RESERVOIR CHARACTERIZATION PROJECT

Seismic Deblending: an Experiment with an Offshore Seismic Acquisition

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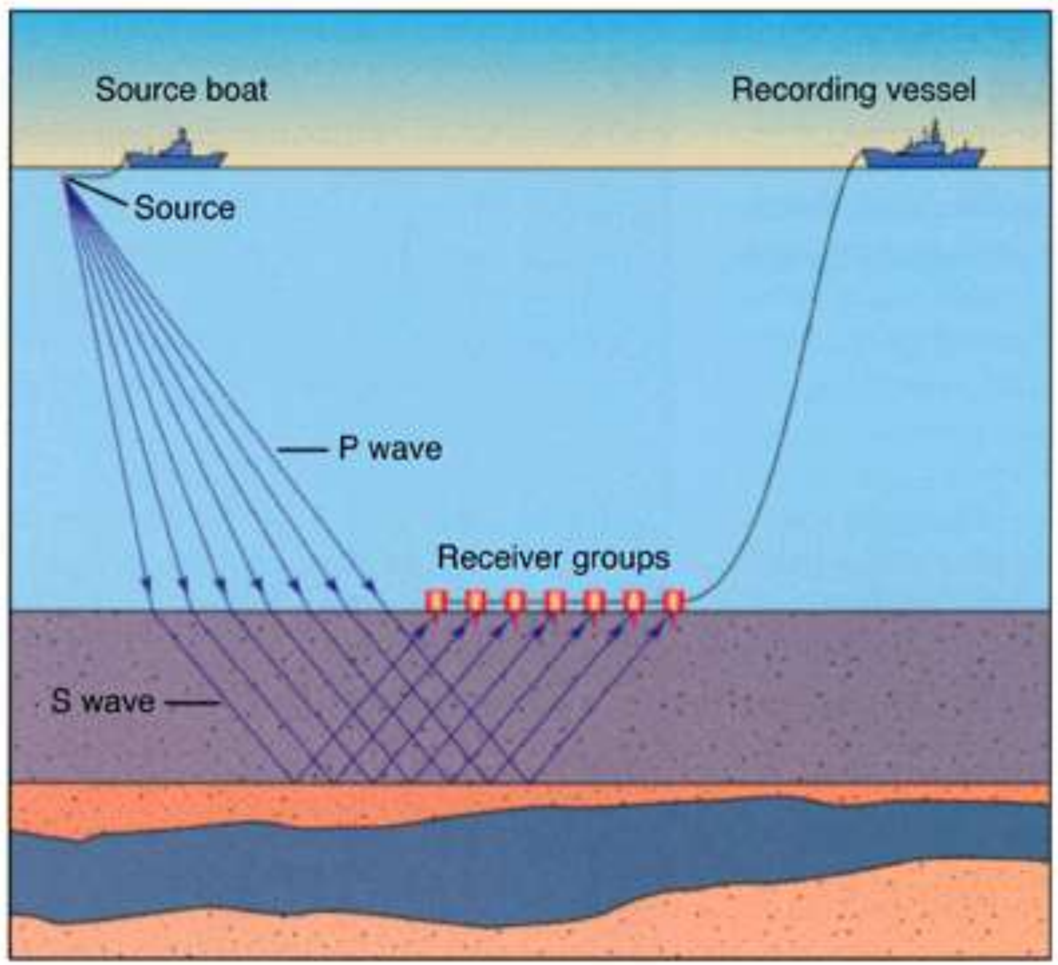
Motivation

