I(x, y, z, x_h, y_h) = \sum_{shots} \sum_t P^r(x + x_h, y + y_h, z, t; \mathbf{S}_i) P^s(x - x_h, y - y_h, z, t; \mathbf{S}_i)$$

- Why?
 - We can construct subsurface offset gathers
 - Velocity / anisotropy / other model deficiencies are manifested here
 - Can then construct angle gathers
 - How WEMVA works
 - Continuous data separation?

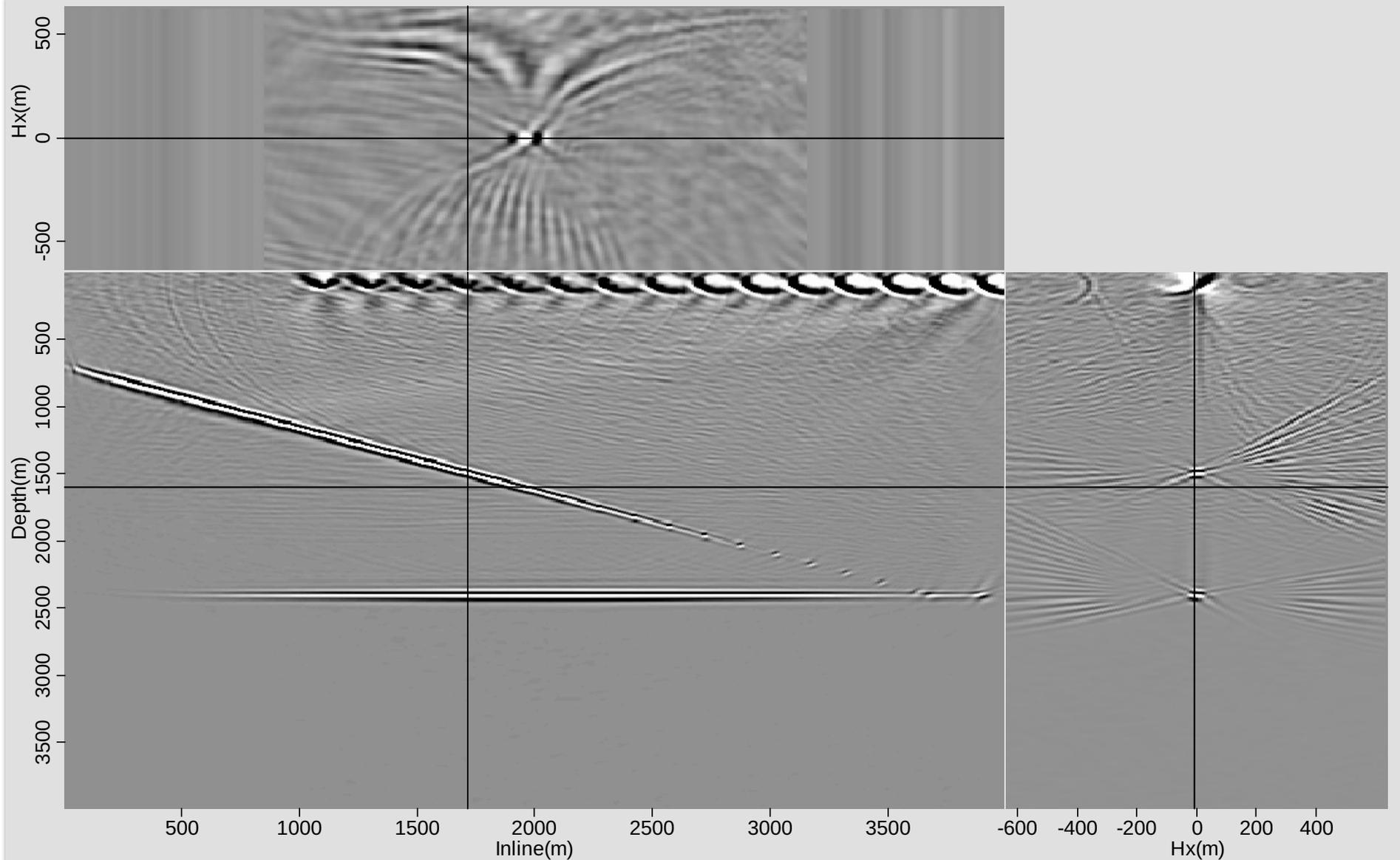
Conventional image



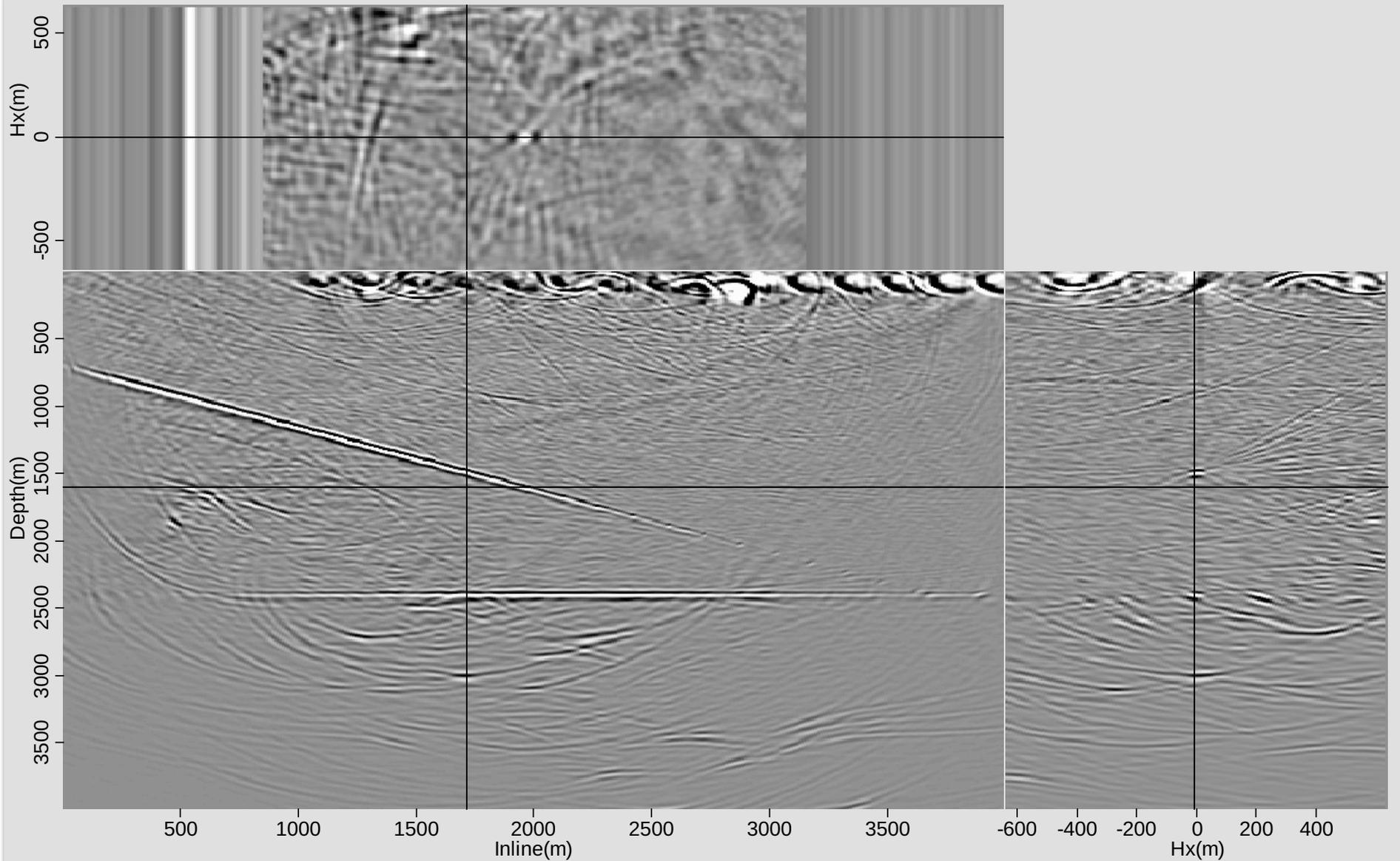
Filter shots in model space

- Non-primary shots are distinguishable in subsurface offset. Three ways to proceed:
 - Filter / iteratively threshold crosstalk in subsurface offset
 - Create a series of models with different crosstalk characteristics
 - Create a model styling operator that removes this crosstalk

