Complex wavelet adaptive multiple subtraction with unary filters

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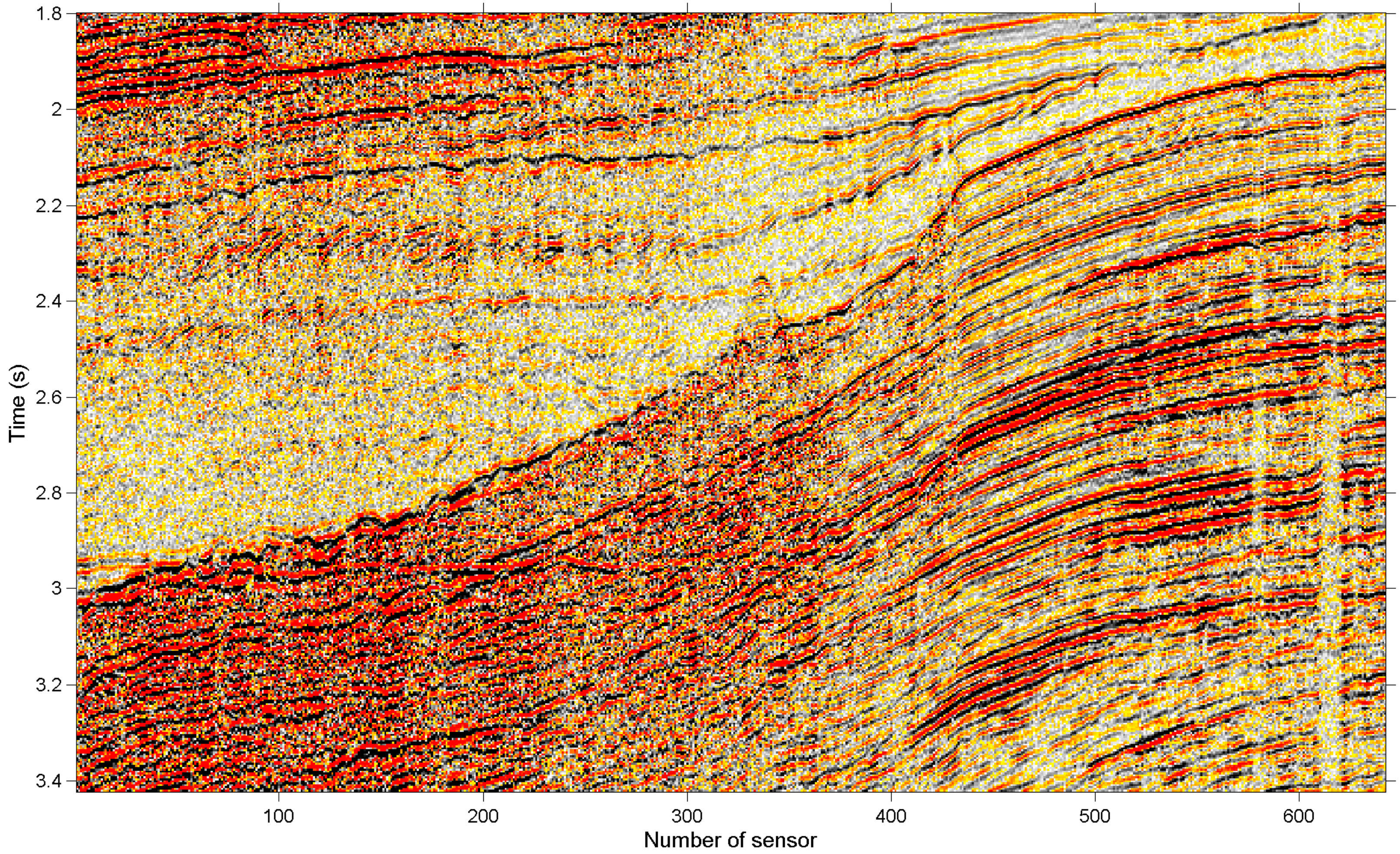
Introduction

- Multiple contamination is one of the greatest challenges in seismic processing (Backus, 1959; Verschuur and Berkhout, 1992; Matson and Dragoset, 2005)
- Multiple recognition - Characteristics
  - Periodicity
  - MoveOut (Velocity and curbature)
- Multiple attenuation methods
  - Filtering methods (Kelamis et al, 2008)
    - Relay on differentiating features
  - Predictive suppression methods (Pica et al, 2005; Dragoset et al, 2010)
    - Relay on prior knowledge to build a multiple model

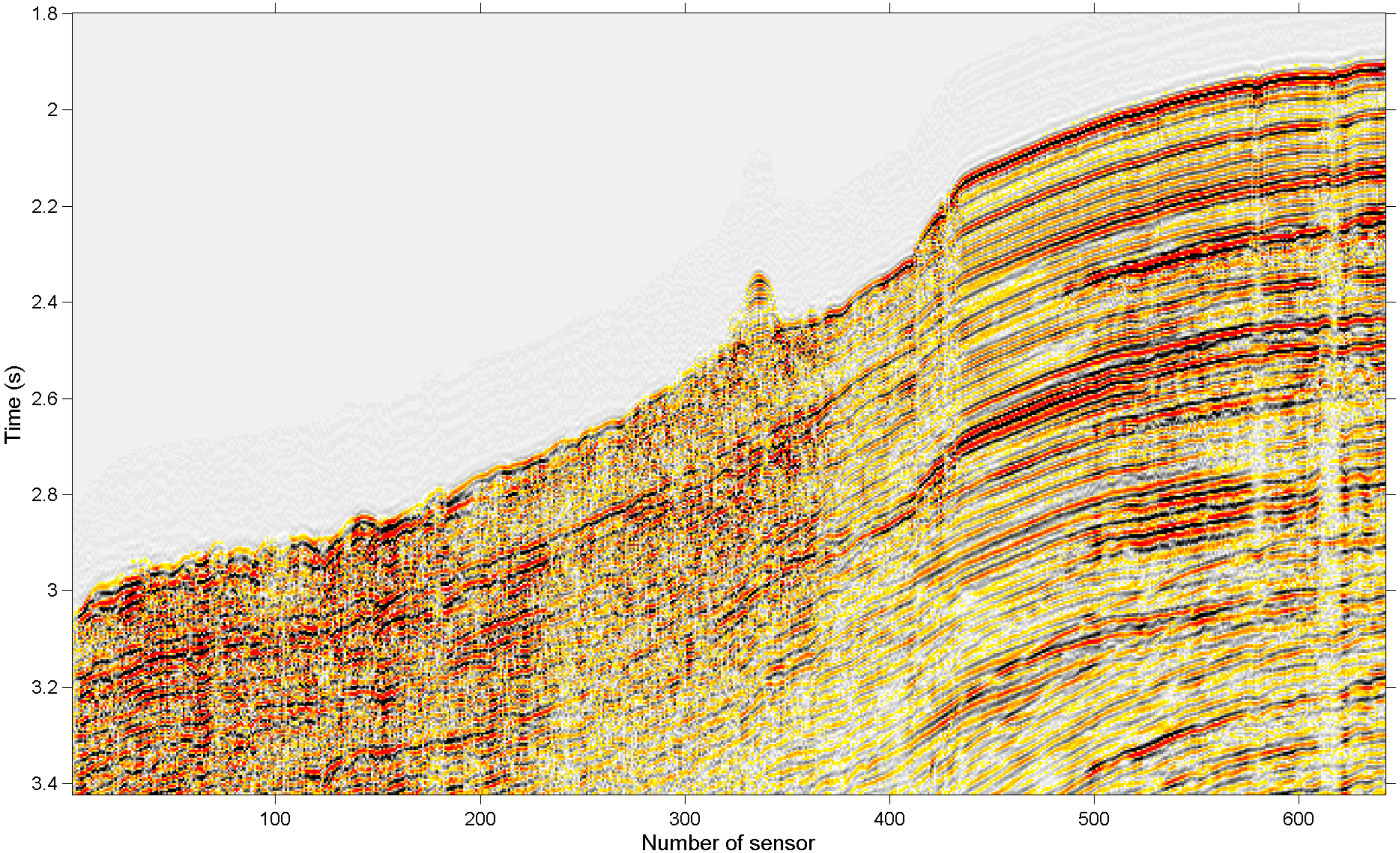
Introduction: Primaries & Multiples

- Original data at near receiver plane (non-stacked)



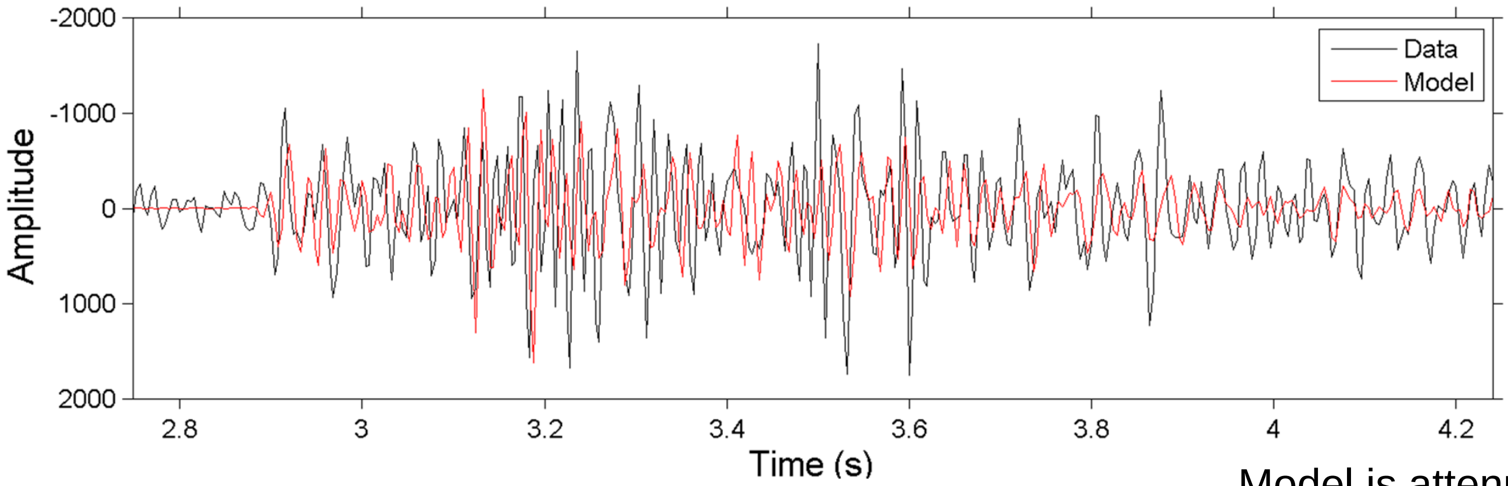
Introduction: Multiple model

- The model is not accurate enough for a plain subtraction.



Introduction: Data & Multiple model

- A piece of the 100th trace



Model is attenuated by a constant factor

- The multiple prediction method has limitations that lead to imperfect multiple models.
  - An adaptive subtraction algorithm is needed.

Introduction: Adaptive subtraction

- Main challenges:
  - Primaries and multiple are not fully uncorrellated, as they are generated from the same source.
  - The variations on amplitude, waveform and delay impose strong constraints on the minimum filter length.
- Standard approaches:
  - Minimum l_2-norm:
    - A long global filter to compensate systematic differences.
    - A short local filter to compensate the differences that remains.
- Other approaches:
  - Minimum l_1-norm (Guitton and Verschuur, 2004)
  - Work in a tranformed domain.

