Edge-preserving smoothing for segmentation of seismic images

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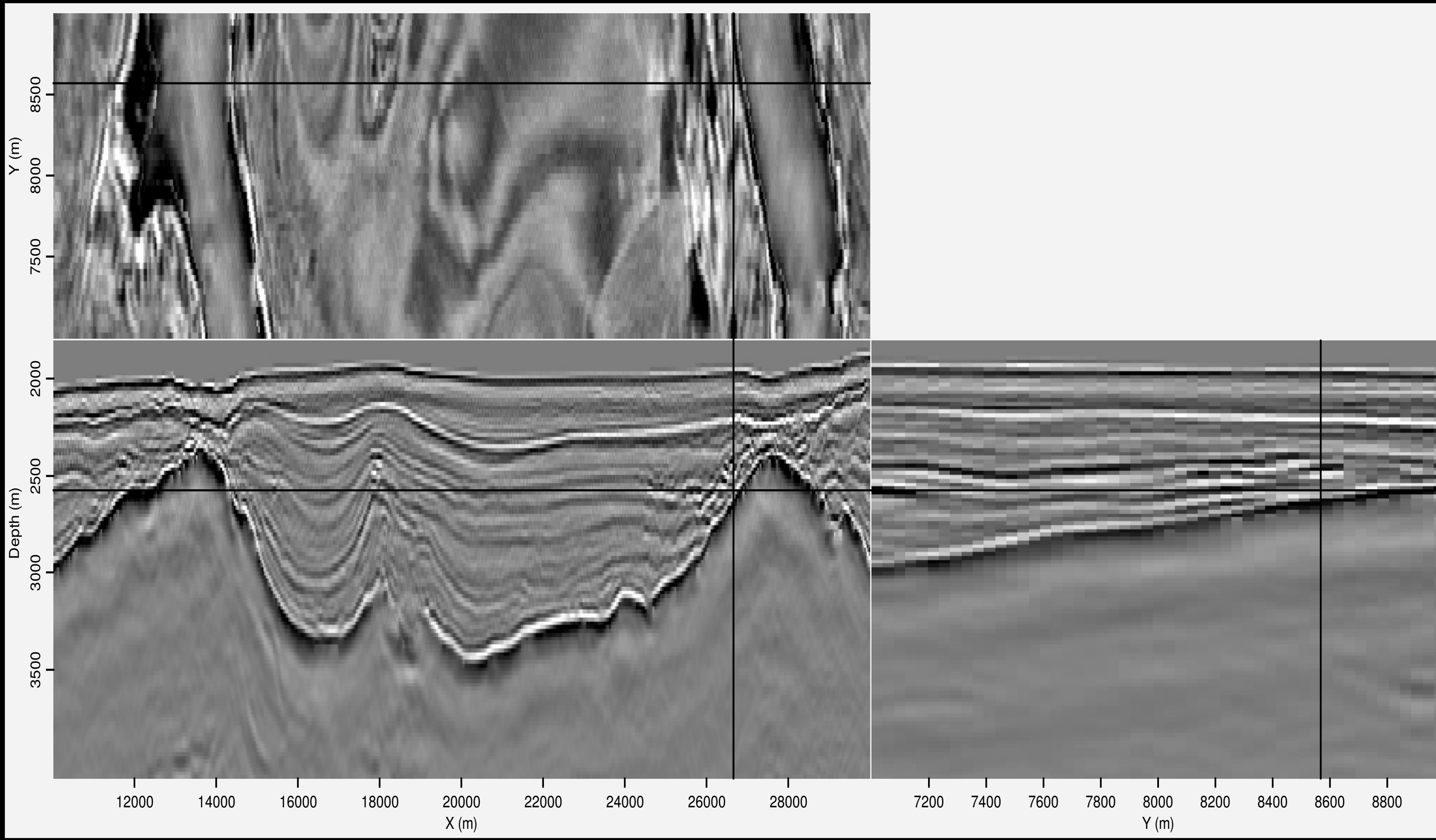
Stanford Exploration Project

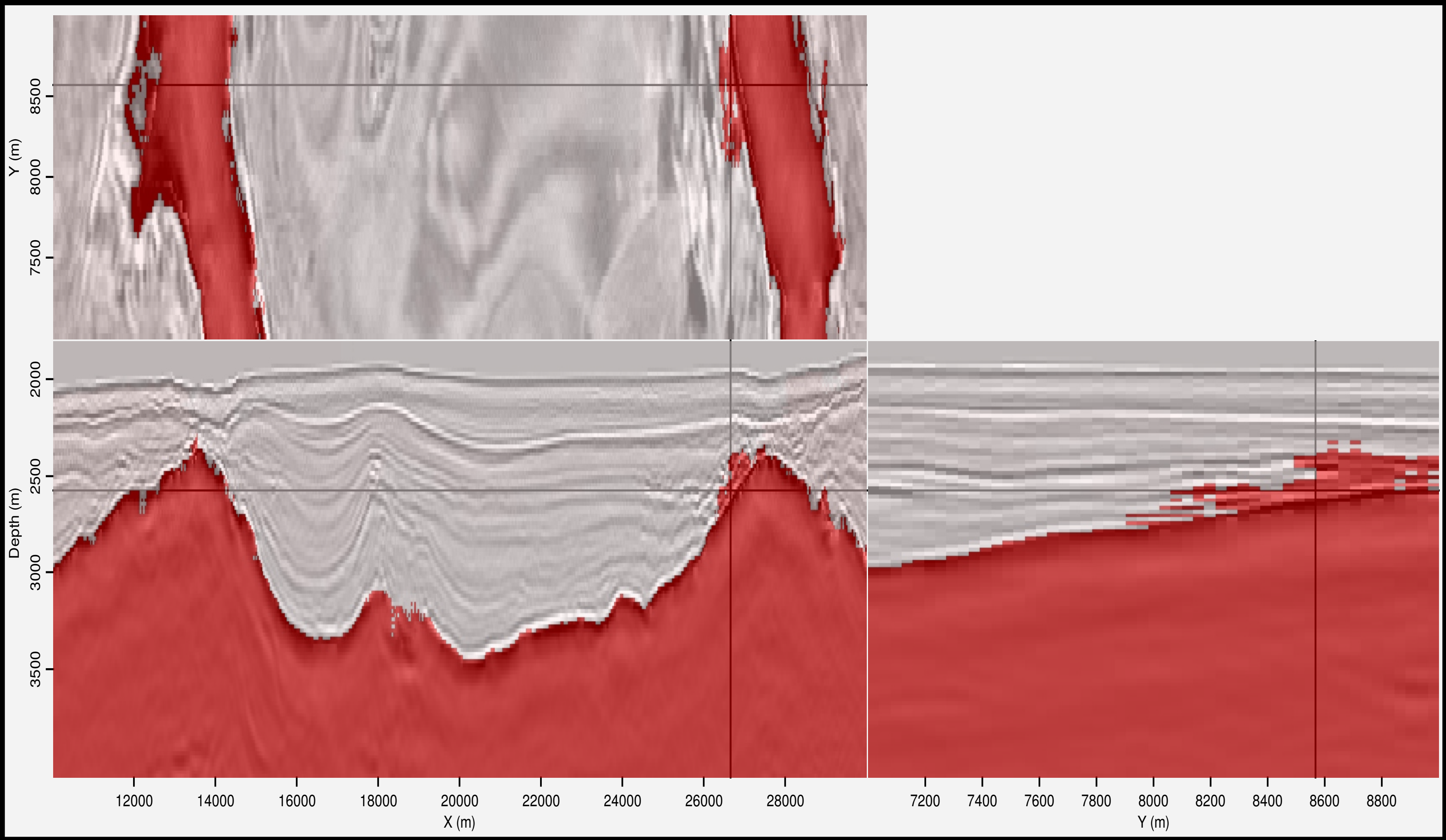
Why EPS?

- Noisy images pose problems for a variety of data/image processing tasks
  - Smoothing is often a simple solution
- For seismic interpretation algorithms, sharp boundaries (edges) provide an image's most important information
  - Reflectors, faults, ...
- Goal: use edge-preserving smoothing (EPS) to remove noise AND preserve the boundaries
  - (Extremely efficiently)

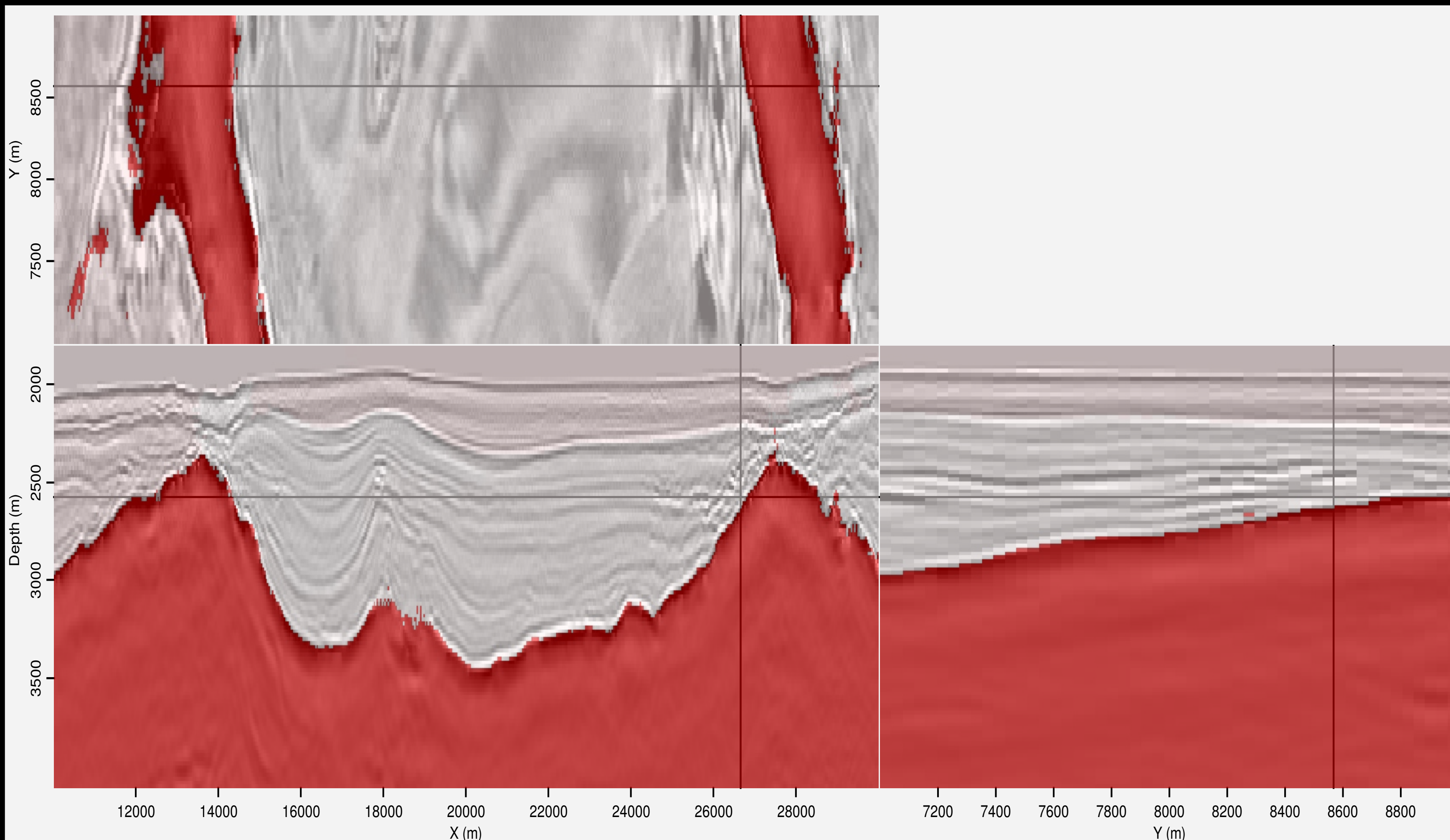
Example image



Original segmentation



After EPS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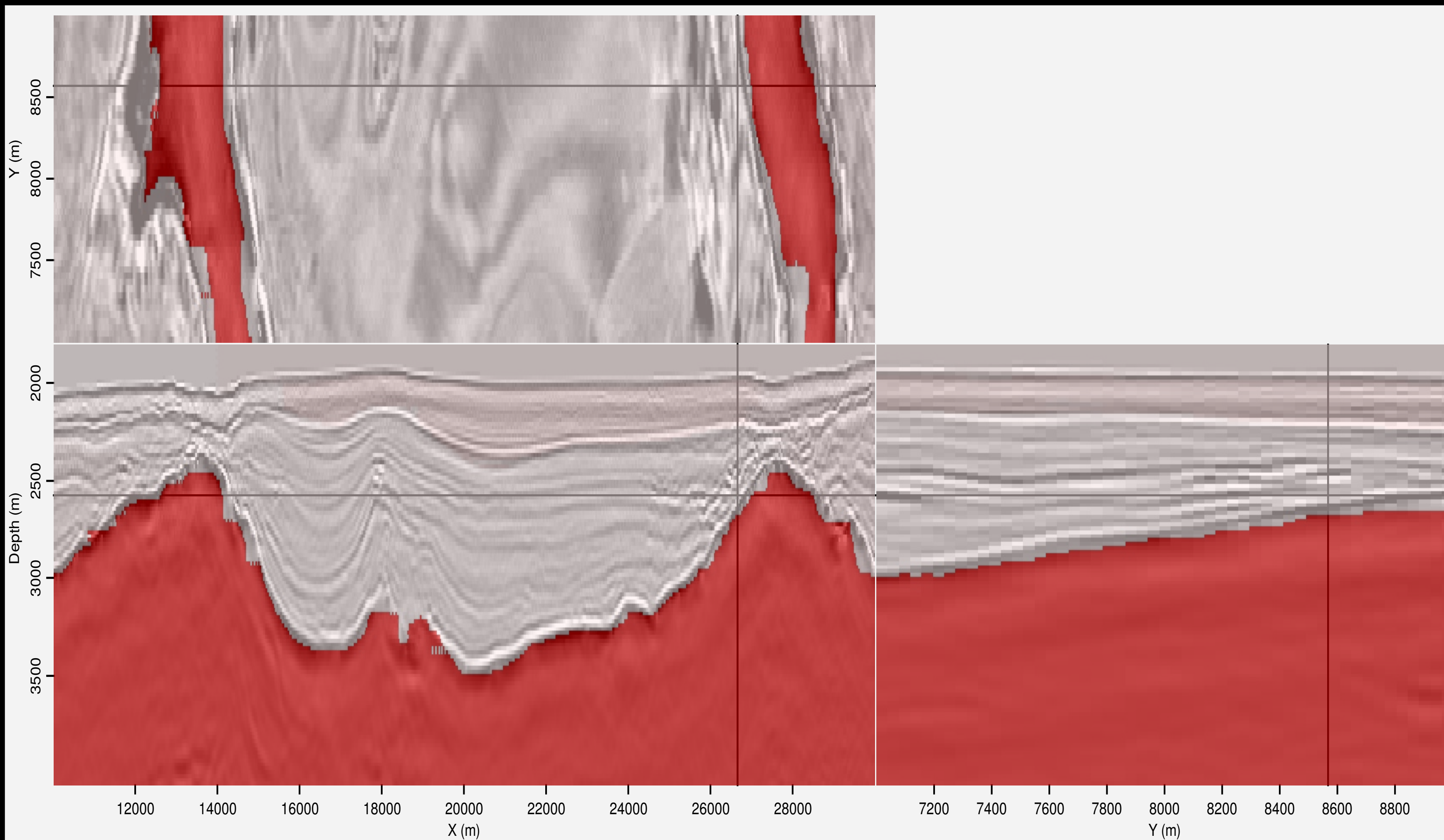
Traditional smoothing

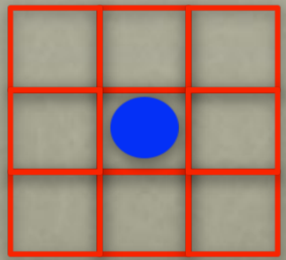


Outline

- Overview of EPS
  - "Maximum homogeneity median" smoothing
- 2.5-D Synthetic example
- "Hybrid" smoothing scheme
  - Combines EPS and traditional smoothing
- 3-D Field data examples
  - Image segmentation results

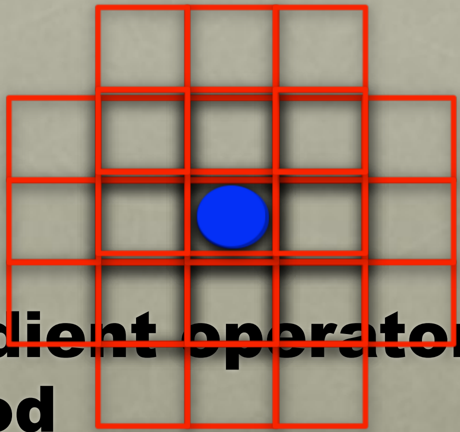
Median filtering

- ***Median filtering*** **(Tukey, 1971) is a standard EPS technique**
  - **Instead of averaging in a neighborhood around the pixel, use the median value**



Maximum homogeneity filtering

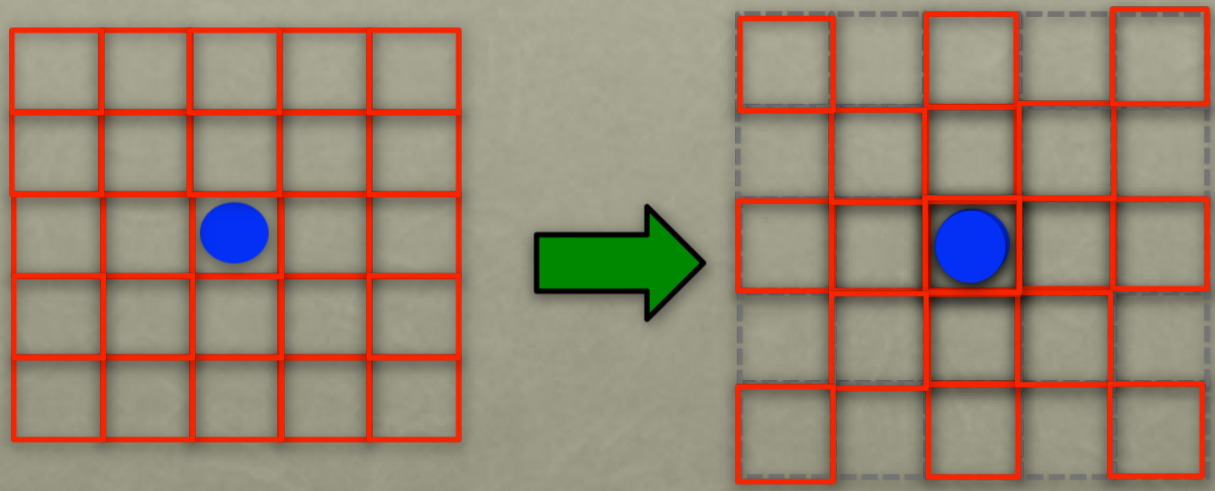
- **Tomita and Tsujui (1977)**
  - **Select 5+ different neighborhoods surrounding the pixel**