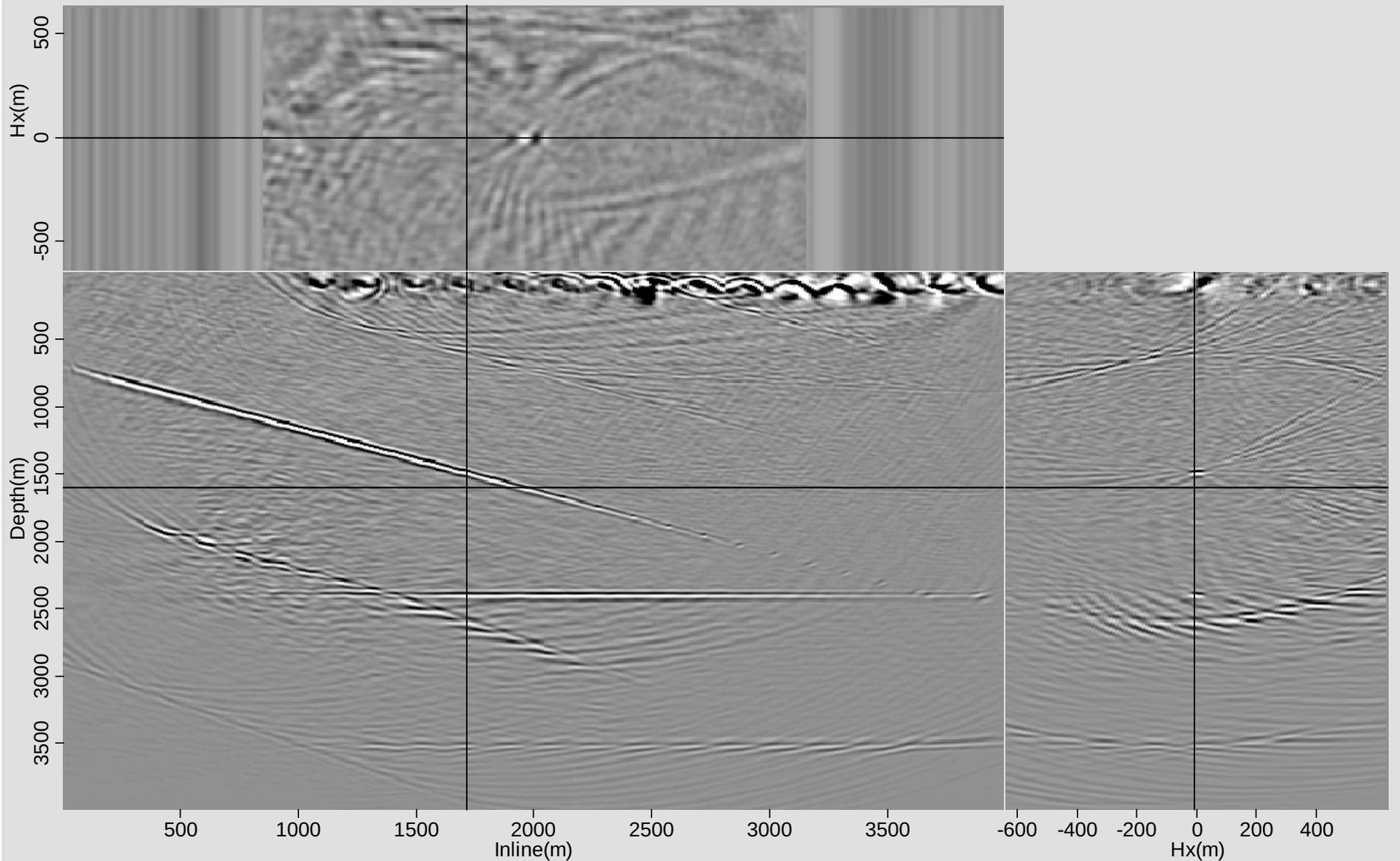
Conventional image



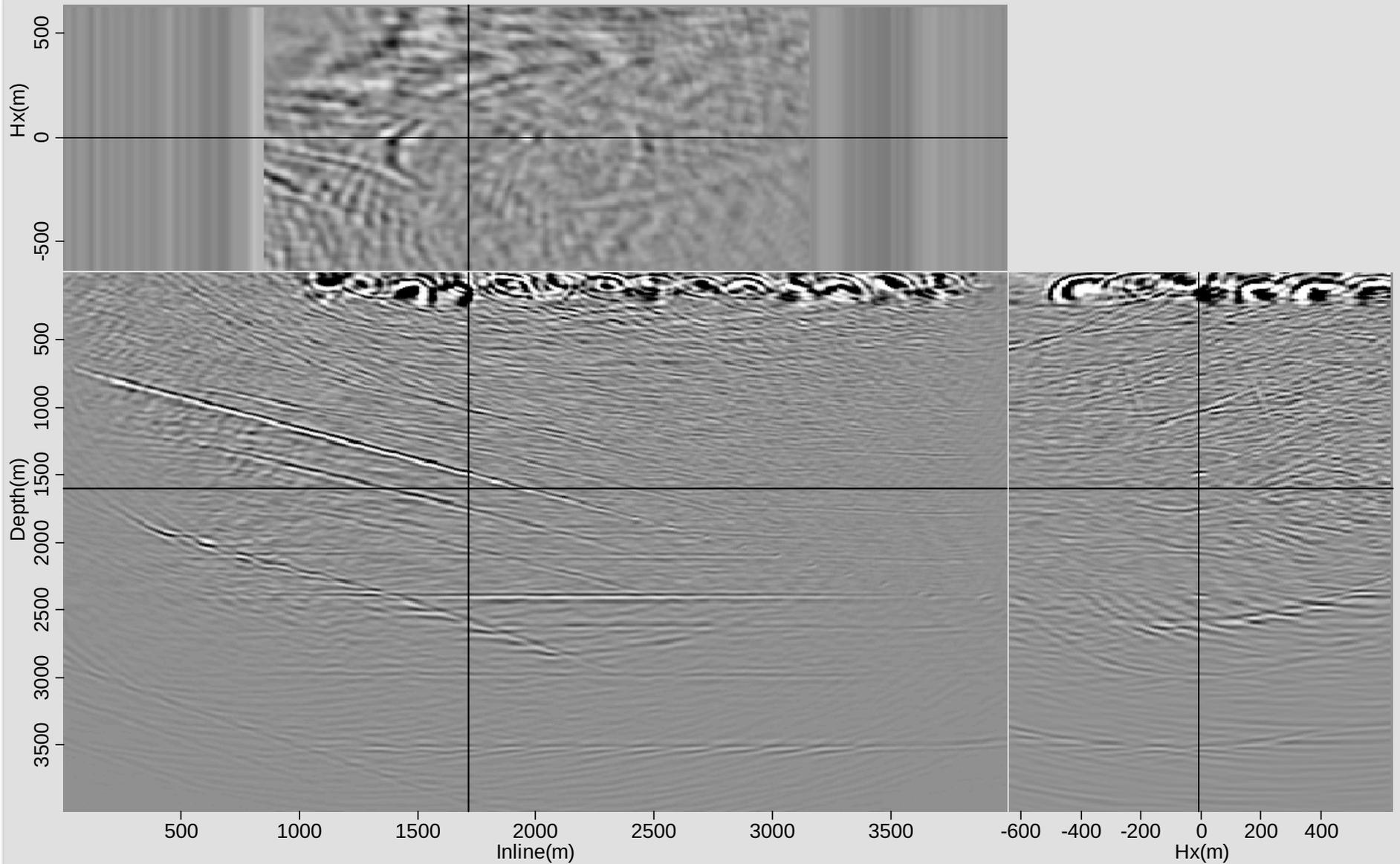
Randomly blended image



Linearly blended (1s delays)



Linear (inline) and random (xline)



Multiple models

- We obtain a series of models, m_i , where