Outline

- Introduction
- Complex wavelet adaptive multiple subtraction with unary filters
  - CWT: Implementation
  - Amplitude and phase estimation
  - Integer delay estimation
- Adaptive subtraction algorithm results

Complex wavelet adaptive unary filters

- Main objective
  - Decompose a complicate wide-band problem into a set of more tractable narrow-band problems.
- Main properties
  - Controlled redundancy with frames of wavelets.
  - Simplifies the filter design:
    - Enables the reduction of the filter length up to a single sample.
  - Increase the adaptation capability.

Complex wavelet adaptive unary filters

- CWT implementation using frames of wavelet
  - Family of functions

$$\psi_{r,j,v}[n] = \frac{1}{\sqrt{2^{j+v/V}}}\psi\left(\frac{nT - r2^j b_0}{2^{j+v/V}}\right)$$

Delay

Scaling

  - Frames of wavelets transform

$$Wd_{j,v}[r] = \langle d[n], \psi_{r,j.v}[n]\rangle = \sum_n d[n]\psi^*_{r,j.v}[n]$$

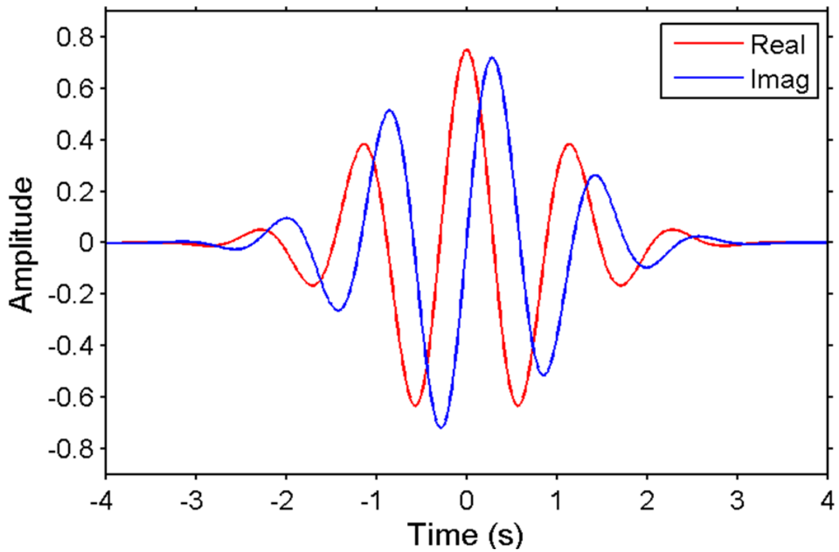
  - Complex Morlet Wavelet

Gaussian

$$\psi(t) = \pi^{-1/4} e^{-j\omega_0 t} e^{-t^2/2}$$

Modulation

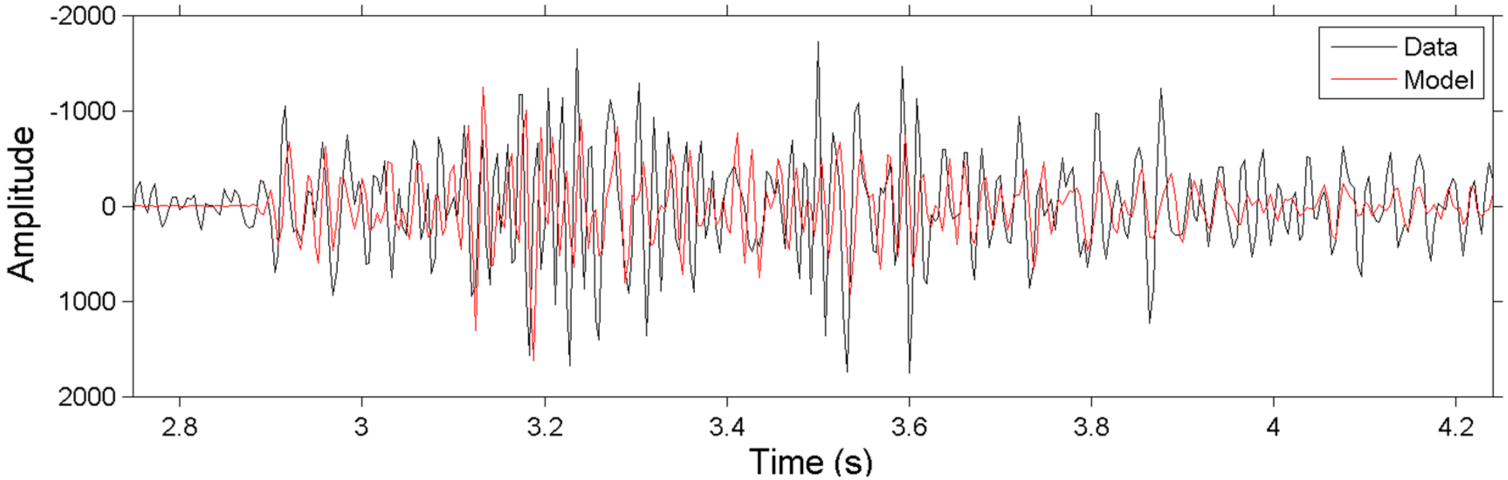
$$\omega_0 = \pi\sqrt{2/\ln(2)}$$
$$Q = 2.27$$



Complex wavelet adaptive unary filters

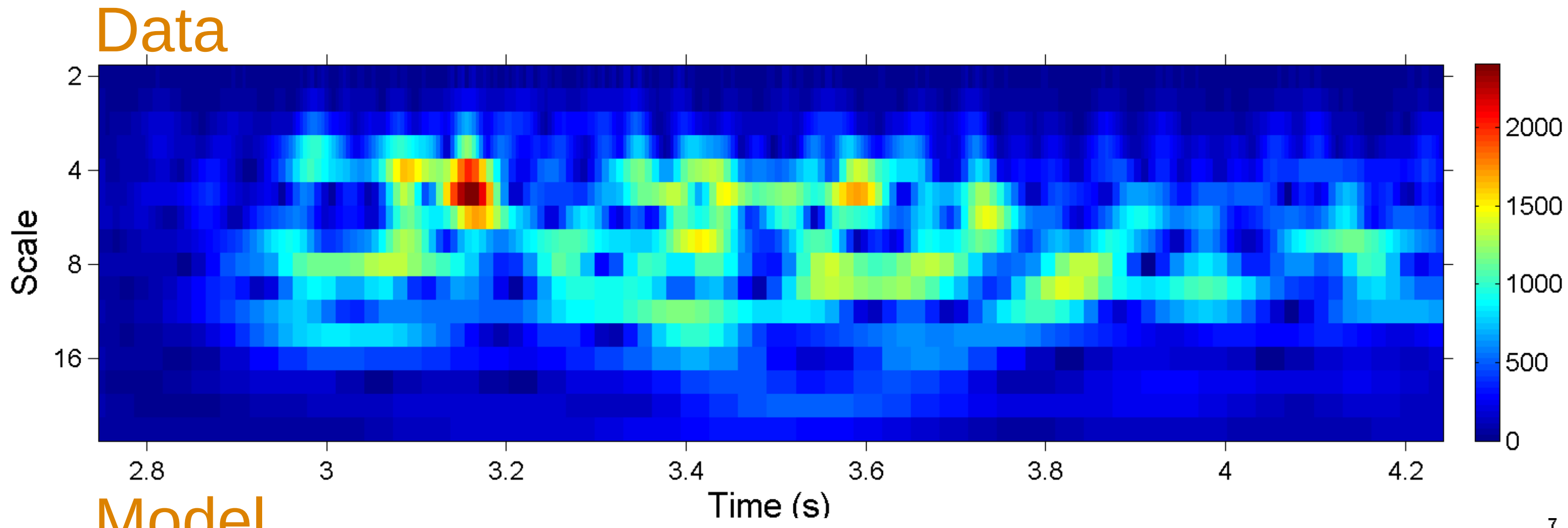
CWT: Implementation

Data and Model

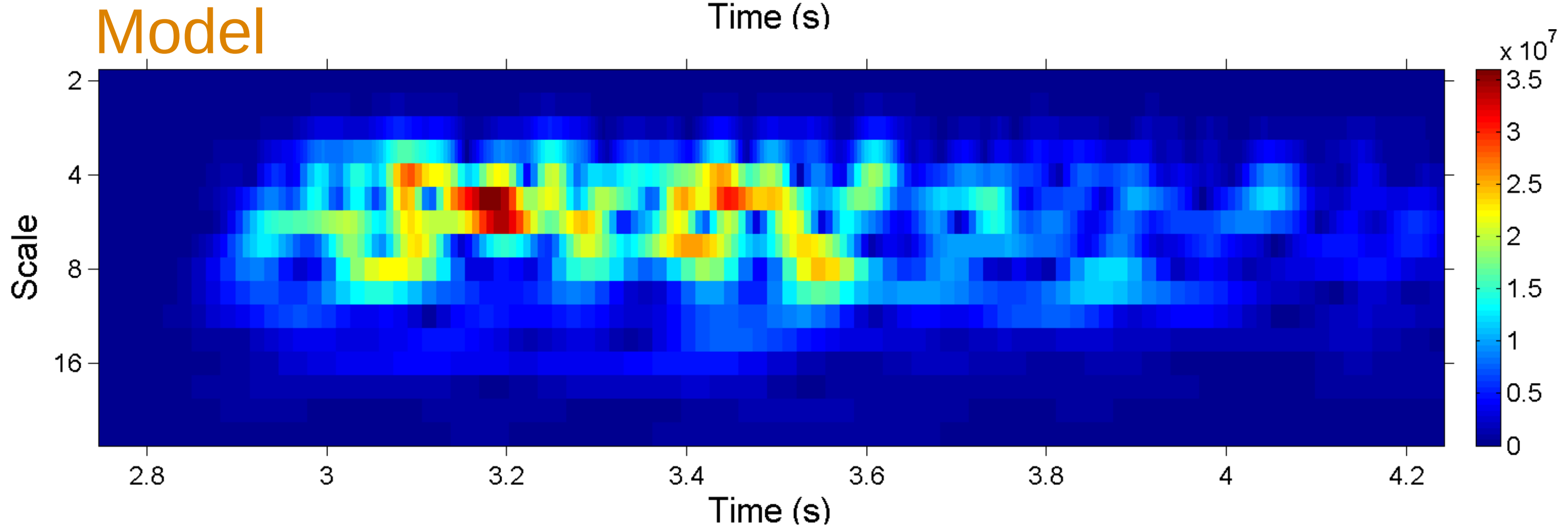


- Main parameters of the CWT
  - Central freq. of the Morlet wavelet: 2π (Q = 2.7)
  - Mid redundancy, 4 voices/octave + complex (8 times the DWT).

