Ground Roll Removal

Ground Roll Removal Using Non-Separable Wavelet Transforms

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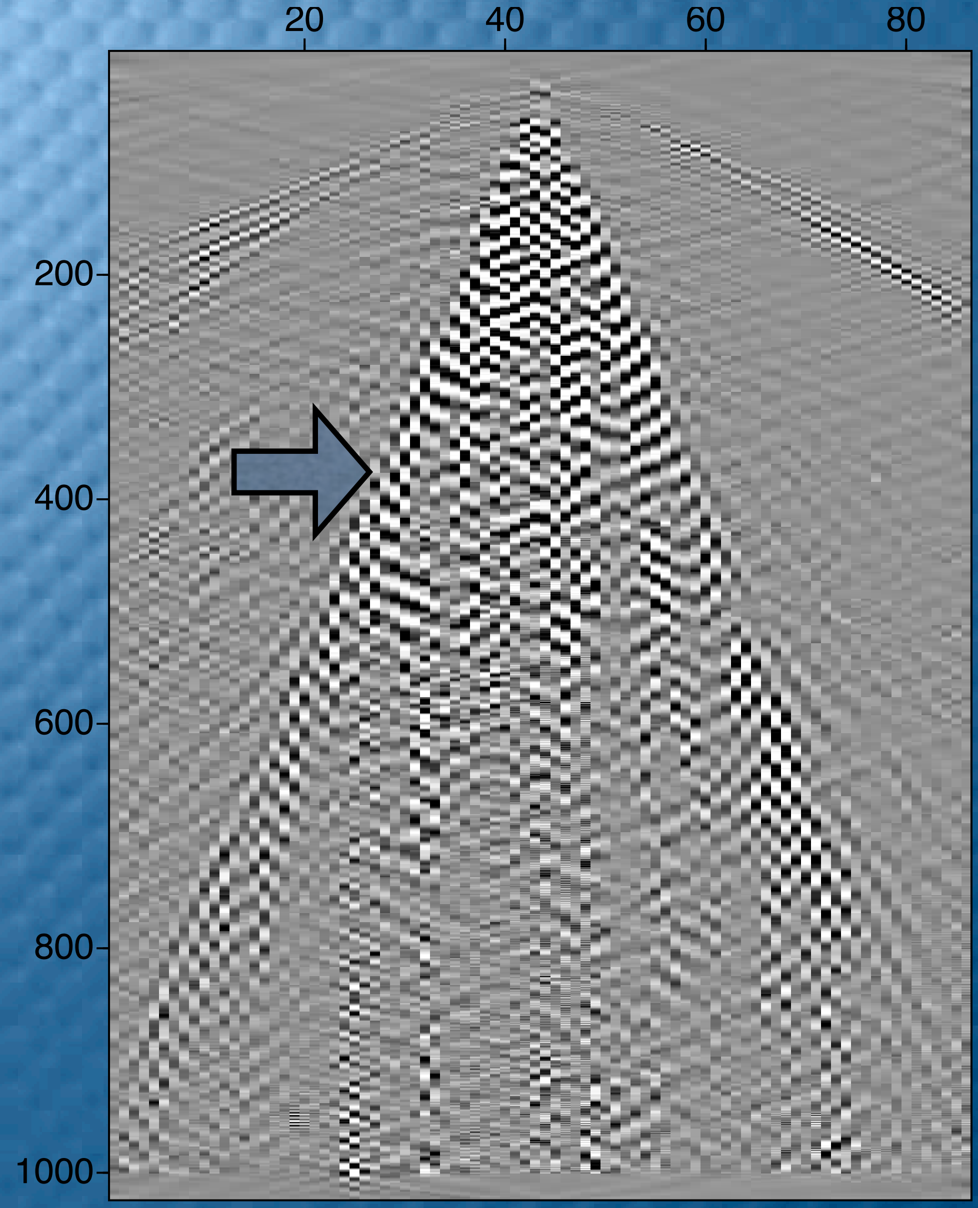
Outline

- The Problem (What?)
- Domains (Where?)
- Methods (How?)
- Examples (Who?)
    - Synthetic
    - Real
    - Iterative Process
- Conclusions (Why?)

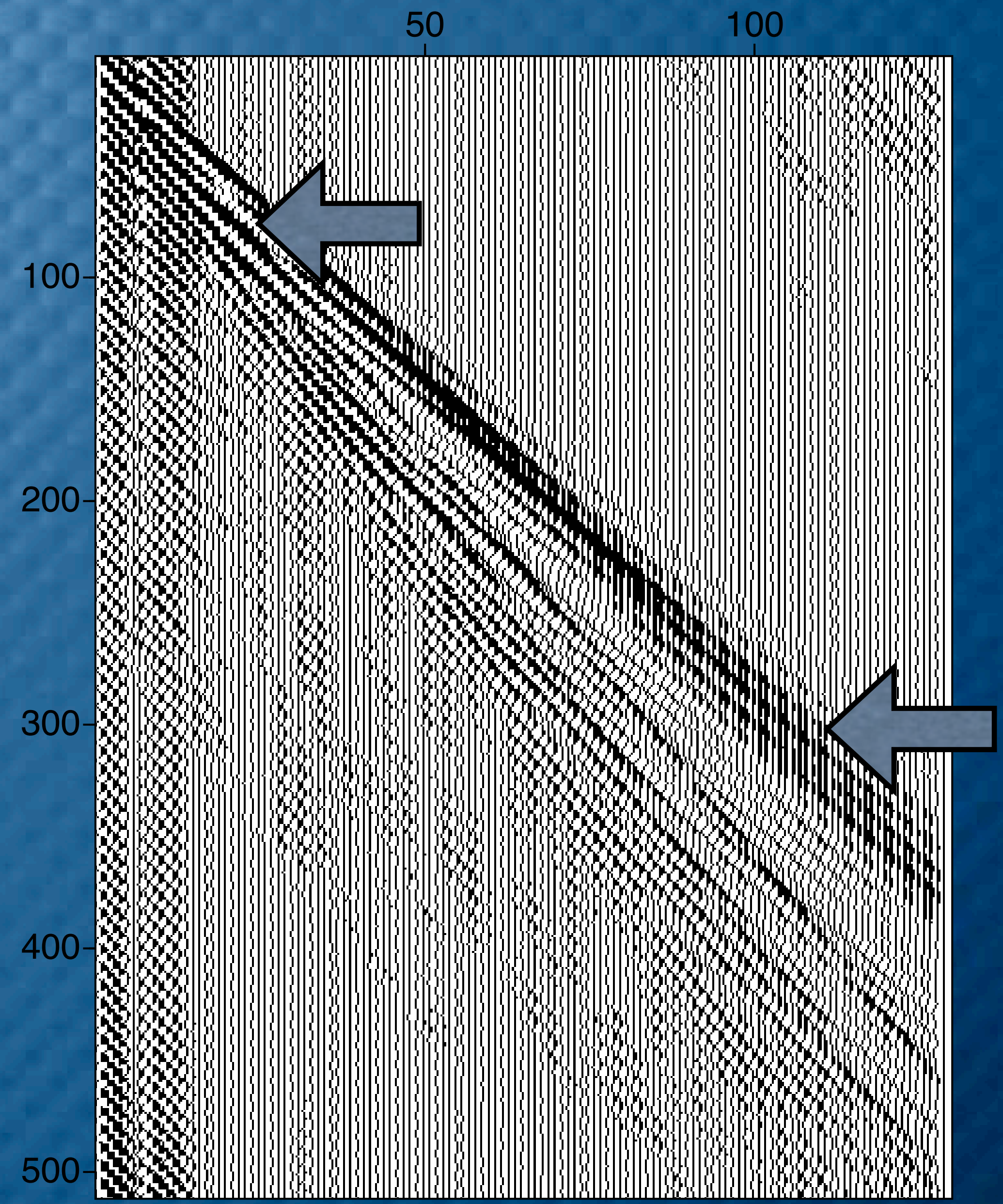
The Problem (What?)



Hyperbolic Radon Ground Roll Prediction from the Oz25 Data Set from Yilmaz's Seismic Data Processing

Ground Roll Properties

- Rayleigh wave moving through near surface materials
- Dispersive
- Low Frequency
- Highly dependent on near surface properties
- Reduces signal-to-noise ratio



Two Problems to Solve

What Do We Remove?

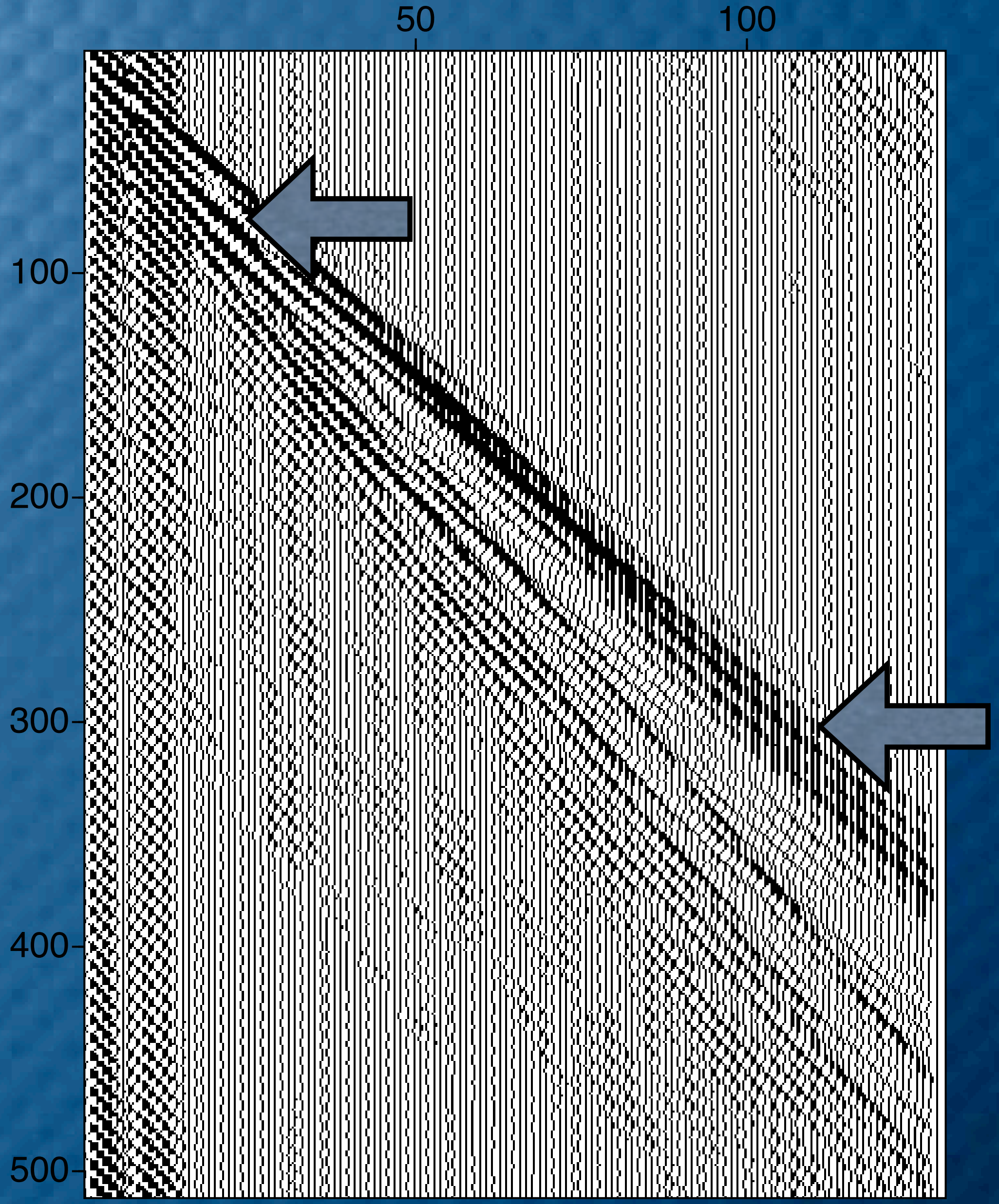
- Modeled Ground Roll
- Noise Prediction From Other Methods

How Do We Remove It?

- Incorporate Prior Predictions
- Use Adaptive Subtraction

Modeling

- Generated in the frequency slope domain in the slant stack transform
- Contains properties associated with ground roll



(A.G. McMechan and M.J. Yeldin, Geophysics, 1981)

Curvelet Adaptive Subtraction

- Smart
  - Local in Position and Dip
  - Allows Incorporation of Prior Predictions
- Flexible
- Phase Insensitive

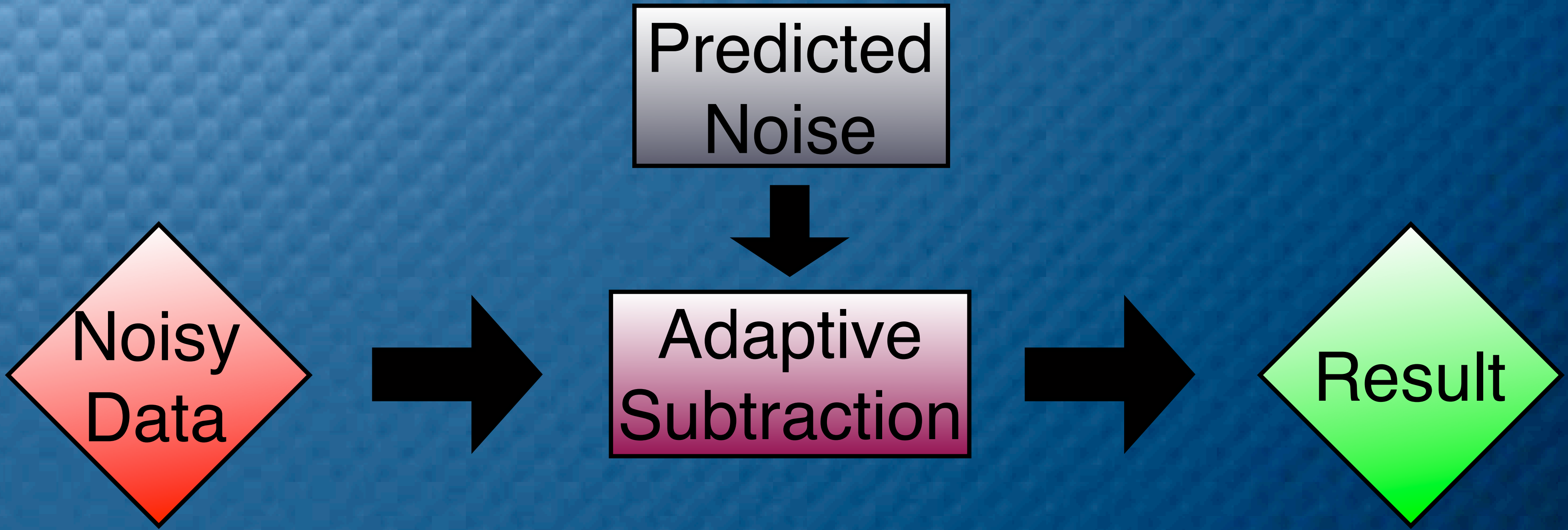
Domains
(Where?)

"In the middle of the journey of our life I came to myself within a dark wood where the straight way was lost."

- Dante Alighieri (1265-1321), The Divine Comedy

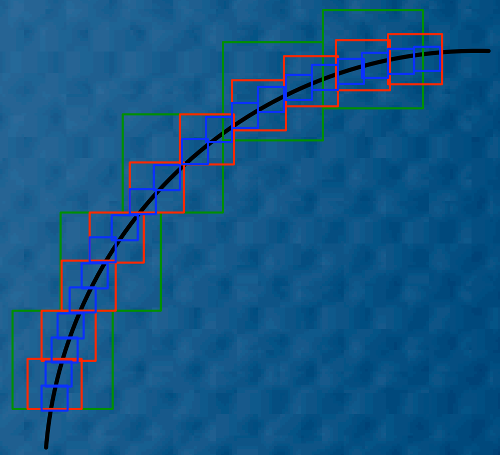
Using Hyperbolic Radon Filtering

- Identifies hyperbolic reflectors from the signal
- May produce artifacts with conventional subtraction
- We can use the predicted noise with adaptive subtraction

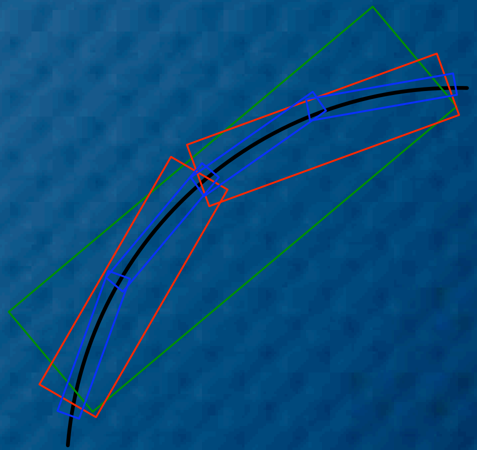


Wavelets and Curvelets

- Wavelets:
  - Represent time and frequency
  - Multi-Scale
- Curvelets:
  - Local in position and angle
  - Strongly anisotropic at fine scales (parabolic scaling principle: length² ~ width)



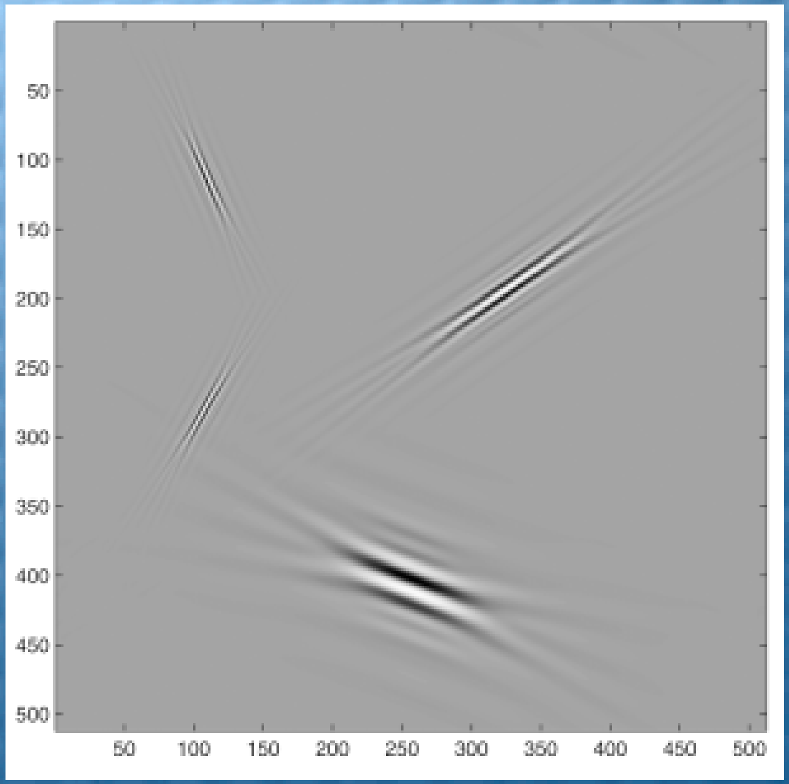
(a)