- **Apply a gradient operator to each neighborhood**
  - **Use the average value of the most homogeneous neighborhood**

MHM filtering

- Even greater edge discrimination is possible
- Maximum Homegeneity Median (MHM) filtering
  - Zahedi and Thomas (1993)
- Two good ideas
  - “Bar masks” instead of square neighborhoods



MHM filtering

- Even greater edge discrimination is possible
- Maximum Homegeneity Median filtering
    - Zahedi and Thomas (1993)
- Two good ideas
    - “Bar masks” instead of square neighborhoods
    - Use variance to measure homogeneity

$$\sigma^2 = \frac{1}{N}\sum_{1}^{N}(\bar{x} - x_i)^2$$

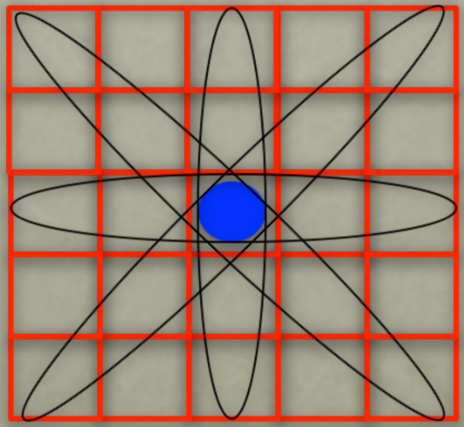
# of pixels in bar mask

Avg value of pixels in bar mask

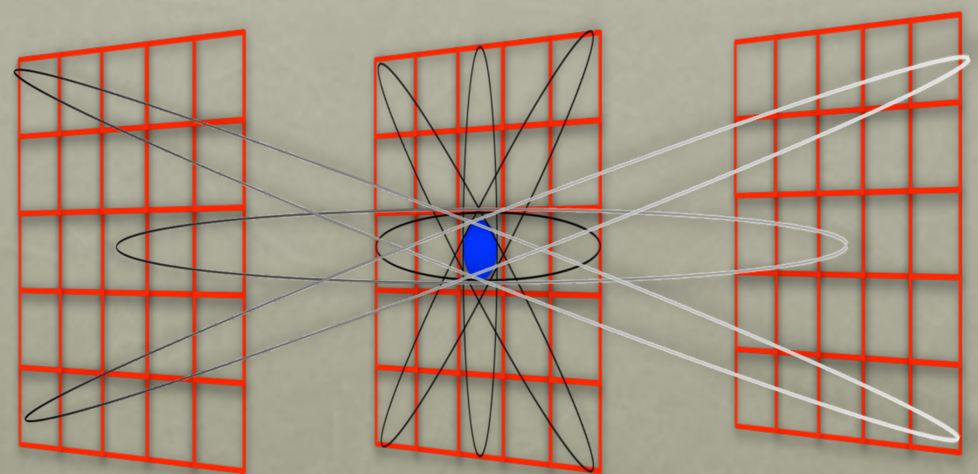
MHM filtering

- Even greater edge discrimination is possible
- Maximum Homegeneity Median filtering
  - Zahedi and Thomas (1993)
- Two good ideas
  - “Bar masks” instead of square neighborhoods
  - Use variance to measure homogeneity
- Assign median value of mask with smallest variance to the pixel

3D MHM filter



3D MHM filter



Other smoothing options

- **Inverse methods (PEF's, etc.)**
  - **Guitton (2005)**
- **Structure- or dip-oriented filtering**
  - **Fehmers and Hocker (2003)**
- **Bilateral filtering**
  - **Hale (2011)**

Compared to these methods, MH filtering is extremely efficient and requires no prior information about the image

MH seismic filtering

- **AlBinHassan et al., 2006**
- **Compute variances within 3D blocks of pixels**
  - **Use mean of most homogeneous block**
- **Less efficient than MH-median filtering**

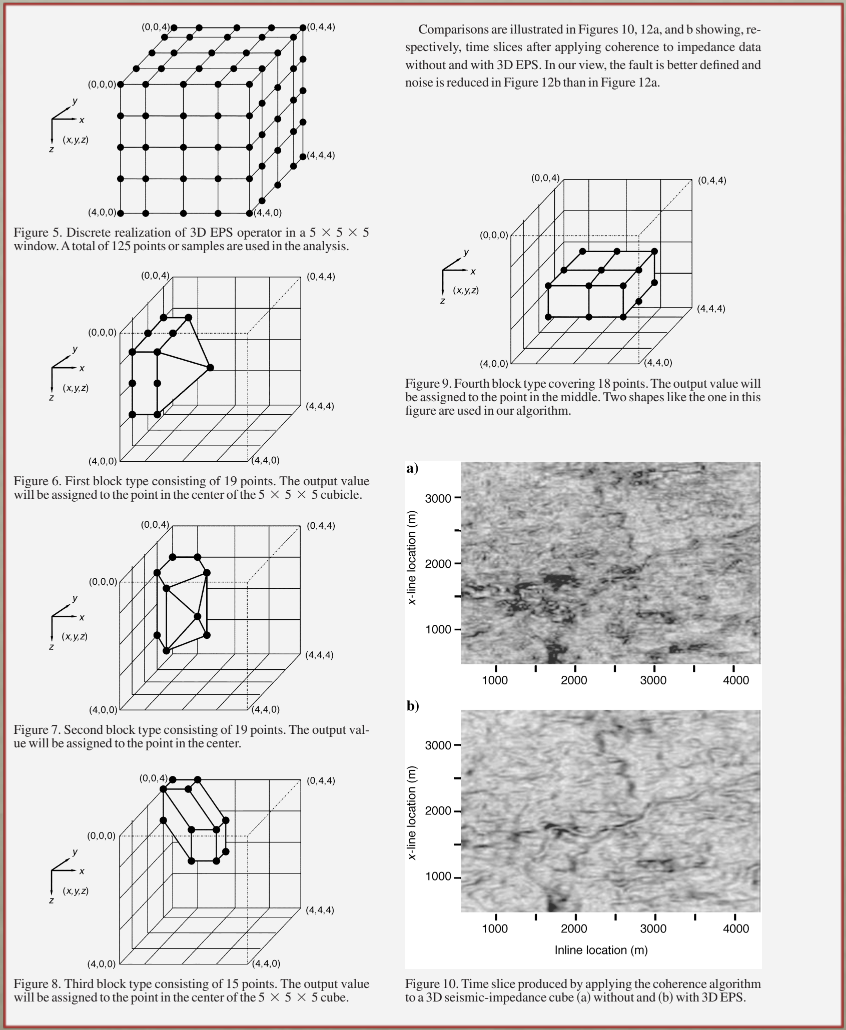

Comparisons are illustrated in Figures 10, 12a, and b showing, respectively, time slices after applying coherence to impedance data without and with 3D EPS. In our view, the fault is better defined and noise is reduced in Figure 12b than in Figure 12a.

Figure 5. Discrete realization of 3D EPS operator in a 5 × 5 × 5 window. A total of 125 points or samples are used in the analysis.

Figure 6. First block type consisting of 19 points. The output value will be assigned to the point in the center of the 5 × 5 × 5 cubicle.

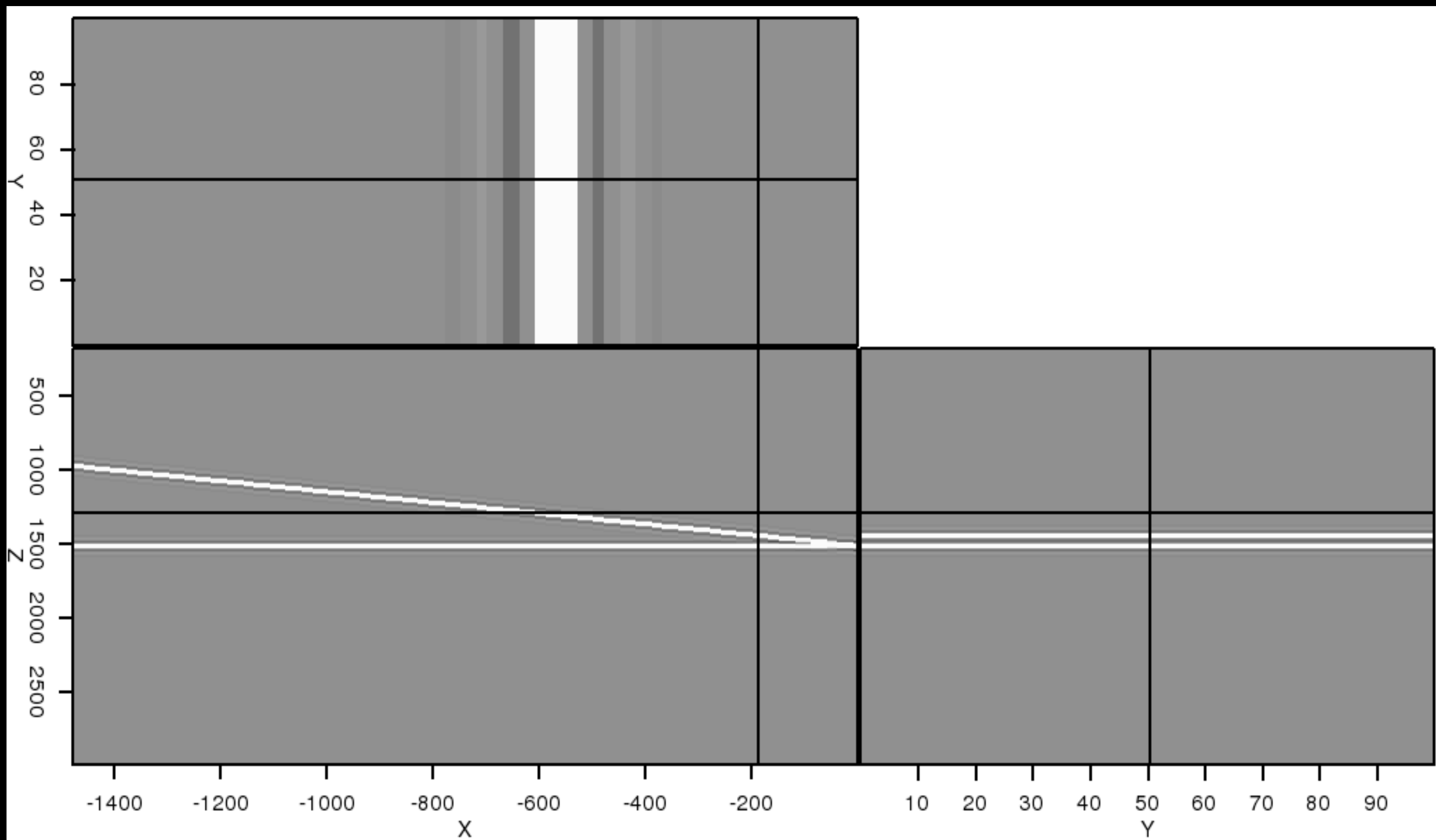
Figure 7. Second block type consisting of 19 points. The output value will be assigned to the point in the center.

Figure 8. Third block type consisting of 15 points. The output value will be assigned to the point in the center of the 5 × 5 × 5 cube.

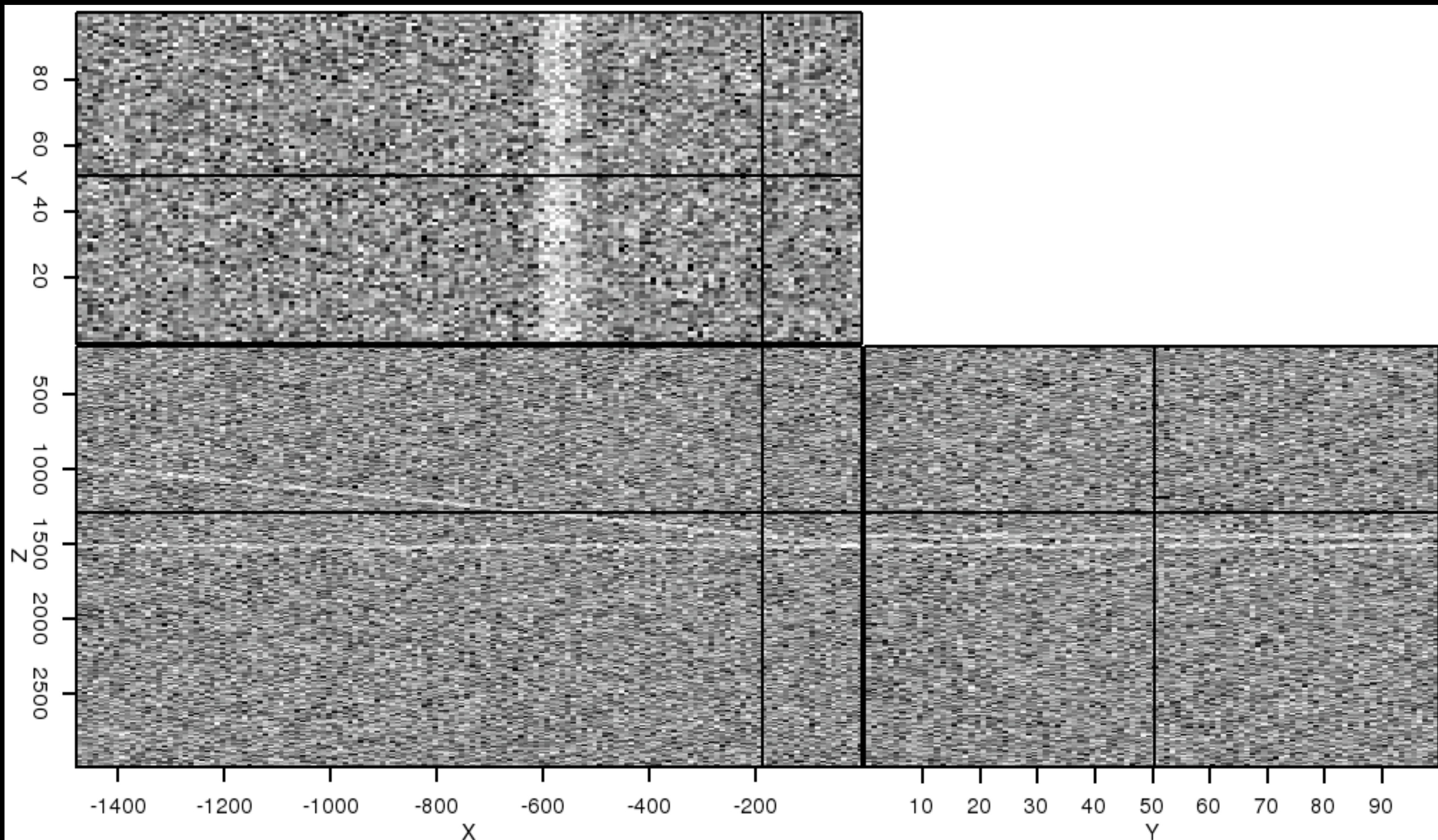
Figure 9. Fourth block type covering 18 points. The output value will be assigned to the point in the middle. Two shapes like the one in this figure are used in our algorithm.

Figure 10. Time slice produced by applying the coherence algorithm to a 3D seismic-impedance cube (a) without and (b) with 3D EPS.