CWT: Example



Data
2
4
8
16
Scale
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Time (s)
2000
1500
1000
500
0



Model
2
4
8
16
Scale
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Time (s)
x 10^7
3.5
3
2.5
2
1.5
1
0.5
0

Amplitude and phase estimation

- Main assumptions:
  - Small delay (less than the half of the period)
  - Minimum energy approach
- Problem to solve <u>for each sample in time-scale</u>
  - Find the optimum value that multiplied with the model minimize the square mean error with the data

Value to estimate

Data

Model

$$a_{\text{opt}} = \arg\min_a \xi(a) = \arg\min_a \|\mathbf{d} - a\mathbf{x}\|^2$$

- Solution

$$a_{\text{opt}} = \frac{\langle \mathbf{d}, \mathbf{x} \rangle}{\|\mathbf{x}\|^2}$$

Optimum unary Wiener filter for complex signals

Integer delay estimation

- Main challenge
  - What can we do when the delay is higher than the half of period of the central frequency?
- One solution
  - Design an unary complex filter with an integer delay.

$$\xi(a,l) = \sum_r |Wd_{j,v}[r] - a_{j,v}Wx_{j,v}[r-l]|^2 = \|\mathbf{d} - a\mathbf{x}_l\|^2$$

$$a_{\text{opt}}[l] = \frac{\langle \mathbf{d}, \mathbf{x}_l \rangle}{\|\mathbf{x}_l\|^2}$$

Integer delay
(new parameter)

- Problem to solve:
  - Find a criterion to select the optimum delay well adapted to the nature of the seismic signals

Integer delay estimation

- Criteria to select the optimum integer delay:
  - Option 1: Minimum mean square error

$$l_{\mathrm{opt}} = \arg\min_{l} \xi(a_{\mathrm{opt}}[l])$$

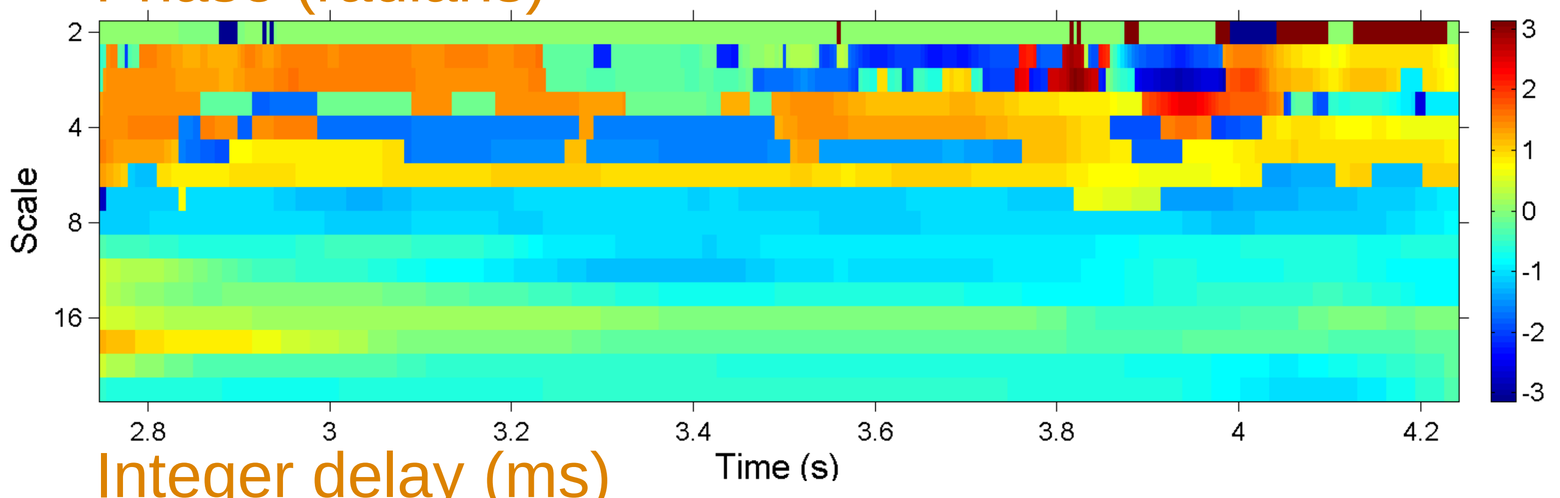
  - Option 2: Maximum normalized crosscorrelation (coherence)
    - Give importance to the waveform over the amplitude

Data Corrected multiples

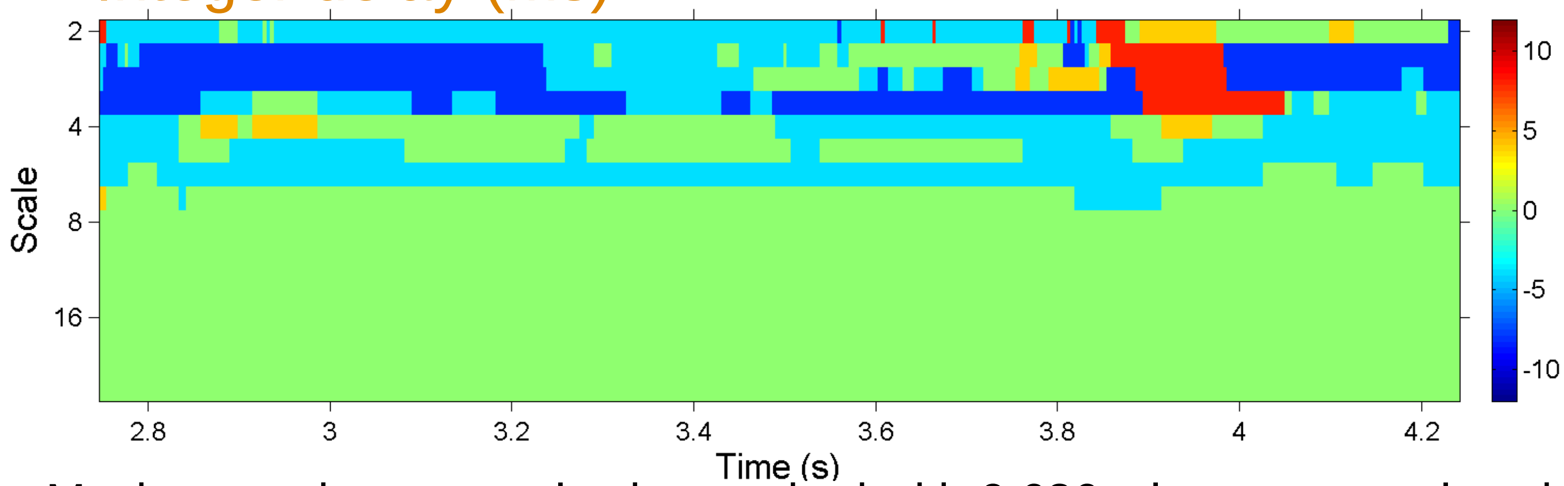
$$l_{\mathrm{opt}} = \arg\max_{l} \ \mathrm{Re}\left[\frac{\langle \mathbf{d}, a_{\mathrm{opt}}[l]\mathbf{x}_l \rangle}{\|\mathbf{d}\| \, \|a_{\mathrm{opt}}[l]\mathbf{x}_l\|}\right]$$

Integer delay estimation

Phase (radians)



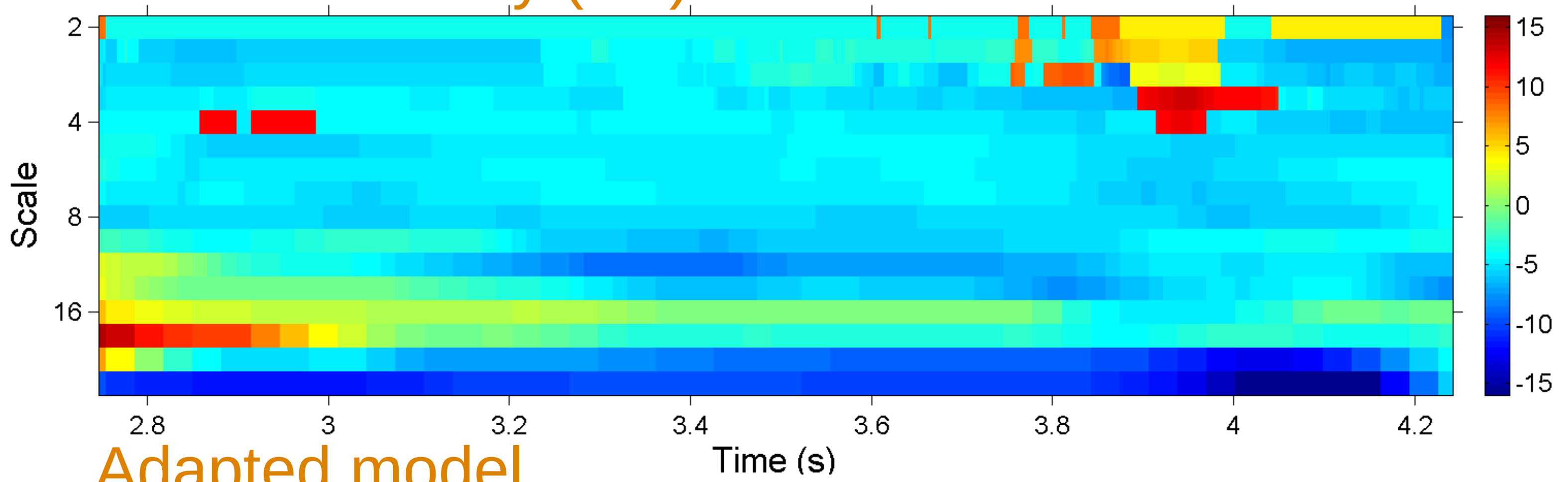
Integer delay (ms)



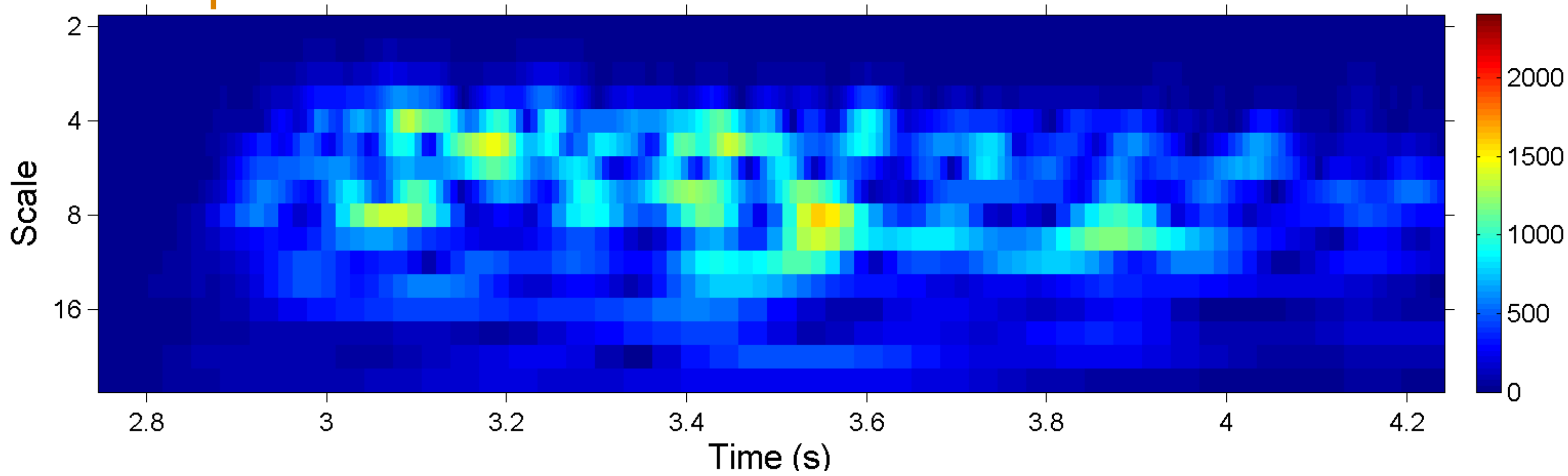
Maximum coherence selection method with 0,636 s long rectangular windows