Adapted from http://www.peakseismic.com/images/OBSgraphic1.gif

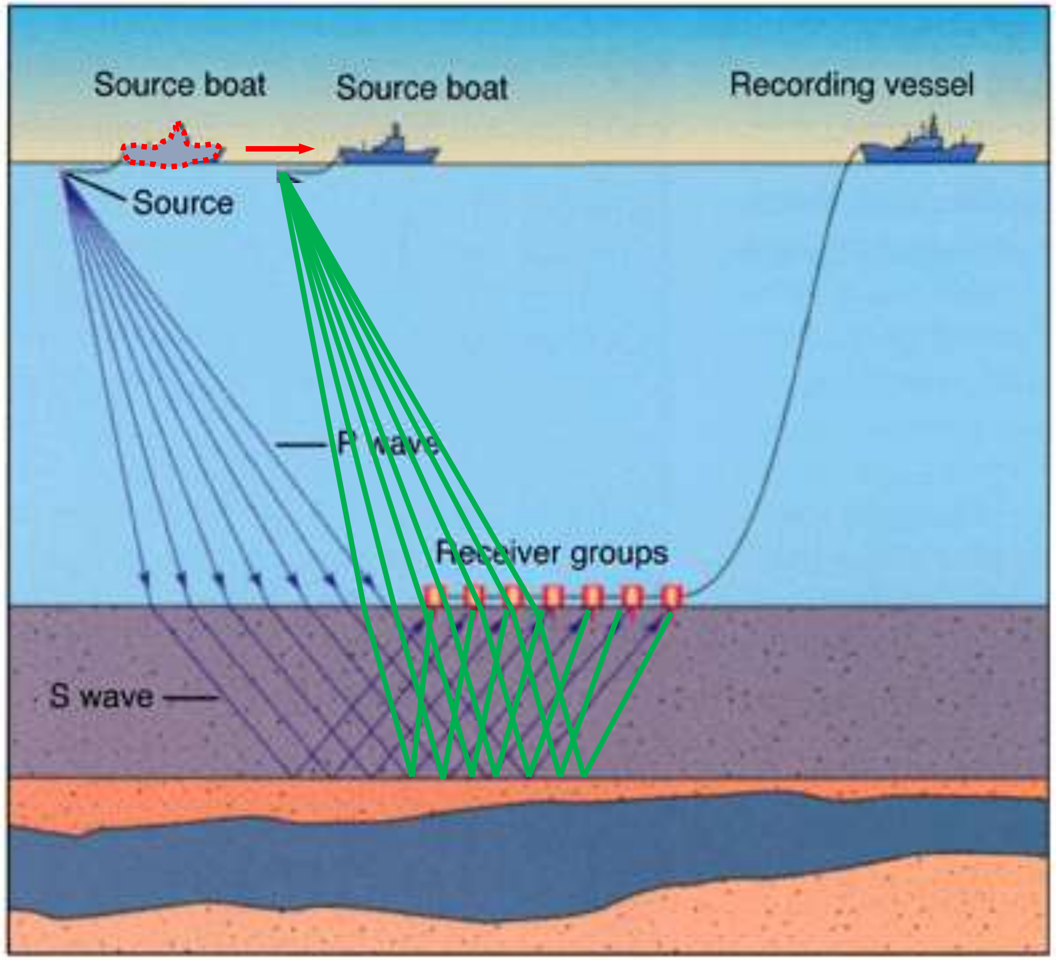


Conventional OBS

- The cost of a seismic acquisition is proportional to the time required to acquire the data;

Motivation

Deblending required



Blended acquisition

Adapted from http://www.peakseismic.com/images/OBSgraphic1.gif

- The cost of a seismic acquisition is proportional to the time required to acquire the data;
- Acquire data faster has the potential do decrease the costs

How will blending noise and deblending procedures affect 4D analysis?

Outline

- Objective
- Theoretical background
  - Blending
  - Deblending
- Results
  - Synthetic data
  - Field data
- Final remarks
- Next steps

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Objective

RCP
In pursuit of new ideas

- Simulate an 4D offshore blended PRM seismic acquisition (using synthetic and Field data);
- Implement, apply and compare different deblending techniques on those datasets;
- Analyze how blending noise affects the 4D signal.