Simple synthetic



Add noise



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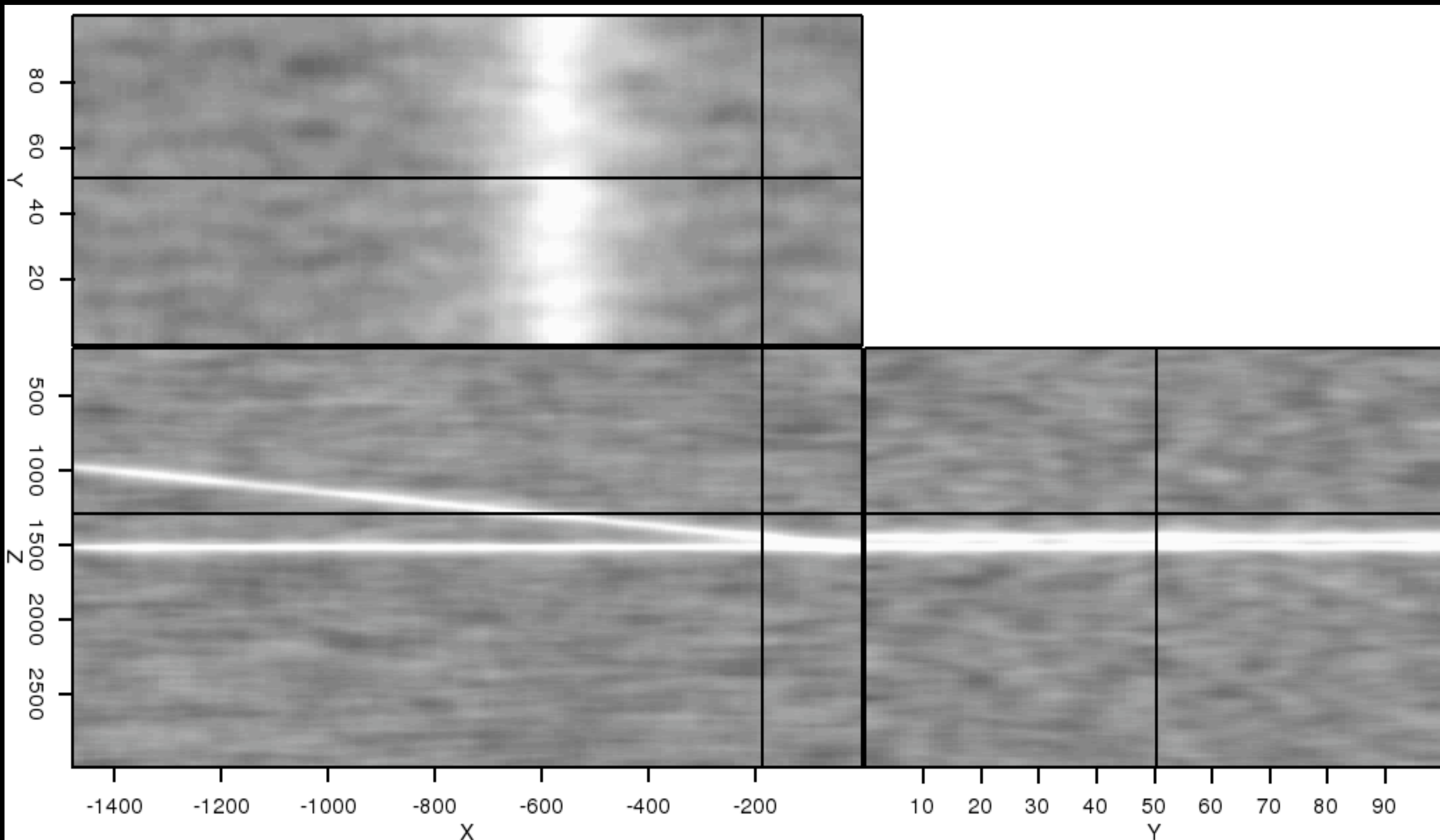
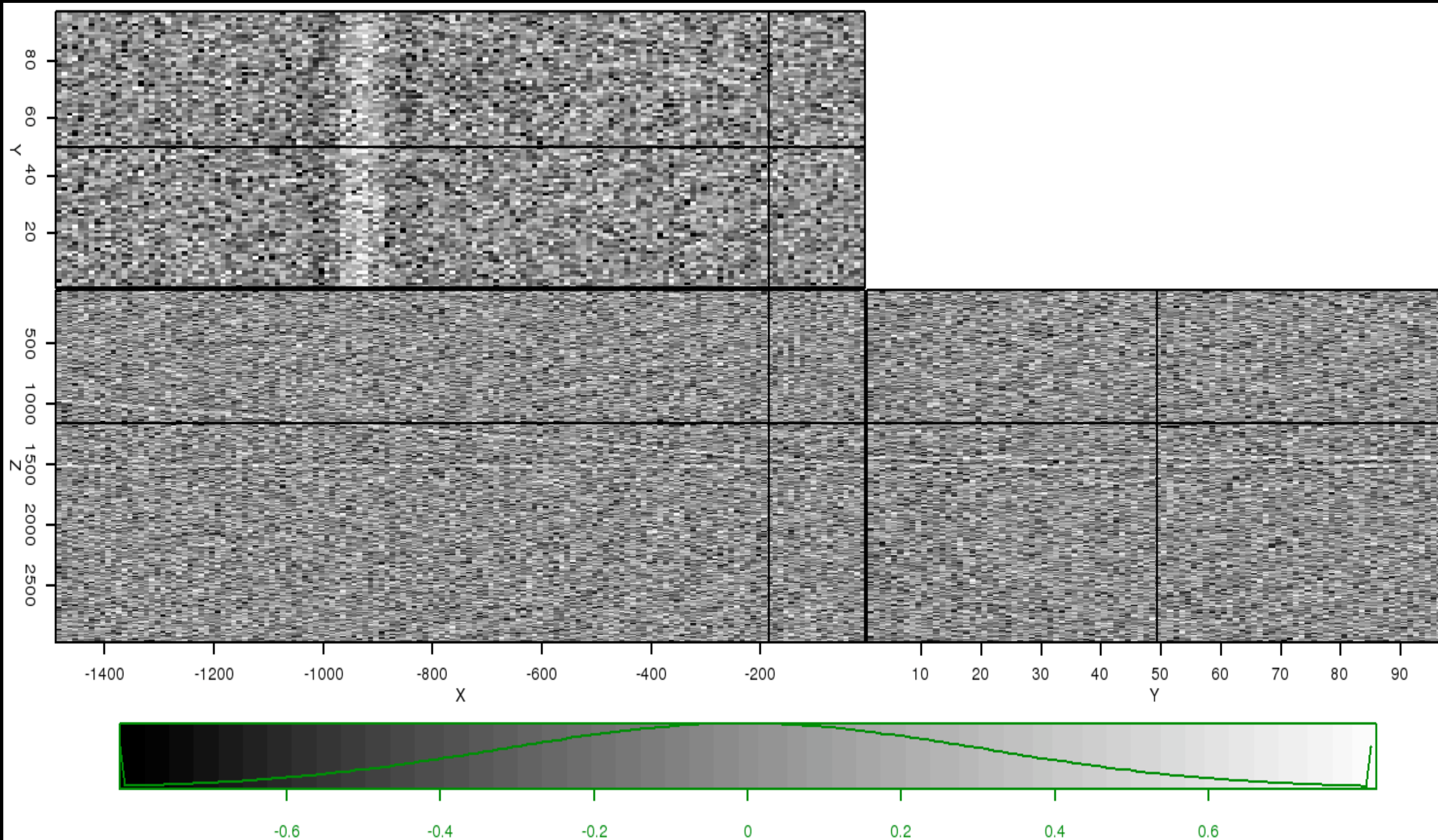
Traditional smoothing



Difference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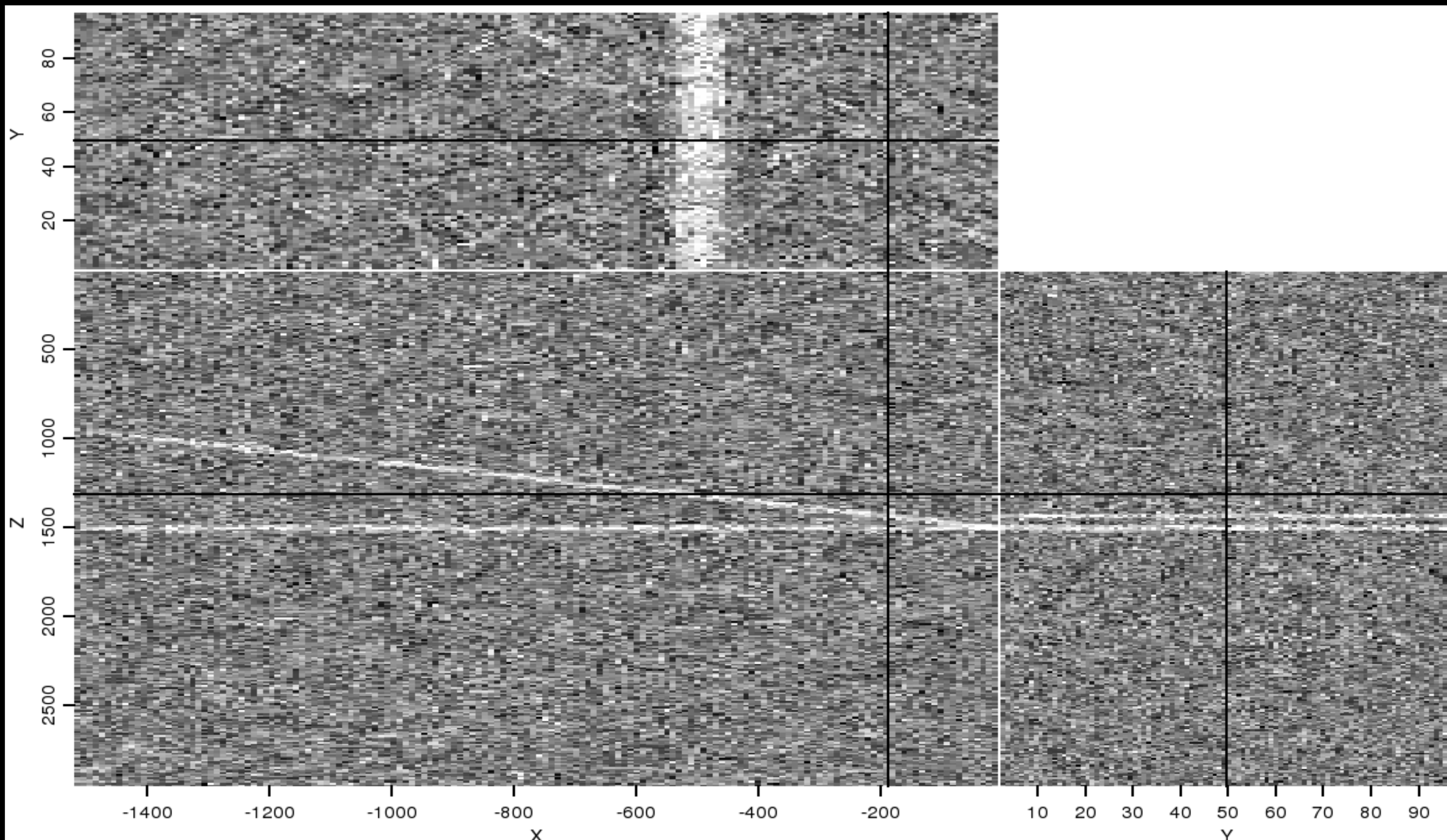
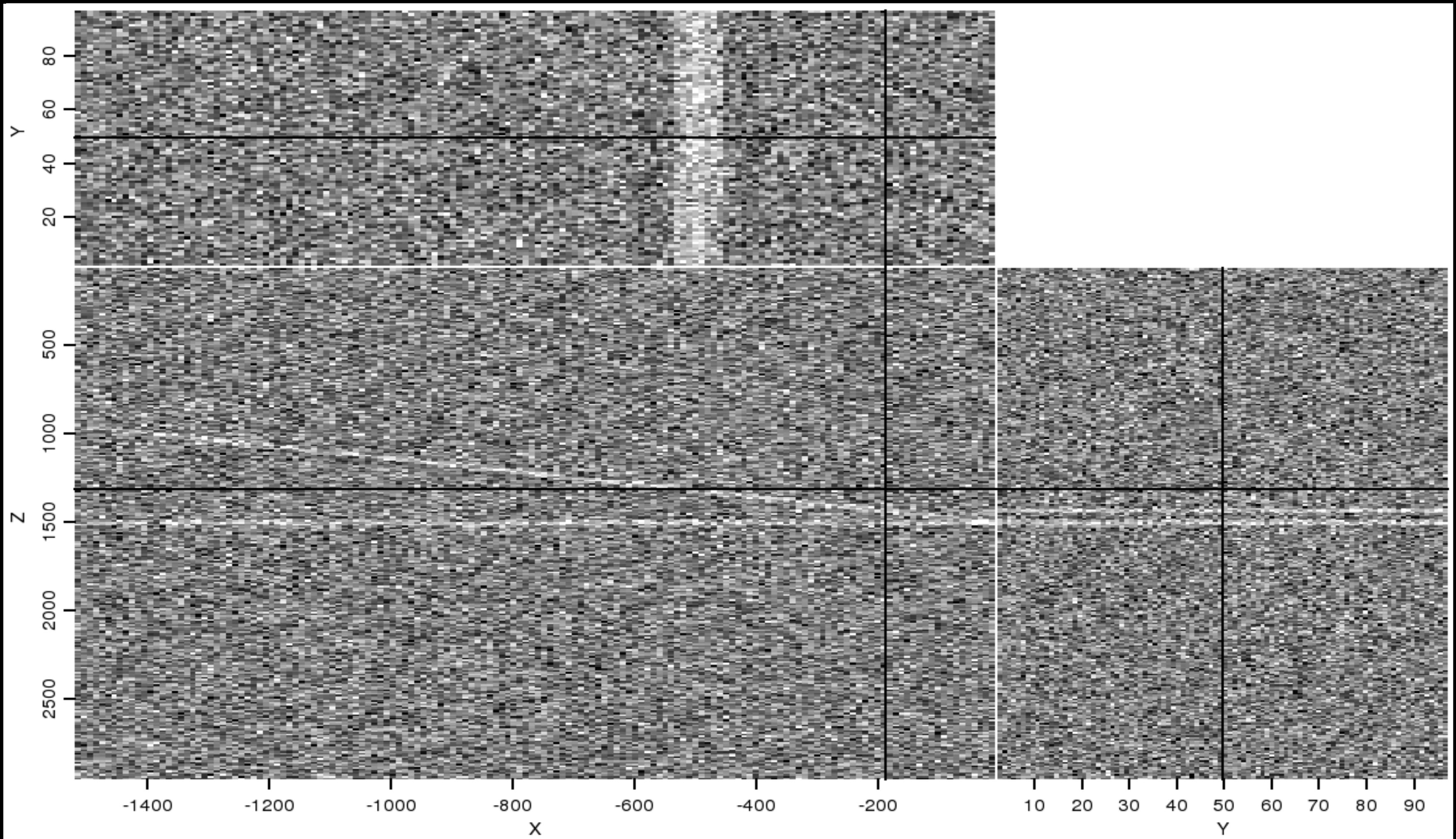
MHM filtering



Original



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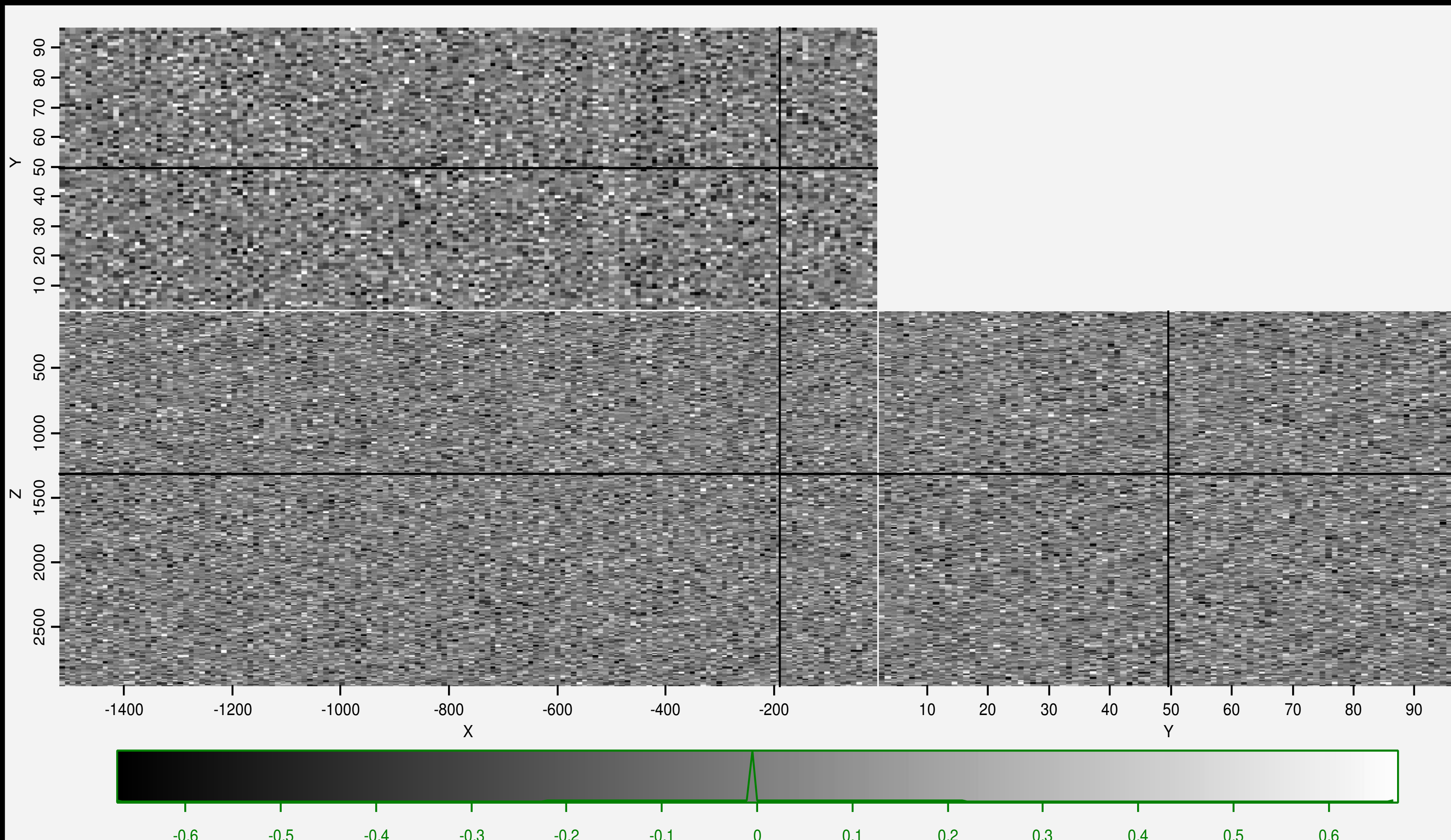