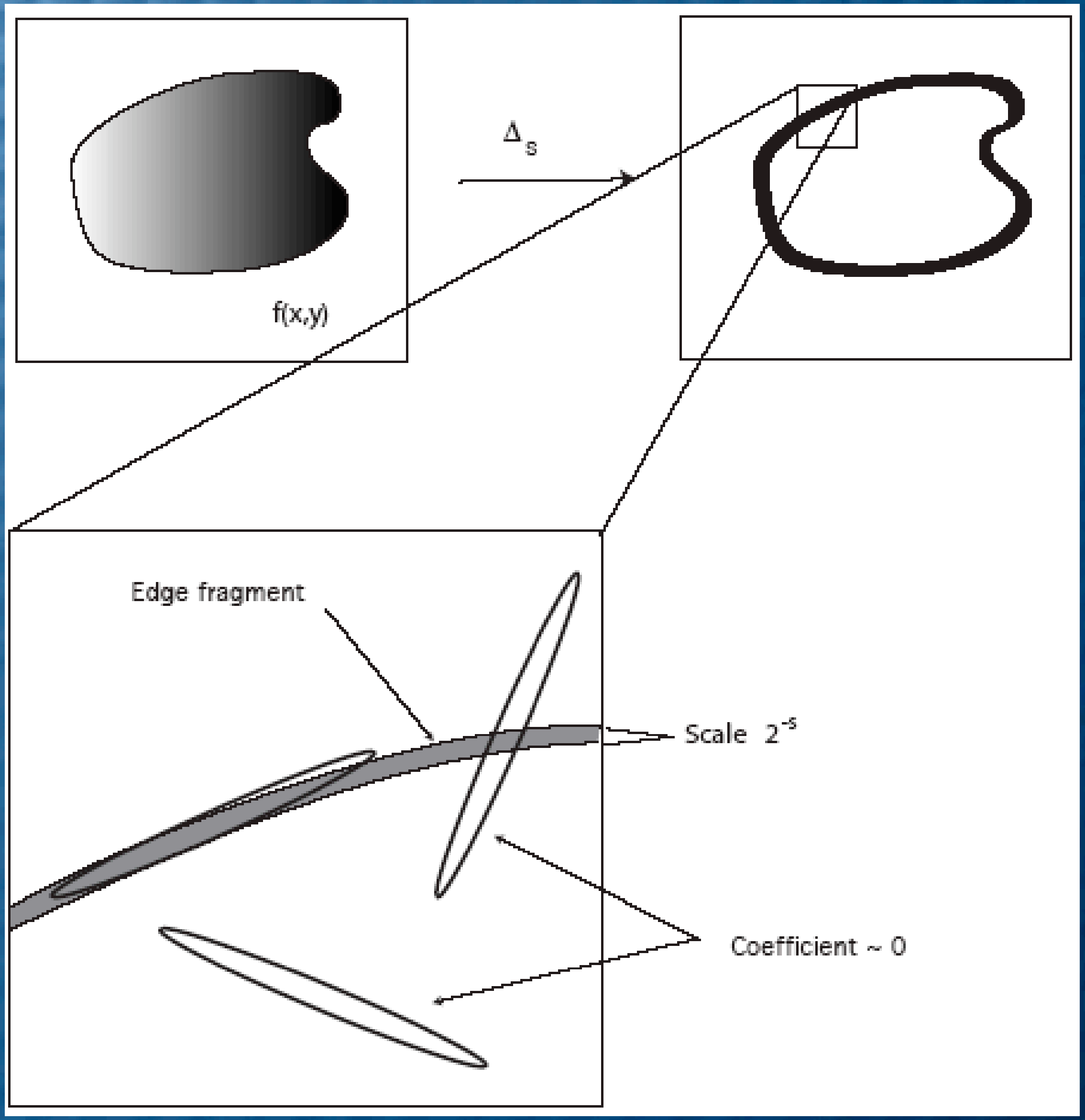
(b)

Candes 00, Donoho 95, Do 01

Curvelets



Candes 02, Do 02



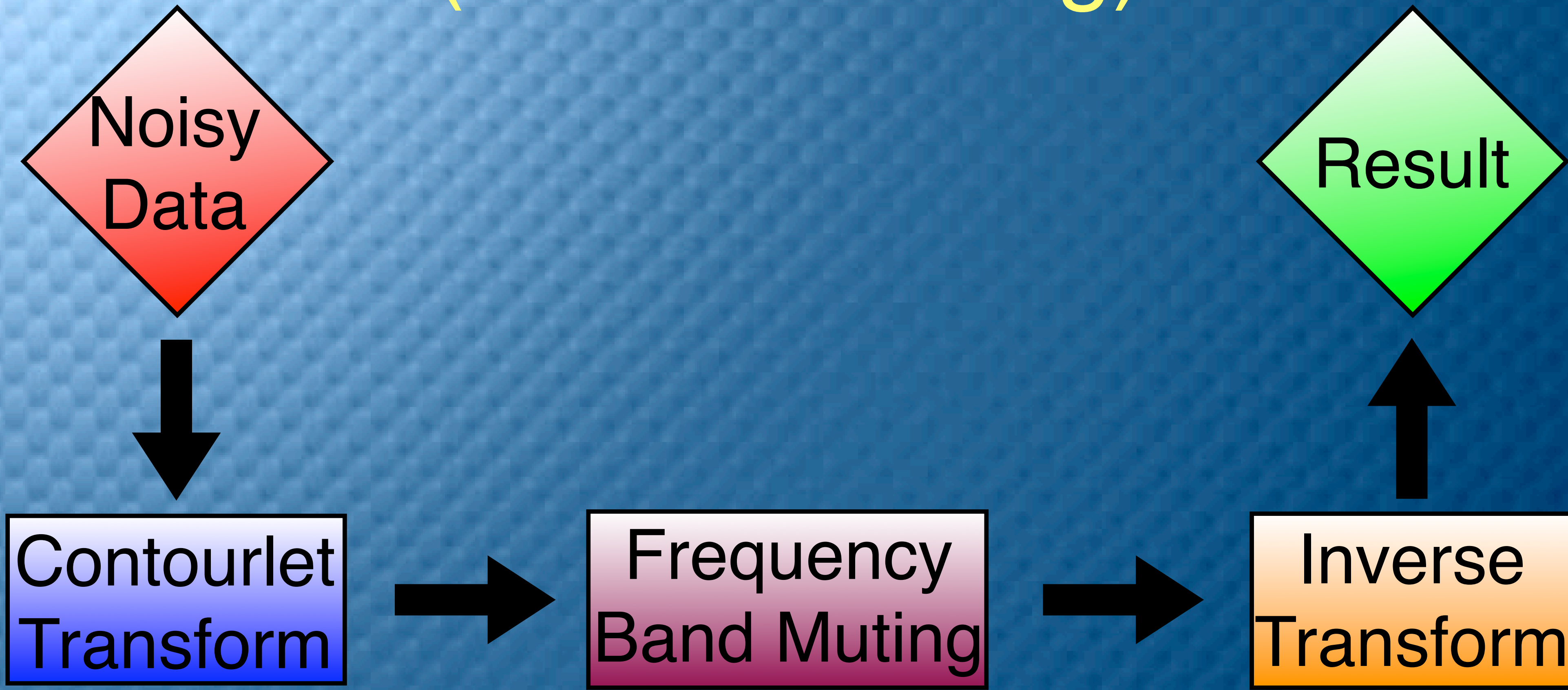
Candes 02, Do 02

Methods
(How?)

I am always doing that which I can not do, in order that I may learn how to do it.

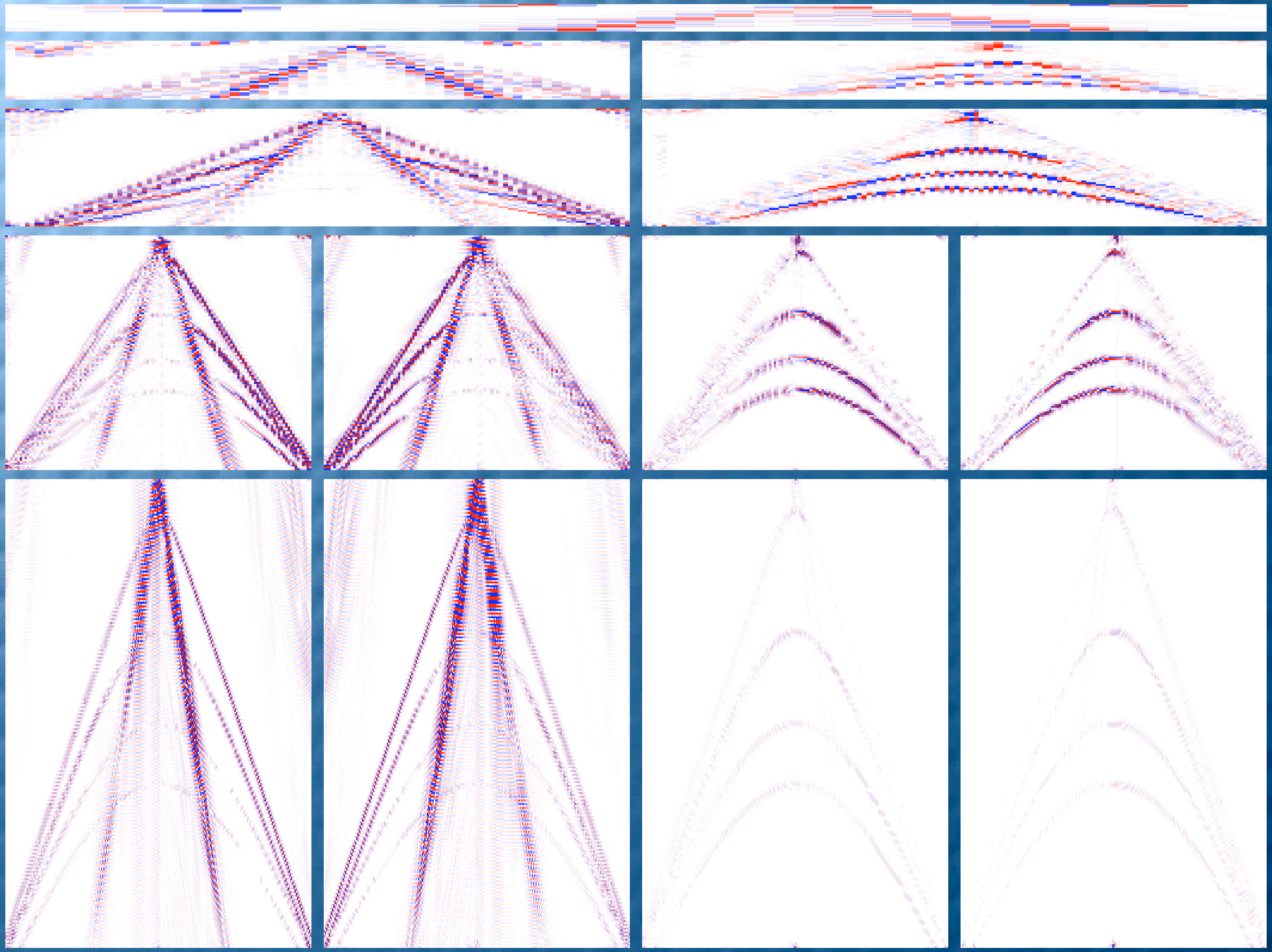
- Pablo Picasso (1881-1973)

Contourlet Band Muting (Linear Filtering)



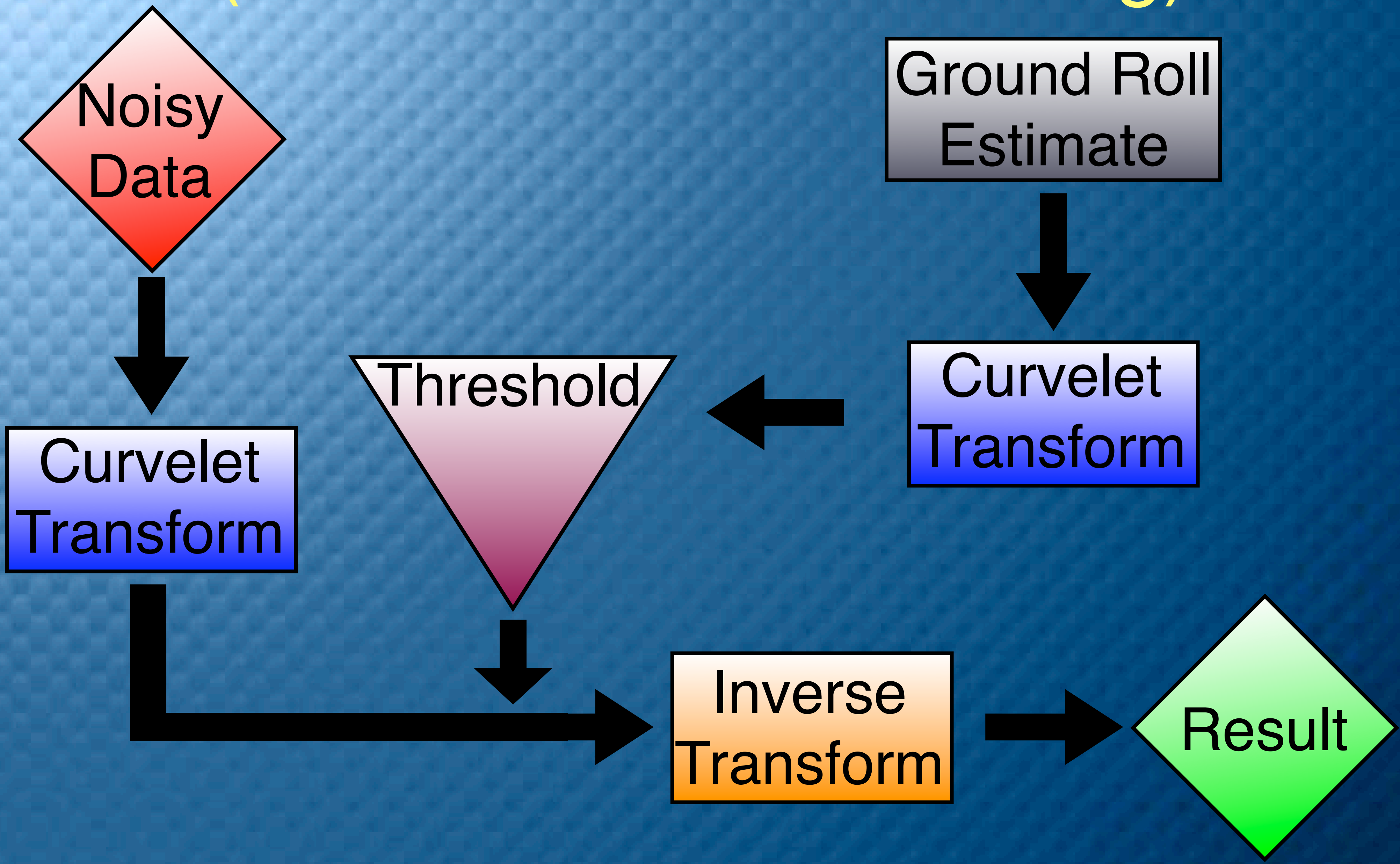
- Global & linear
- Similar to F-K Filtering

Contourlet Coefficient Sectors



Each band represents a group of coefficients that represents and individual part of the signal

Curvelet Adaptive Subtraction (Non-Linear Thresholding)



Curvelet Adaptive Subtraction

$$d = m + n$$

$$\Downarrow$$

$$\min_{m} \frac{1}{2} \| C_n^{-\frac{1}{2}} (d - m) \|_2^2$$

$$\Downarrow$$

$$\min_{\tilde{m}} \frac{1}{2} \| \Gamma^{-1} (\tilde{d} - \tilde{m}) \|_2^2$$

$C_n =$ Covariance $\quad \Gamma^2 =$ Diagonal of the Covariance

Curvelet Adaptive Subtraction

$$\Gamma = |B(n_p)|$$

$$\Downarrow$$

$$\widehat{m} = B^{-1}\Theta_{\lambda\Gamma}(Bd)$$

$\Theta_{\lambda\gamma} =$ Hard or Soft Threshold

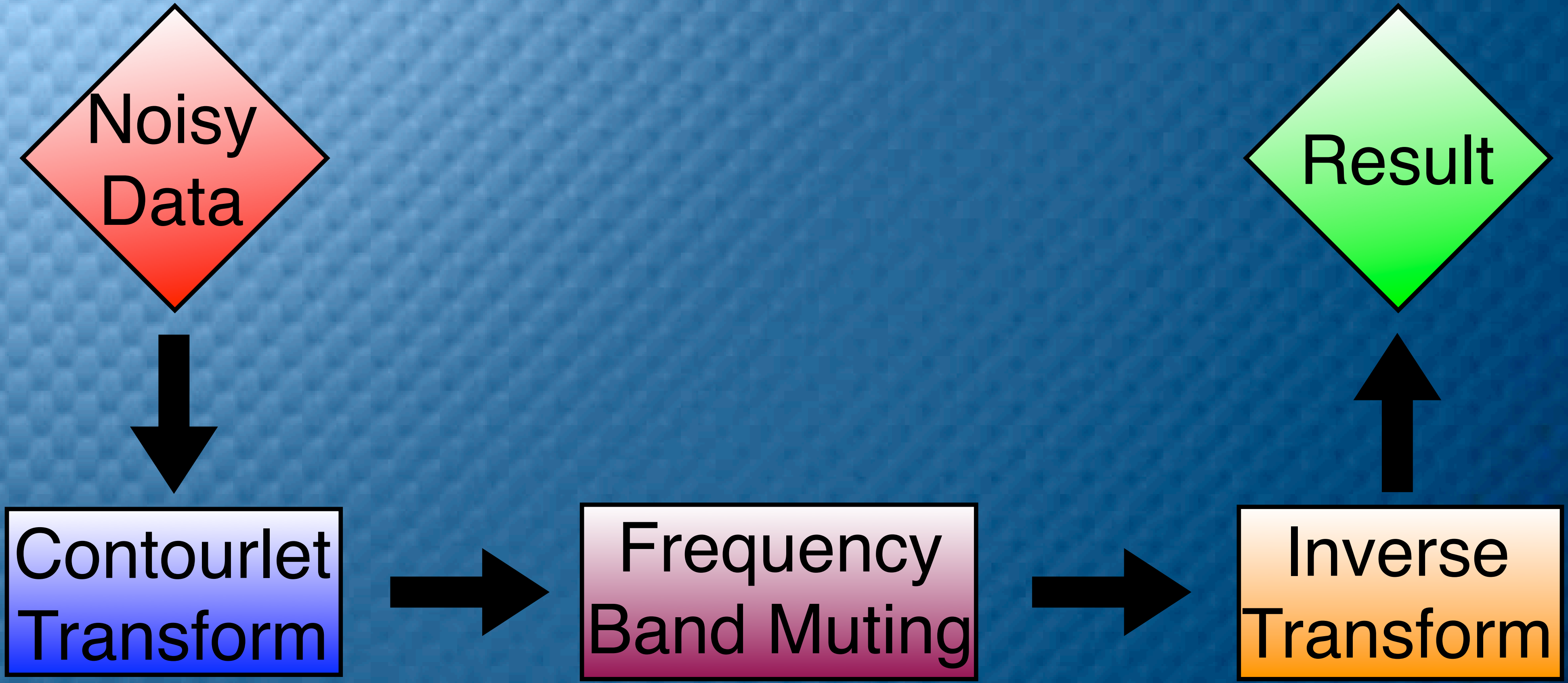
$\lambda =$ Control Parameter

Examples (Who?)