Integer delay estimation

Fractional delay (ms)

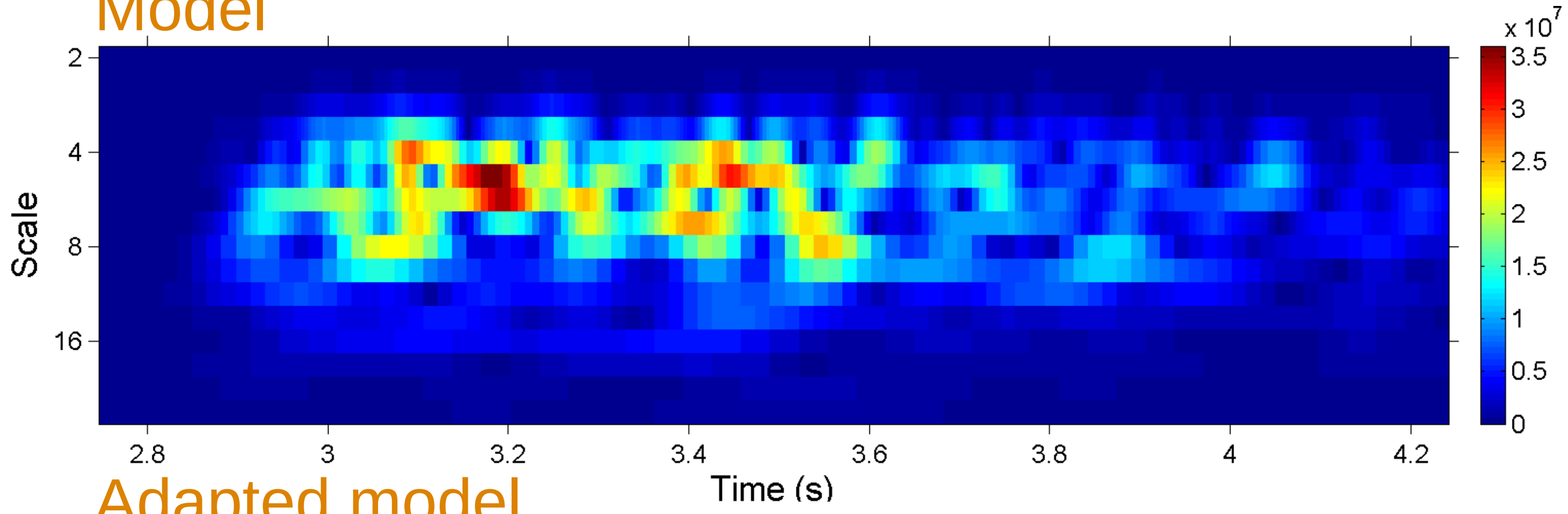


Adapted model



Integer delay estimation

Model



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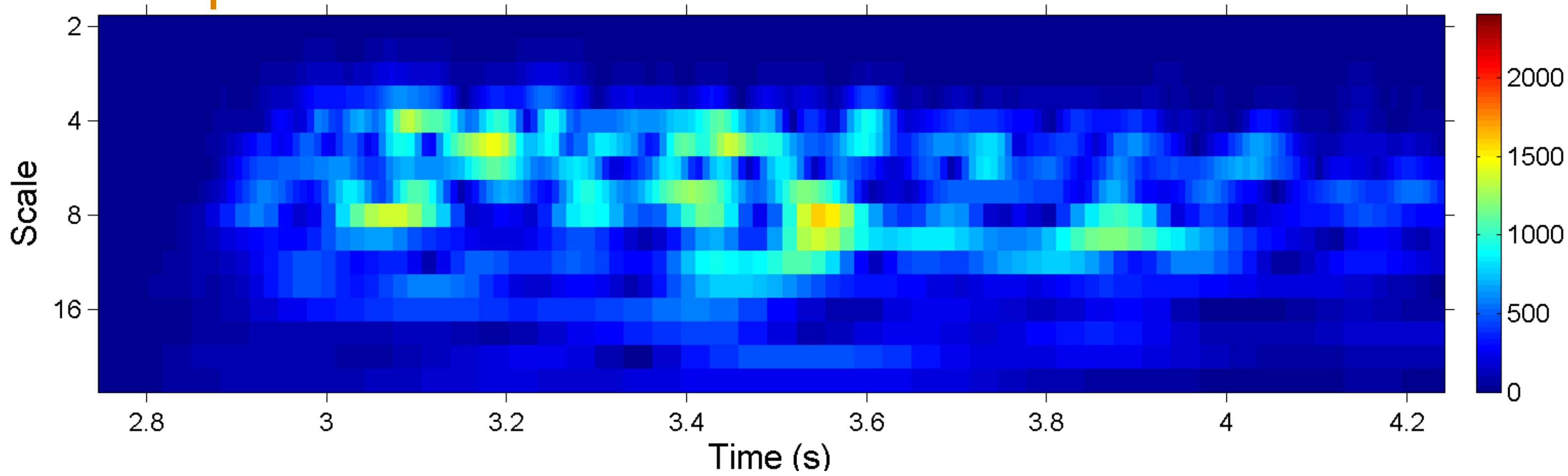
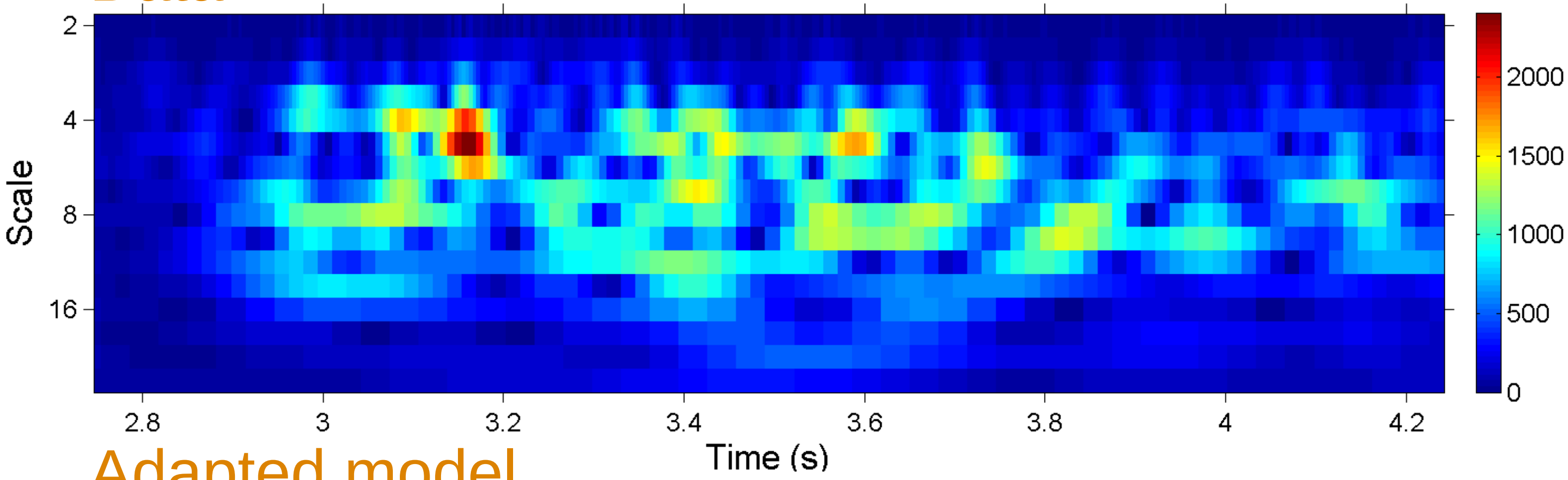