$$\mathbf{m}_i = \mathbf{L}'_i \tilde{\mathbf{d}}_{\text{obs}}$$

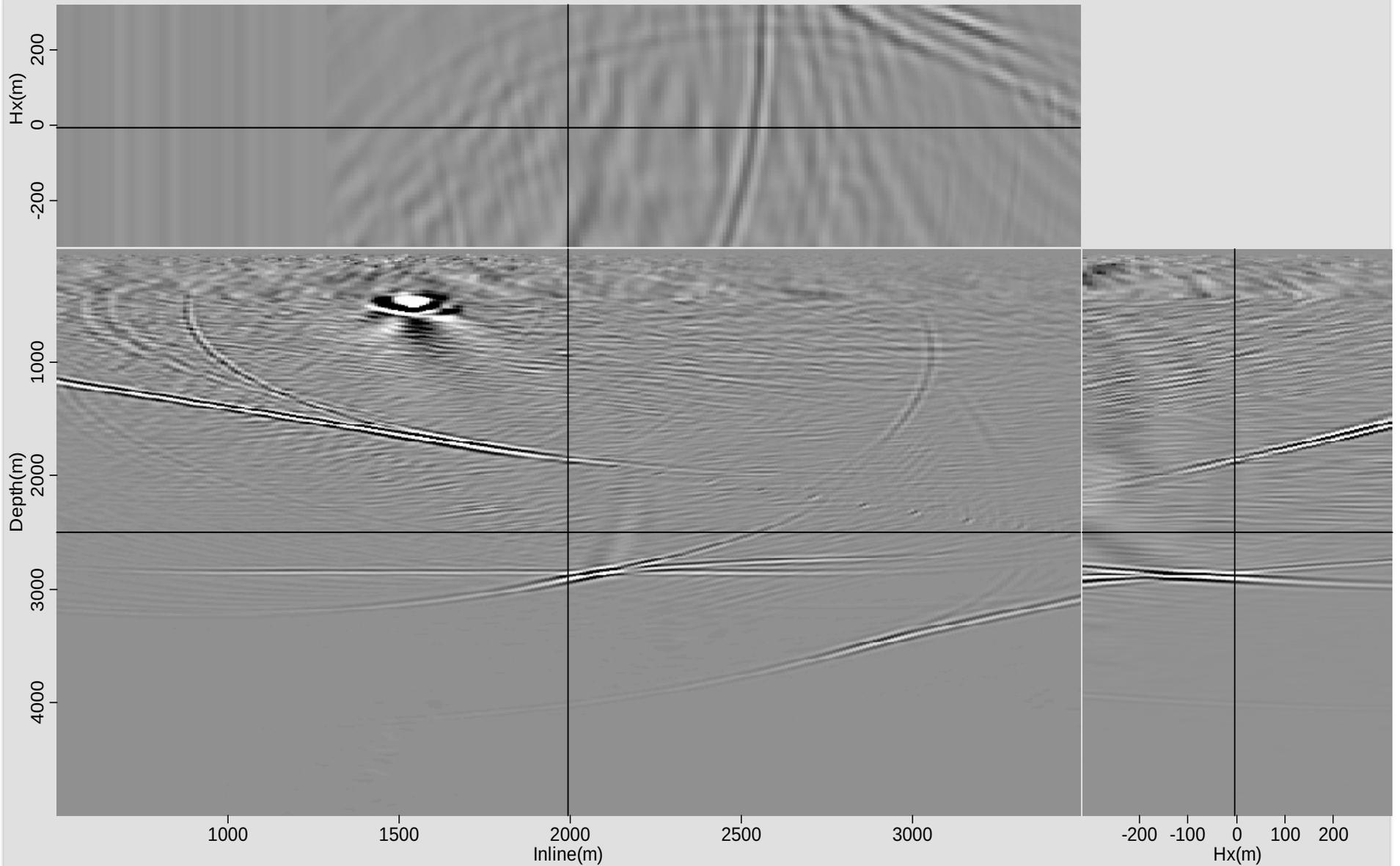
- and
$$\sum_i \mathbf{m}_i = \sum_i \mathbf{L}'_i \tilde{\mathbf{d}}_{\text{obs}} = \tilde{\mathbf{L}}' \tilde{\mathbf{d}}_{\text{obs}}$$

m : model (image)