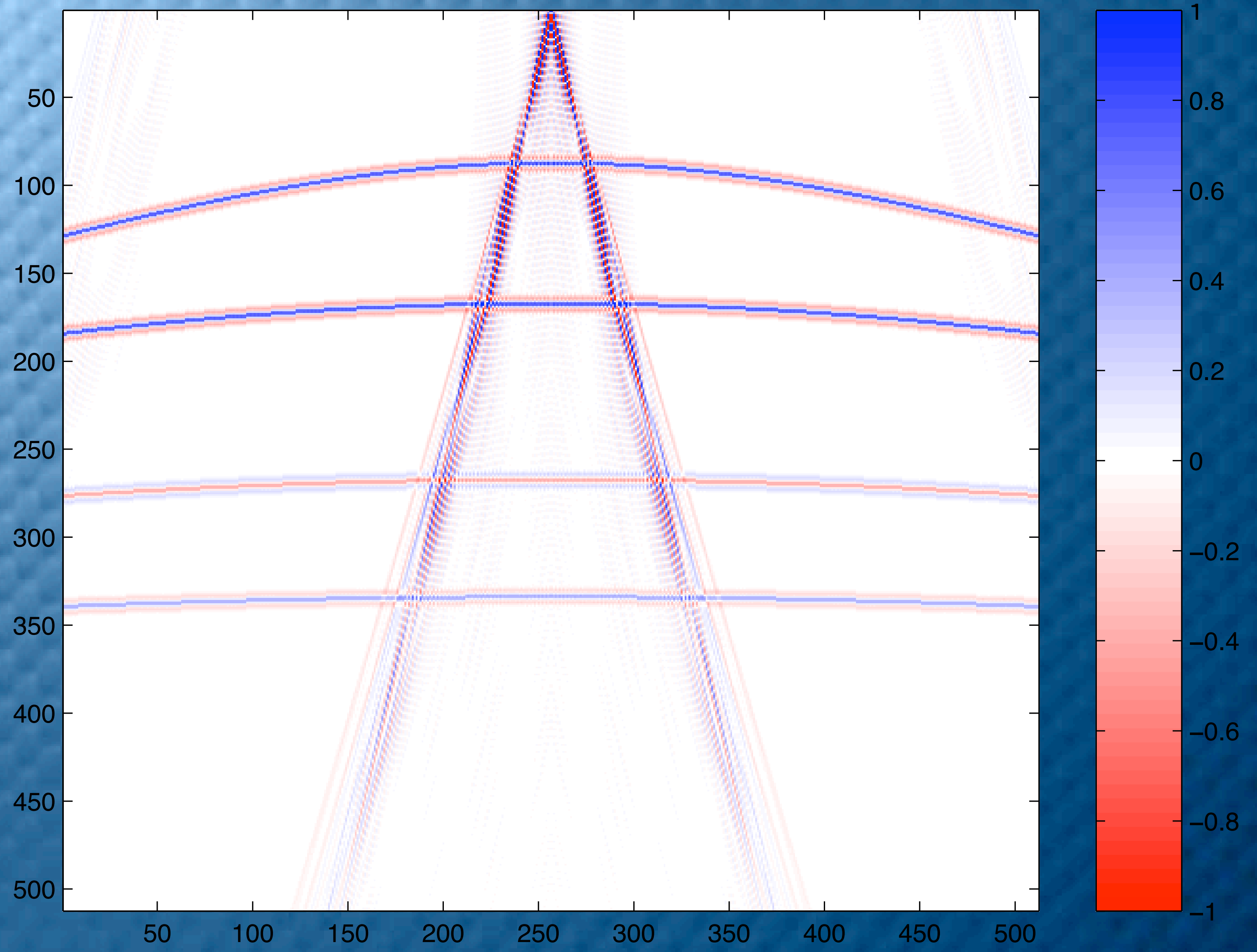
He who wonders discovers that this in itself is wonder.

- M.C. Escher (1898-1972)

Linear Filtering (Contourlets)

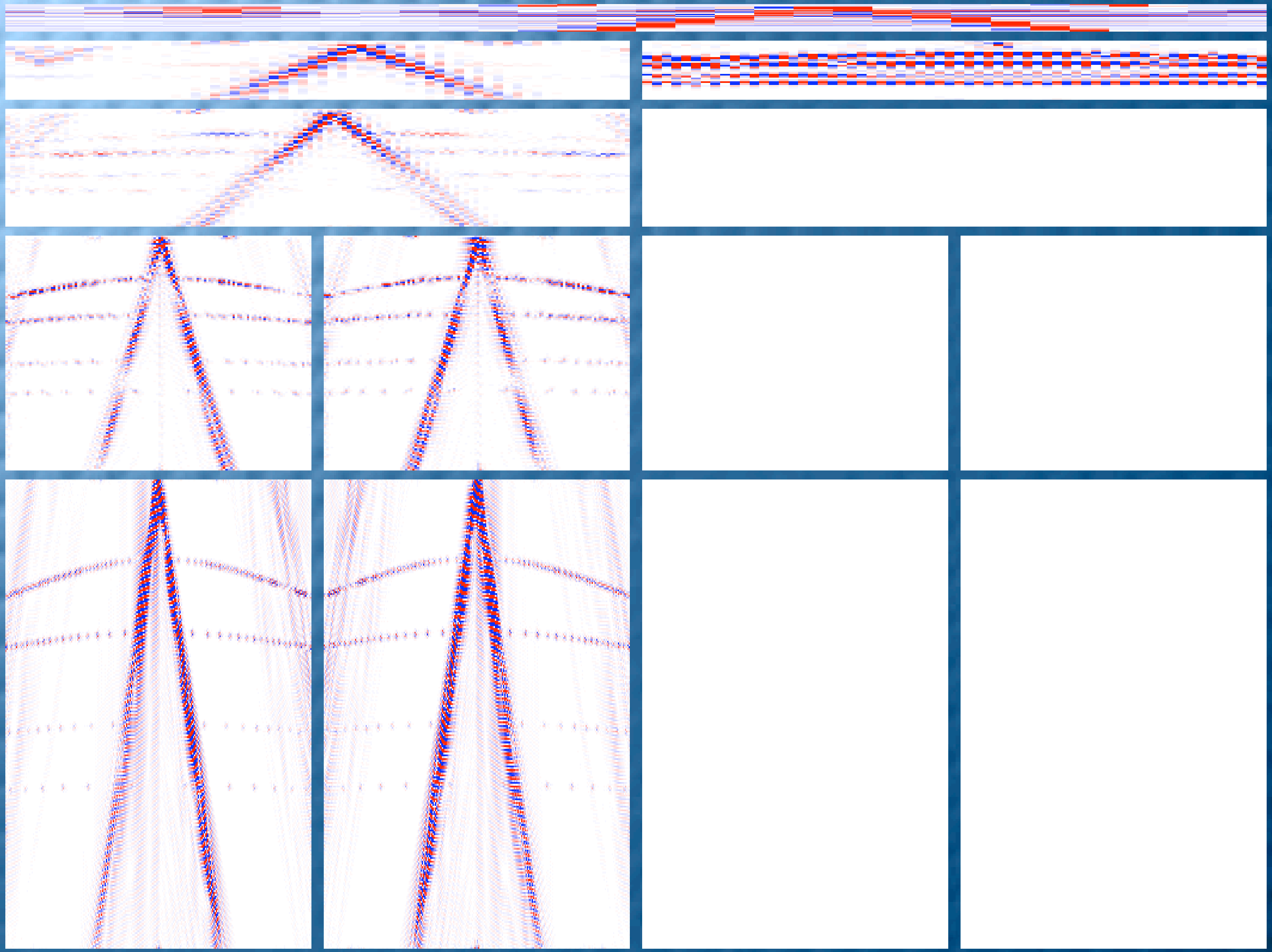


Contourlet Band Filtering
Synthetic Example 1:



Wide Parabolic Curves and Dispersive Ground Roll

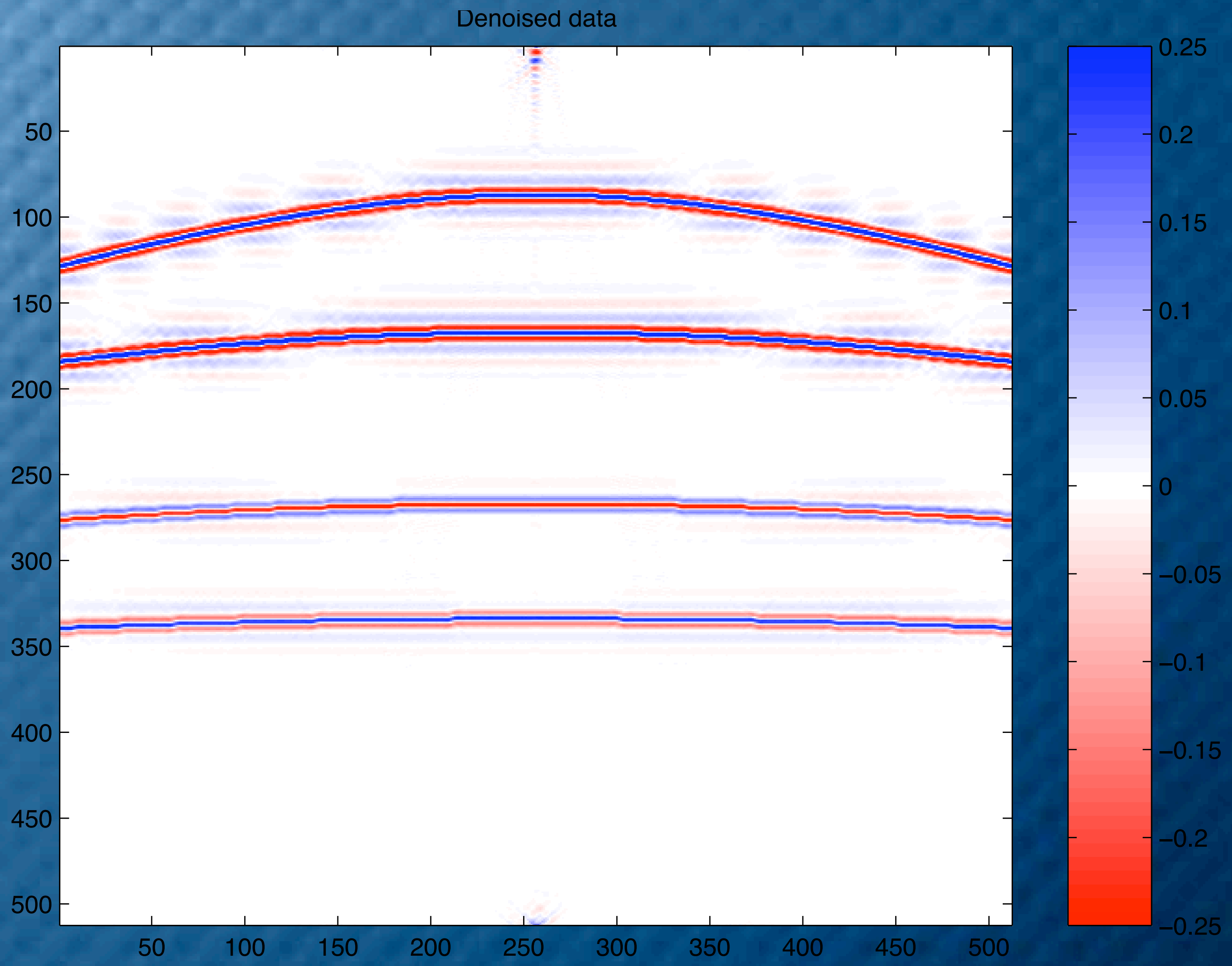
Removed Frequency Bands



Indicates Bands Removed In Thresholding

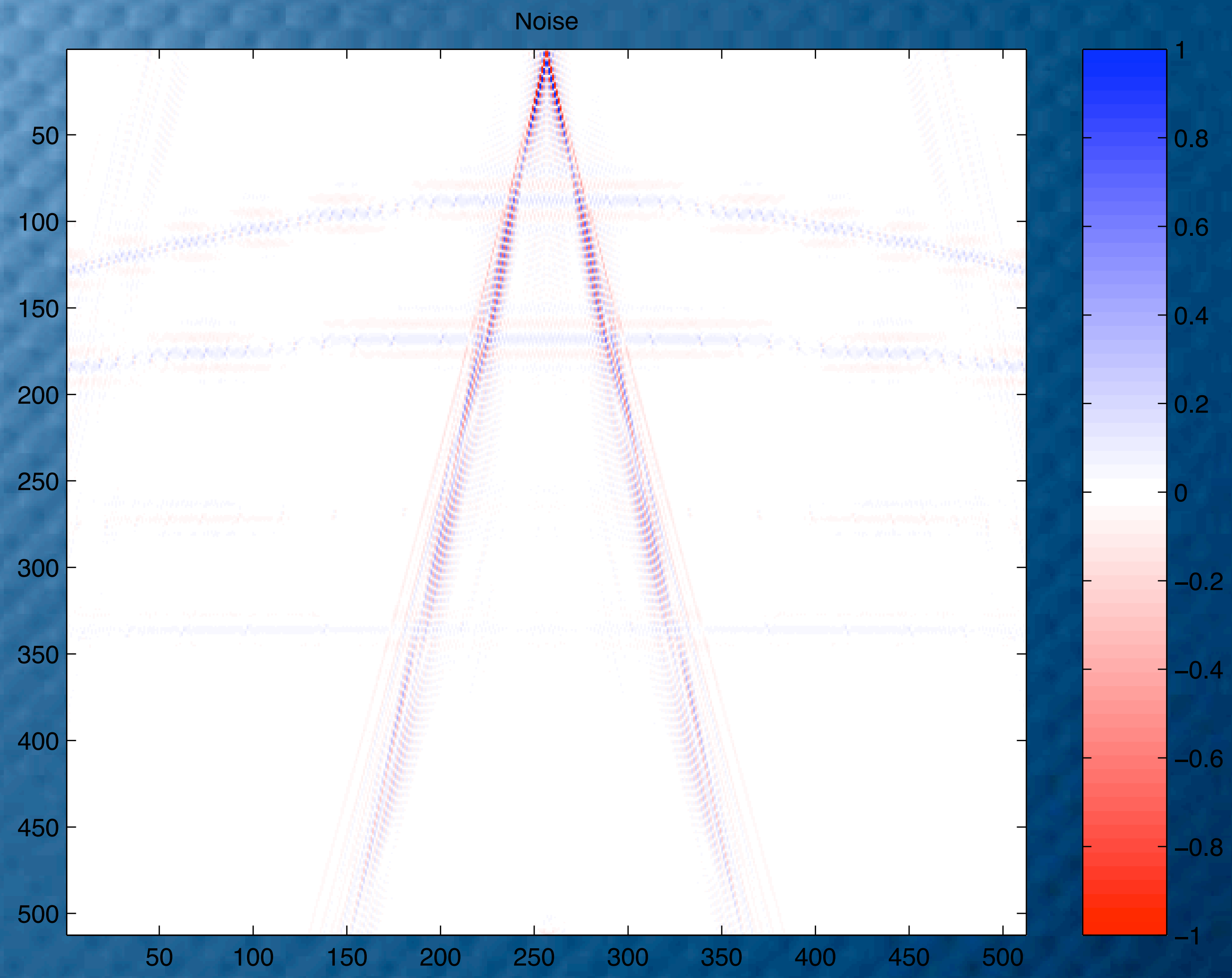
Reconstructed Contourlet Denoised Signal