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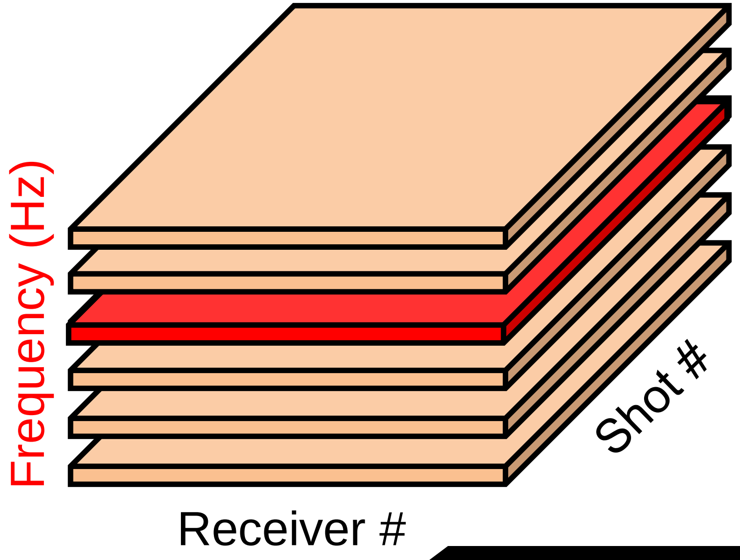
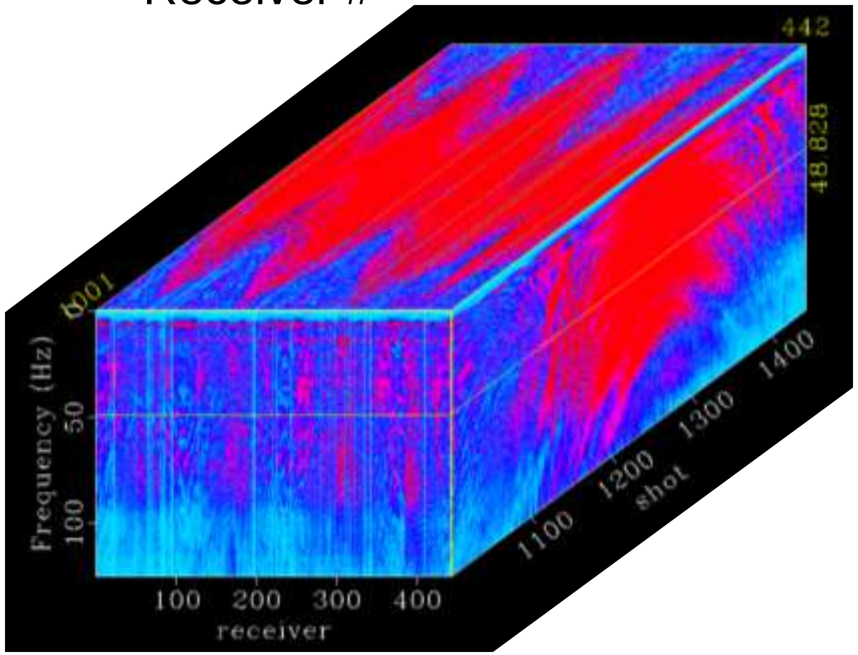
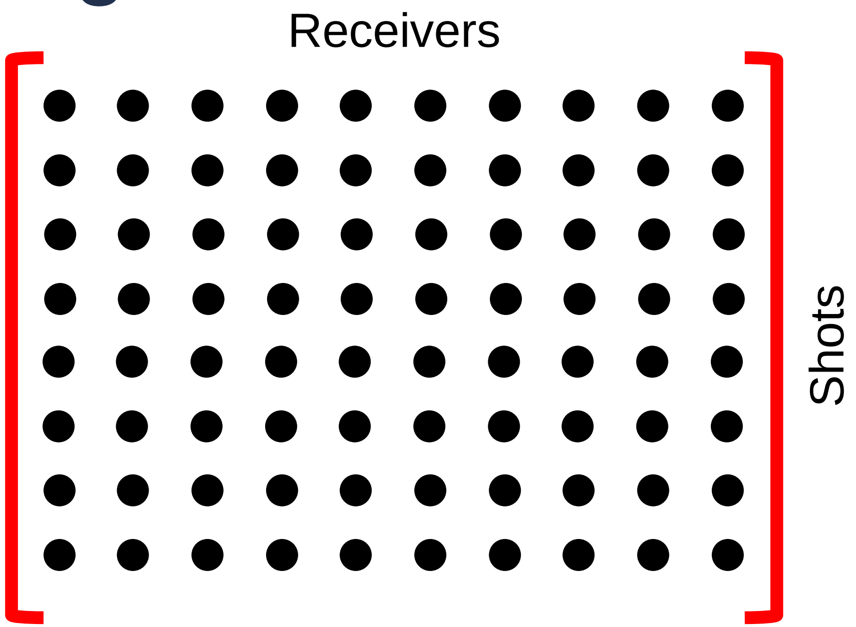
Theoretical background – Blending





$$P =$$



In this representation, a blending acquisition (*P*') can be described as a matrix multiplication:

$$P' = \Gamma P$$

Where Γ is the Blending operator

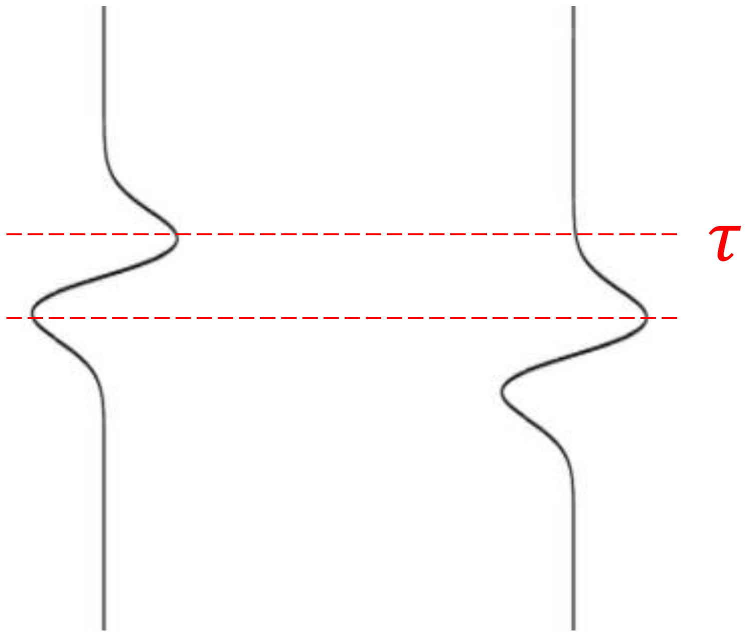
Berkhout (1982, 2008)

Theoretical background – Blending

How does it work?

$$P' = \Gamma P$$

In off-shore acquisitions the most common blending approach is the "**linear phase**" encoding, which is described as random time shifts between shots.