Integer delay estimation

Data



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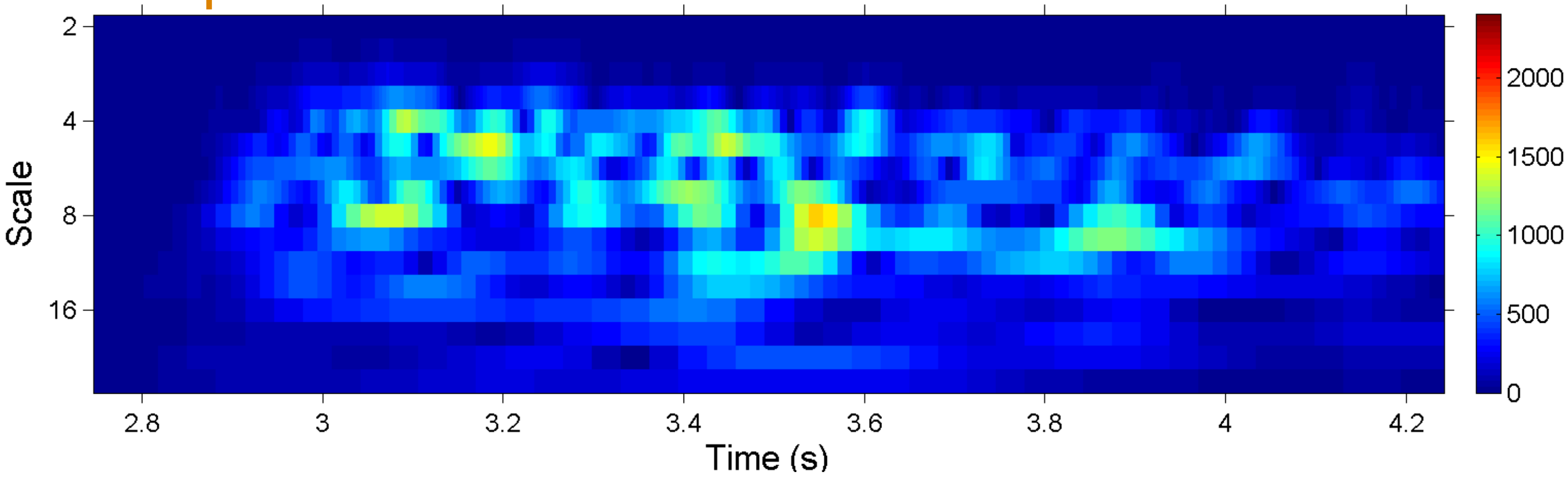
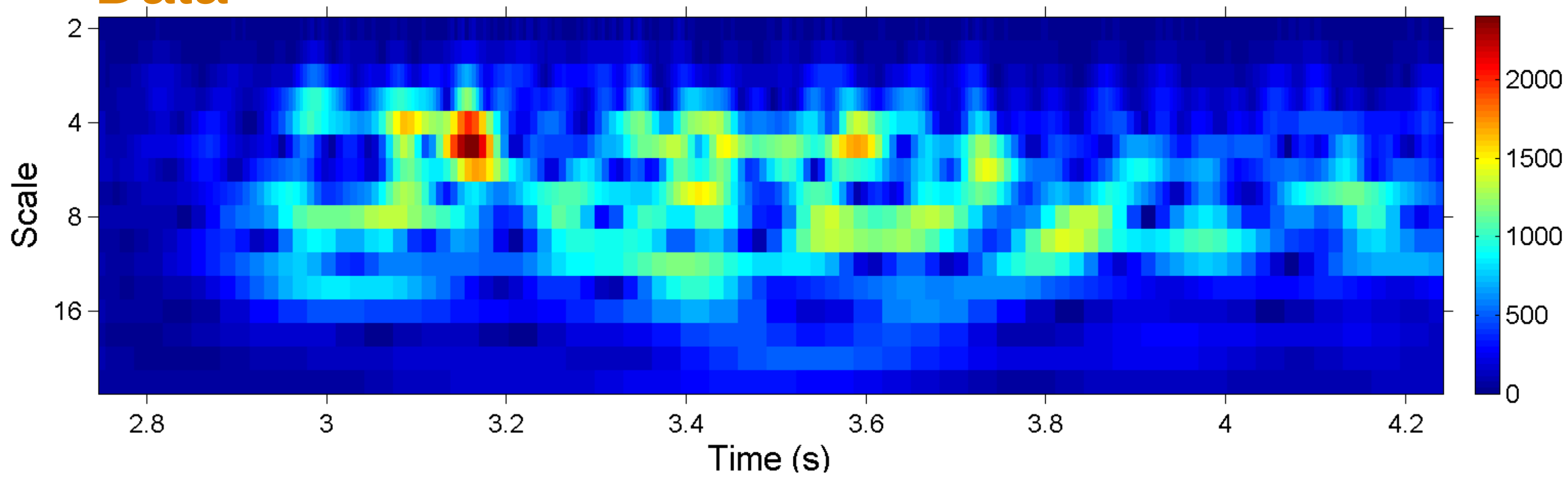
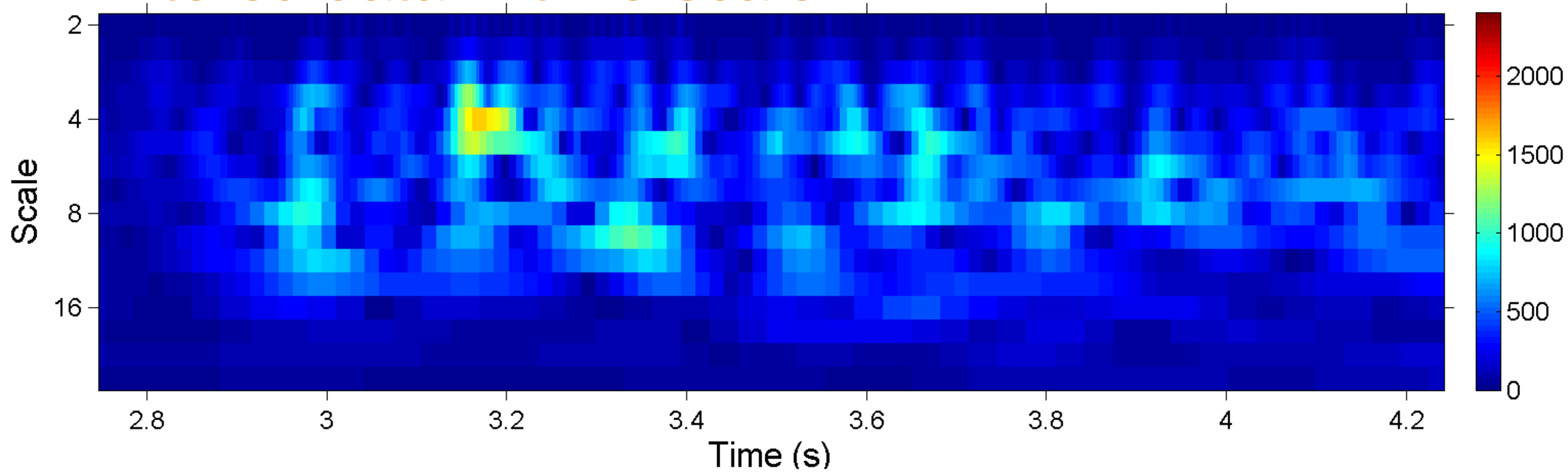