- Reflectors generally preserved
- Ground roll removed

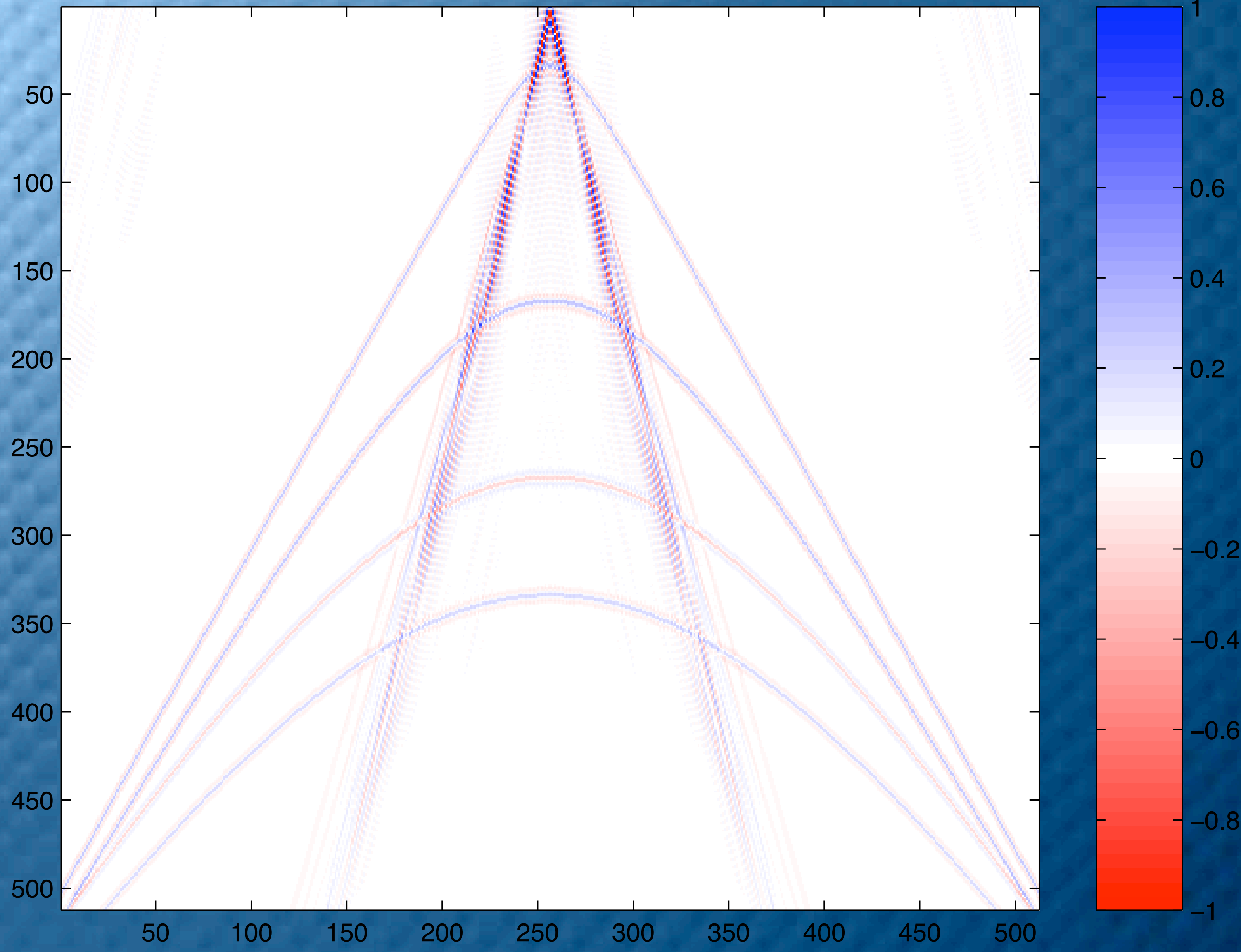


Predicted Noise

- Contains ground roll signal
- Vertical components of reflectors slightly muted

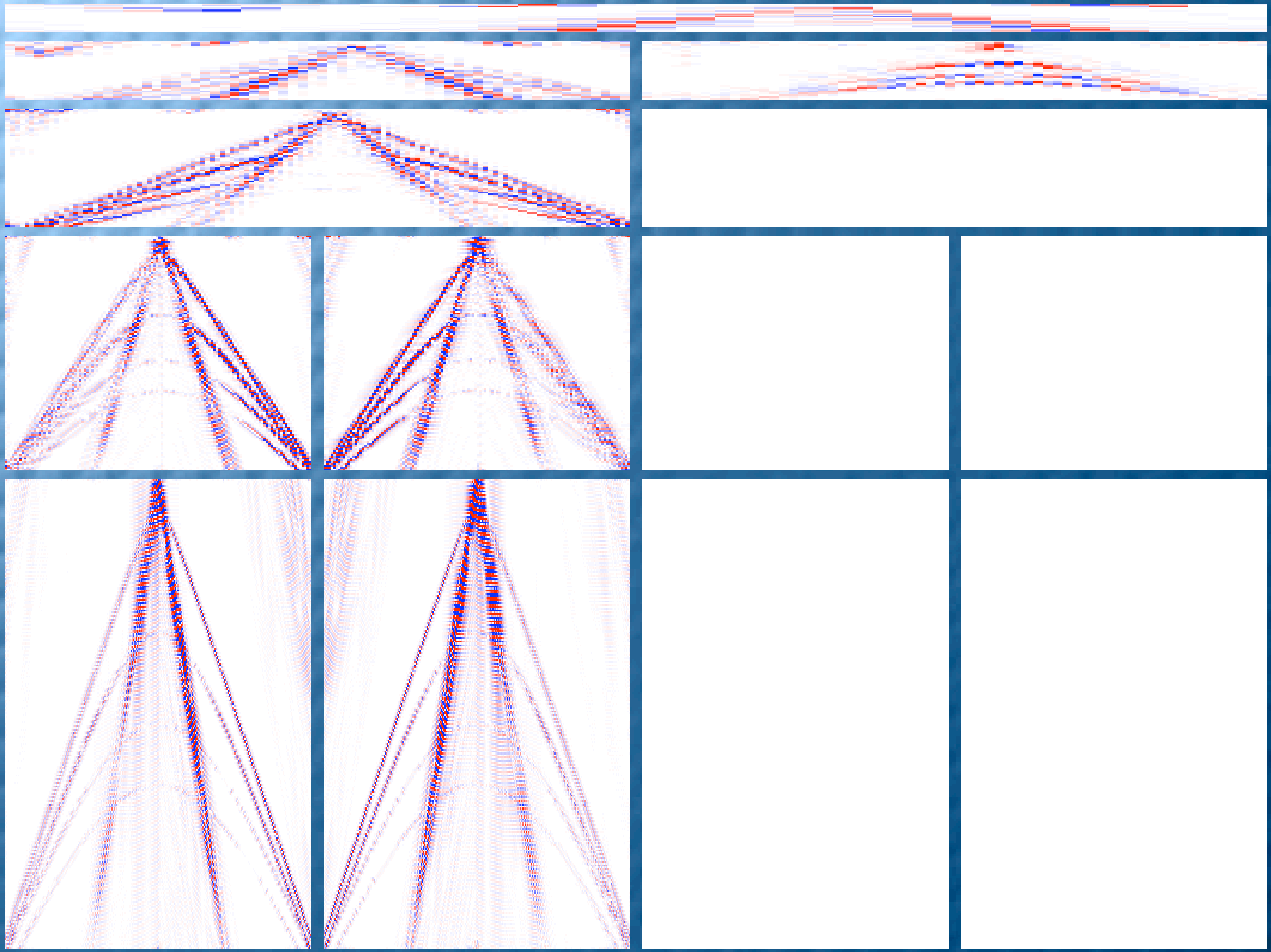


Contourlet Band Filtering Synthetic Example 2:



Steep Parabolic Curves and Dispersive Ground Roll

Removed Frequency Bands

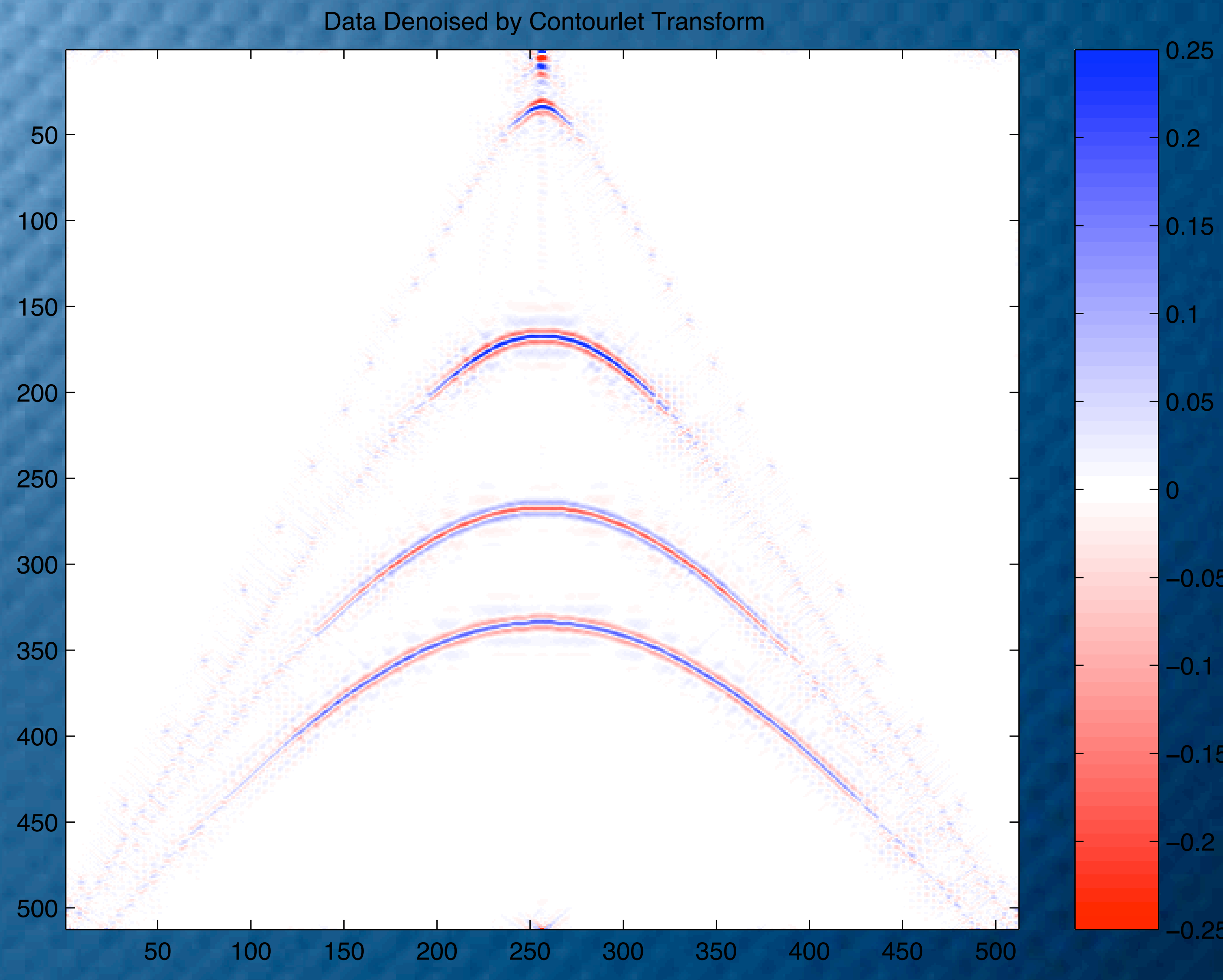


Indicates Bands Removed In Thresholding

Reconstructed Contourlet Denoised Signal

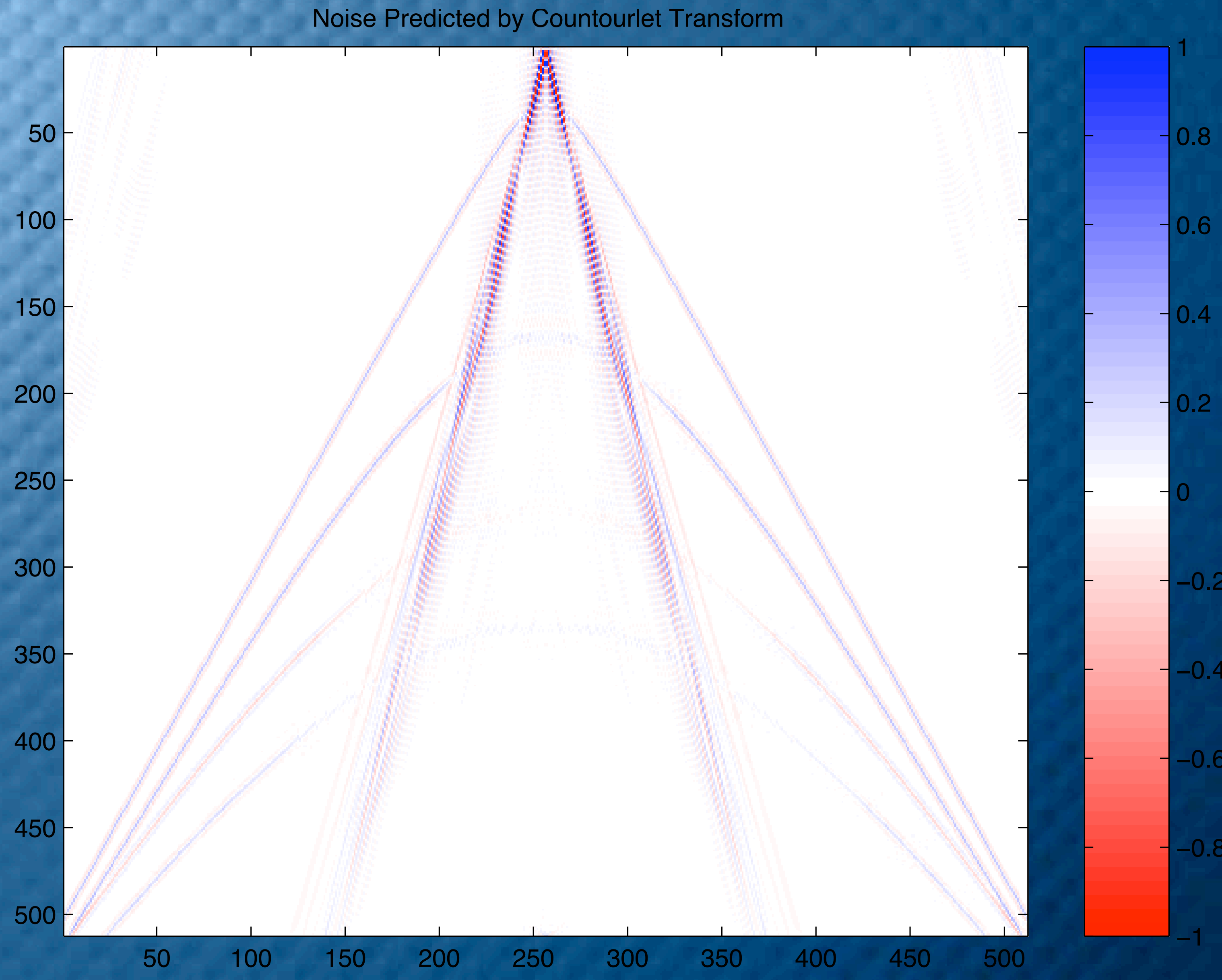
Problems:

- Steep events removed
- Artifact located at apex

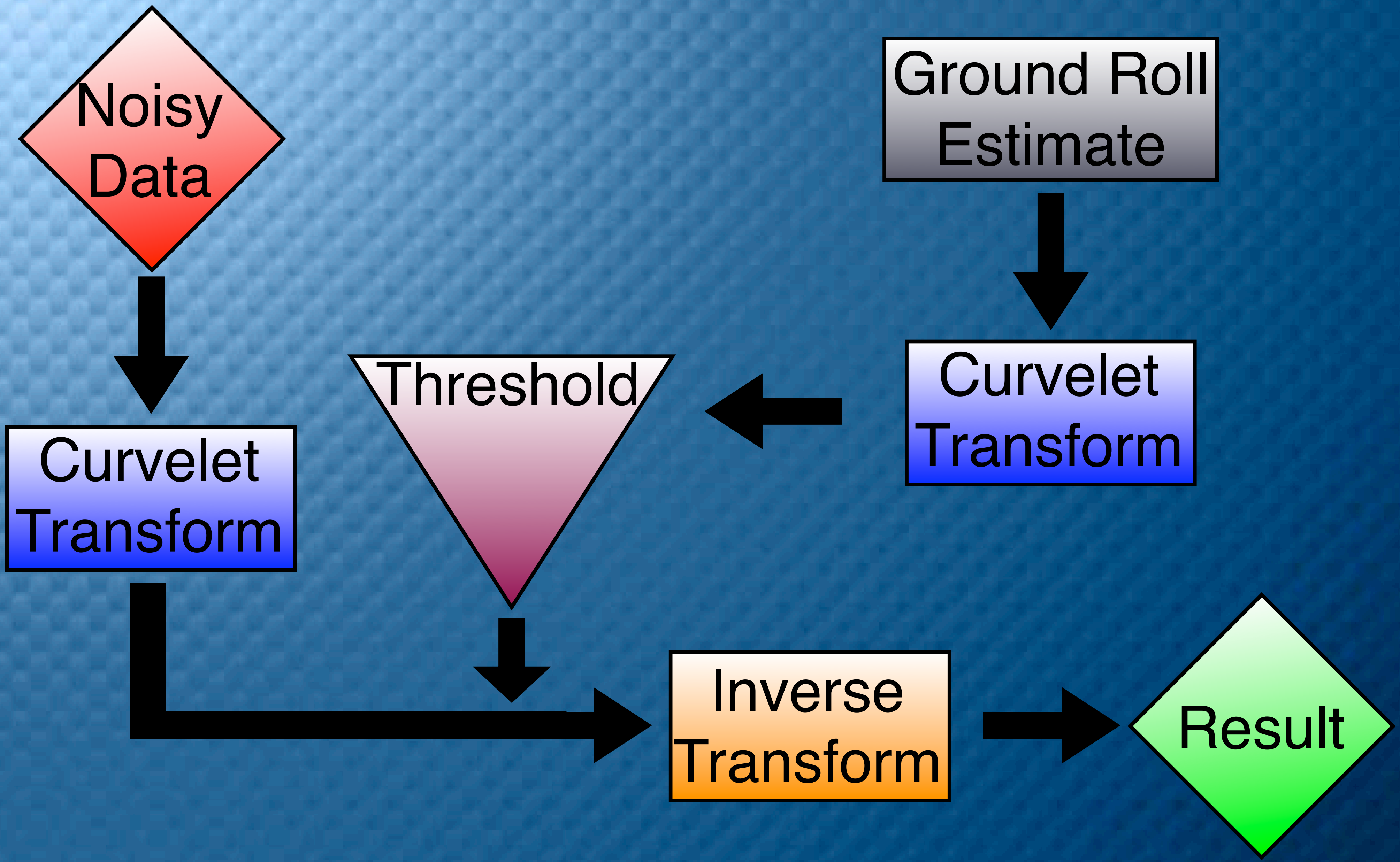


Predicted Noise

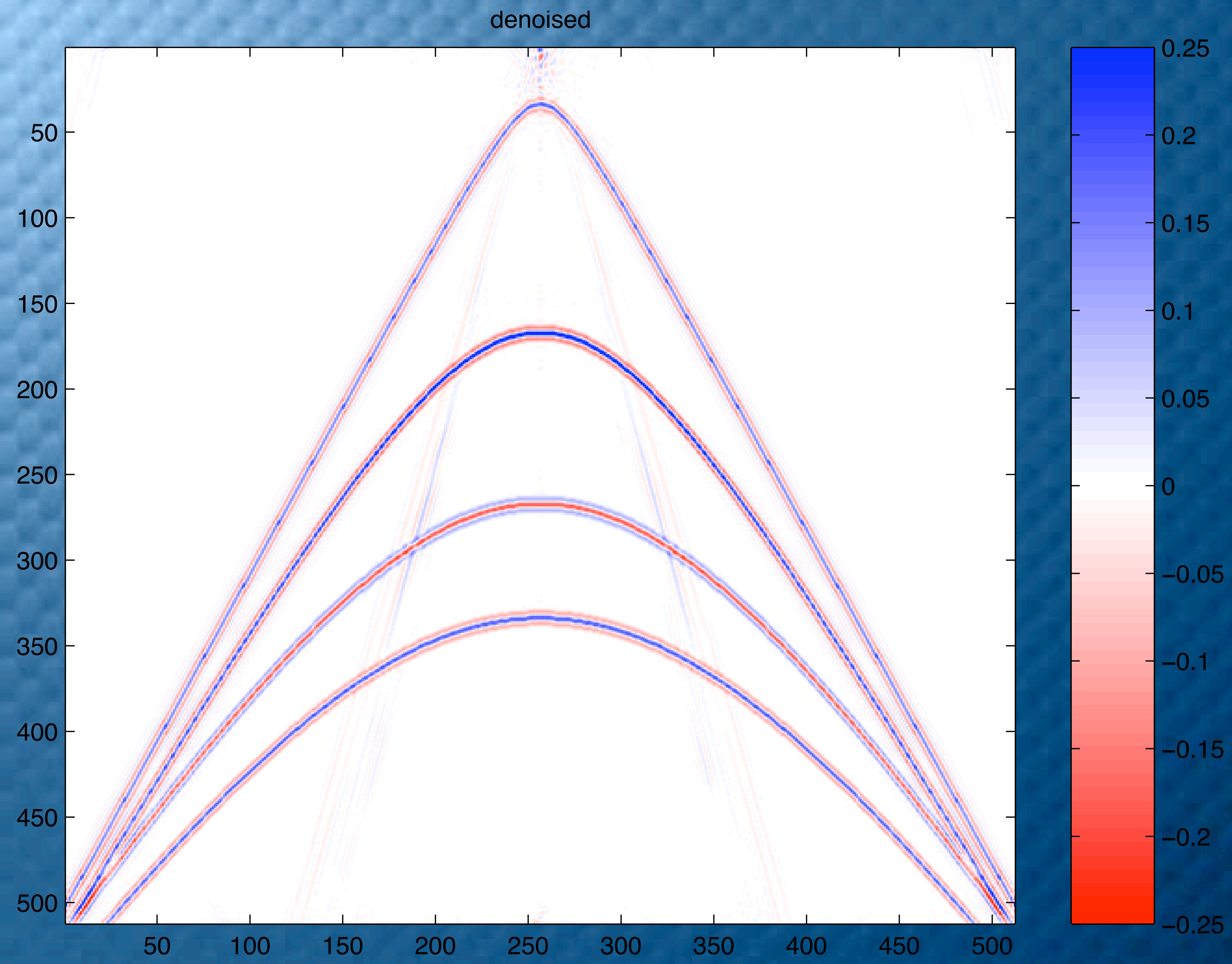
- Steep reflectors predicted as noise along with the ground roll
- Can Adaptive Subtraction do better?