$f(t)$ ⇩ $F(\omega)$

$f(t-\tau)$ ⇩ $F(\omega)e^{-i\omega\tau}$

"**linear phase**" encoding

Theoretical background – Blending

How does it work?

$$P' = \Gamma P$$

And the matrix "Γ" takes the form:

$$\Gamma_{\mathrm{kl}} = \mathrm{e}^{-i\omega\tau_{kl}}, \quad \text{where } \tau_{kl} \text{ is the firing time.}$$

For example: An acquisition with 8 shots and 8 receivers, where **2 sequential shots were acquired together**:

$$\Gamma_{S2} = \underbrace{\begin{pmatrix} \mathrm{e}^{-i\omega\tau_1} & \mathrm{e}^{-i\omega\tau_2} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \mathrm{e}^{-i\omega\tau_3} & \mathrm{e}^{-i\omega\tau_4} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \mathrm{e}^{-i\omega\tau_5} & \mathrm{e}^{-i\omega\tau_6} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \mathrm{e}^{-i\omega\tau_7} & \mathrm{e}^{-i\omega\tau_8} \end{pmatrix}}_{4 \times 8}$$

Theoretical background – Blending

How does it work?

$$P' = \Gamma P$$

And the matrix "Γ" takes the form:

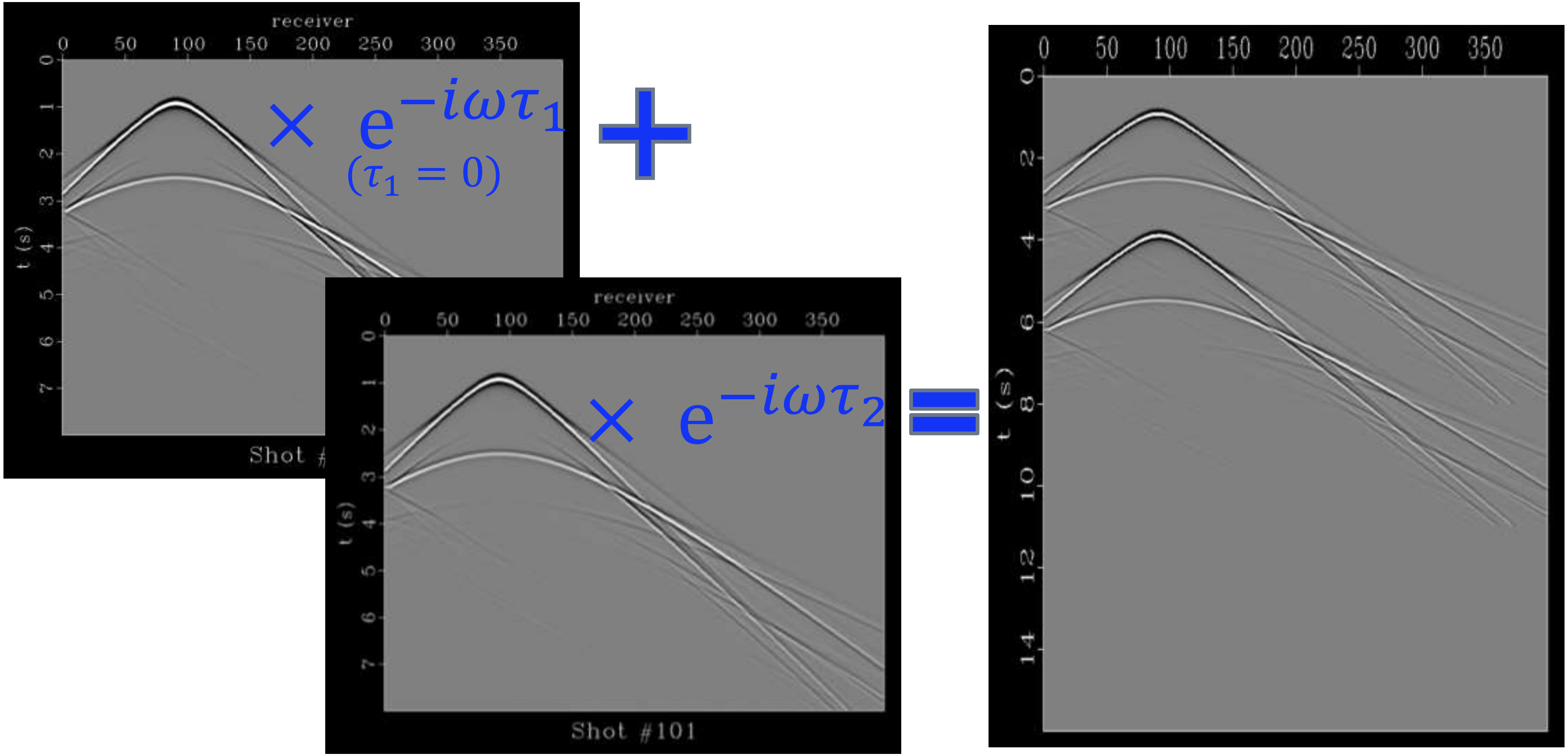
$$\Gamma_{\mathrm{kl}} = \mathrm{e}^{-i\omega\tau_{kl}}, \quad \text{where } \tau_{kl} \text{ is the firing time.}$$