Integer delay estimation

Data

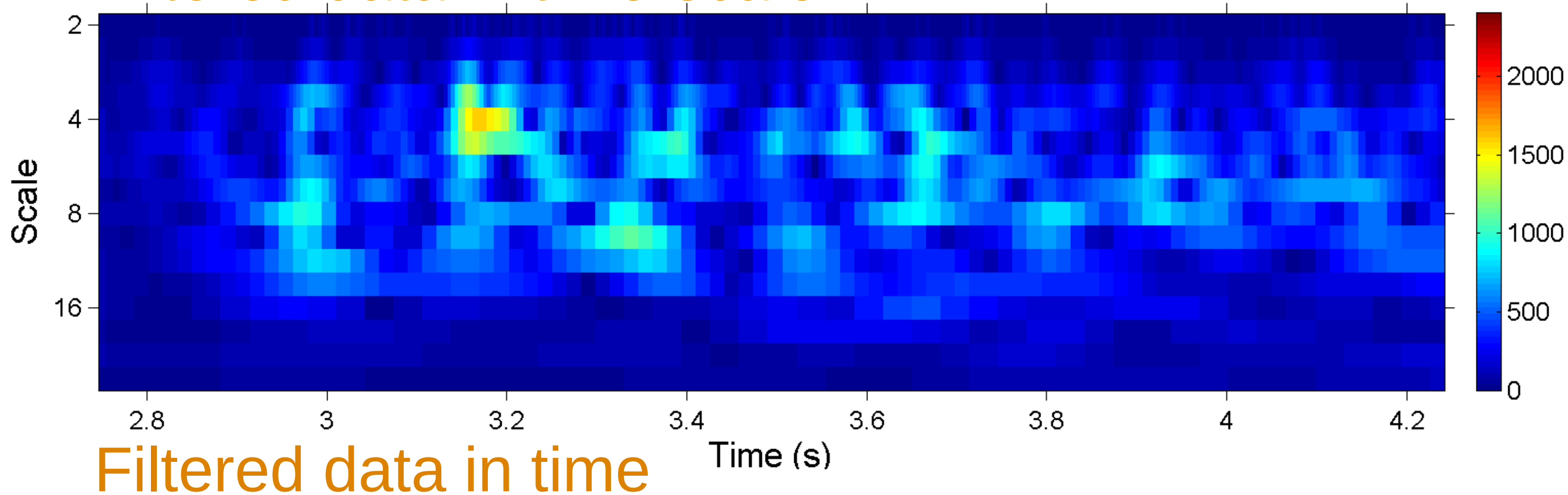


Filtered data in time-scale

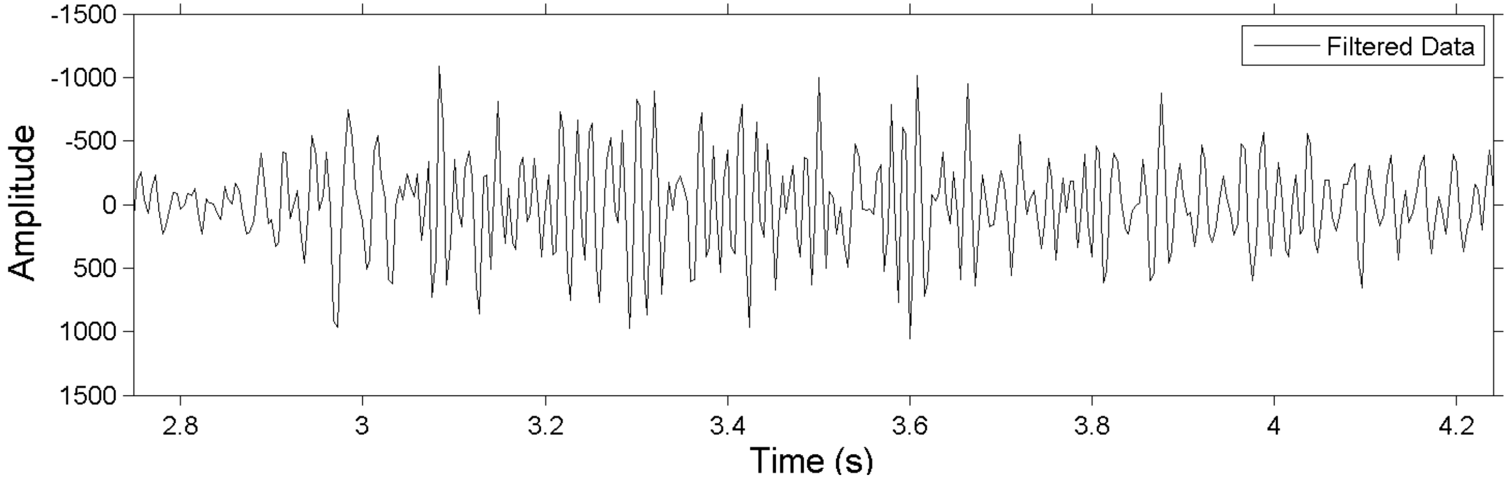


Integer delay estimation

Filtered data in time-scale

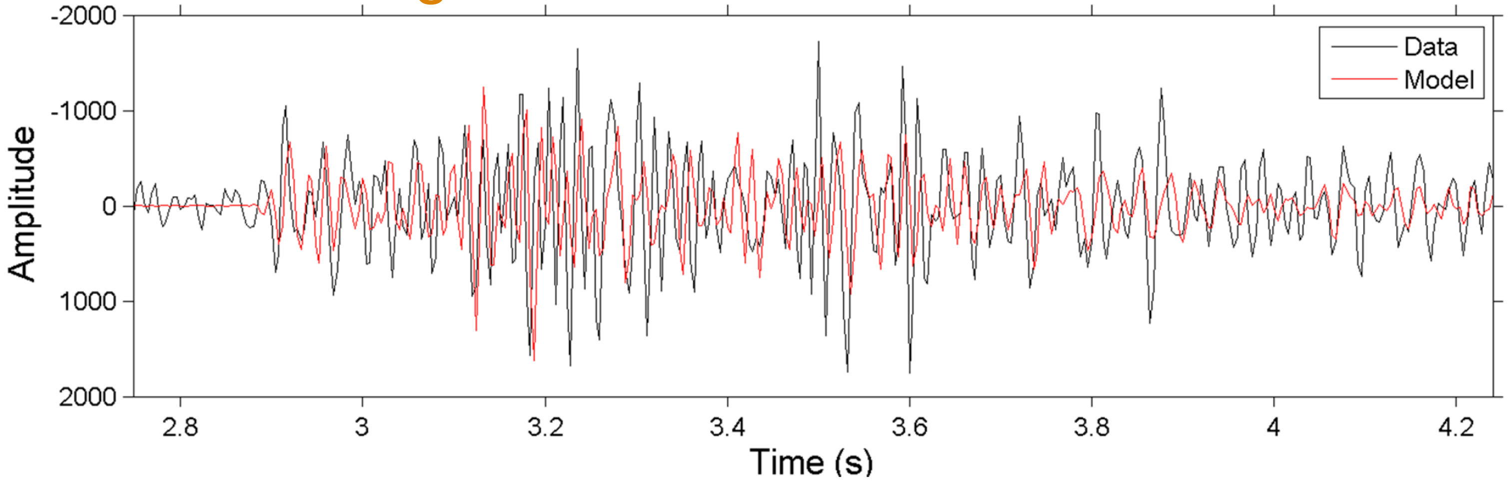


Filtered data in time

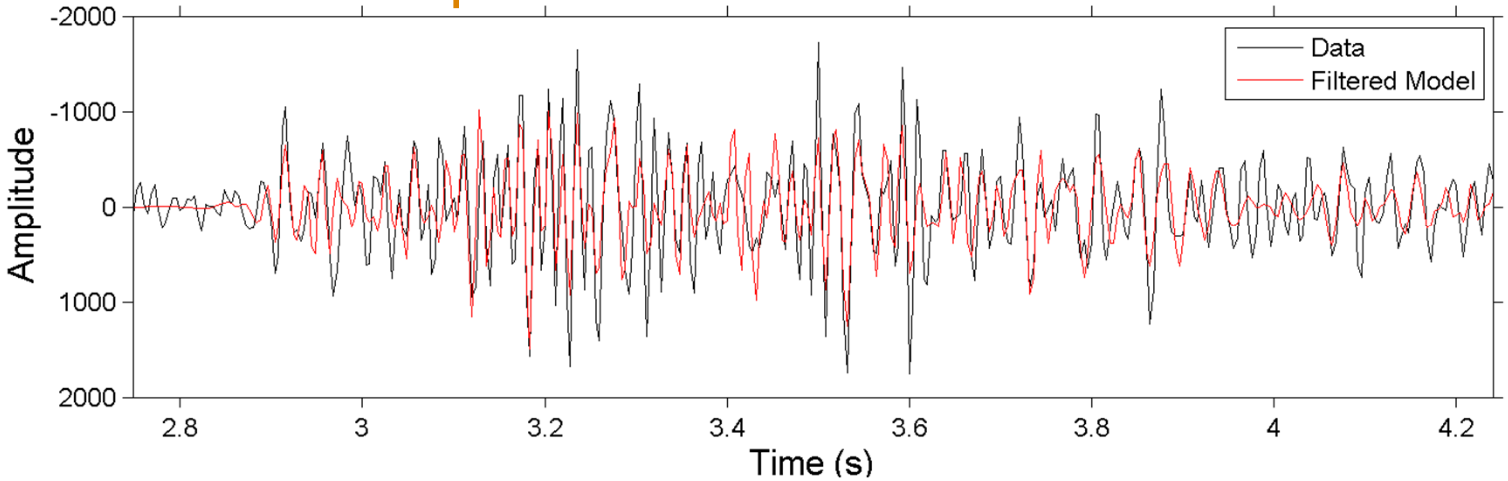


Integer delay estimation

Data & original model

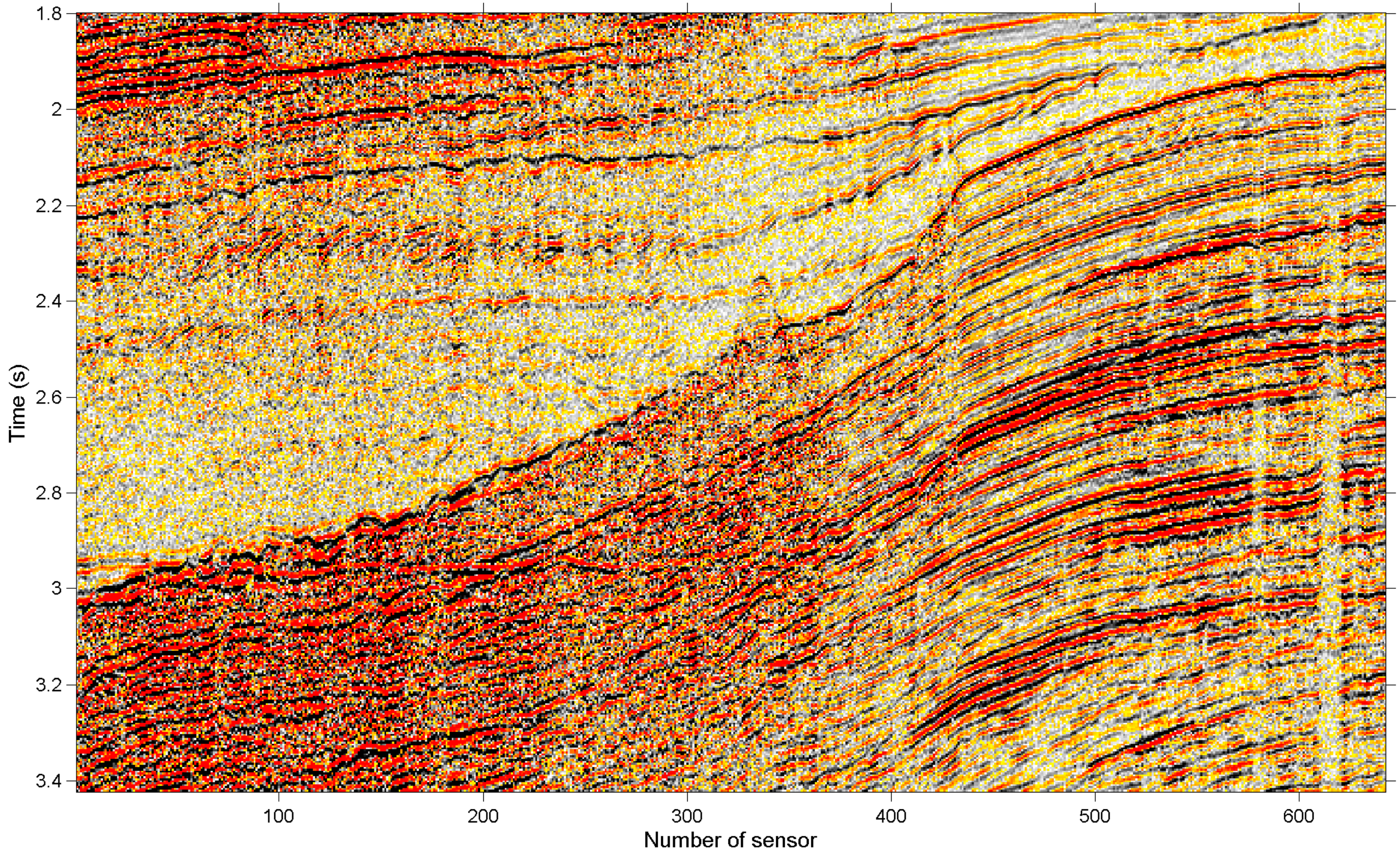


Data & adapted model



Subtraction algorithm results: Original data

- Near receiver plane.



Subtraction algorithm results: Multiple model

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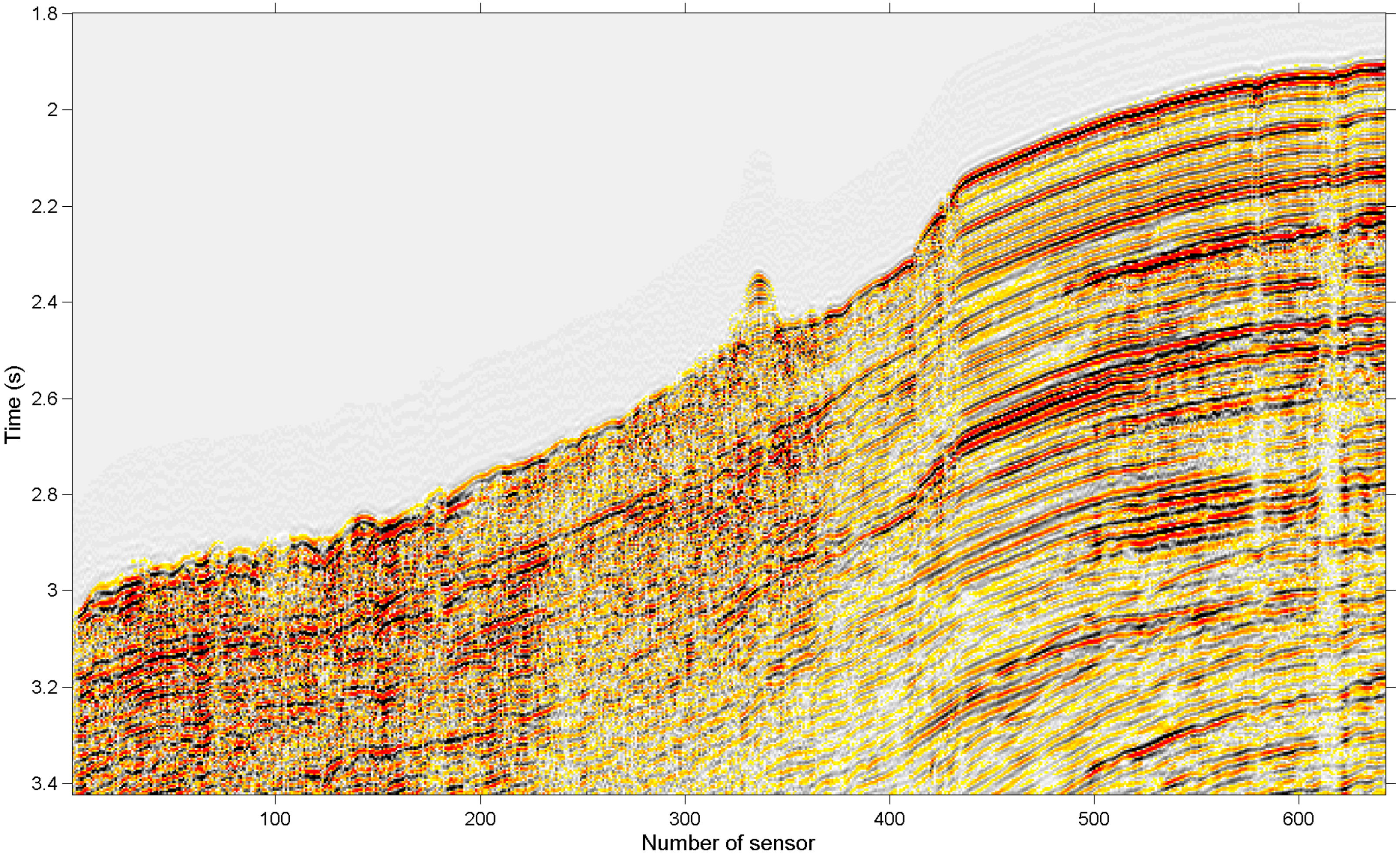
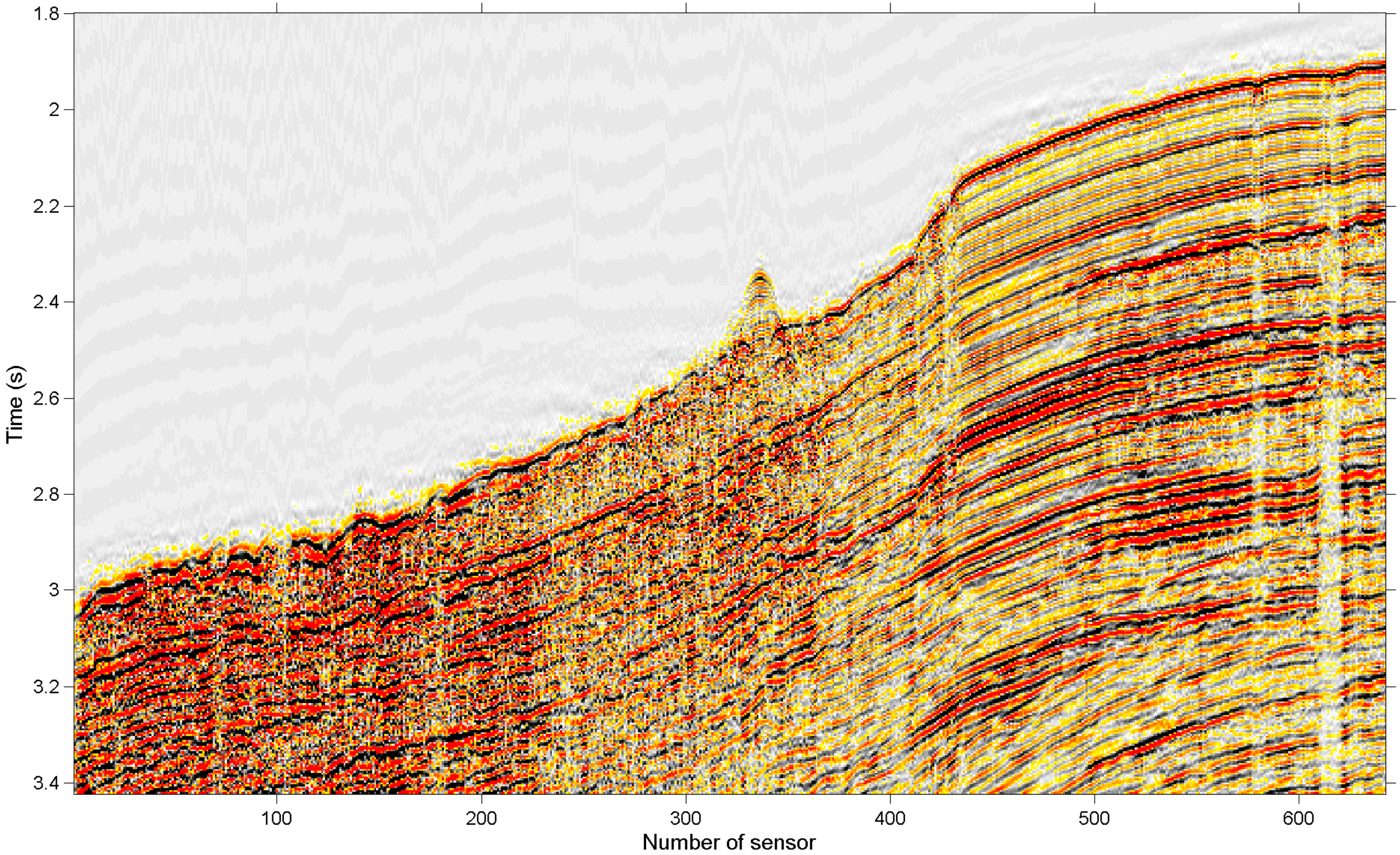