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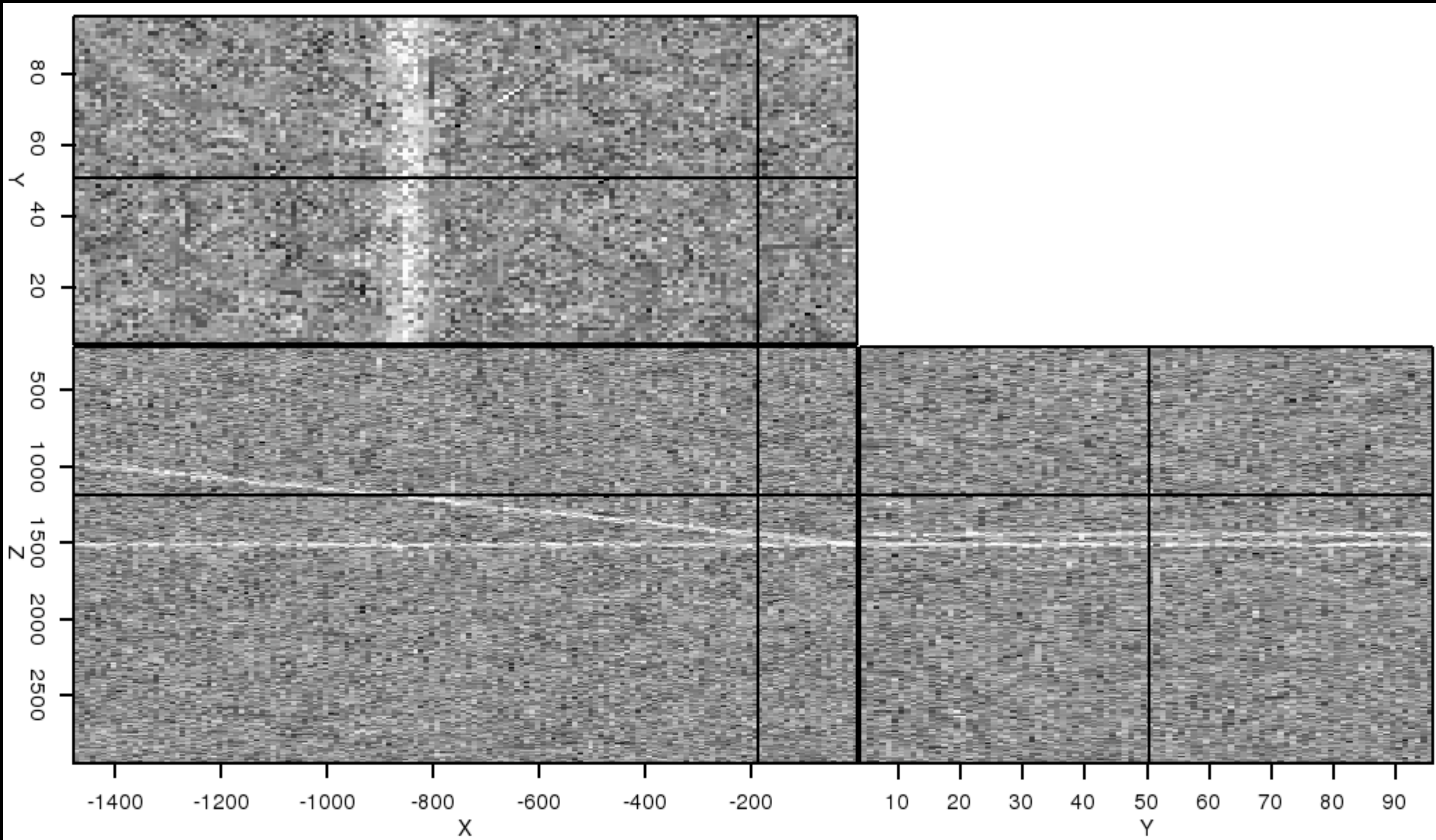
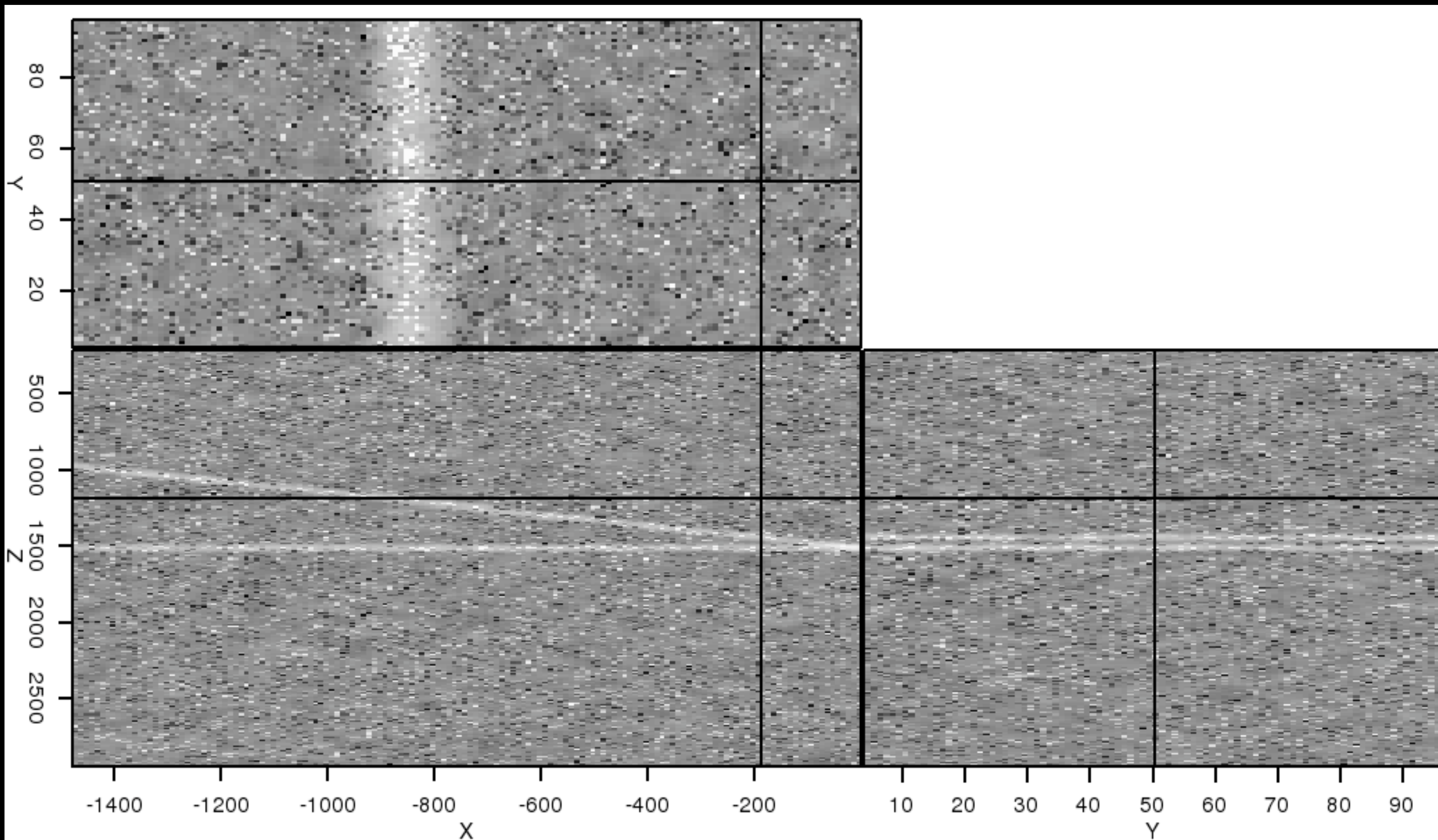
Hybrid approach

- **Still a lot of noise on MHM result**
- **Why not employ low-pass smoothing whenever a pixel's neighborhood is very "isotropic"?**
- **If** $\frac{\min(\sigma^2)}{\max(\sigma^2)} > \alpha,$ **use the cube's mean value**
    - **Otherwise, use the MHM filter**

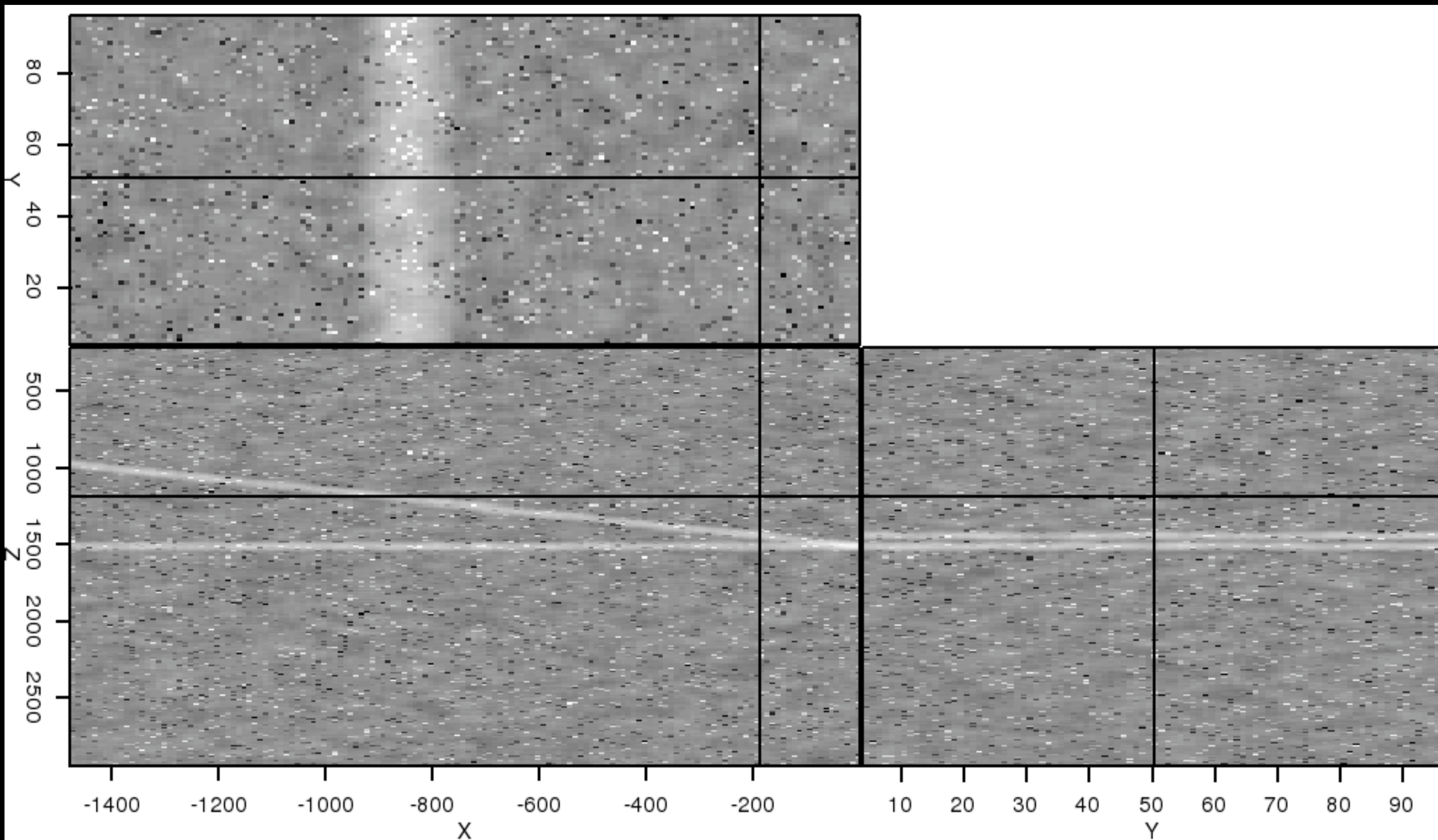
MHM filtering



Hybrid, α=.5



Hybrid, α=.25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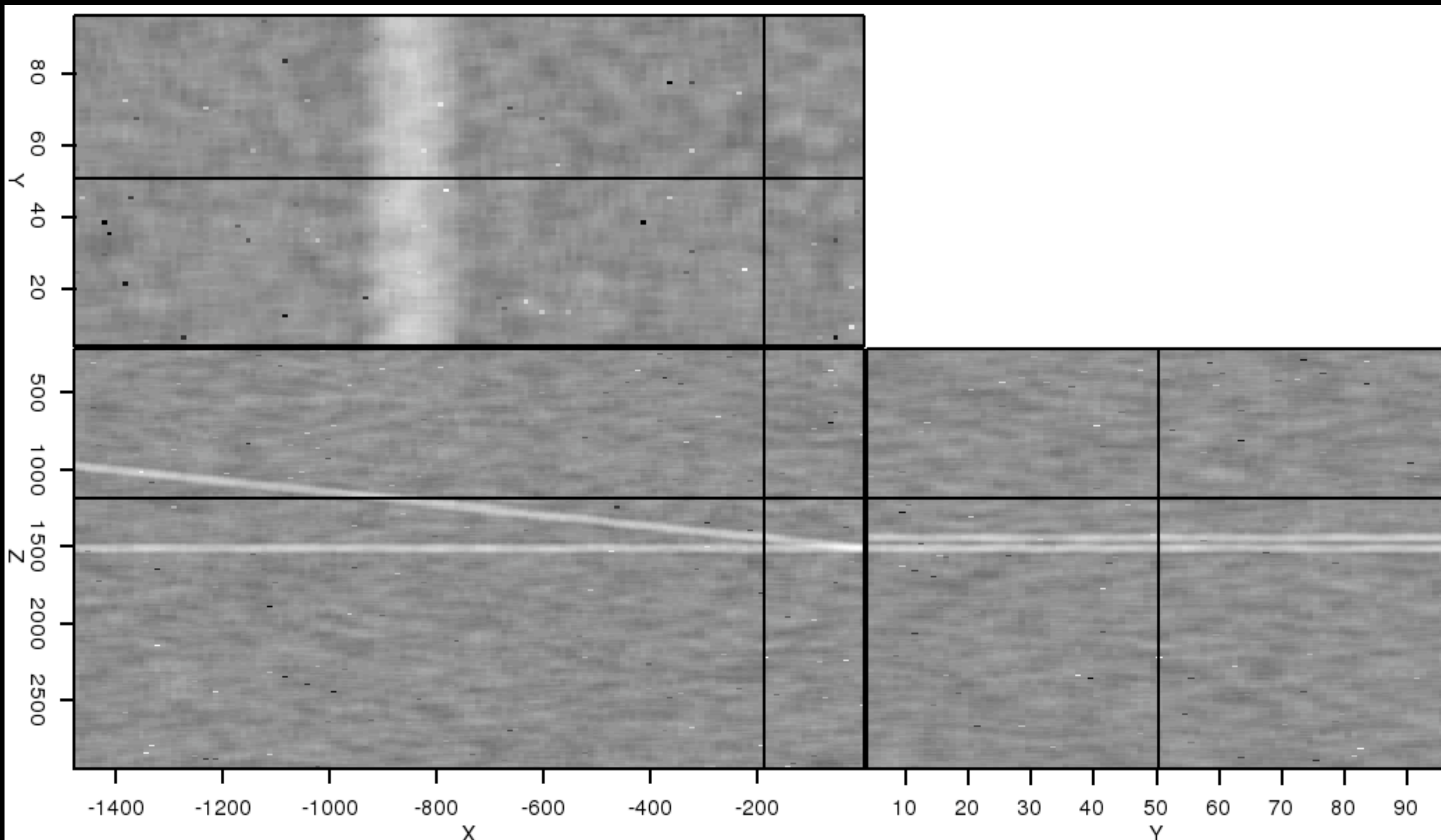
Hybrid, α=.1



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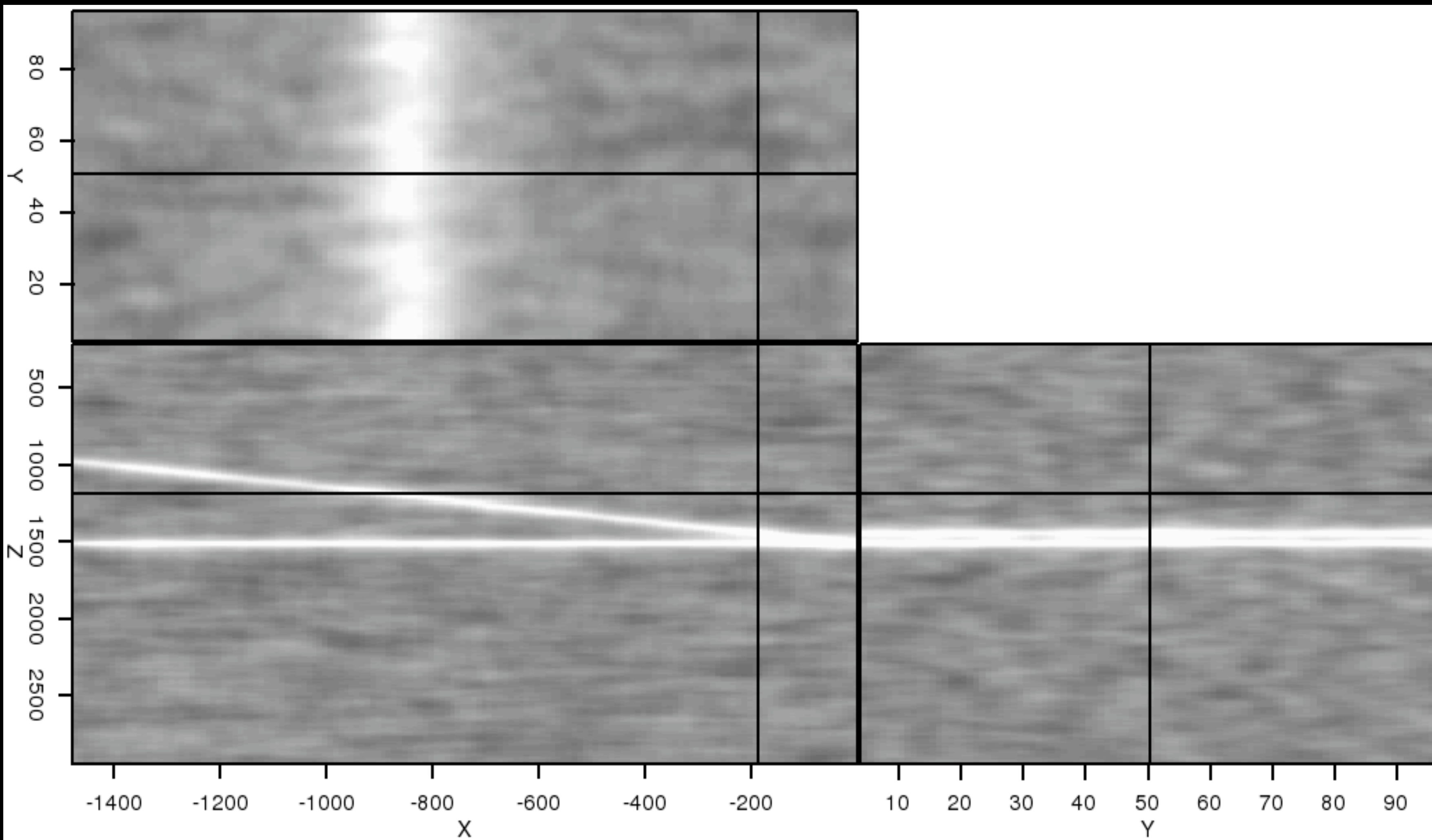
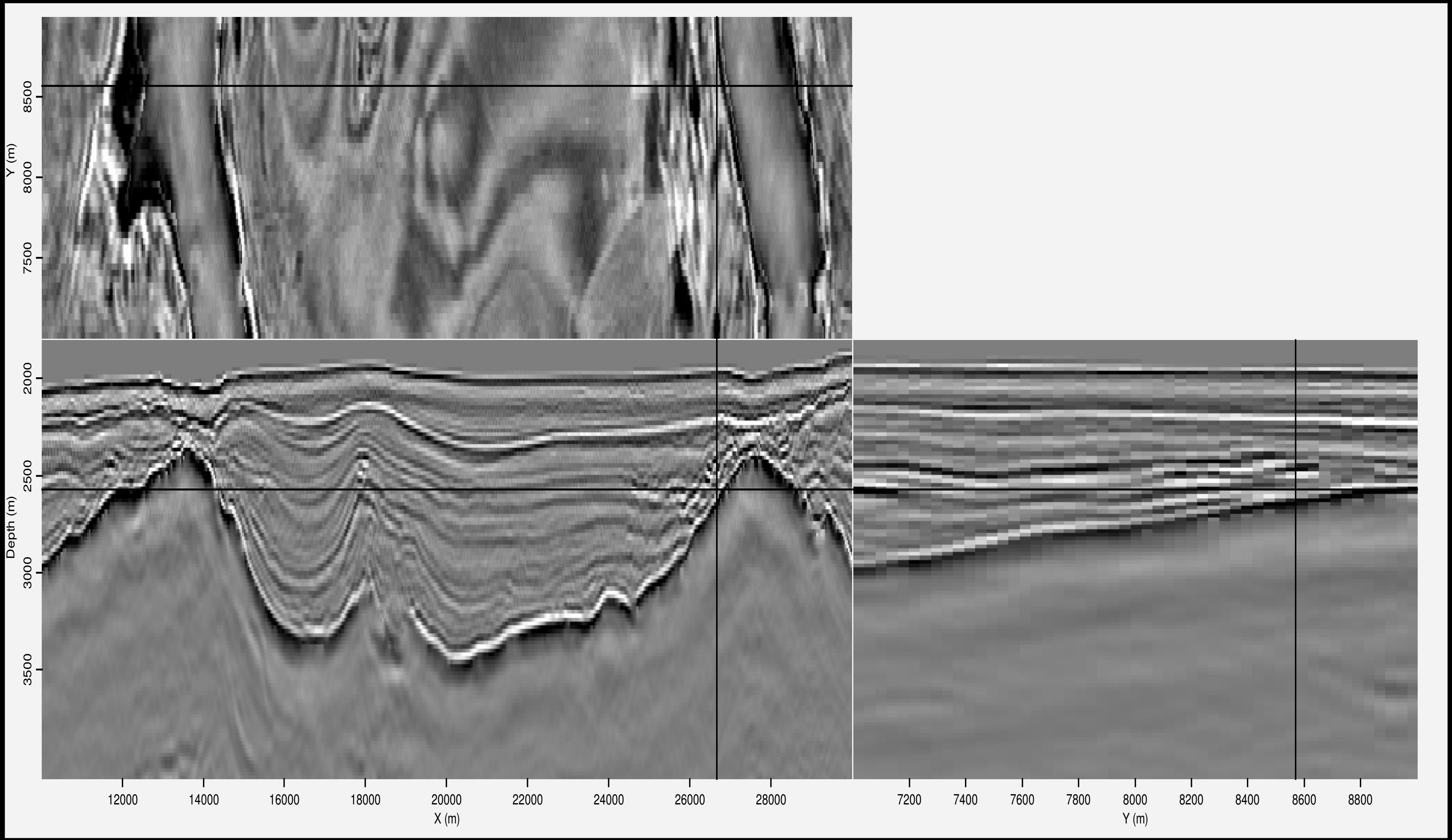
Traditional smoothing