For example: An acquisition with 8 shots and 8 receivers, where **4 sequential shots were acquired together**:

$$\Gamma_{S4} = \underbrace{\begin{pmatrix} \mathrm{e}^{-i\omega\tau_1} & \mathrm{e}^{-i\omega\tau_2} & \mathrm{e}^{-i\omega\tau_3} & \mathrm{e}^{-i\omega\tau_4} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \mathrm{e}^{-i\omega\tau_5} & \mathrm{e}^{-i\omega\tau_6} & \mathrm{e}^{-i\omega\tau_7} & \mathrm{e}^{-i\omega\tau_8} \end{pmatrix}}_{2 \times 8}$$

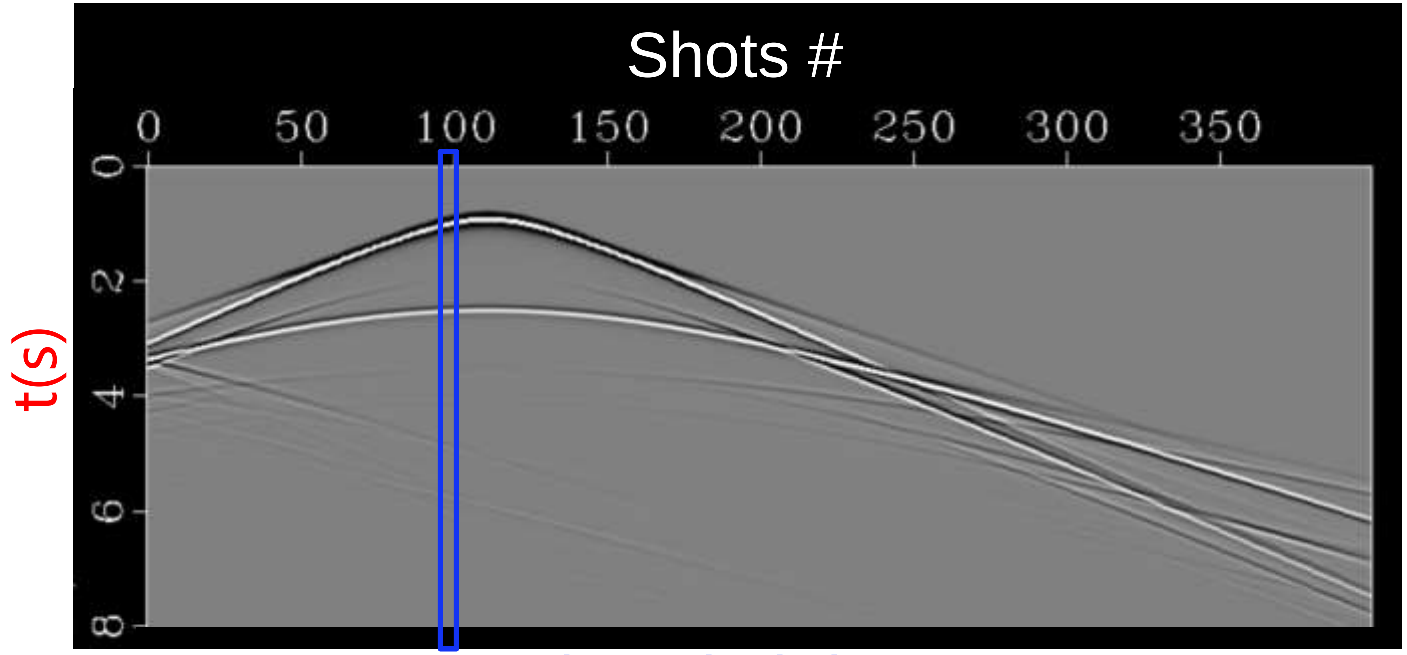
Theoretical background – Blending

Example – 2 sources (Shot domain)