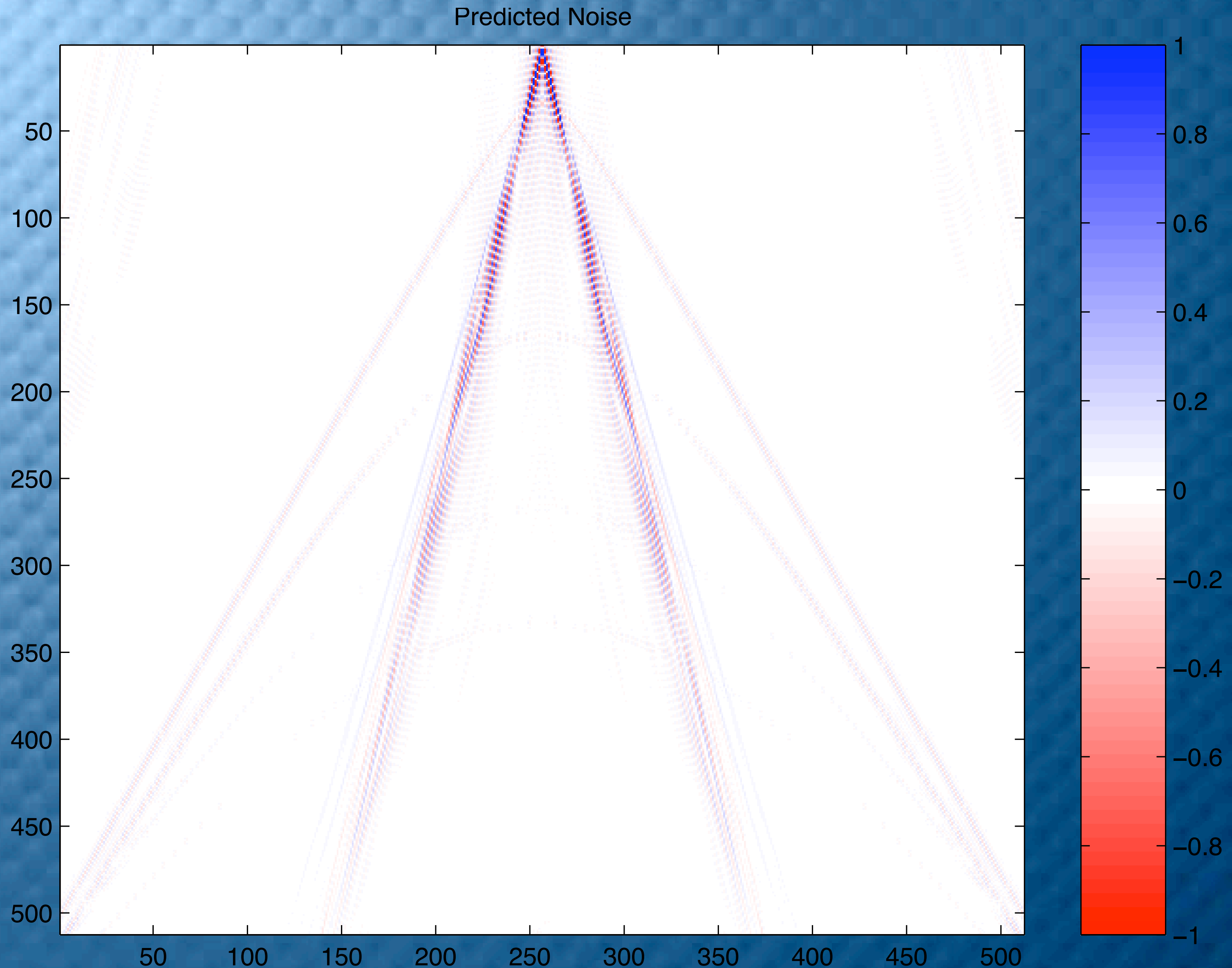
Non-Linear Thresholding (Curvelet Adaptive Subtraction)



Reconstructed Curvelet Denoised Signal

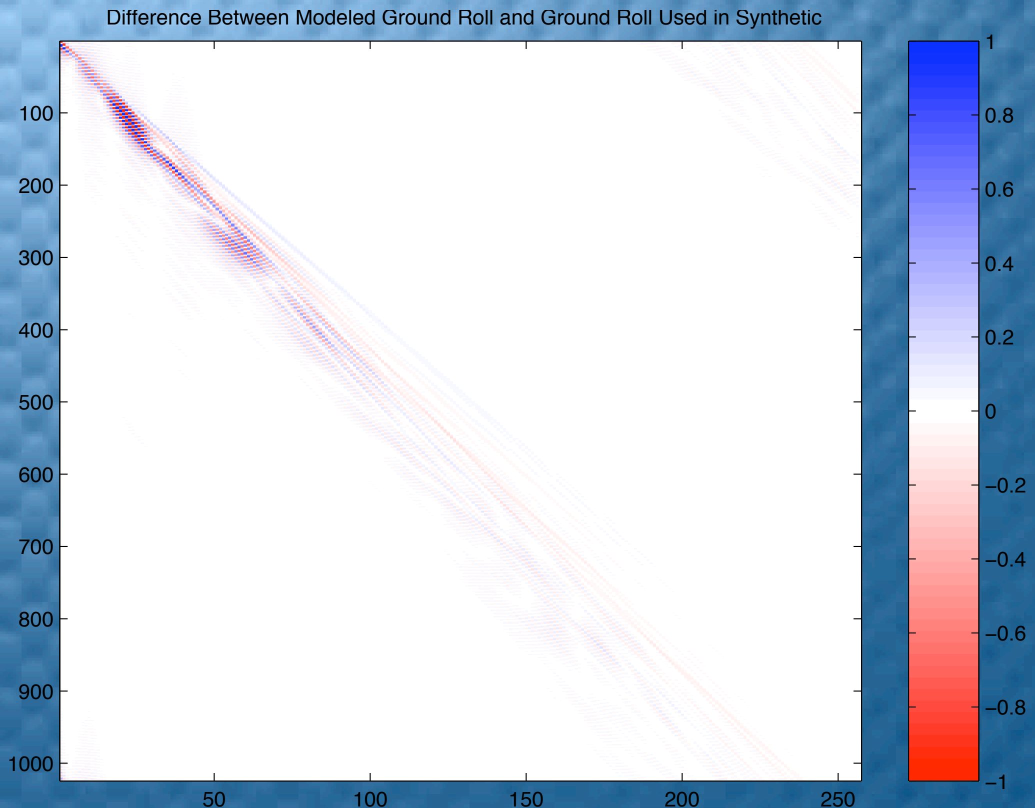


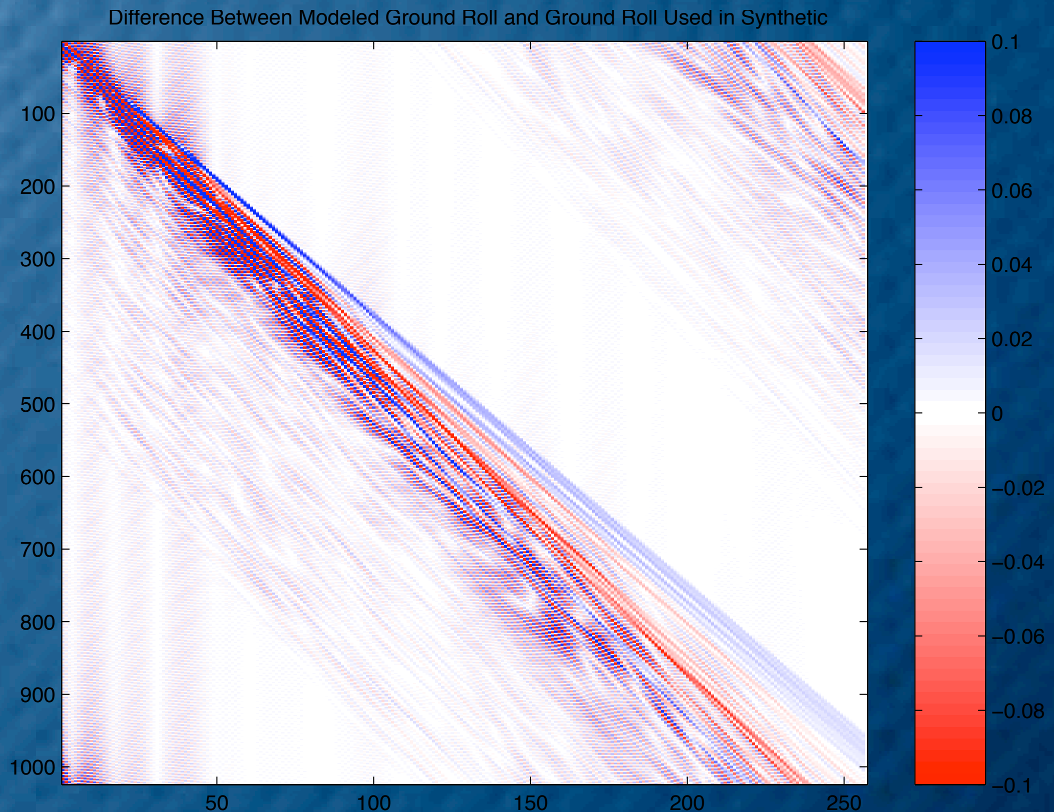
Predicted Noise



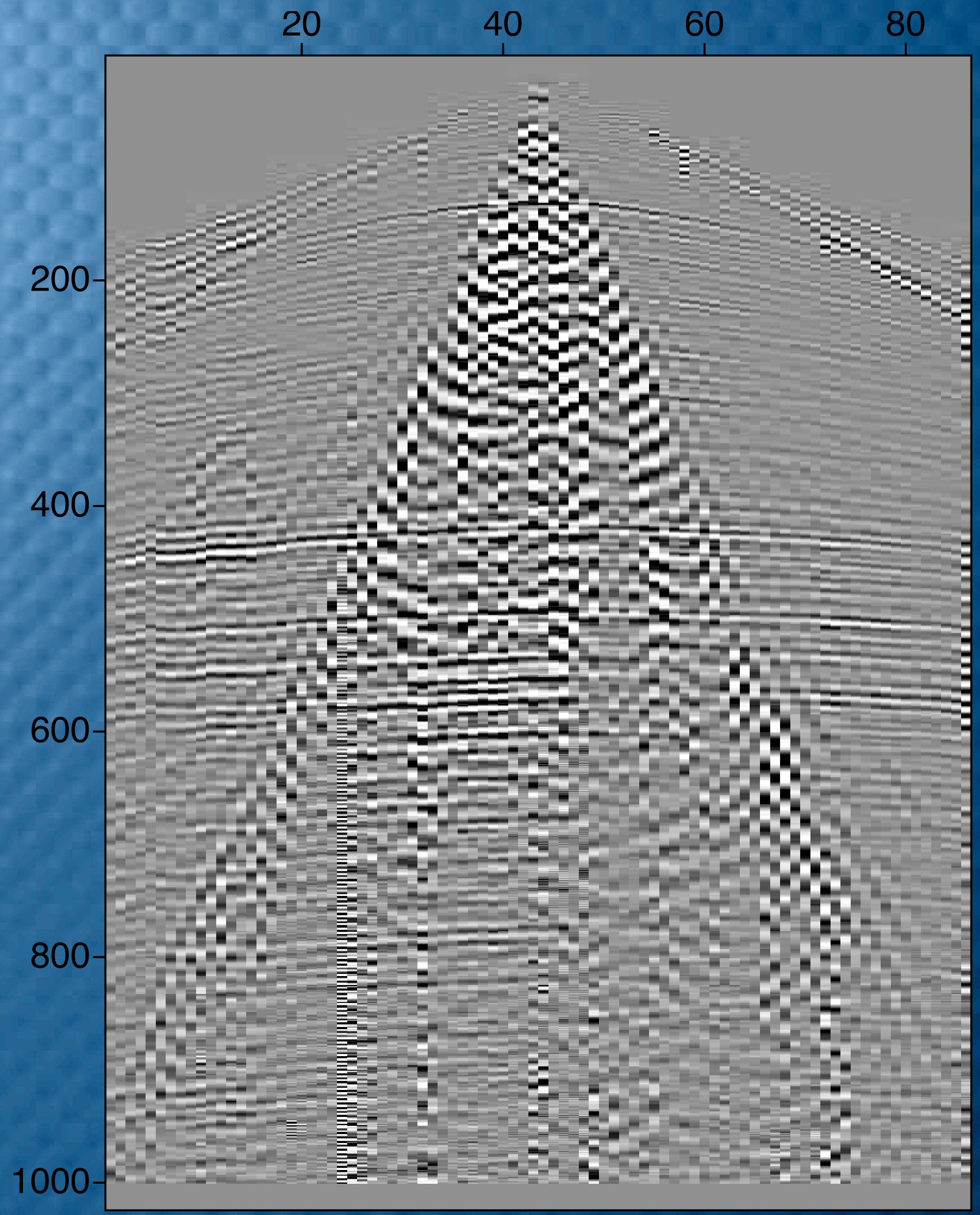
Ground Roll Difference:

Shown is the difference between the estimated ground roll and the actual ground roll



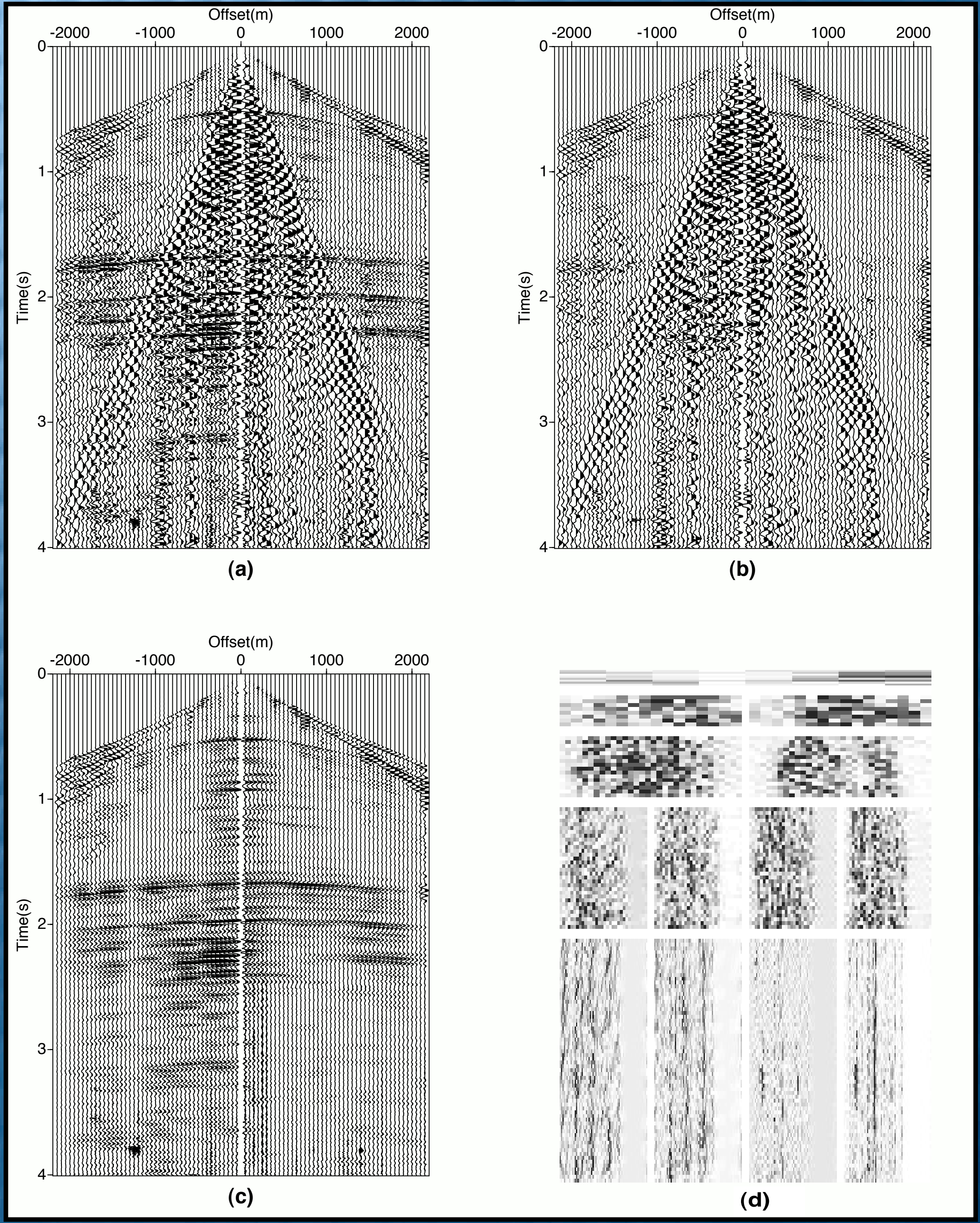


Curvelet Adaptive Subtraction Real Data Example: Contourlets vs Curvelets vs Radon