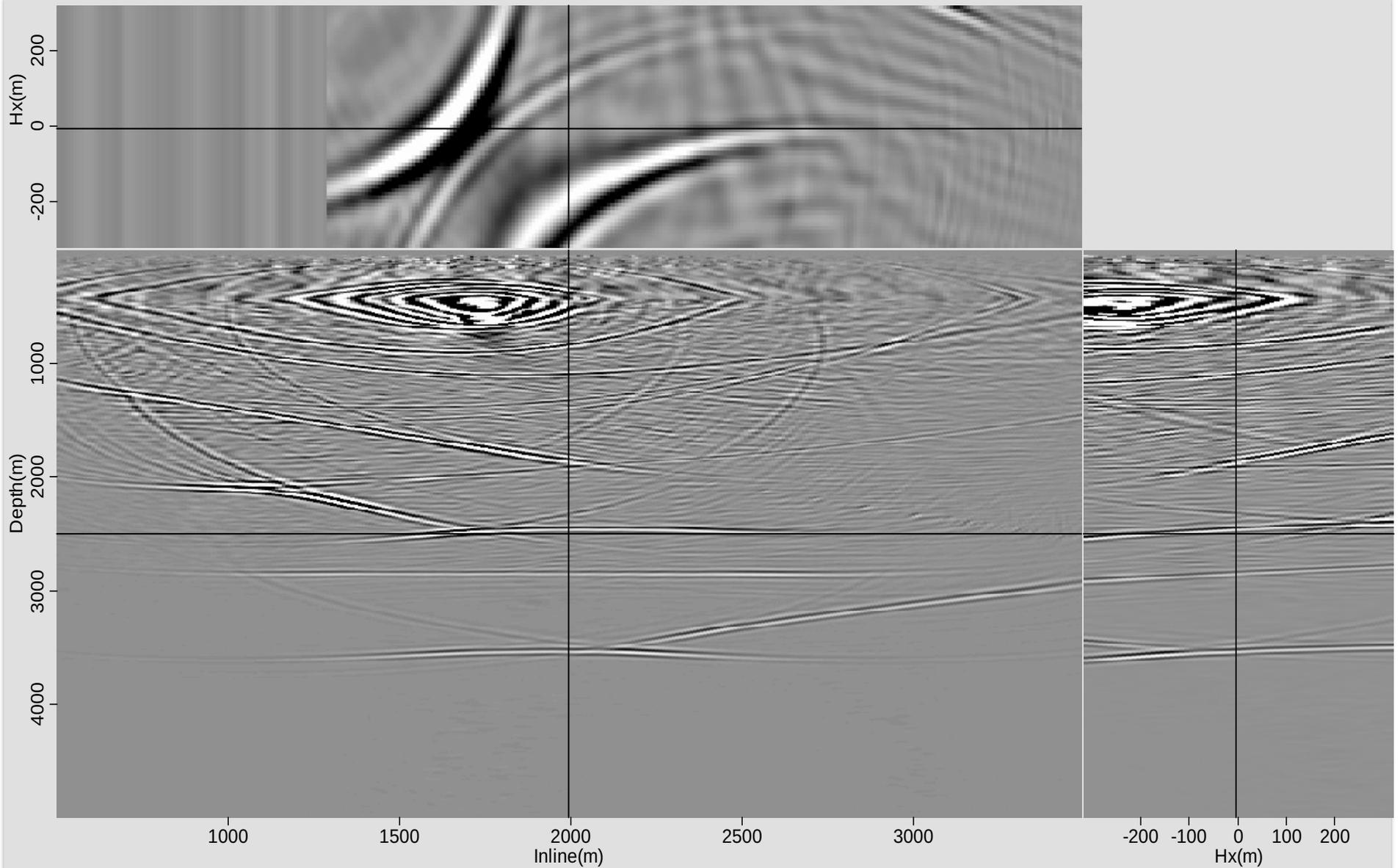
L : linearised modeling operator

d : data

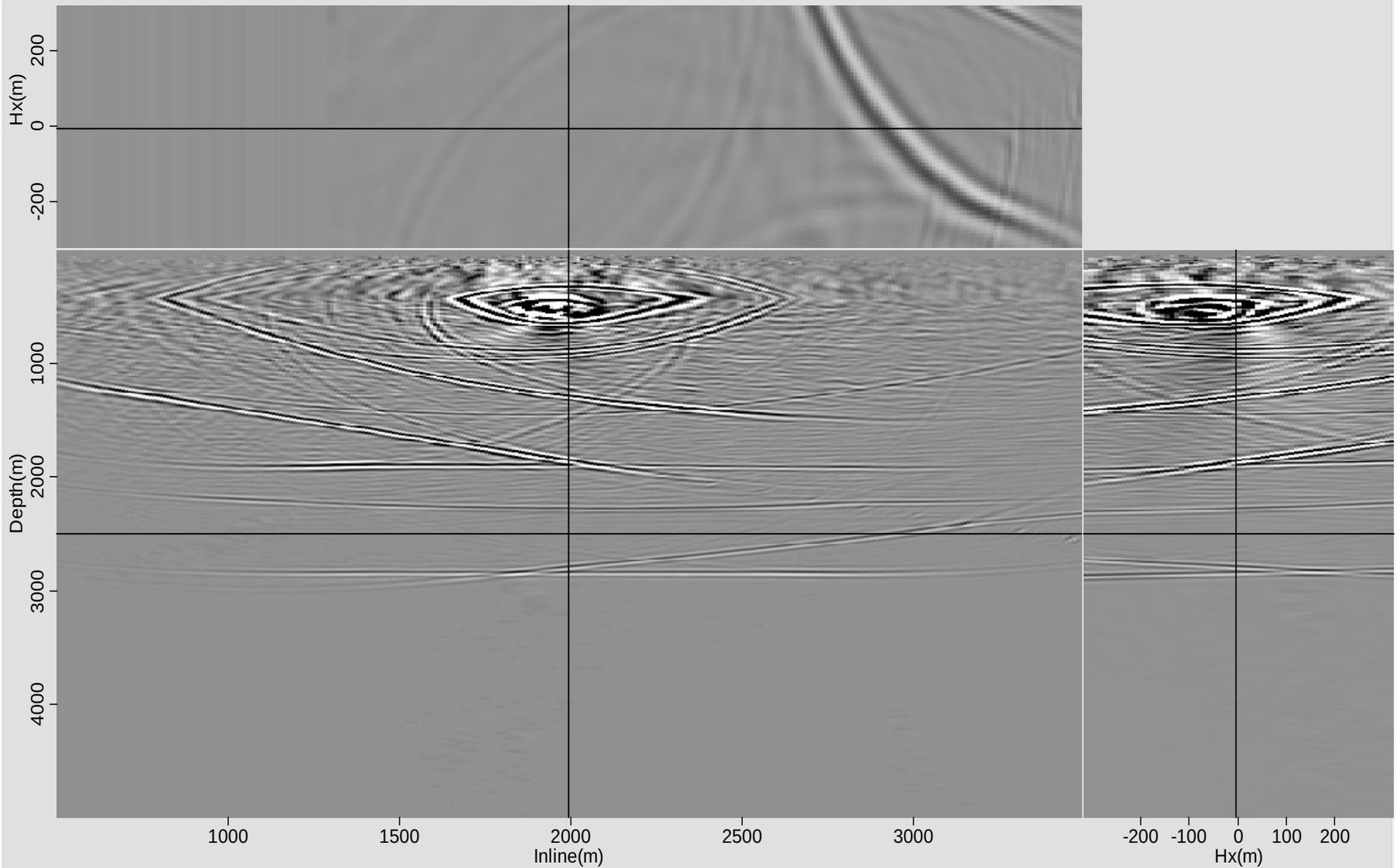
Images from random blending



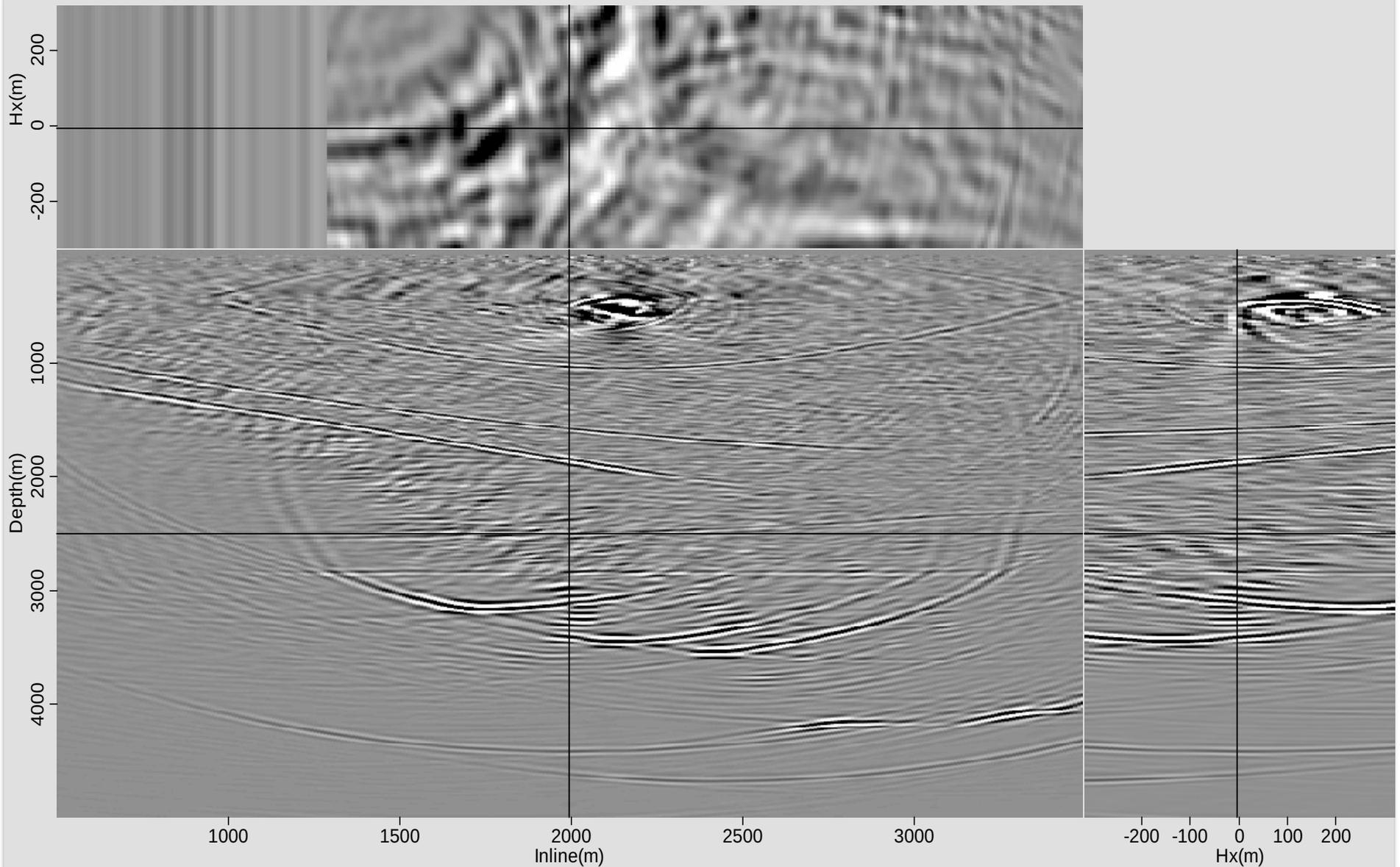
Images from random blending



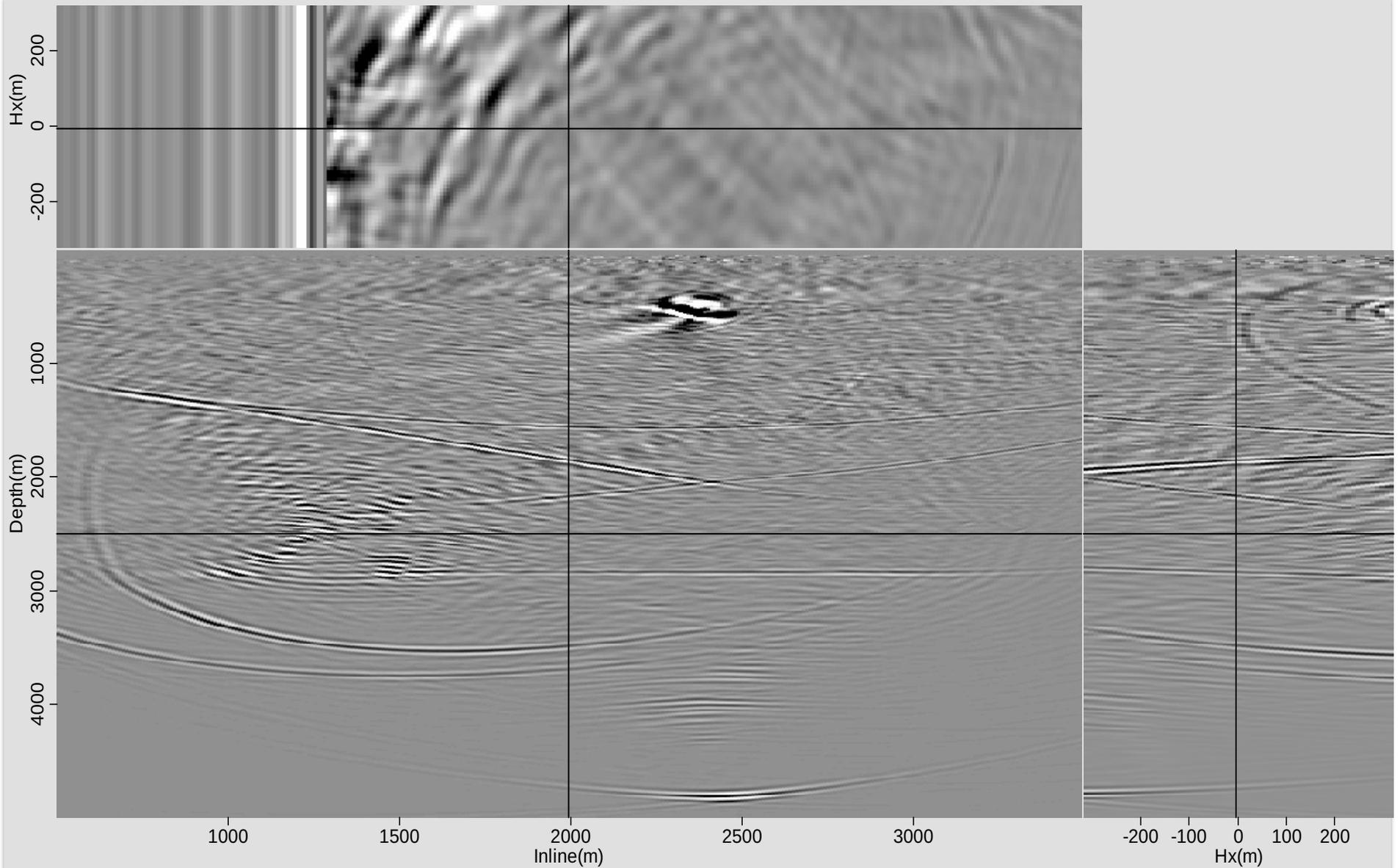
Images from random blending



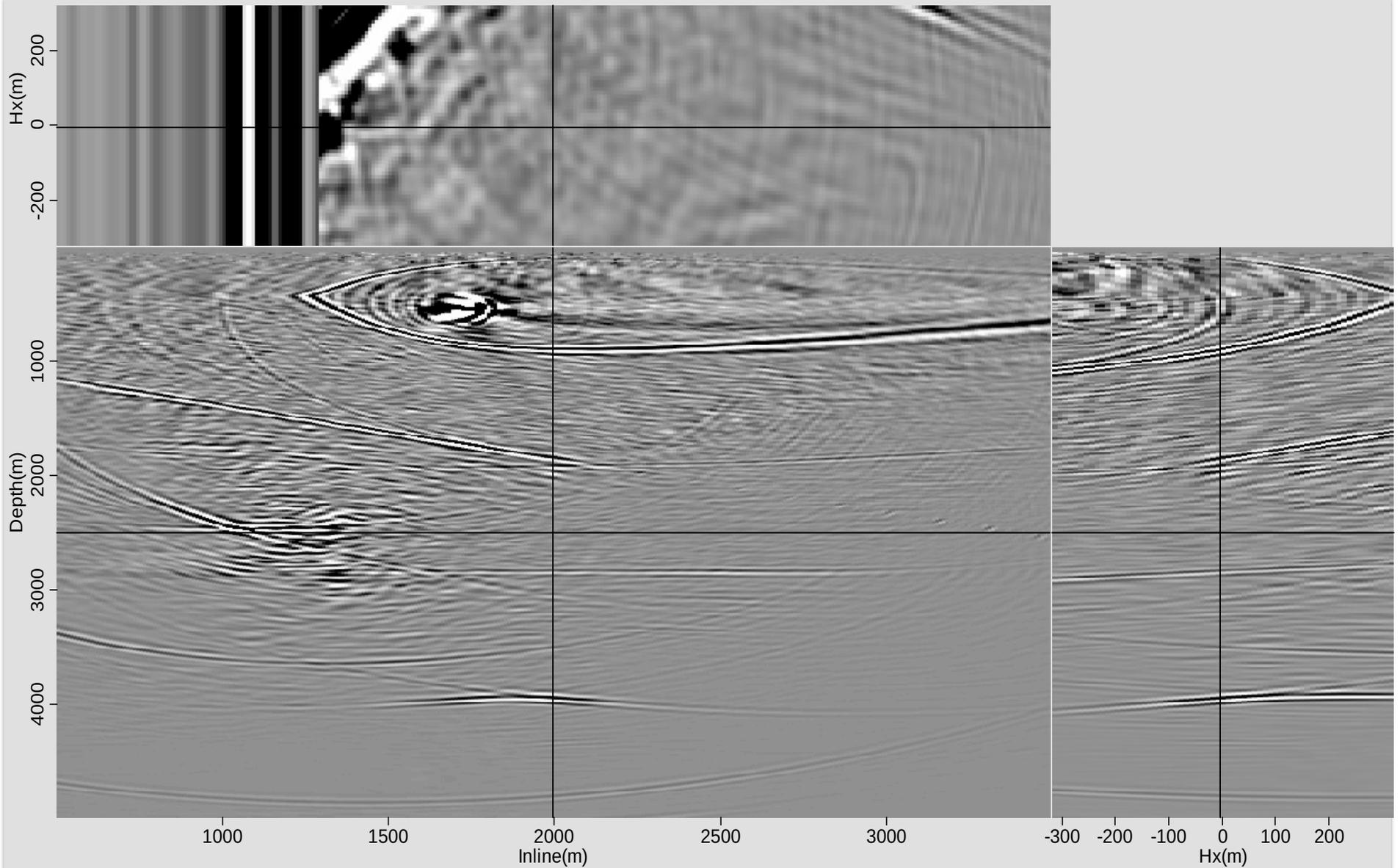
Images from random blending



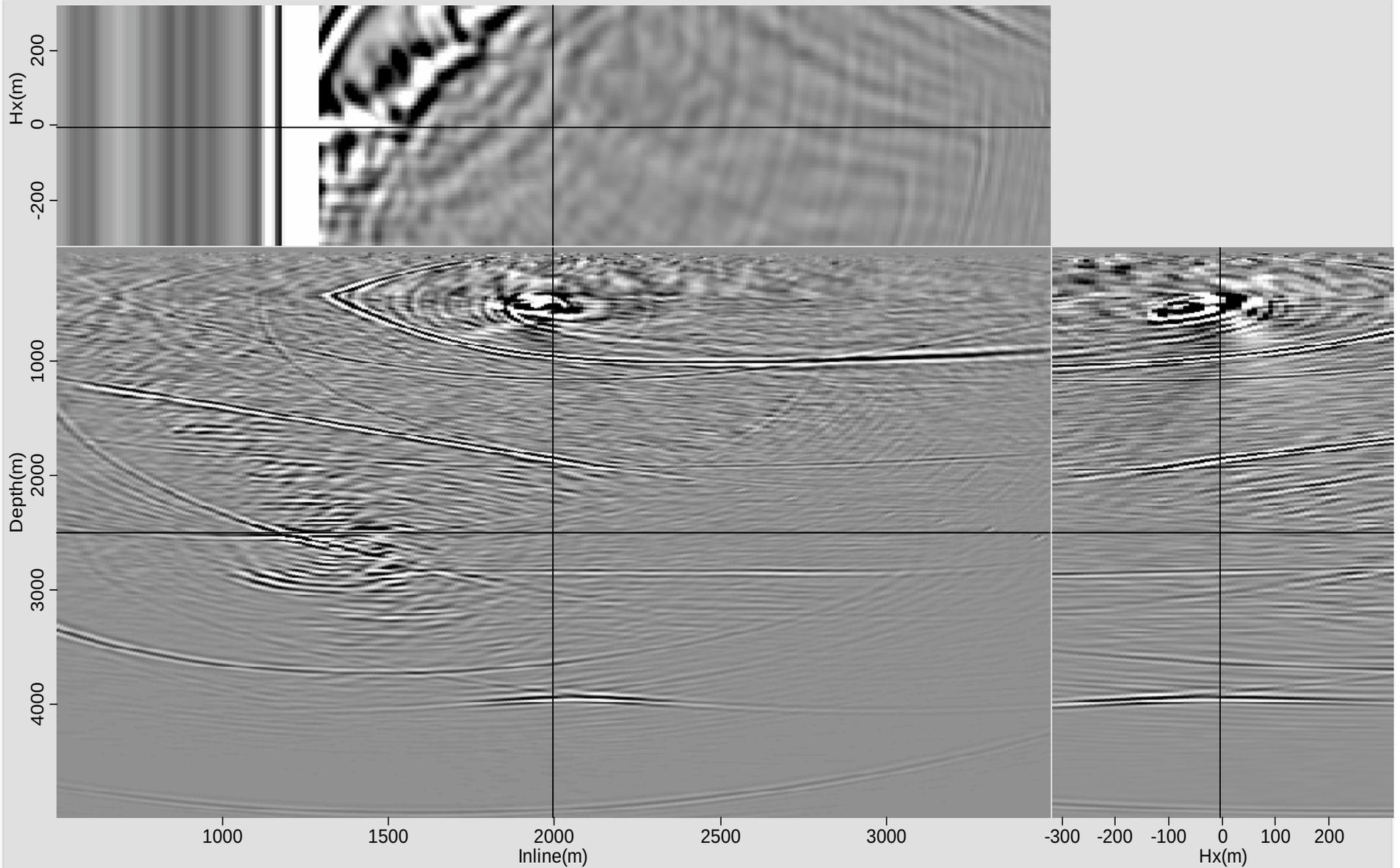
Images from random blending



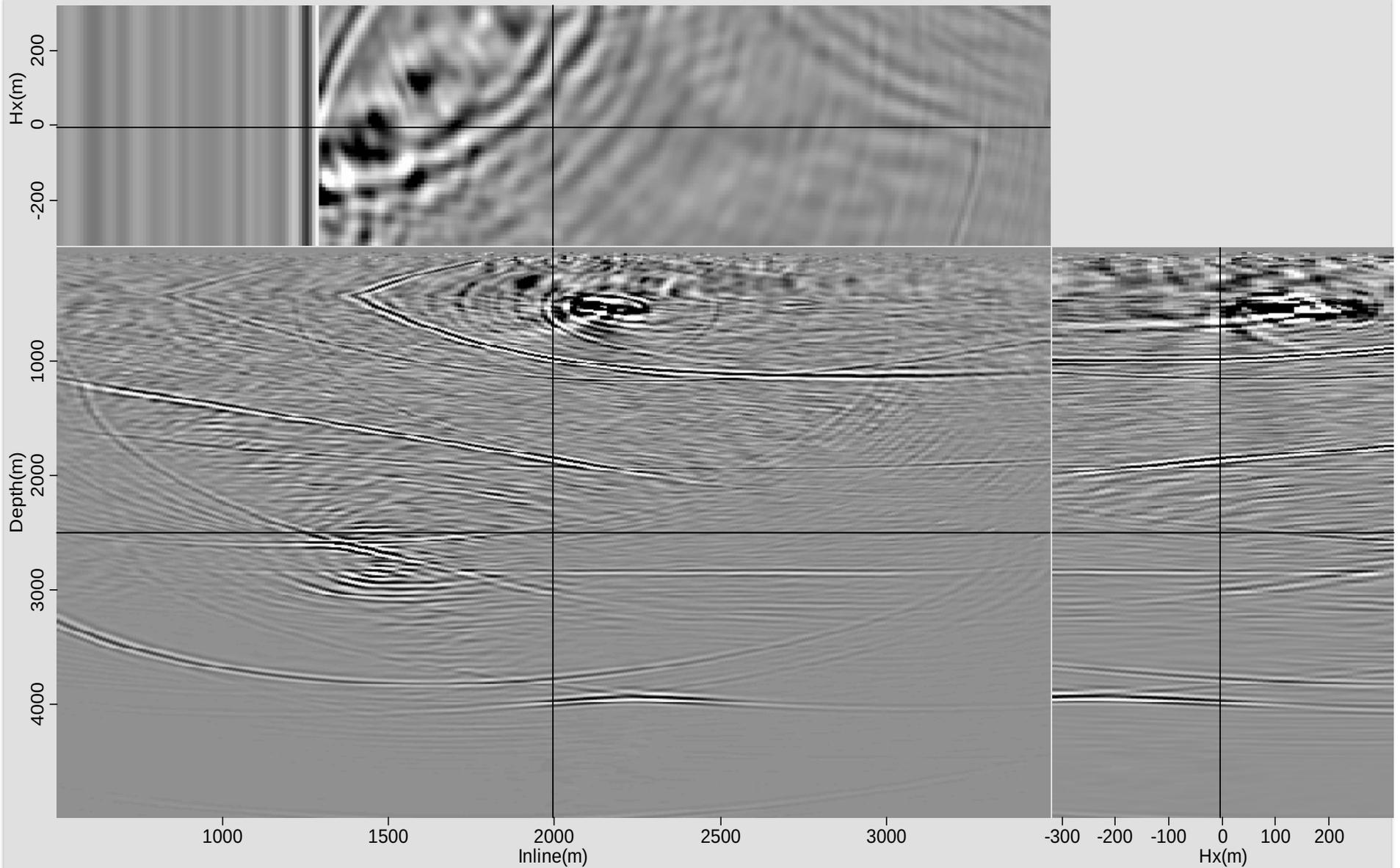
Images from linear blending