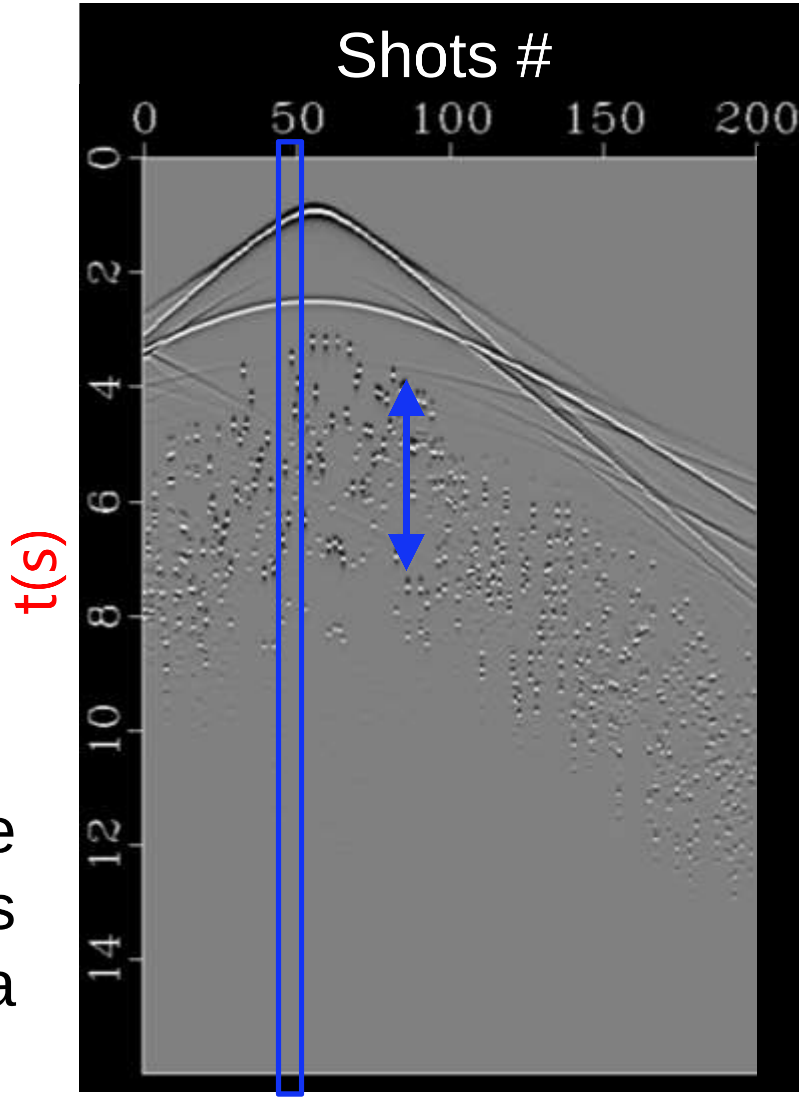
Theoretical background – Blending

Example – 2 sources (Receiver domain)



Unblended data

The firing times (τ_{kl}) should be random at some level/interval to make the deblending process achievable in a domain where the blended data becomes random.



Blended data

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- Objective
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  - Deblending
    - Methods
    - Iterative estimation and subtraction of blending noise
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Theoretical background – Deblending

- Filtering
  - Pure denoise methods

- Inversion (based on sparse solutions)
  - Iterative estimation and subtraction of blending noise ✓
  - The compressive sensing approach

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Deblending - Iterative Estimation And Subtraction

Considering the matrix representation for a blending acquisition (P') as:

$$P' = \Gamma P$$

The deblending procedure would be represented by a matrix inversion:

$$P = \Gamma^{-1} P'$$ ← Underdetermined problem. Γ is not invertible (Γ is not even a squared matrix)

In this case, we will look for the least-squares solution:

$$minimize\ J = \|P' - \Gamma P\|_2^{\ 2} \longrightarrow P \cong \left(\Gamma^{\dagger}\Gamma\right)^{-1}\Gamma^{\dagger}P' \cong \Gamma^{\dagger}P'$$

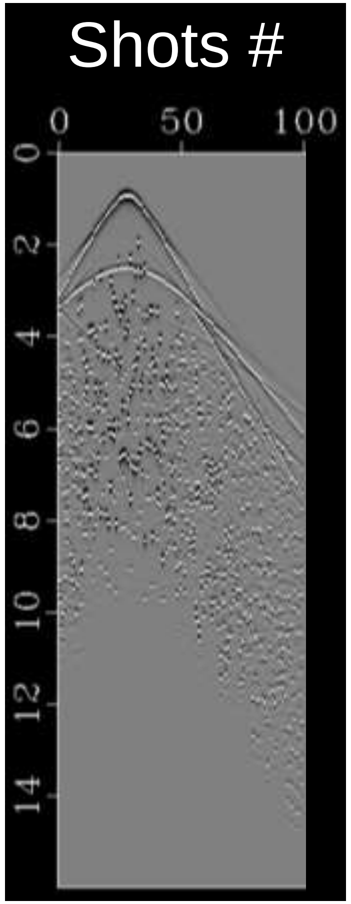
← Pseudo-deblending (contain "blending noise")

Mahdad (2011)

Deblending - Iterative Estimation And Subtraction

<u>BLENDING NOISE</u> – 100 shot records with 4 sources (Receiver domain)