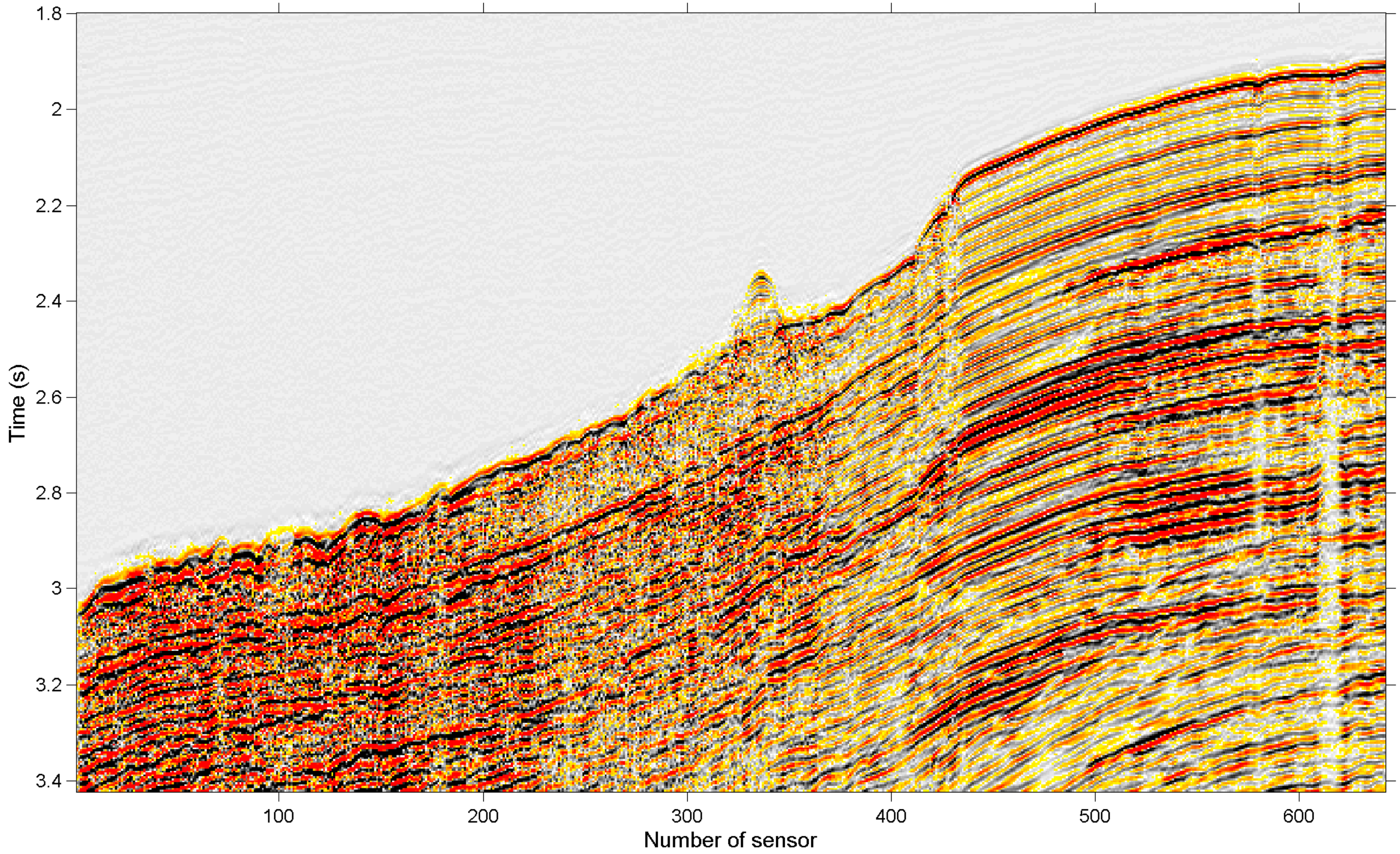
Subtraction algorithm results: Receiver plane

- Adapted model with the 1-D adaptive unary filter.



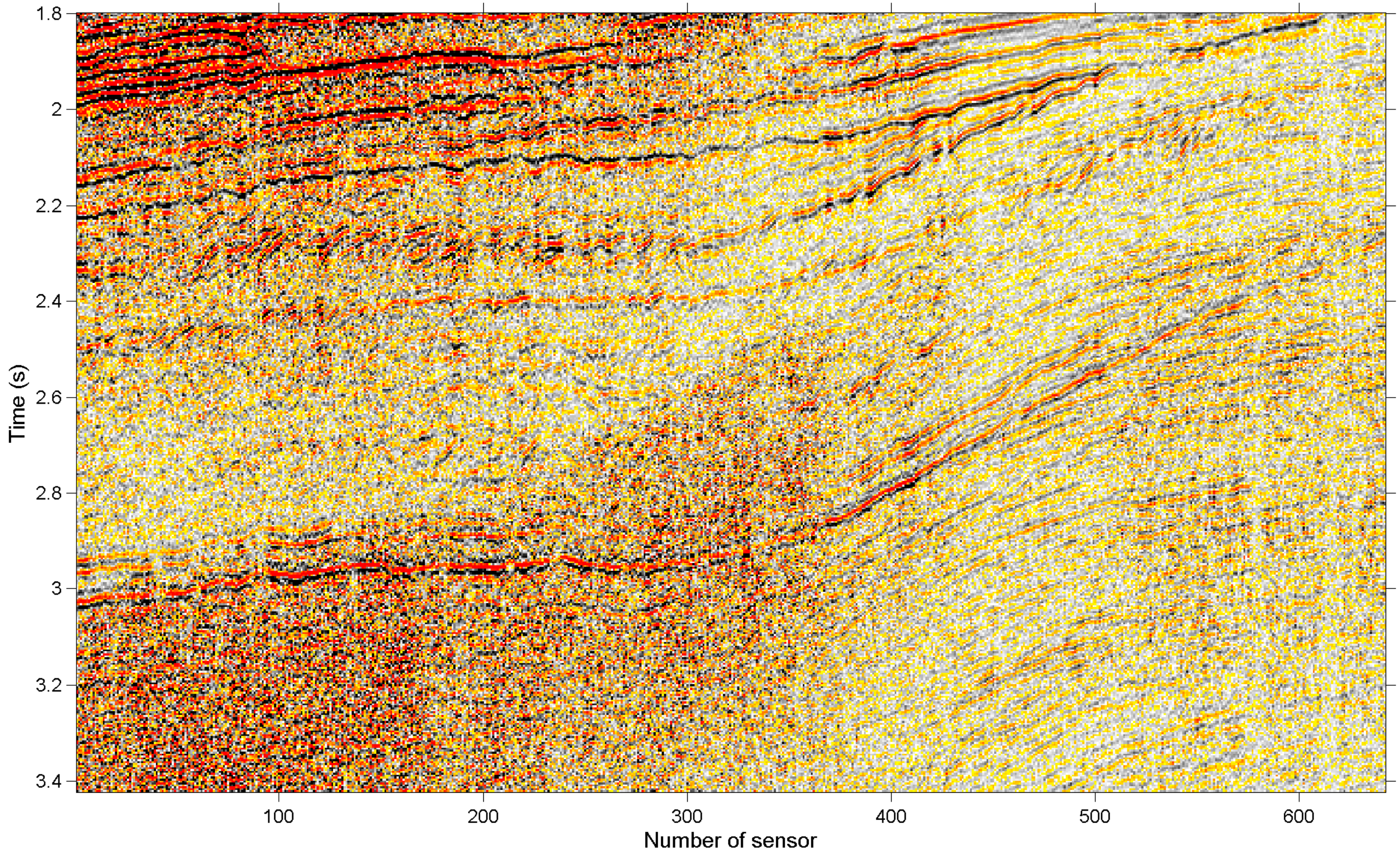
Subtraction algorithm results: Receiver plane