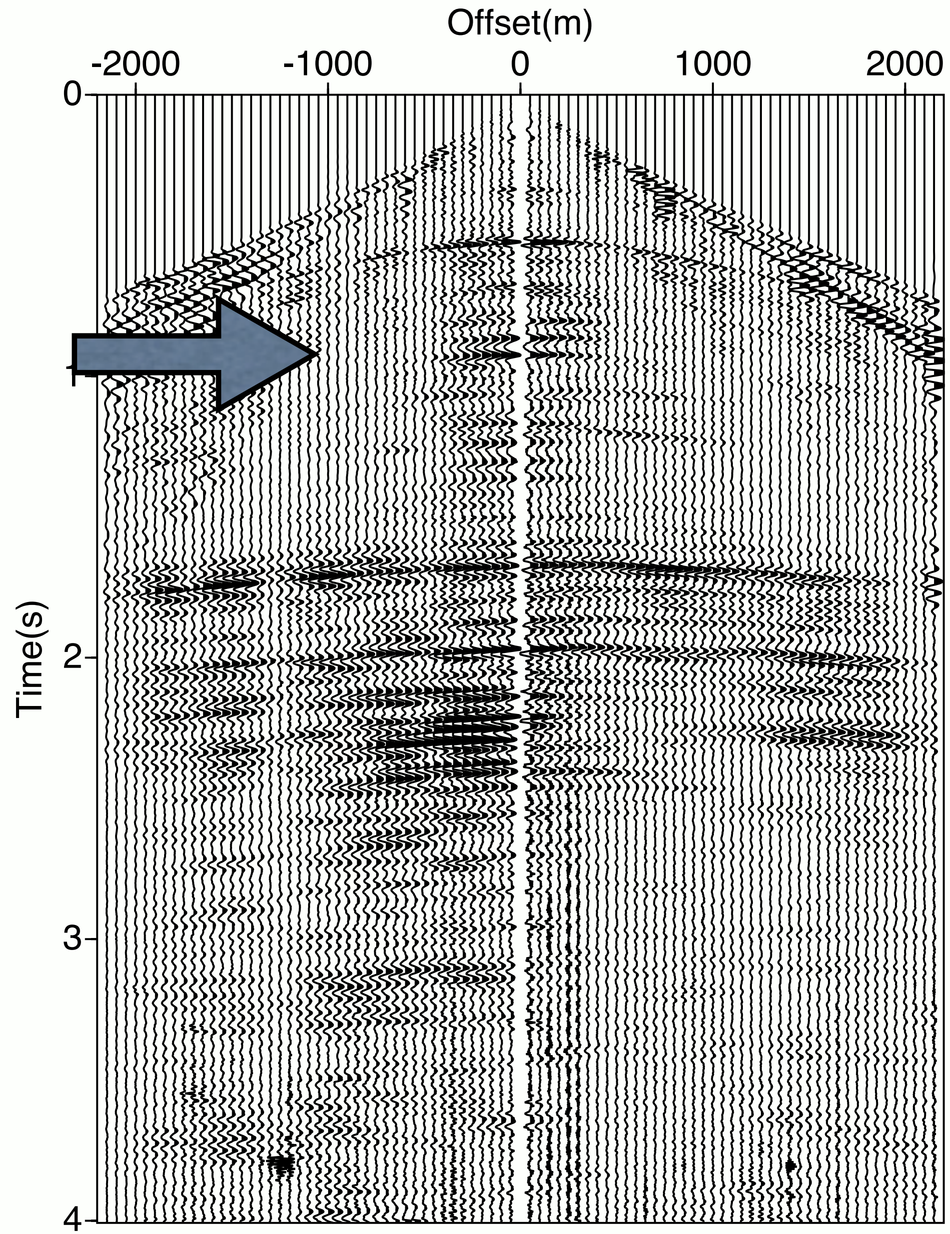
Oz25 Signal With Ground Roll

Contourlets (Linear Filtering)



Contourlet Denoised Result

- Ground Roll Removed
- “Shadow” Left Behind



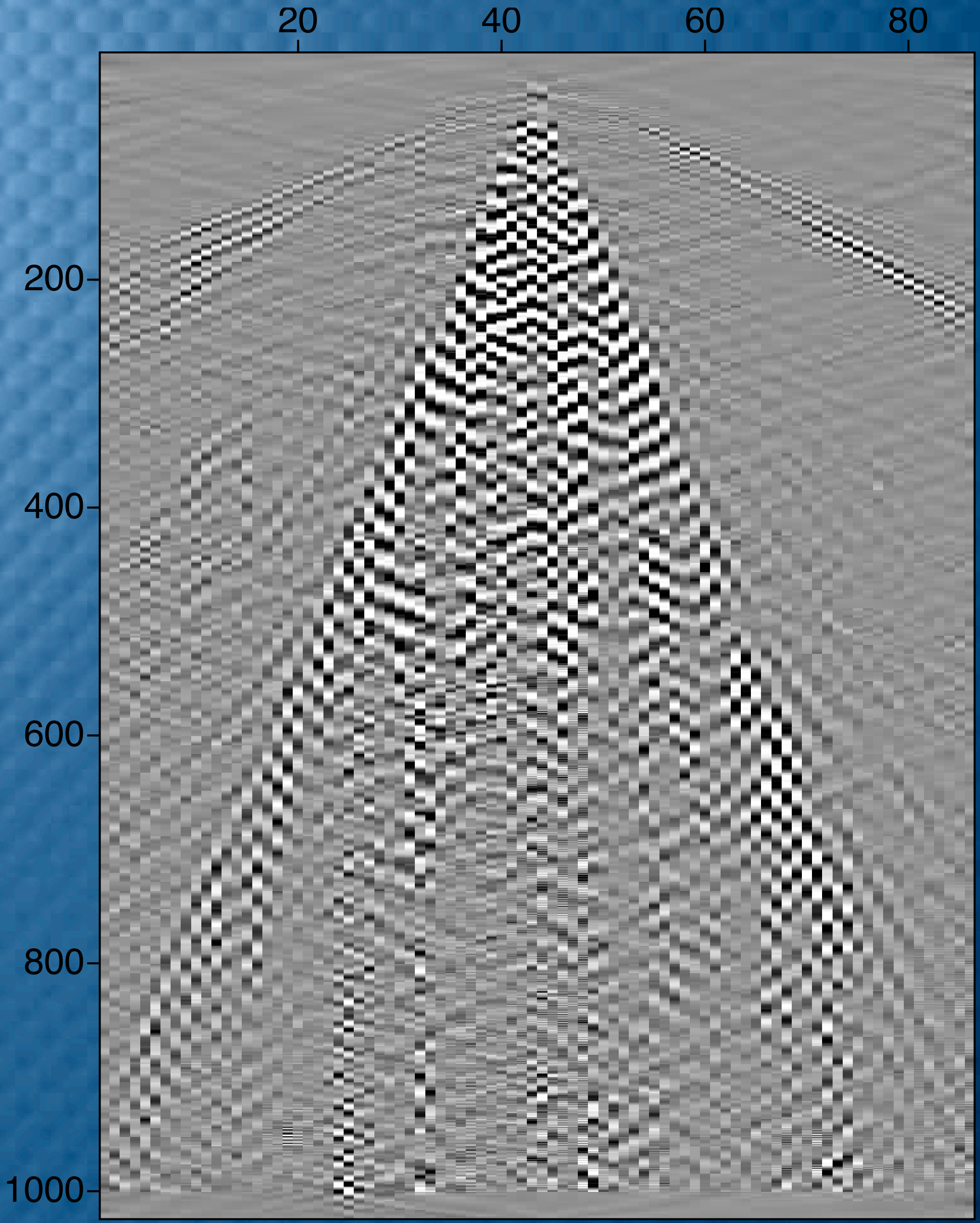
(c)

Radon Predicted Noise:

Two Choices:

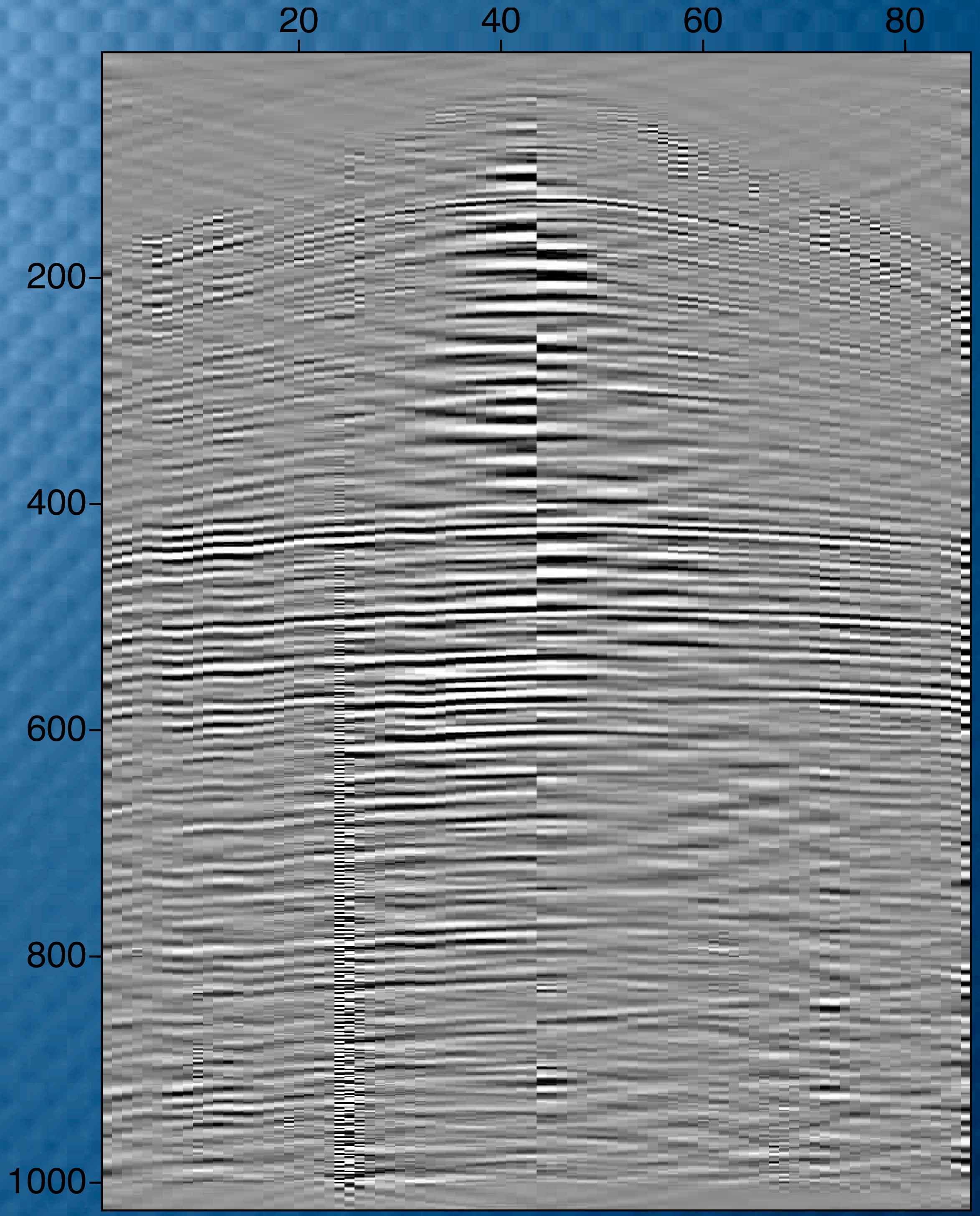
1. Subtract predicted noise from data

2. Use predicted noise to define threshold for curvelet adaptive subtraction



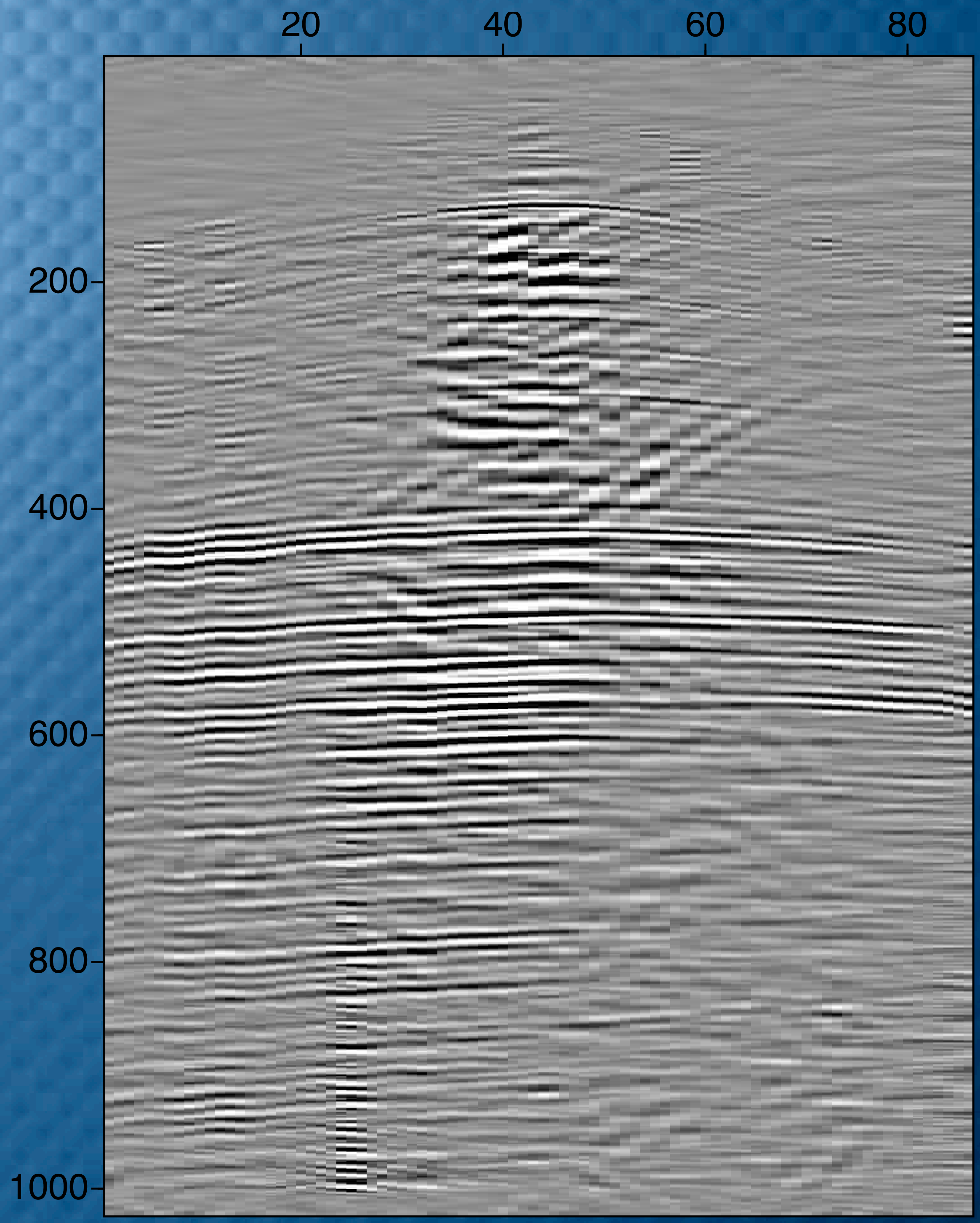
Radon Denoised Data

Subtraction of the Radon predicted noise from the data

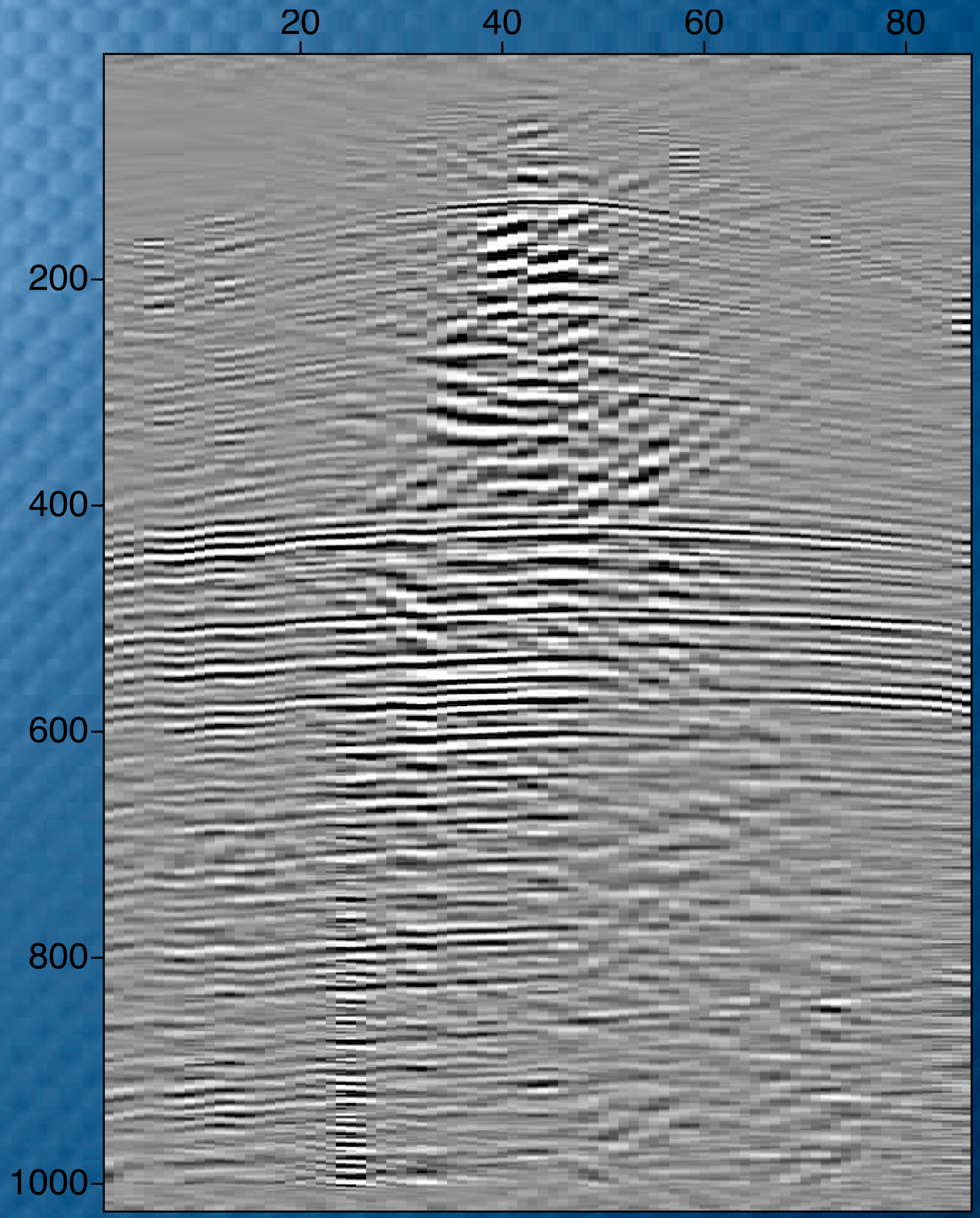


Curvelet Denoised Data From Soft Non-Linear Threshold

- Increased Smoothing
- Some removal of top reflectors and right side of mid reflectors