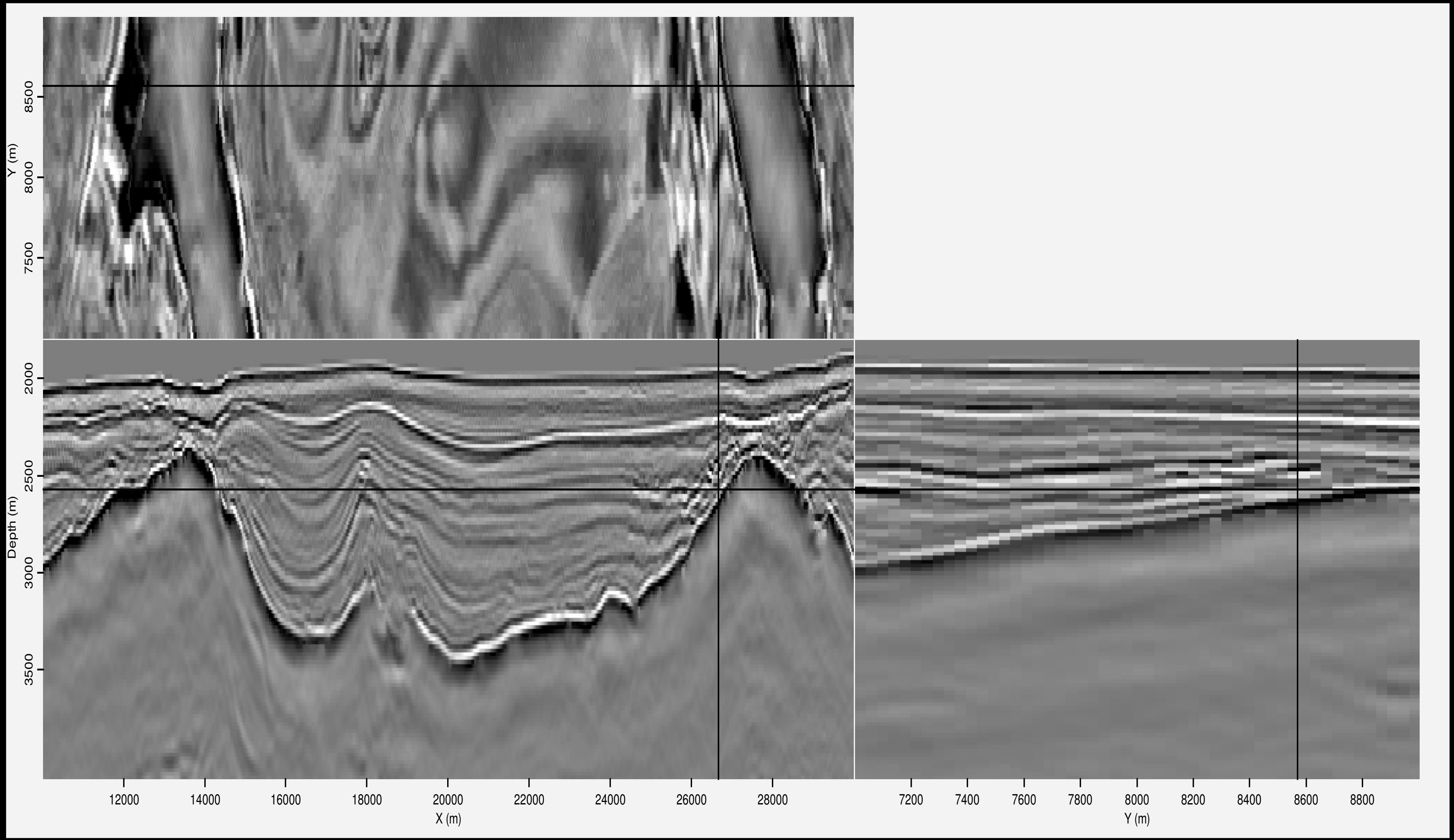


EPS overview ◆ **Synthetic** ◆ **Hybrid scheme** ◆ **Field examples**

Field example



MH filtered



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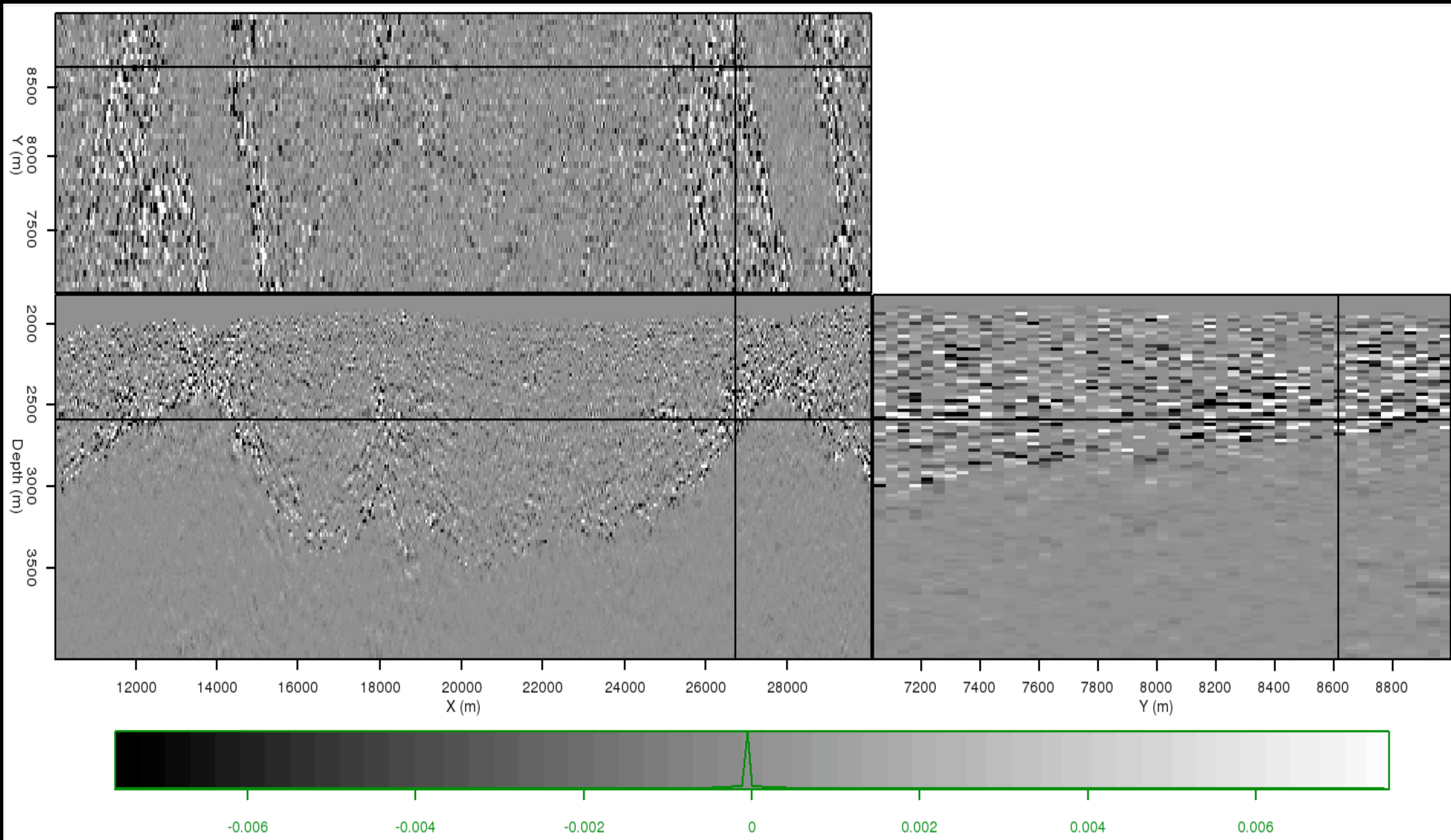
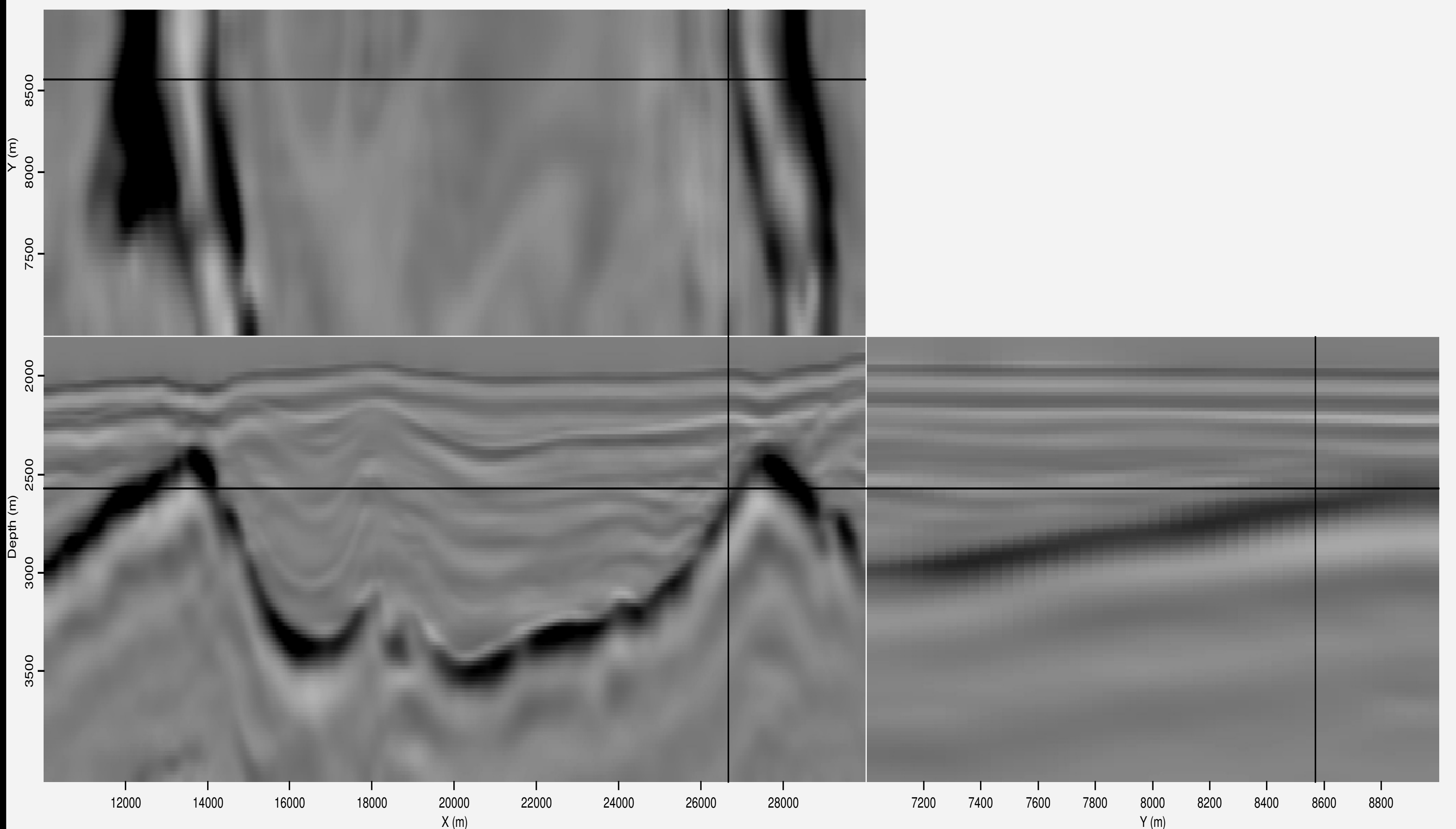
Y (m)

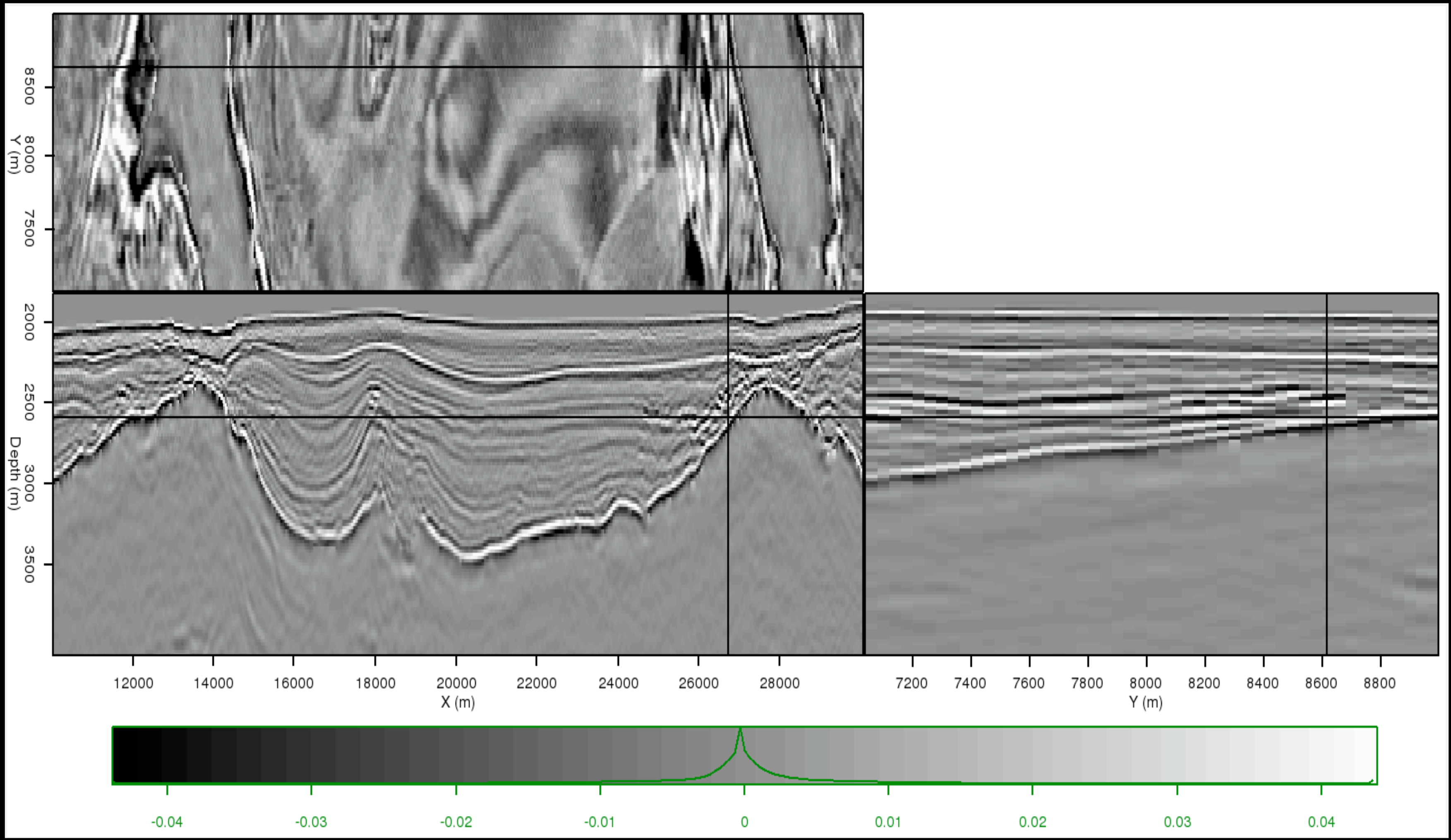
Difference (MHM)