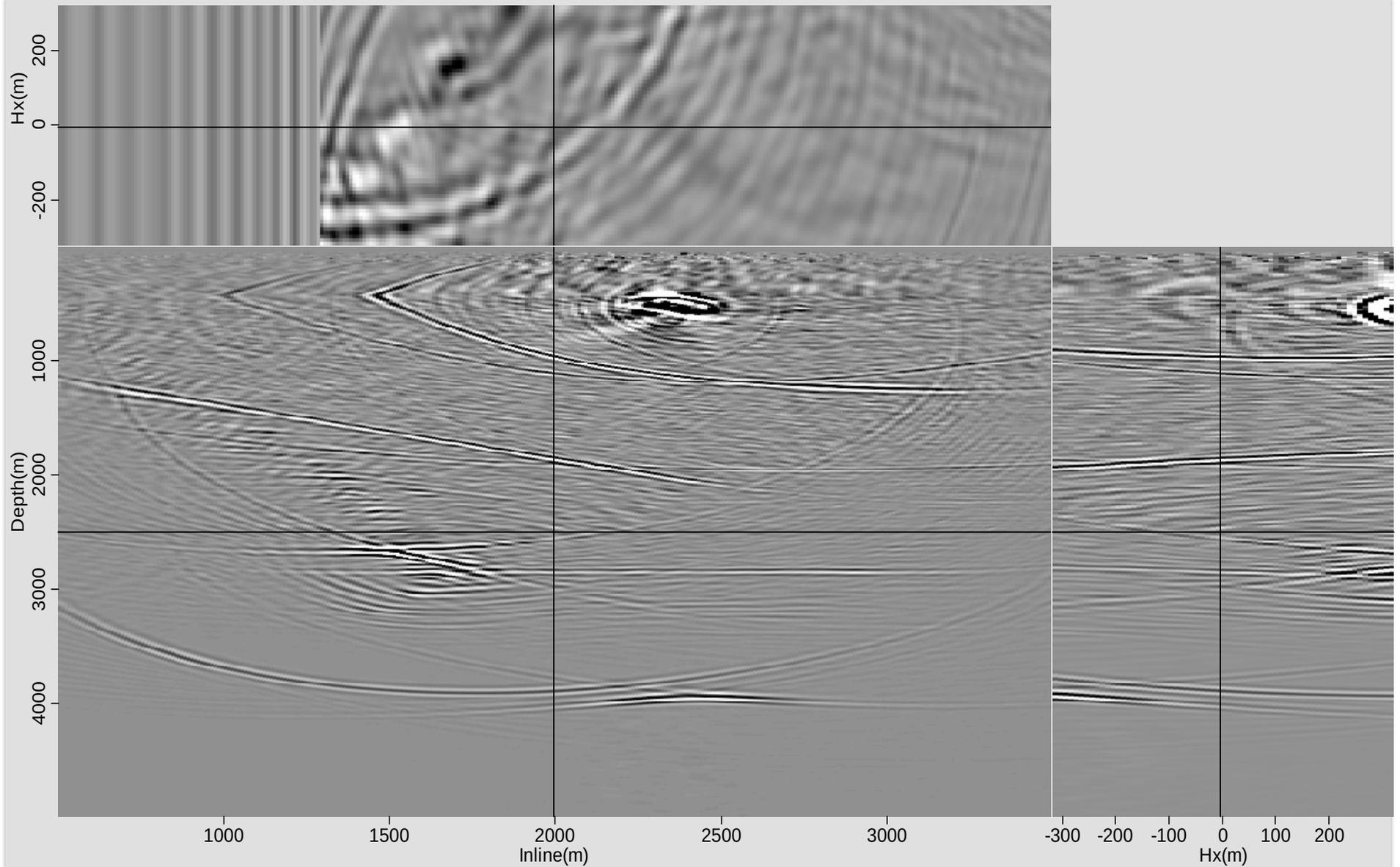
Images from linear blending



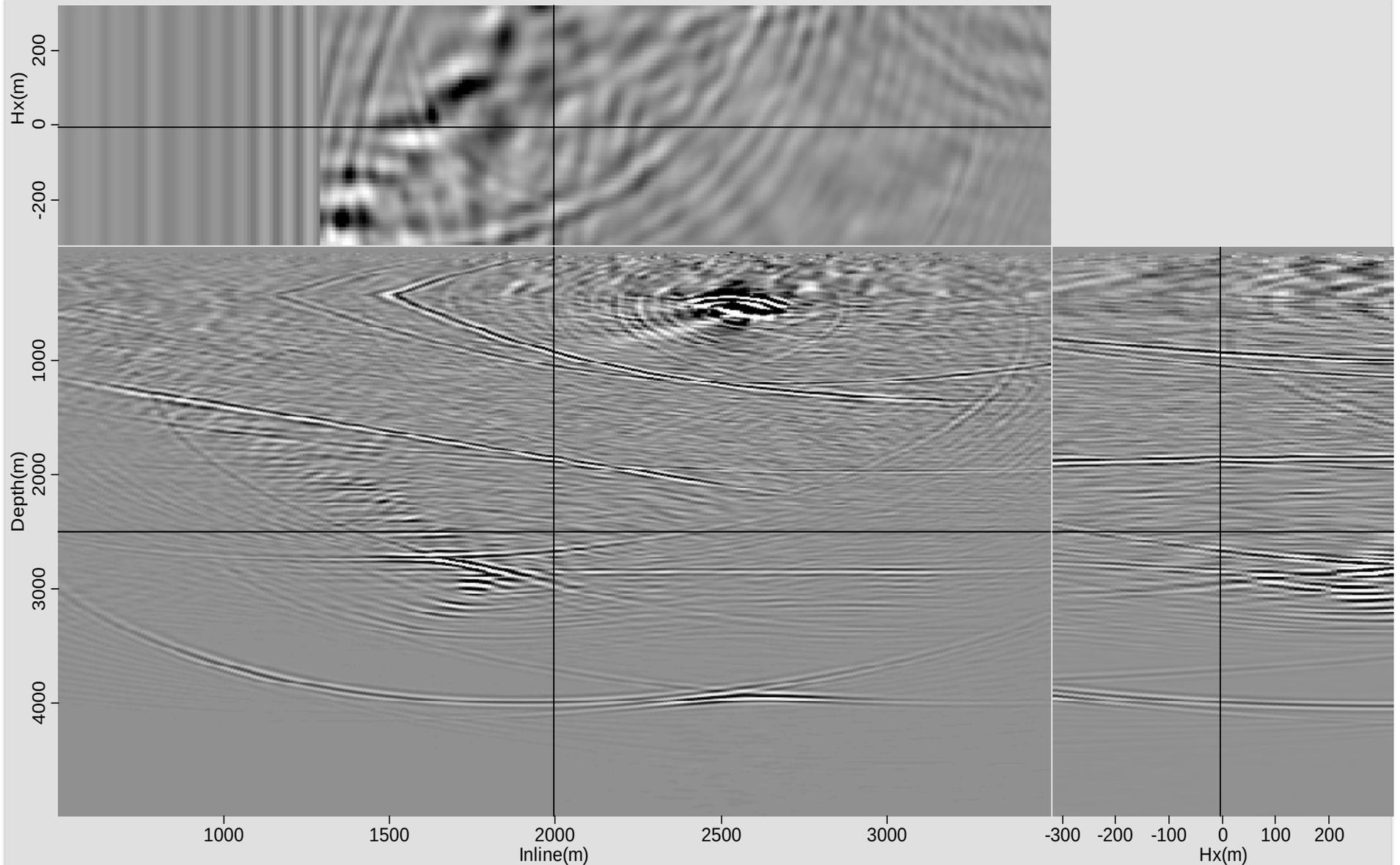
Images from linear blending



Images from linear blending



Images from linear blending



Today's outline

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Discussion

- Acquiring simultaneous data could provide huge survey cost reductions
- Existing separation techniques can not handle linearly delayed source timings
- Image space separation has the potential to deblend any sort of delays