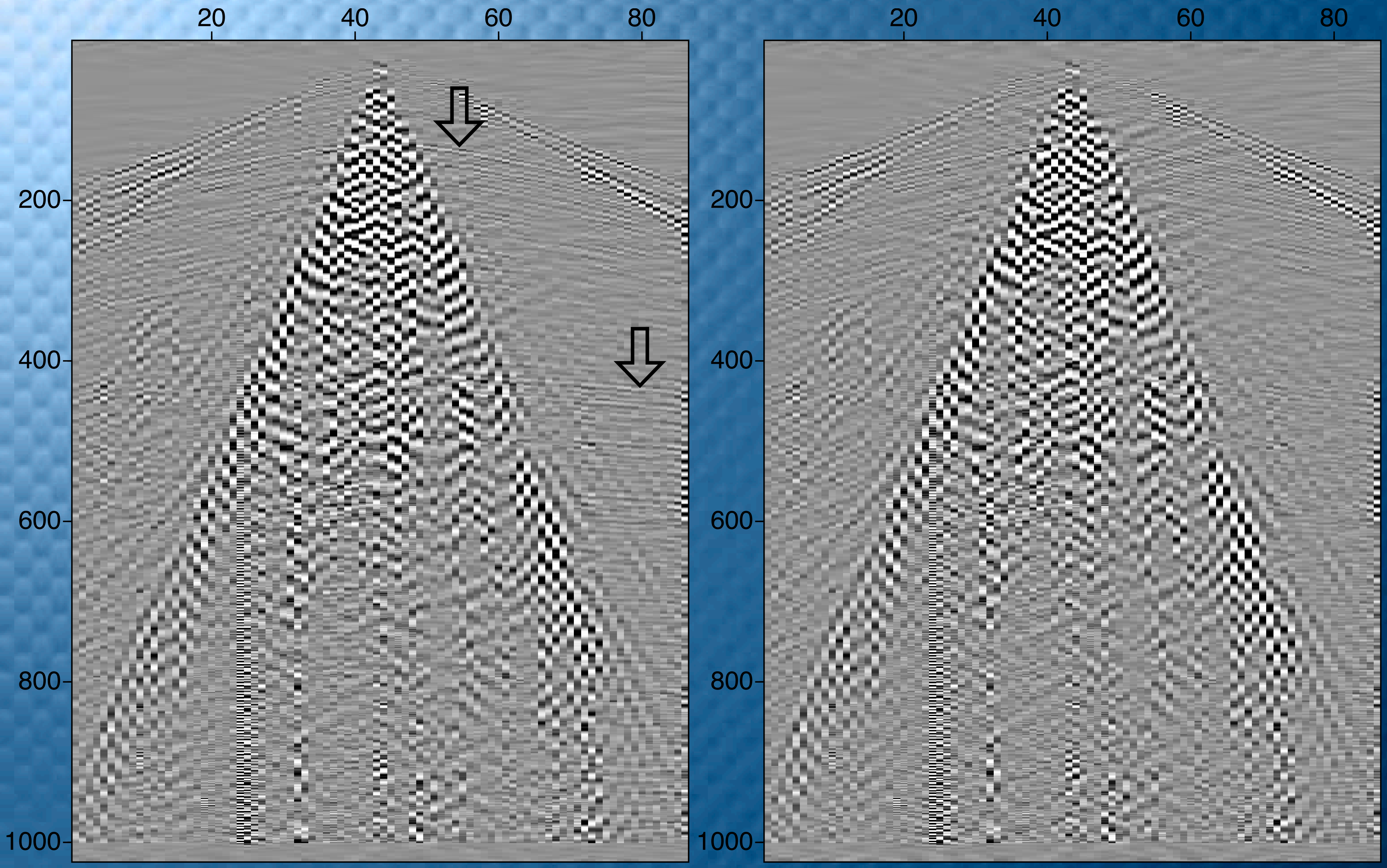


Curvelet Denoised Data From Hard Non-Linear Threshold



- Better reflector preservation
- Less smoothing

Curvelet Predicted Noise



Soft Thresholding

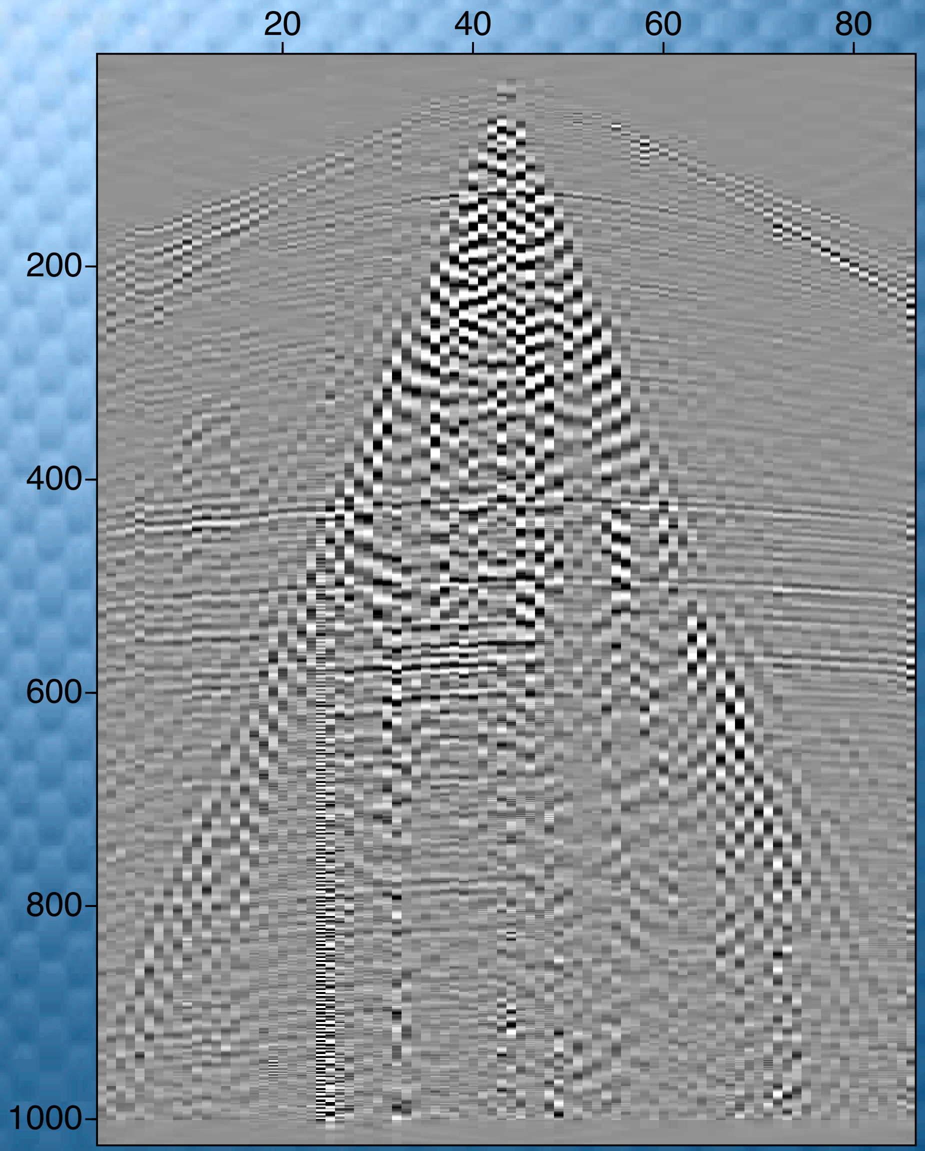
Hard Thresholding

Phase Preservation

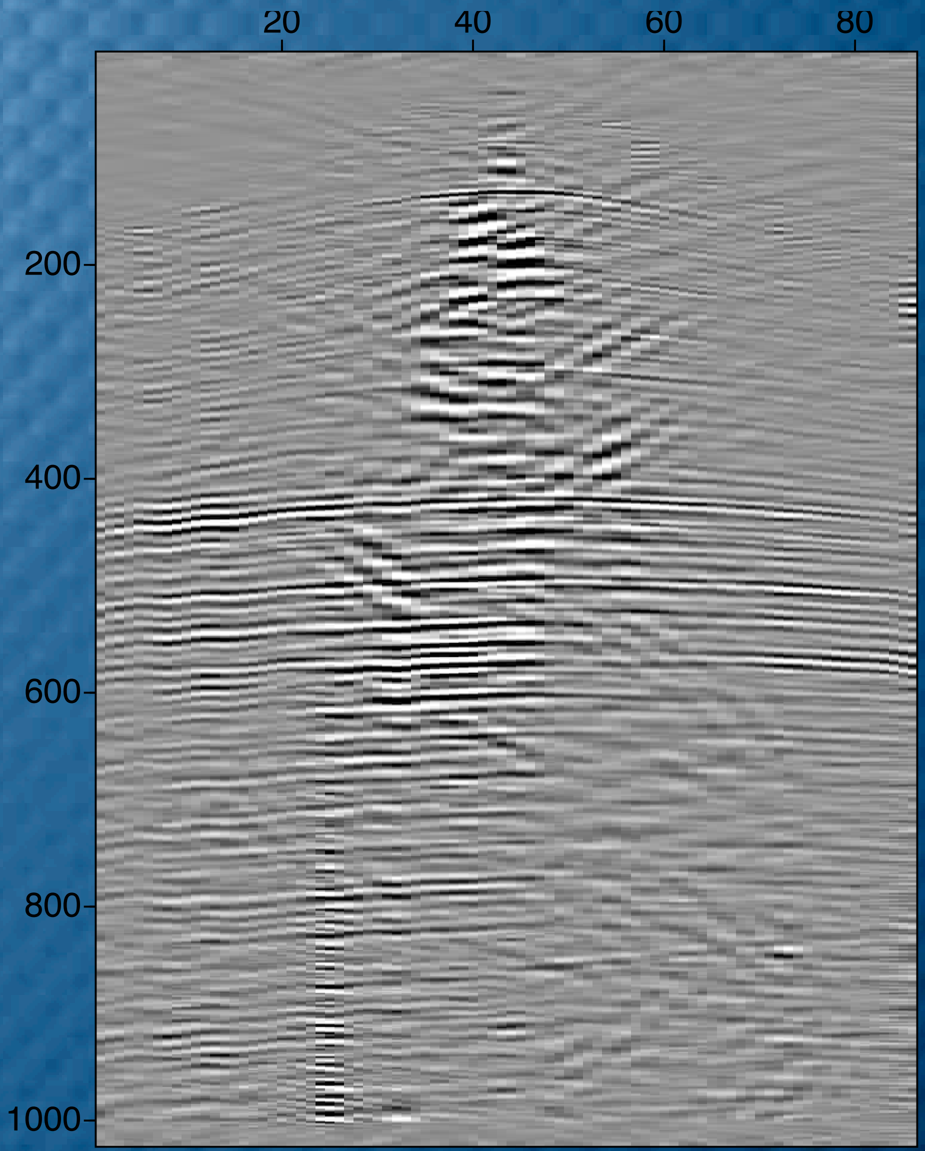
Give the predicted ground roll a 90 degrees phase shift. What would happen?

- Direct subtraction will no longer be useful as the result will only amplify the differences.
- Curvelet adaptive subtraction works without a problem.