- Adapted model with the standard 2-D adaptive filter



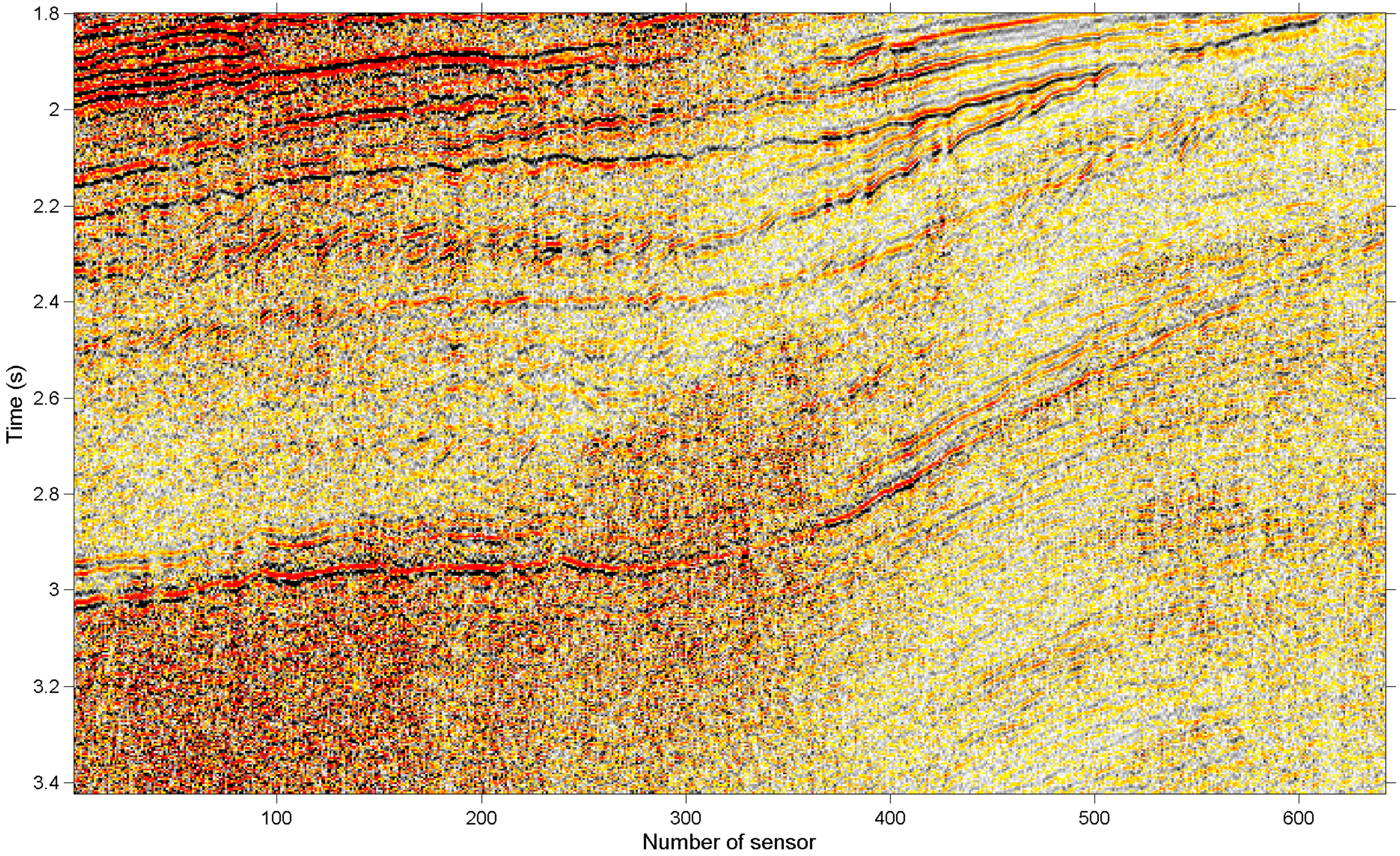
Subtraction algorithm results: Receiver plane

- Results with the 1-D adaptive unary filter in time-scale.



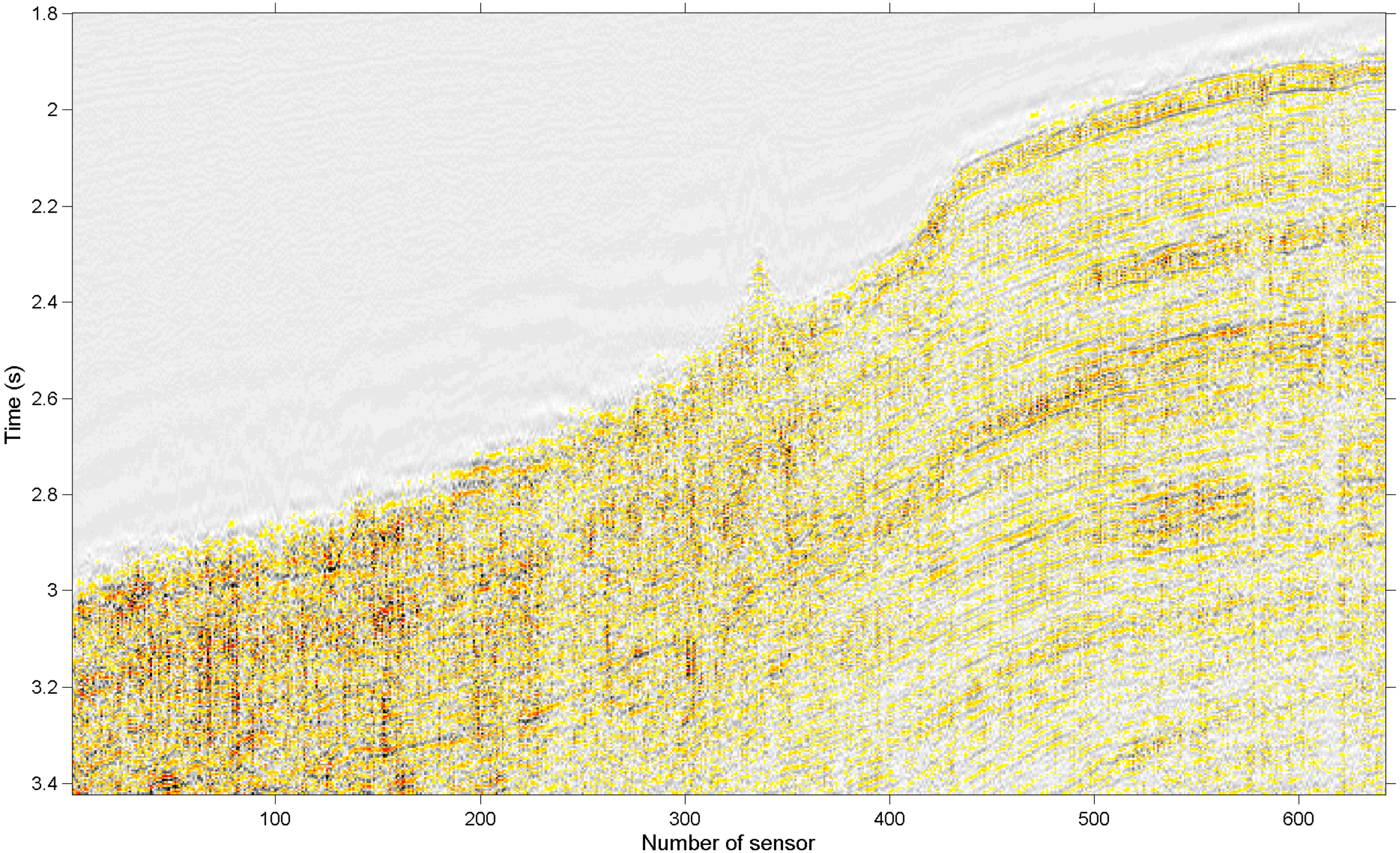
Subtraction algorithm results: Receiver plane

- Results with the standard 2-D adaptive filter

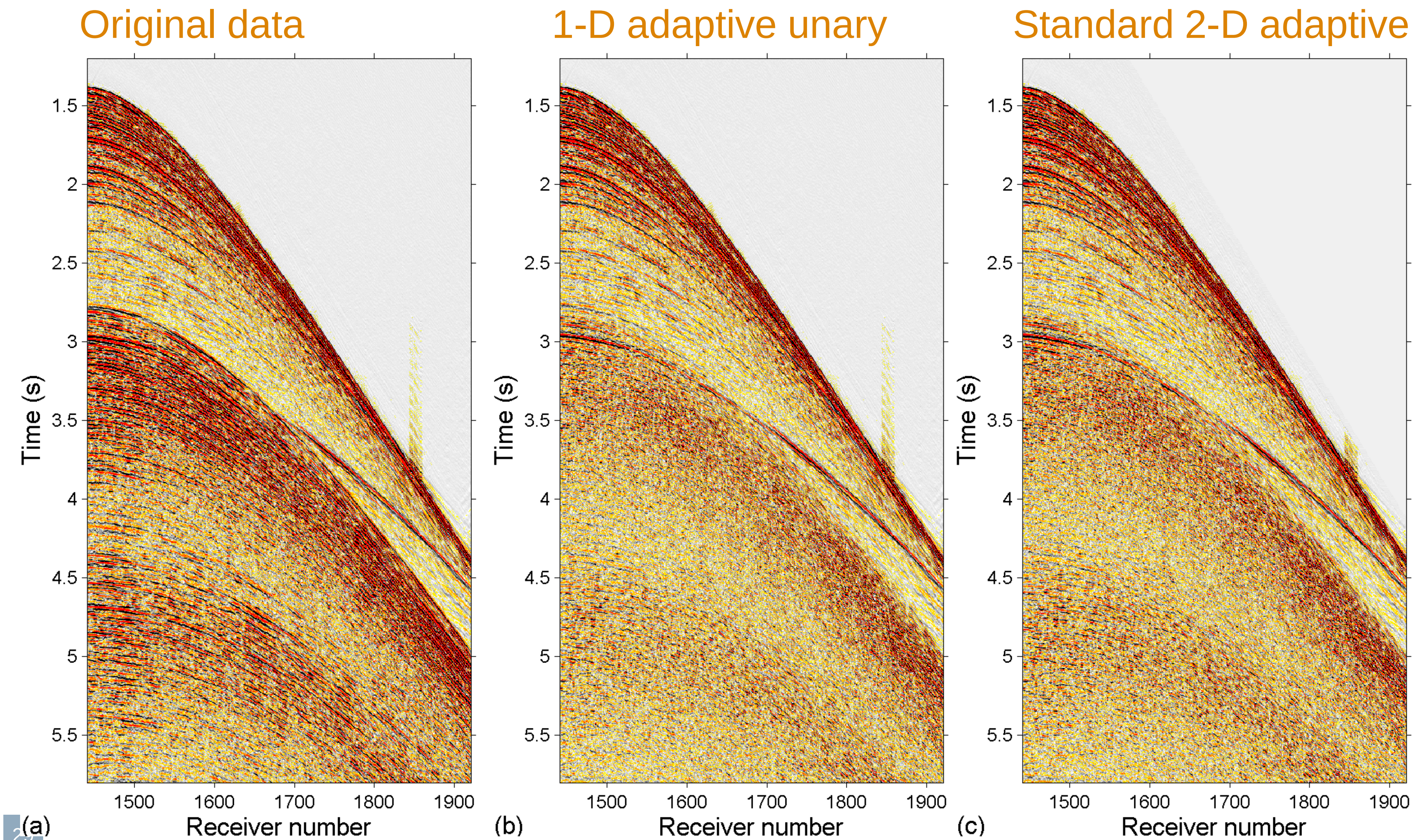


Subtraction algorithm results: Receiver plane

- Difference



Subtraction algorithm results: Shot plane



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