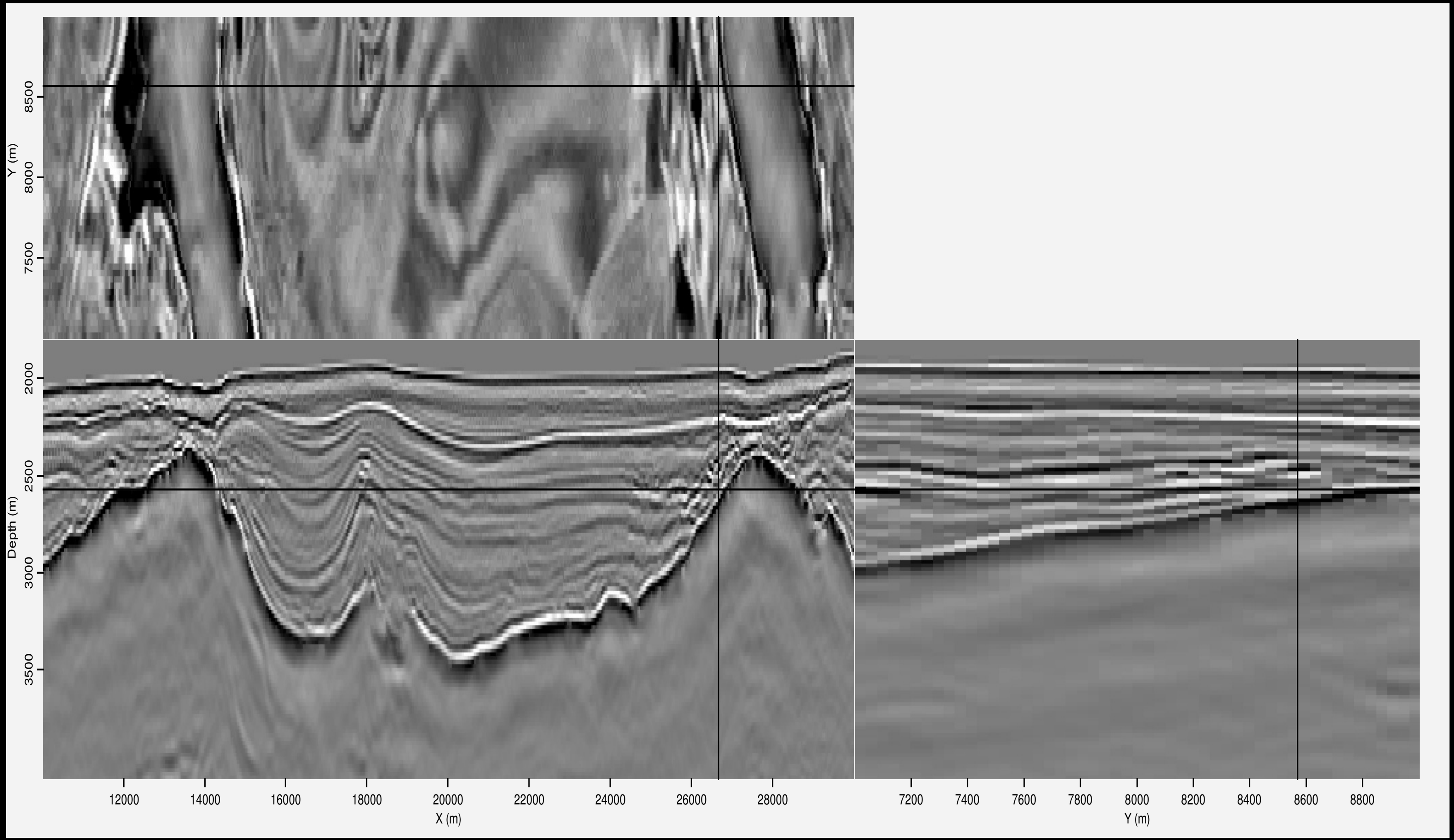
Traditional smoothing



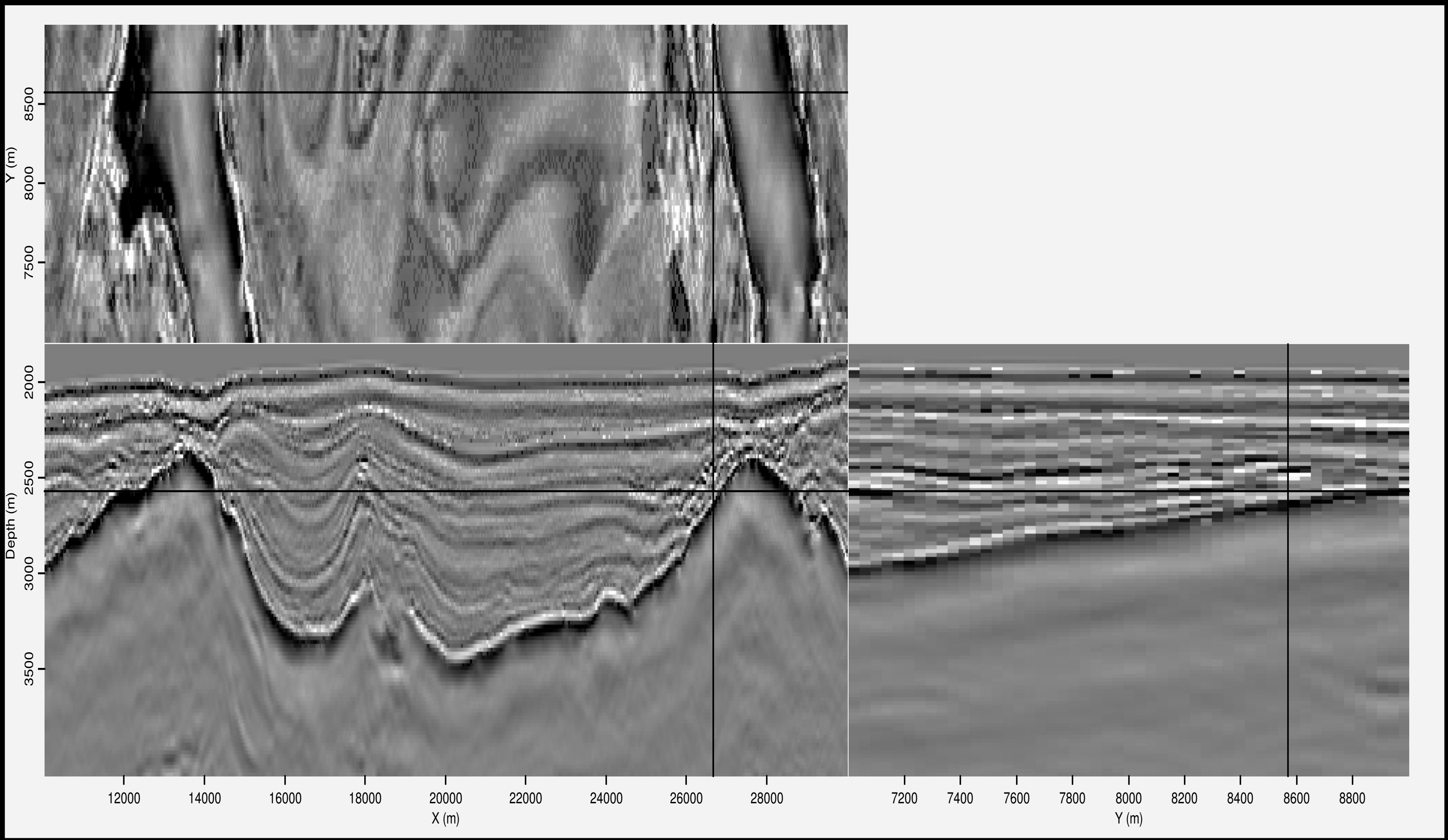
Difference (traditional)



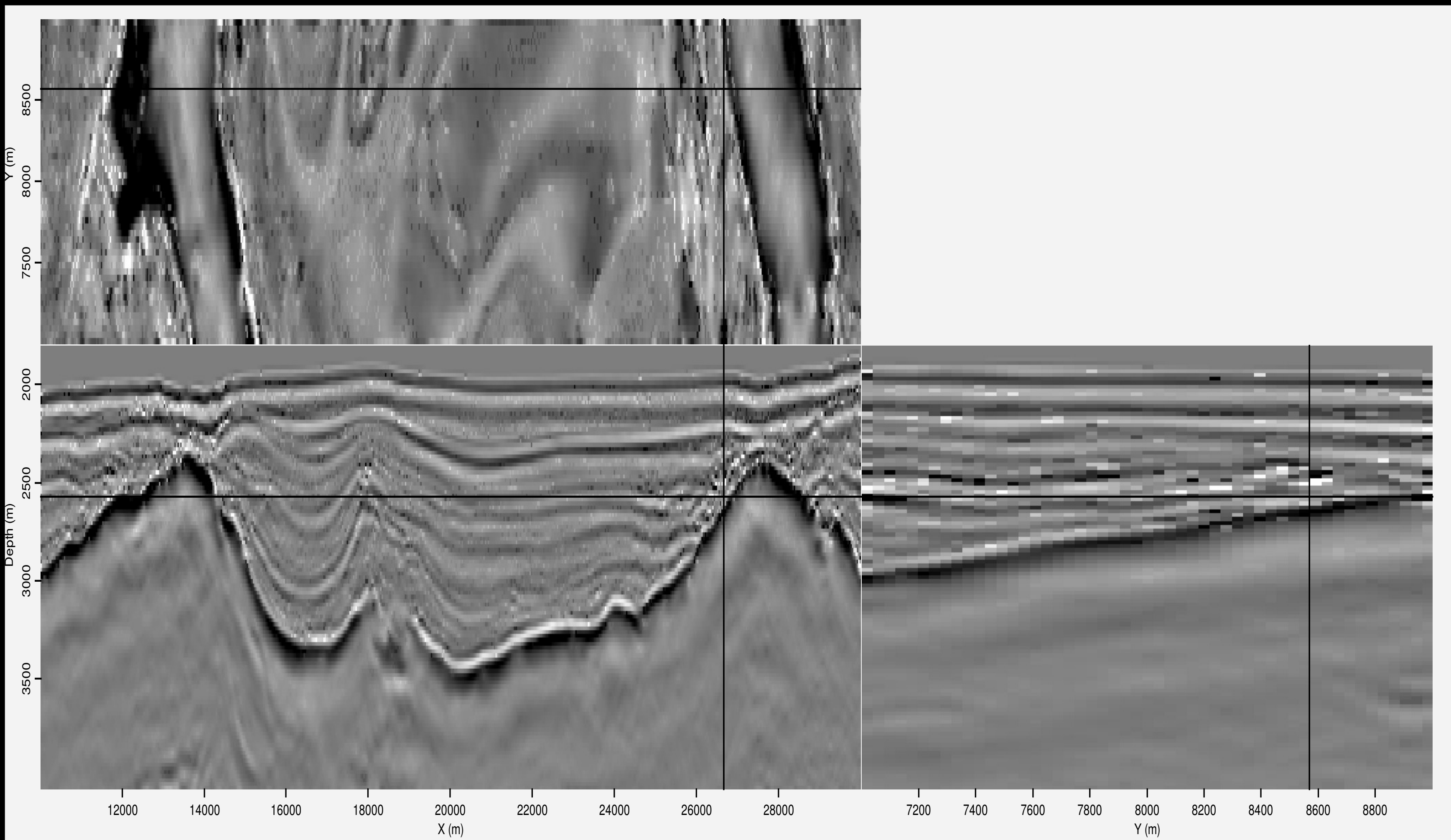
Hybrid, α=.5



Hybrid, α=.2



Hybrid, α=.1



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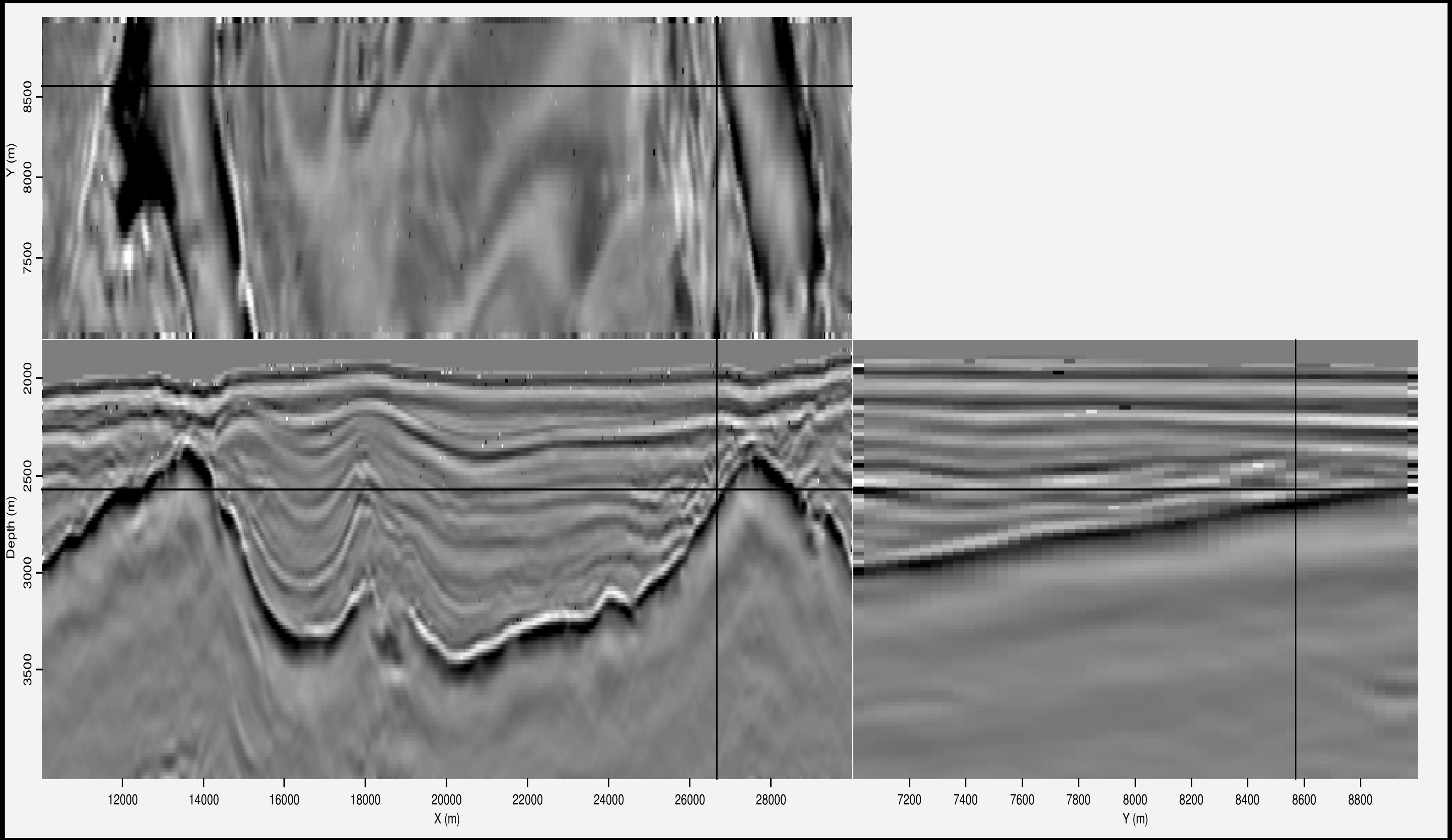
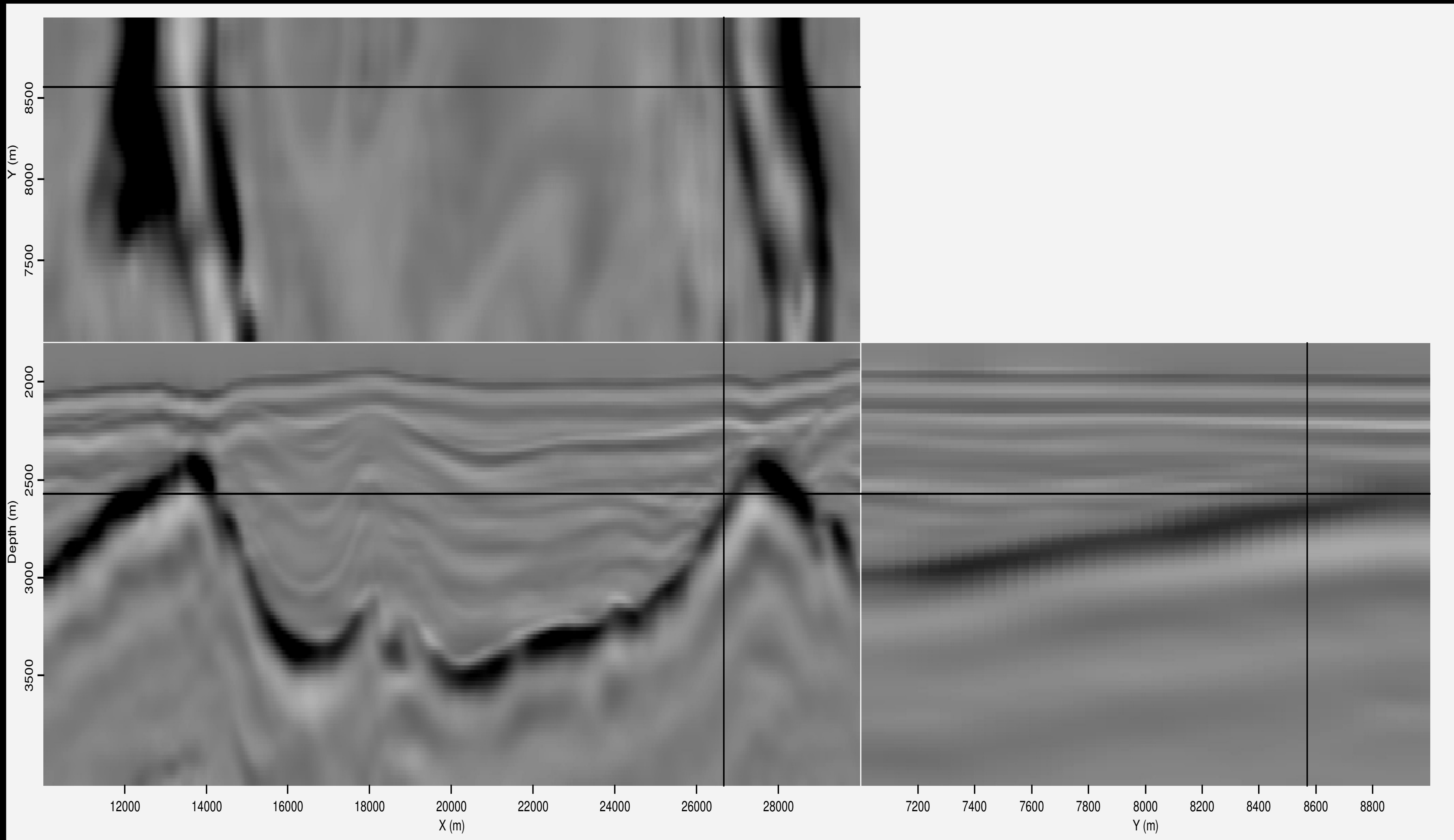
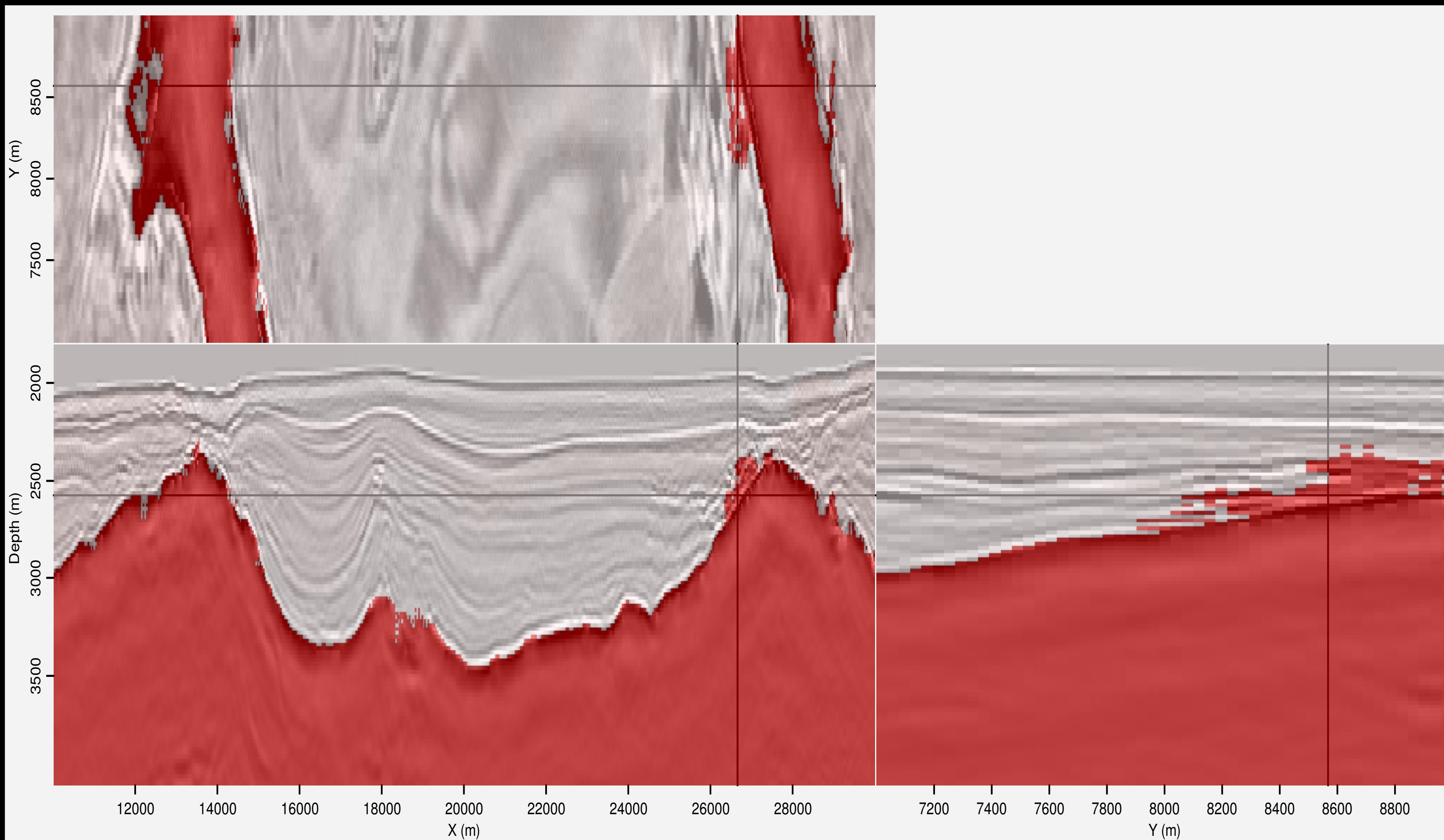
Hybrid, α=.01