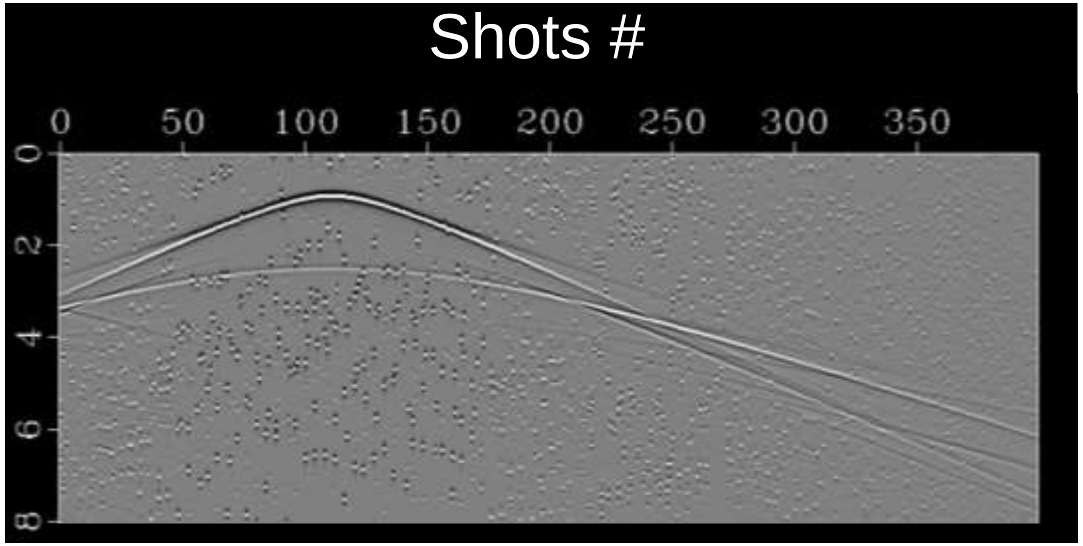
Blended receiver gather



t(s)

P'

Receiver gather after LS solution



t(s)

$\Gamma^{\dagger} P'$

<u>Decompression</u>

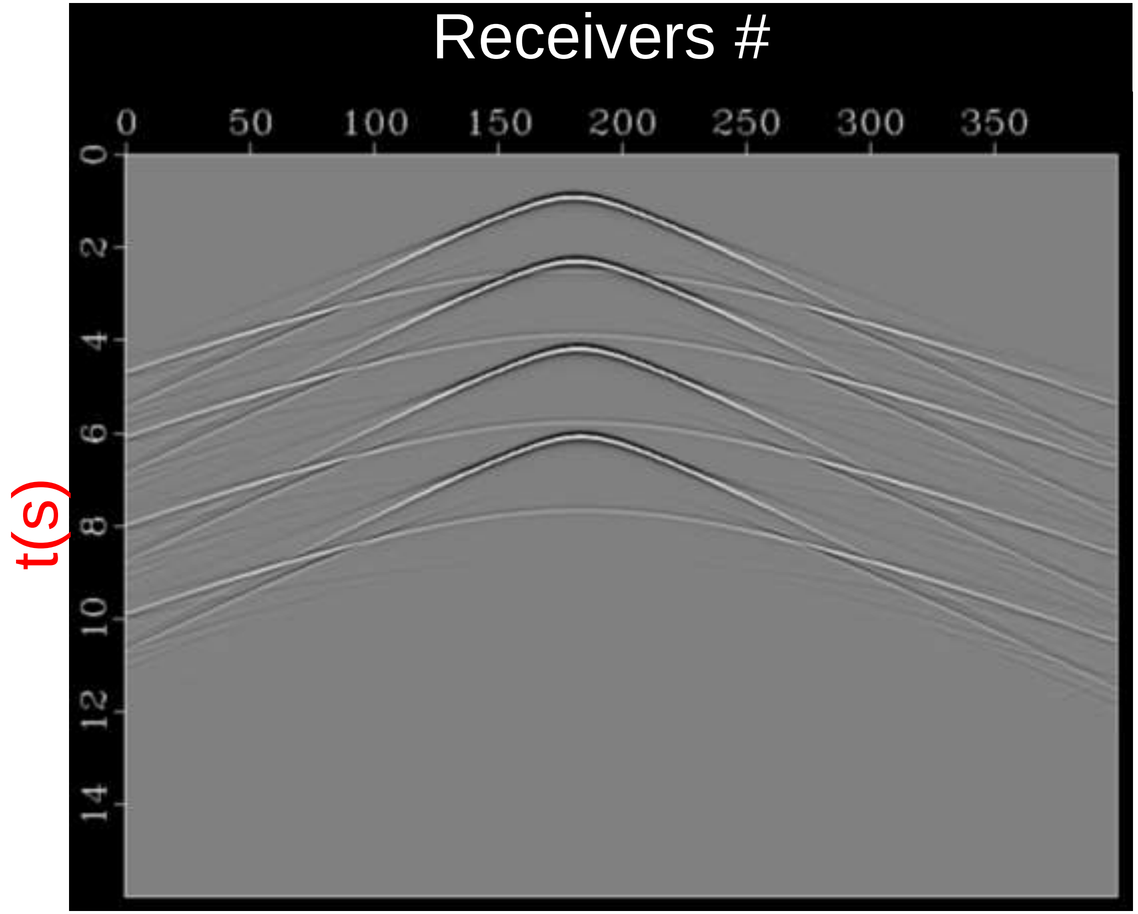
100 records (with 4 sources by record) to 400 shots