 - Potentially without stringent velocity model restrictions

Acknowledgments

- All SEP sponsors

**Thanks for
listening!**

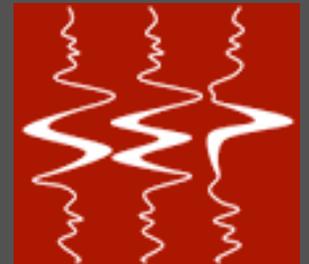


Image space inversion

- Conventional image space inversion

$$\mathbf{Lm} = \mathbf{d}_{\text{est}}$$

$$J(\mathbf{m}) = \|\mathbf{d}_{\text{obs}} - \mathbf{Lm}\|_2^2 + \varepsilon \|\mathbf{Am}\|_2^2$$

L: our operator

d: our data

A: optional regularisation term

ε : balances objective function

m: the model we are inverting for

Image space inversion

- We have two options
 - Treat non-primary energy as noise

$$\tilde{\mathbf{d}}_{\text{obs}} = \mathbf{d}_{\text{obs}} + \textit{noise}$$

- Model all shots and iteratively reduce crosstalk

Blended image space inversion

$$\tilde{\mathbf{L}}\mathbf{m} = (\mathbf{L}_p + \mathbf{L}_s)\mathbf{m} = \tilde{\mathbf{d}}_{\text{est}}$$

$$\tilde{\mathbf{d}}_{\text{est}} = \mathbf{d}_{\text{est}} + \mathbf{d}_s$$

$$J(\mathbf{m}) = \|\tilde{\mathbf{d}}_{\text{obs}} - \tilde{\mathbf{L}}\mathbf{m}\|_2^2 + \varepsilon\|\mathbf{A}\mathbf{m}\|_2^2$$

\mathbf{L}_p : our primary operator

\mathbf{L}_s : our secondary operator

\mathbf{d}_s : all overlapping shots

\mathbf{A} : regularisation operator to remove events from \mathbf{d}_s

Blended image space inversion

- Direct inversion requires the knowledge of m
- Here, we are trying to create the equivalently unblended data
 - The process is independent of m , if we are trying to create d
- We can design A to remove non-primary energy
 - Overlapping shots are identifiable in subsurface offset gathers