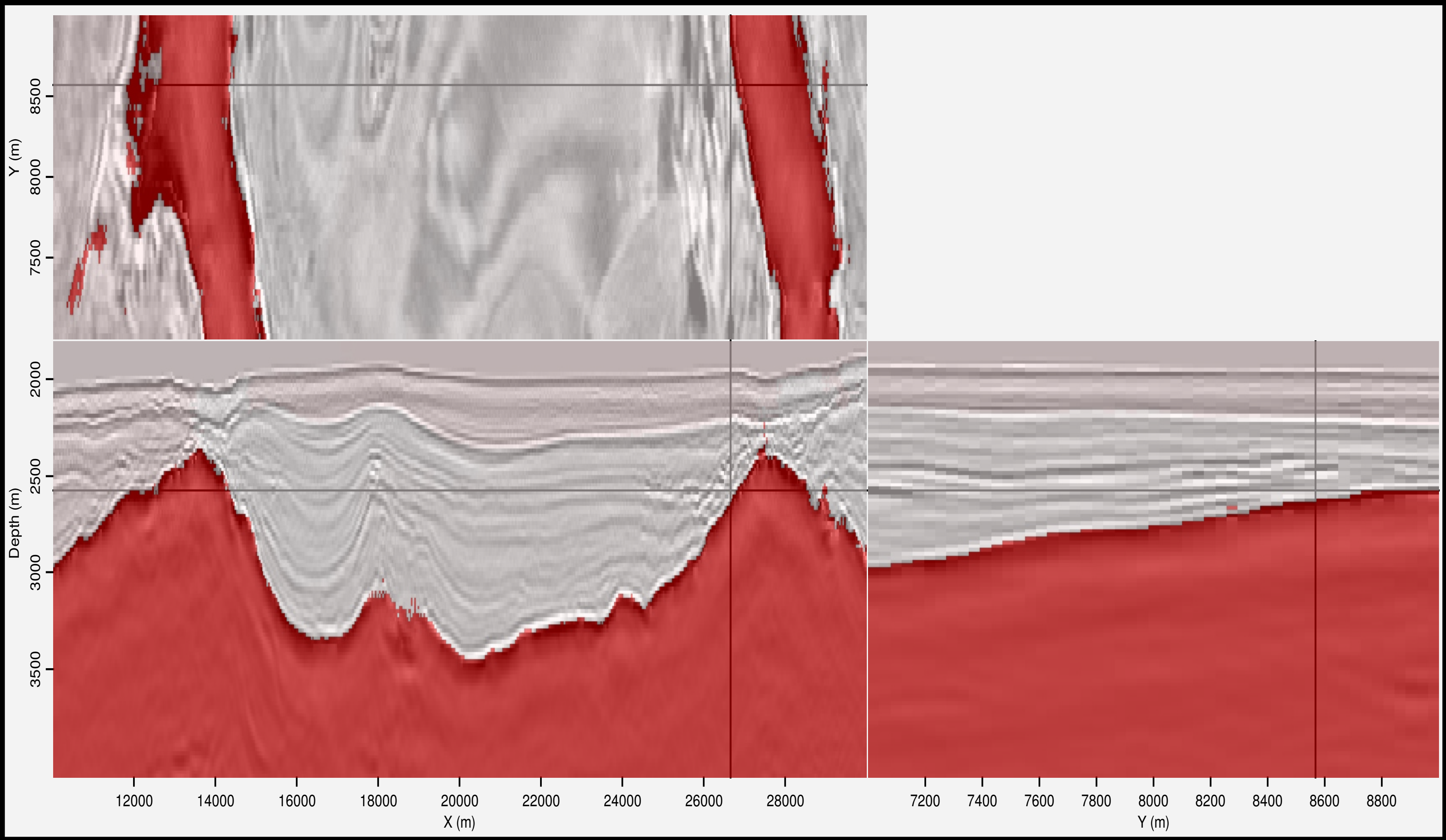
Traditional smoothing



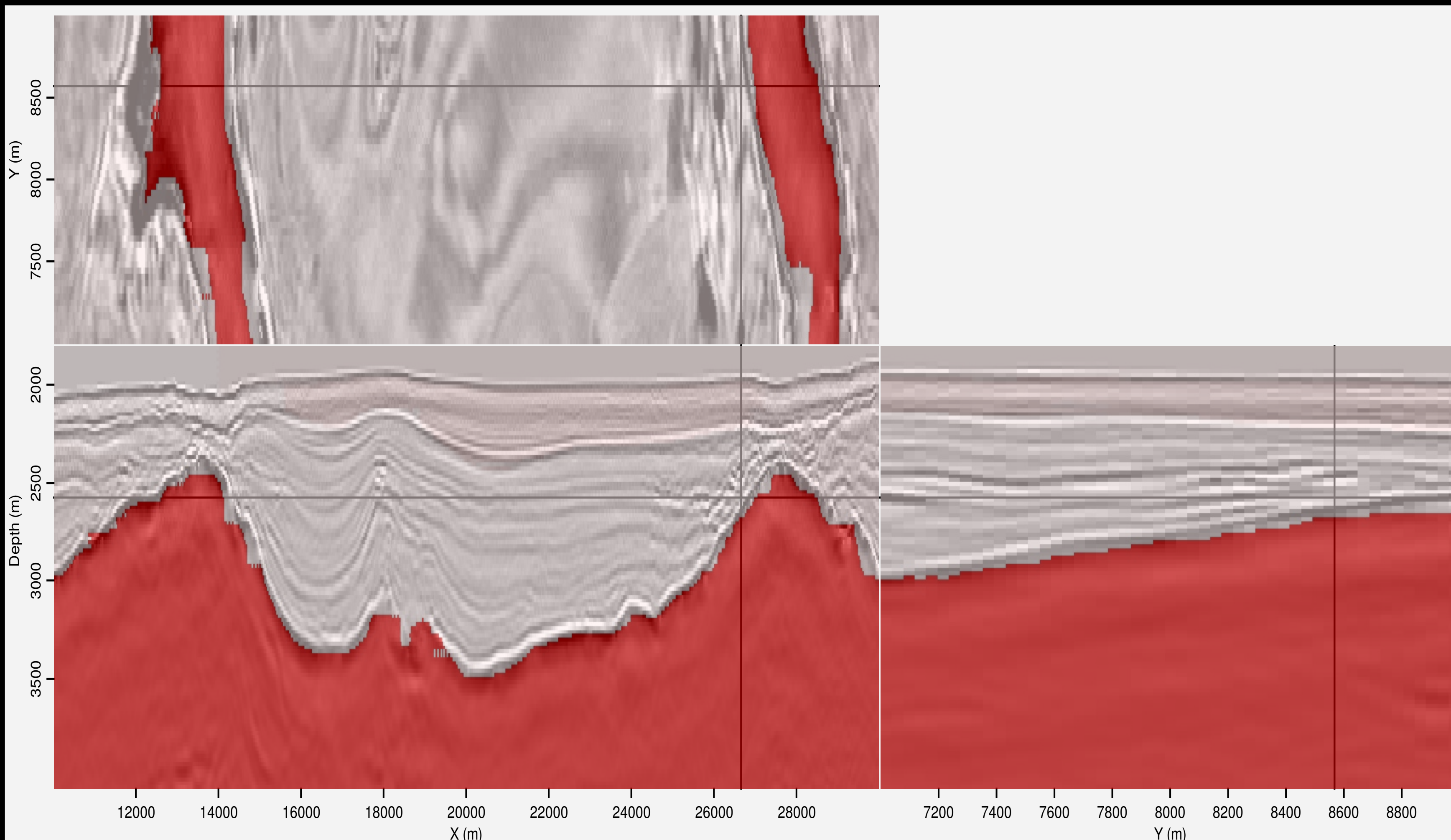
Original segmentation



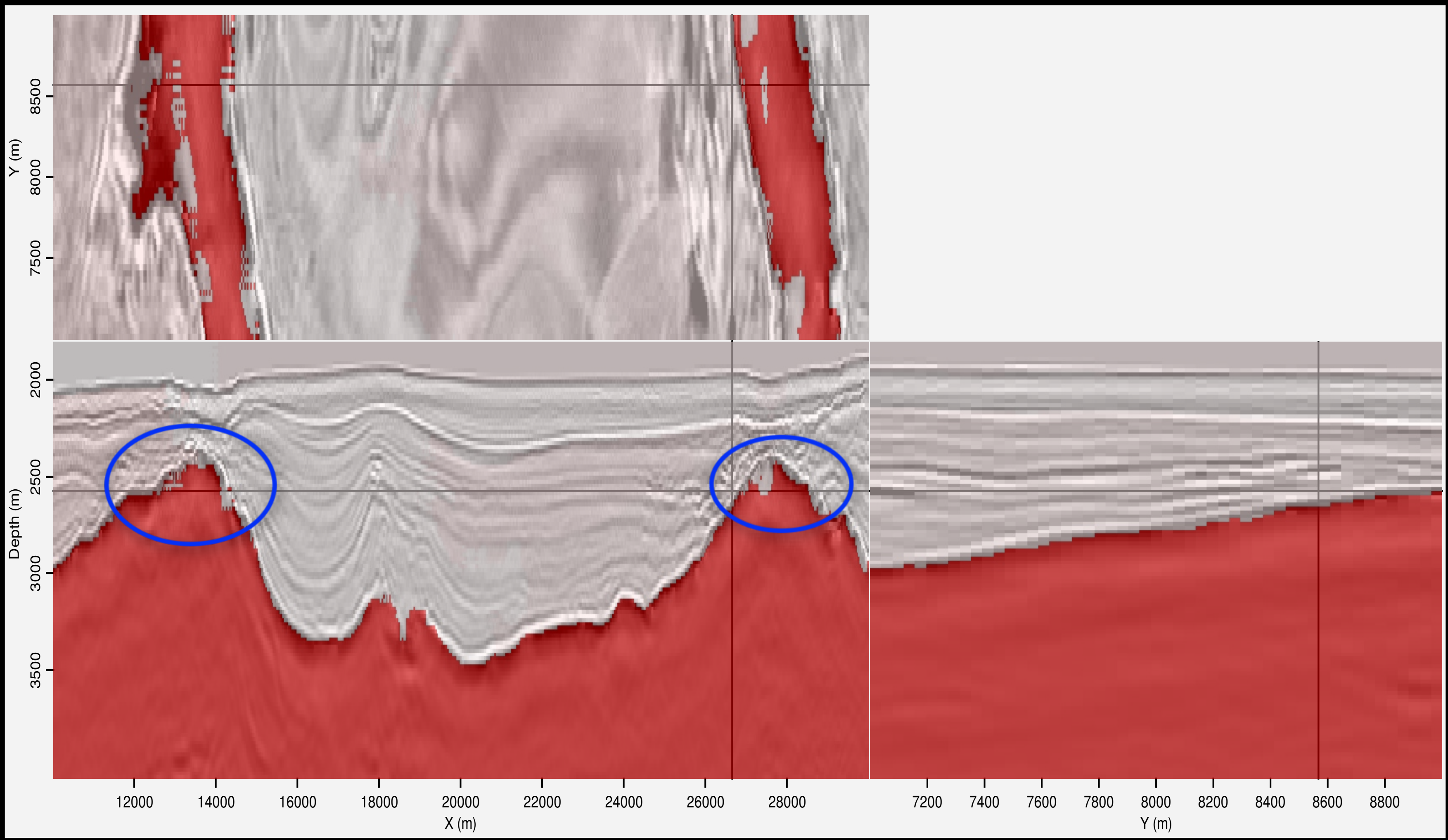
MHM segmentation



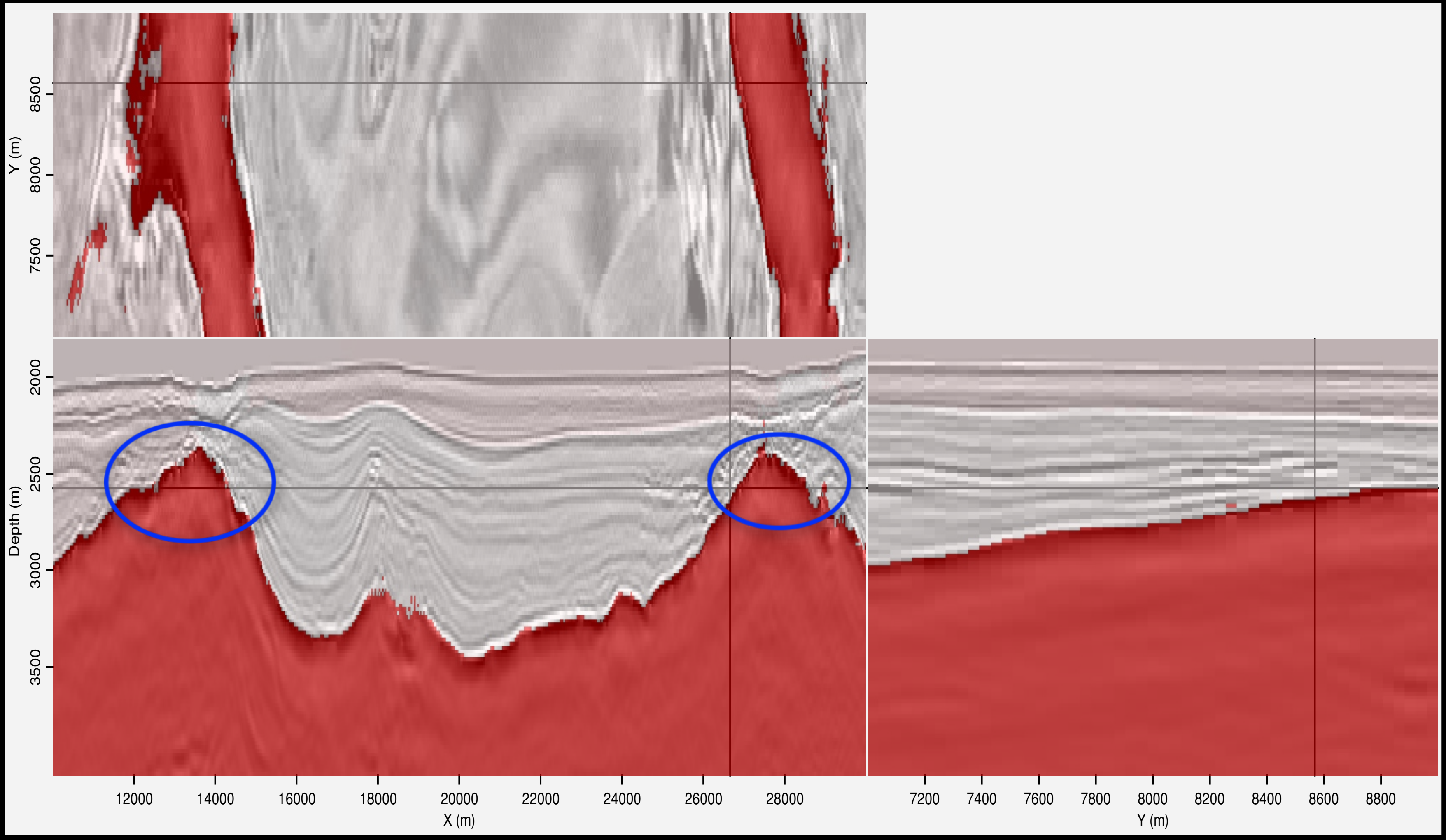
Traditional smoothing



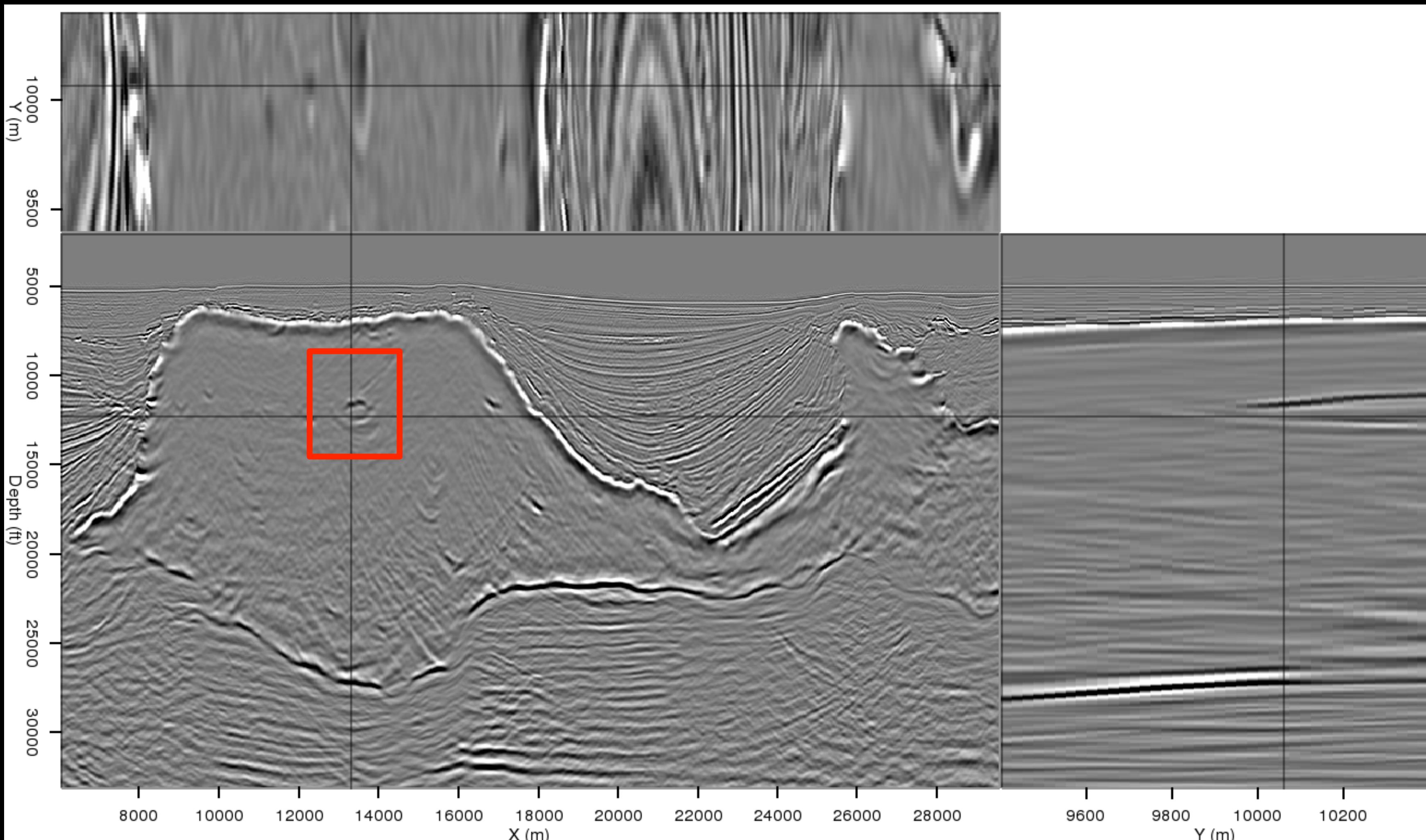
Minimal smoothing



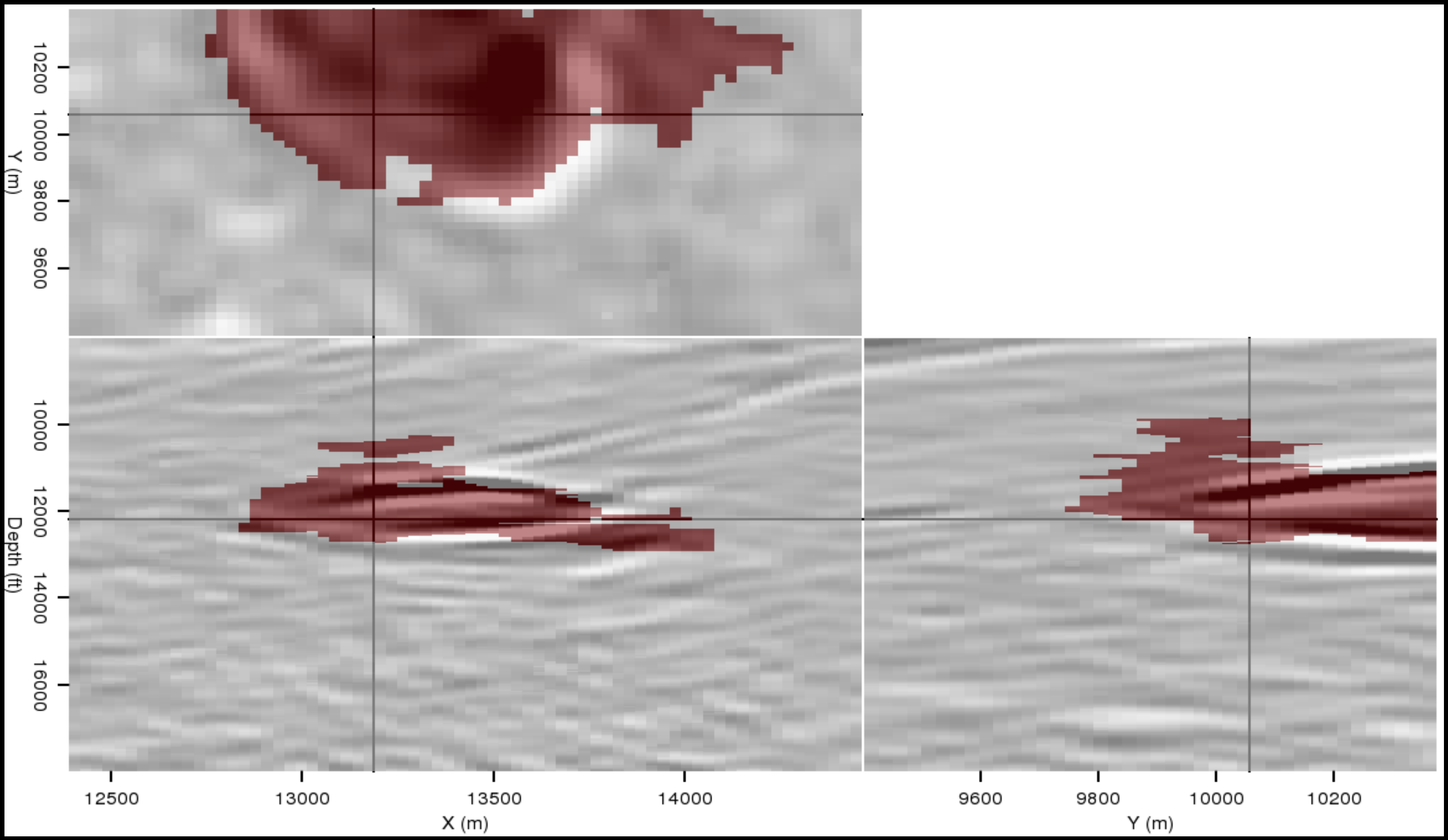
MHM segmentation



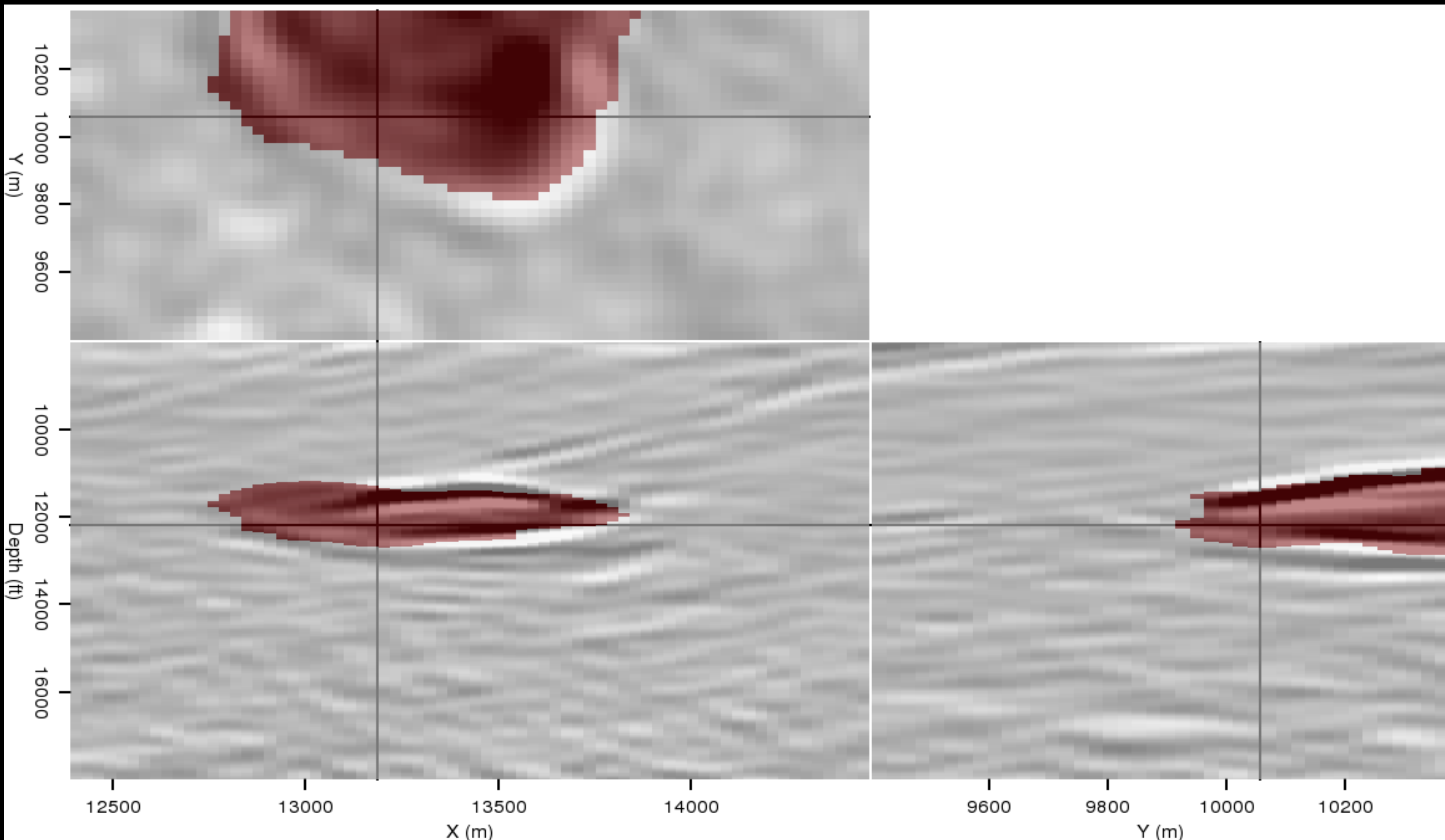
Field example #2



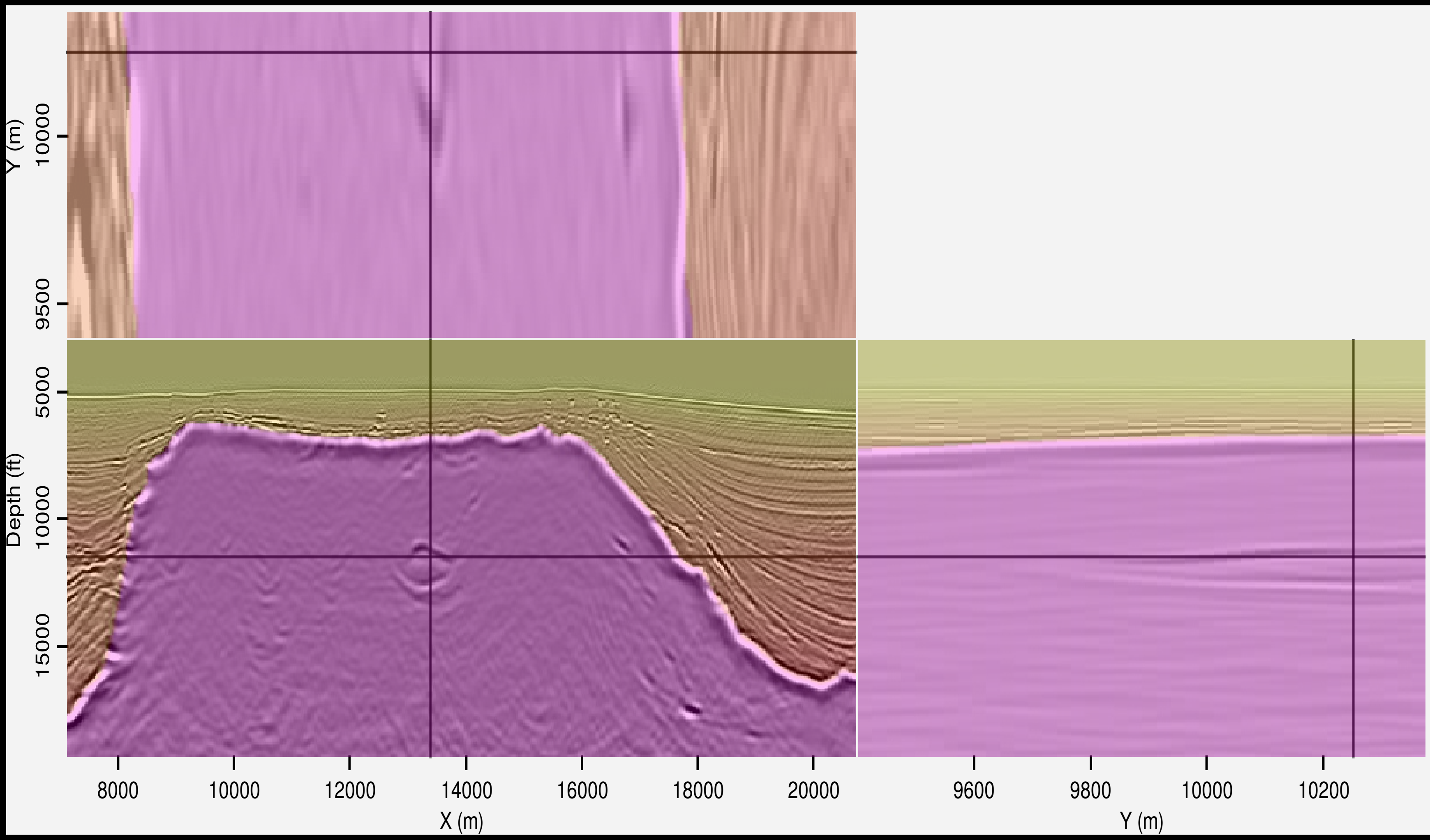
Original segmentation



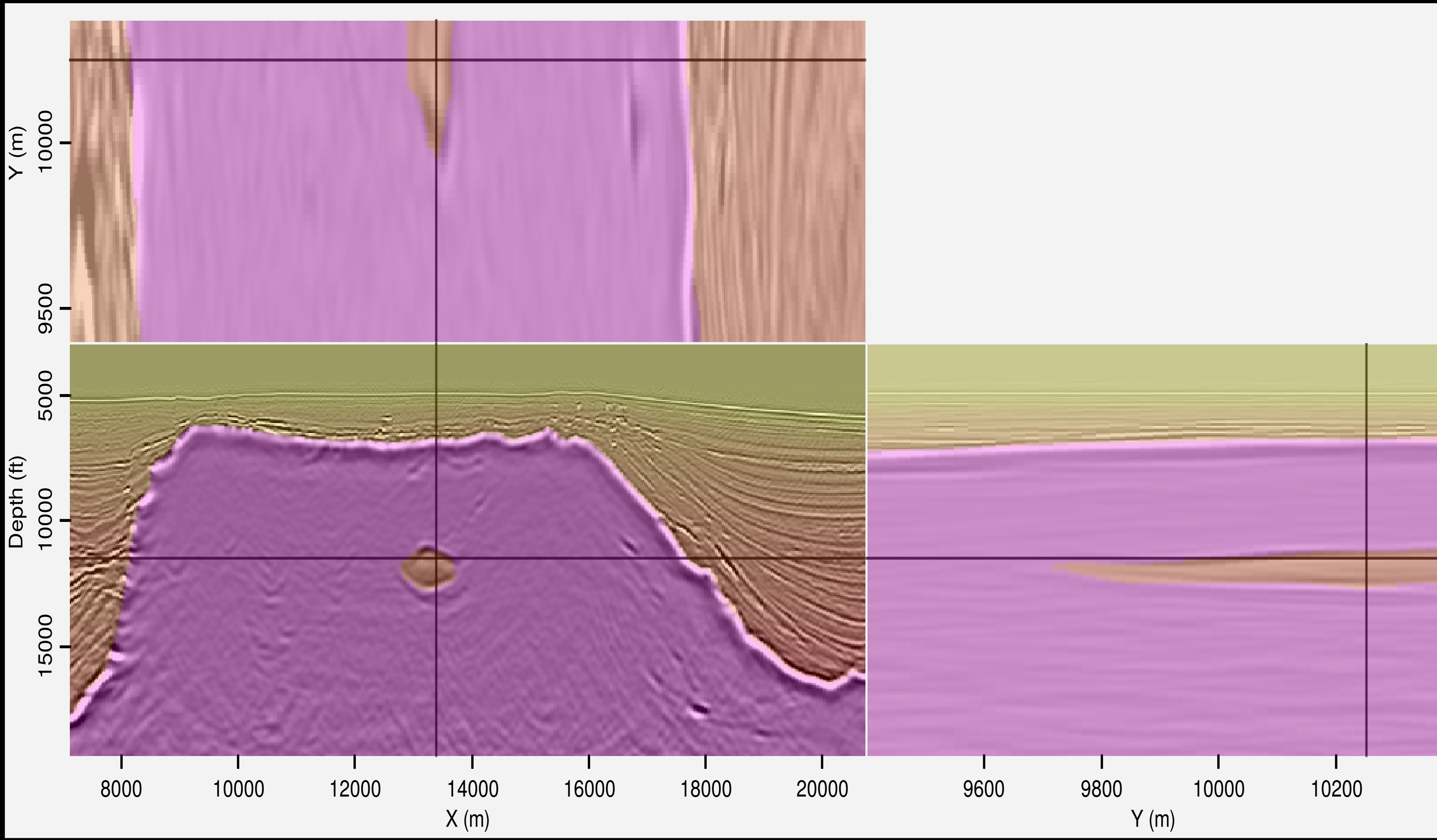
MHM segmentation



Original velocity



Edited velocity



Conclusions

- **A maximum homogeneity EPS filter can remove noise from an image while preserving sharp boundaries**
- **A "hybrid" of traditional and edge-preserving smoothing can effectively combine the advantages of each**
- **Using EPS prior to image segmentation can greatly improve accuracy for model-building**

Acknowledgments

I am grateful to WesternGeco and Unocal/Chevron for providing the data used for examples, and all sponsors of the Stanford Exploration Project for their support