Phase Shifted Model Results

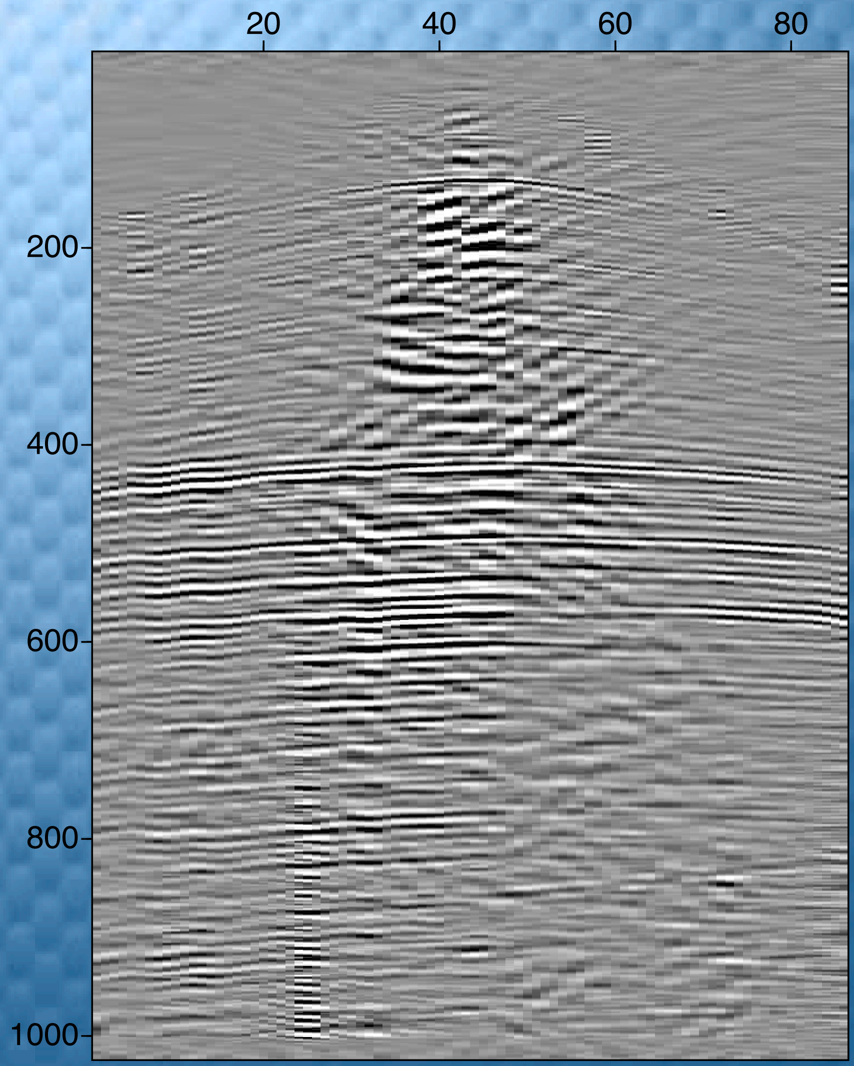


Subtraction

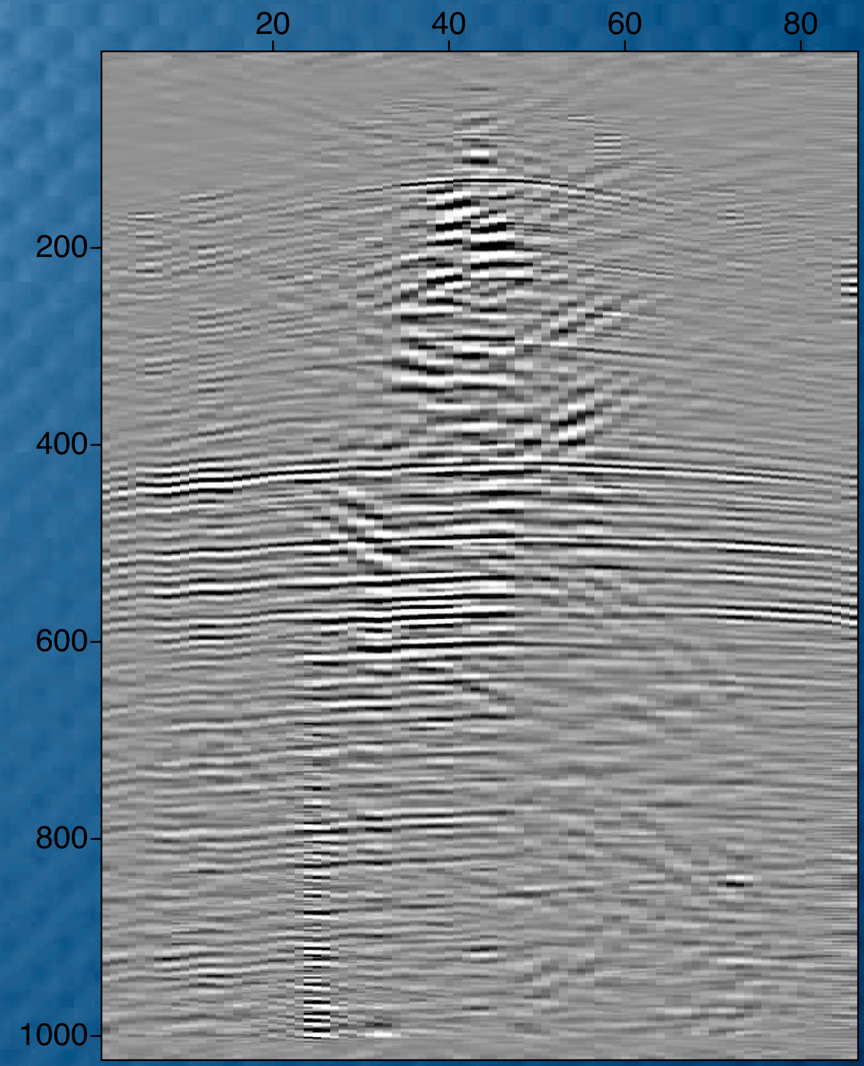


Curvelet Adaptive Subtraction

Phase Shifted Model Results

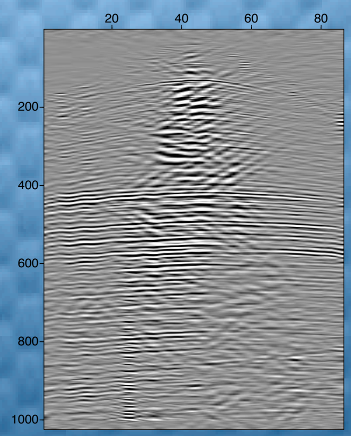


Results Without Phase Shift

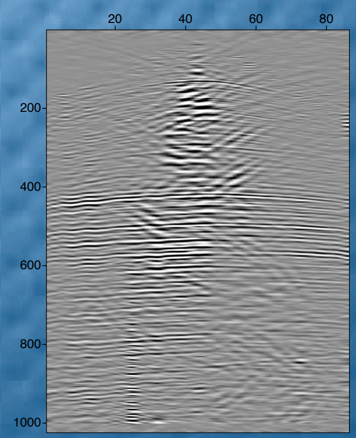


Results With Phase Shift

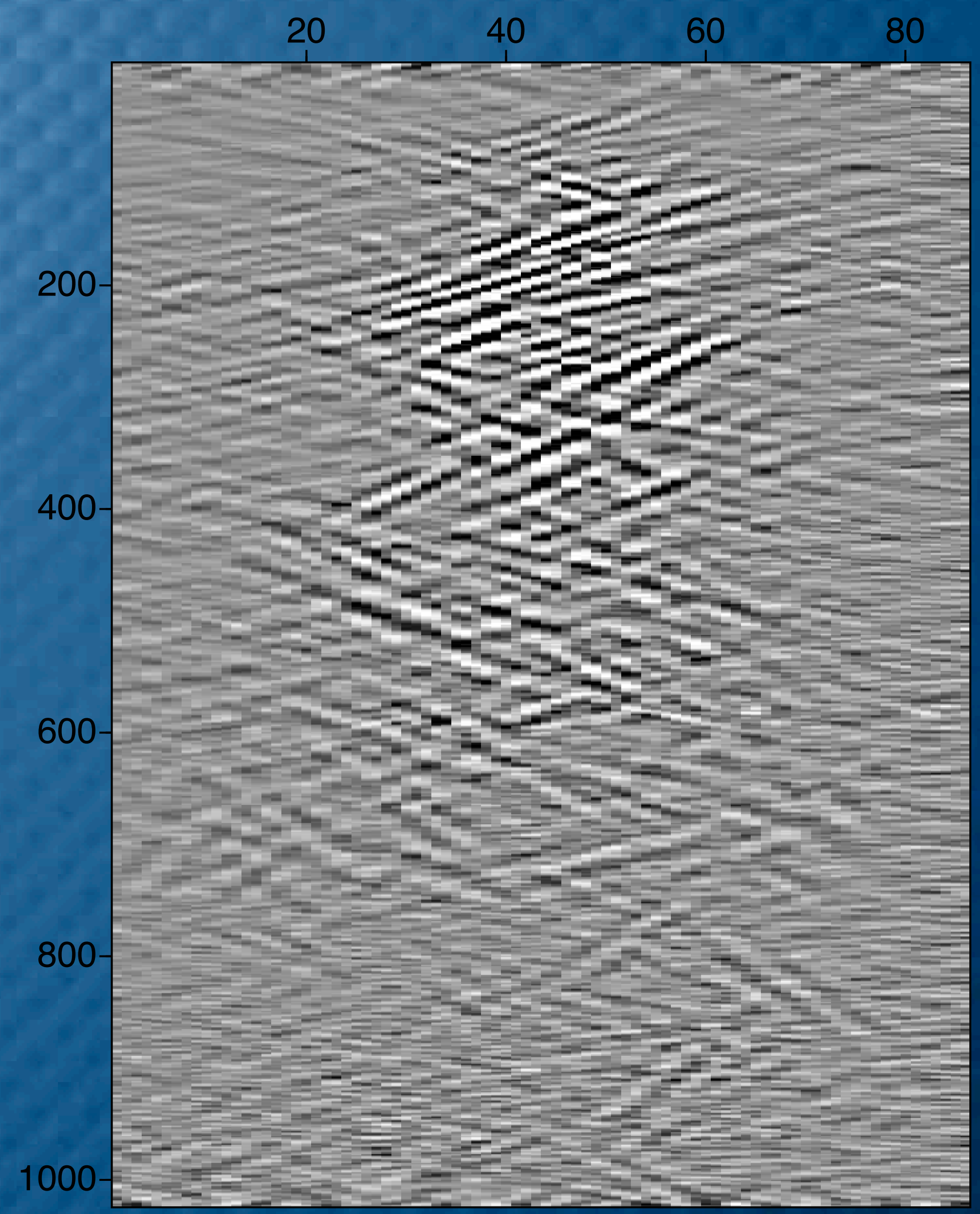
The Difference



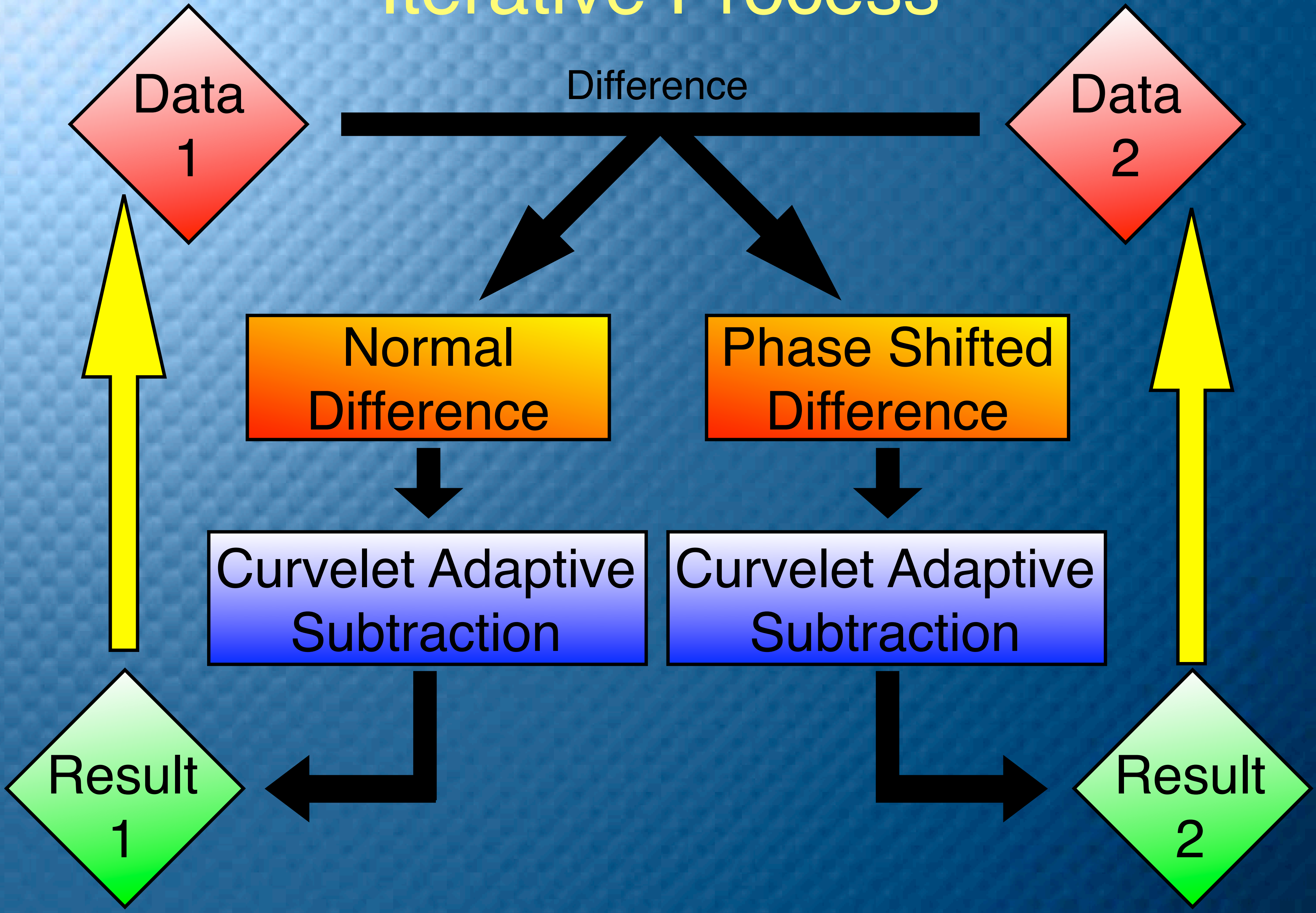
Results Without Phase Shift



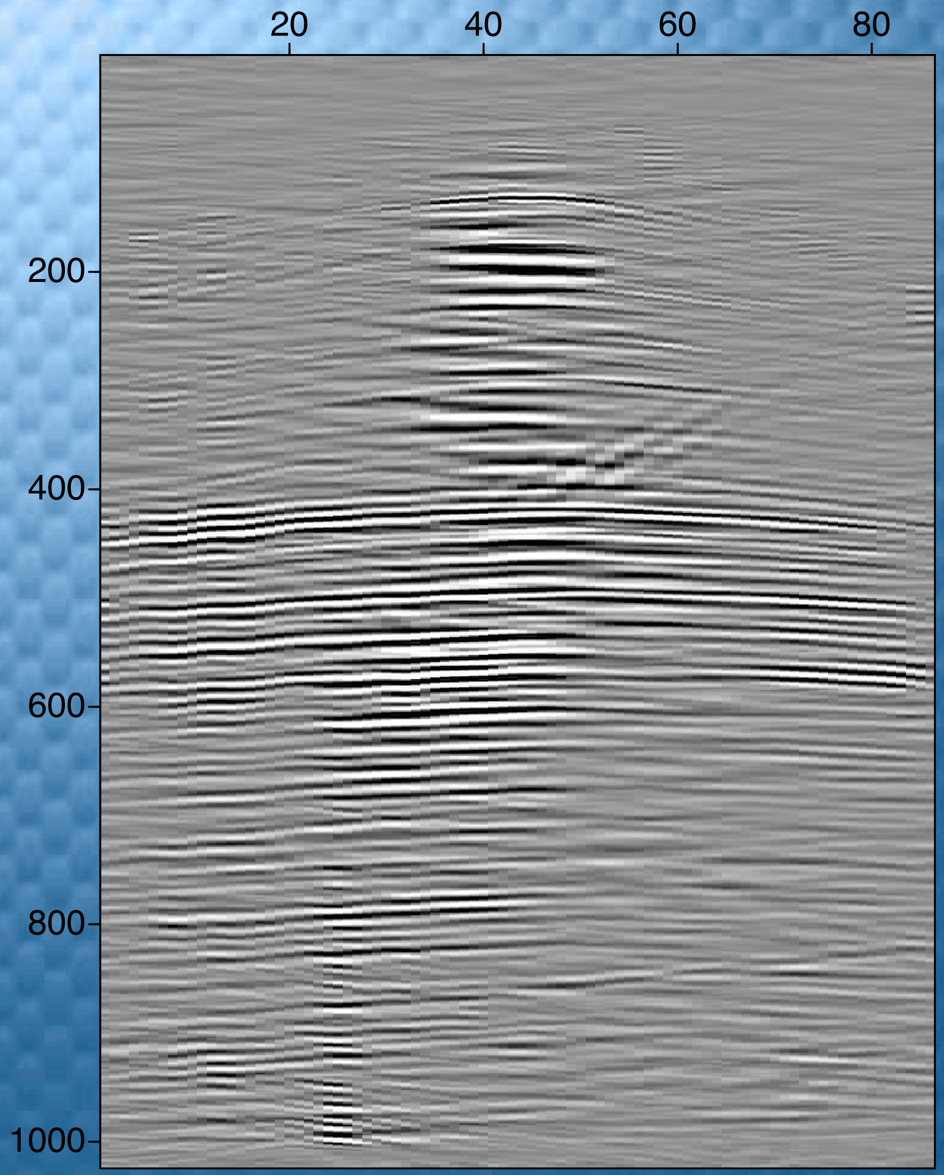
Results With Phase Shift



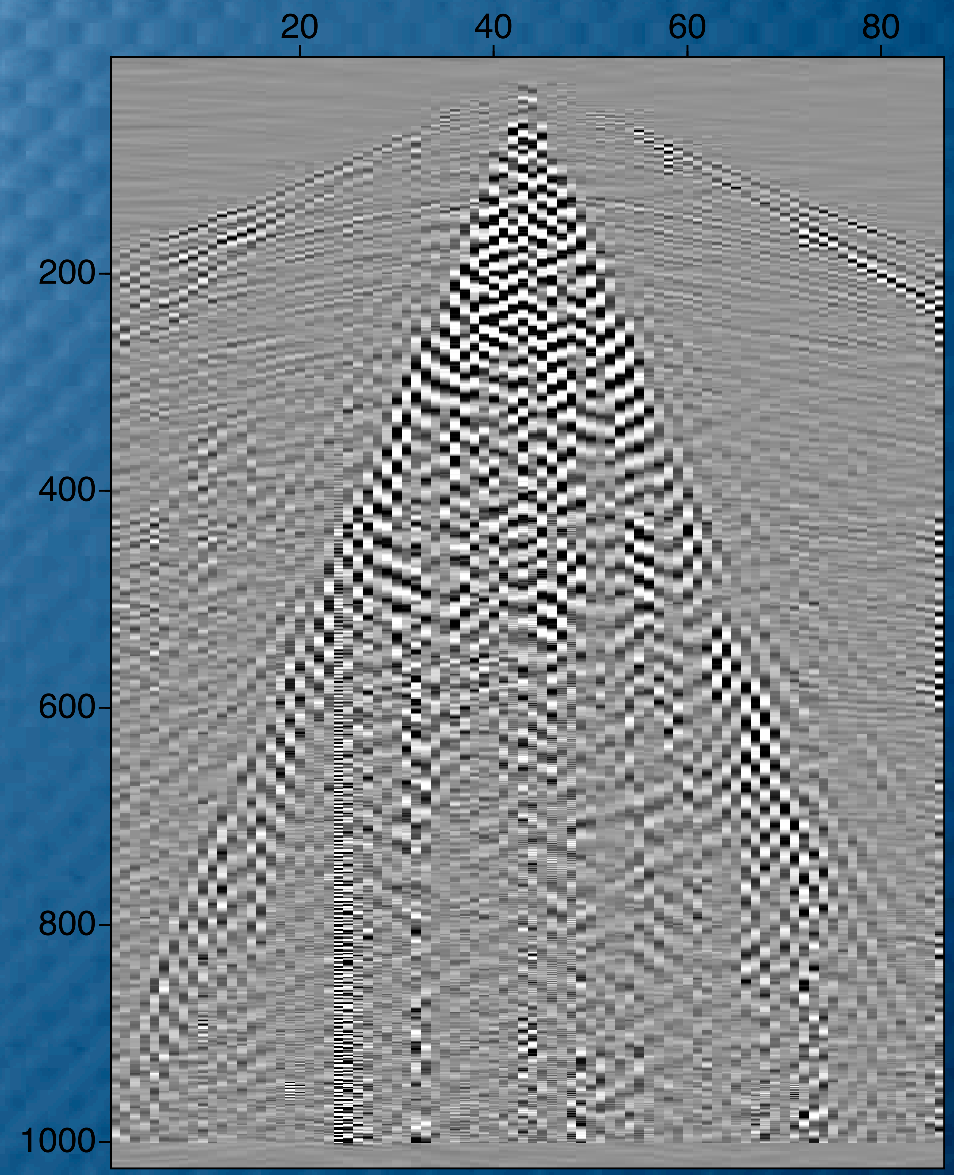
Iterative Process



Iterative Results

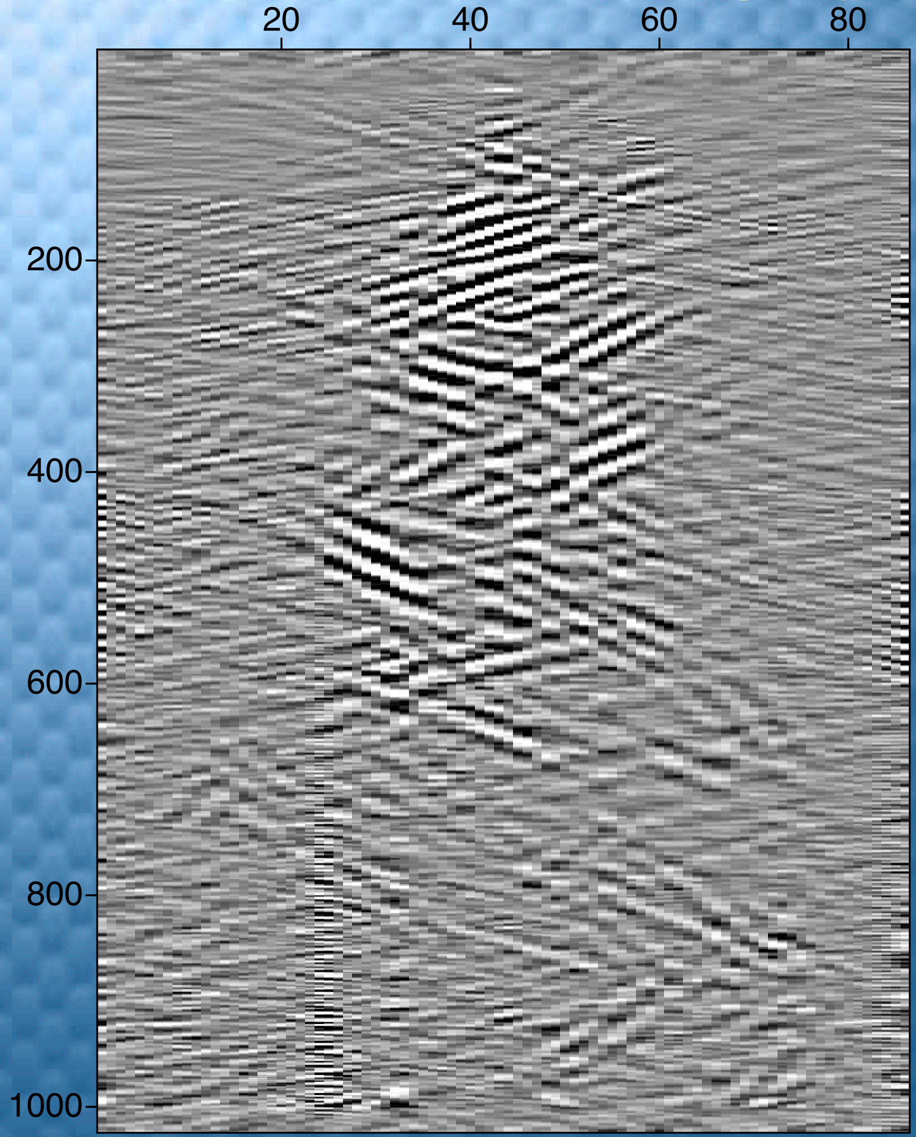


Result After 3 Iterations

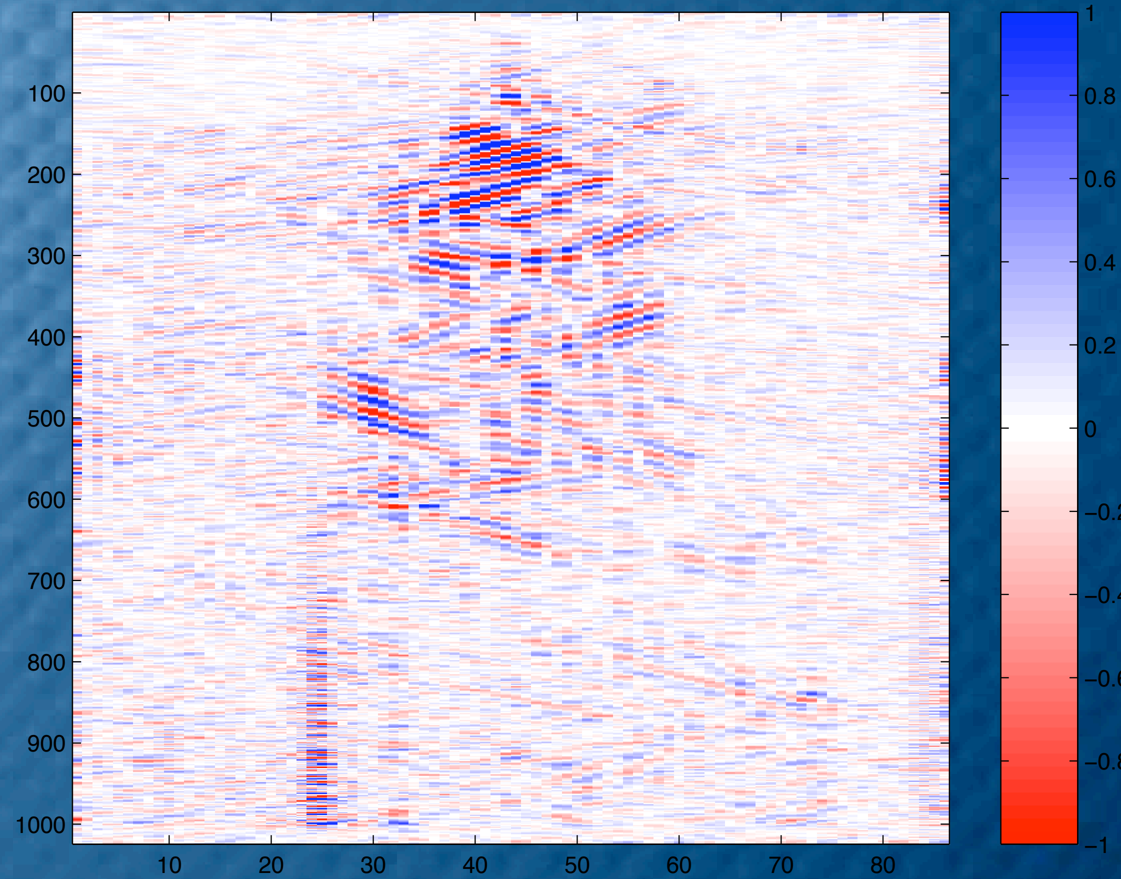


Predicted Noise

Iterative Effects



Difference Between Iterative Result and Initial Result



- Improves Signal to Noise Ratio
- Must Be Careful Not to go to Far!

Conclusions

- Curvelet and Contourlets can be used to effectively remove ground roll
- Adaptive Subtraction works best with the use of high quality noise modeling
- Curvelet flexibility allows for effective adaptive subtraction which is phase independent
- Iterative process can further improve signal to noise ratio