Deblending - Iterative Estimation And Subtraction

RCP
In pursuit of new ideas

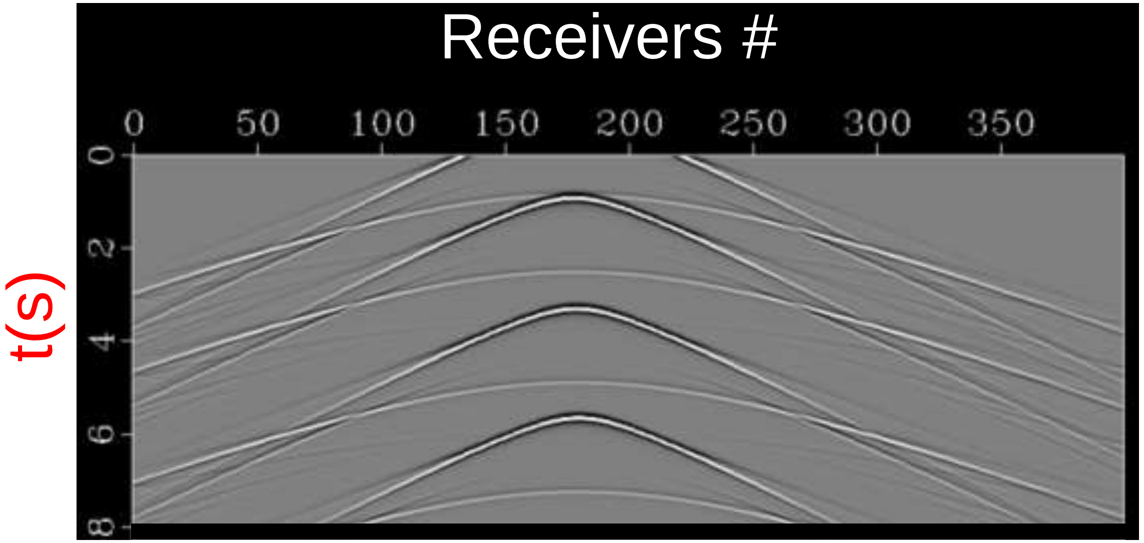
<u>BLENDING NOISE</u> – 100 shot records with 4 sources (Shot domain)

Blended shot gather



P'

Shot gather after LS solution



$\Gamma^{\dagger} P'$

Deblending - Iterative Estimation And Subtraction

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Additional constrains should be imposed:

$$minimize\ J = \|P' - \Gamma P\|_2{}^2 \quad subject\ to\ \|P\|_0 < \epsilon$$

Sparsity-promoting term ($\ell_0\ norm$)

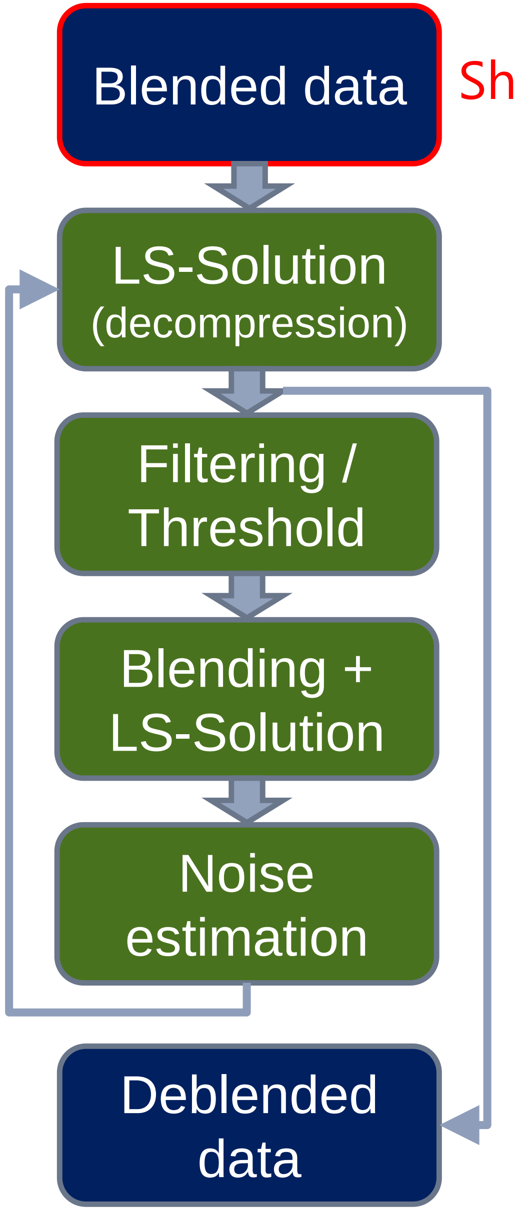
Since this problem quickly becomes intractable, a iterative solution will be considered:

$$P_{i+1} = \Gamma^{\dagger} P' - \underbrace{[\Gamma^{\dagger}\Gamma - I]T(P_i)}_{Blending\ noise\ for\ i^{th}\ iteration}$$

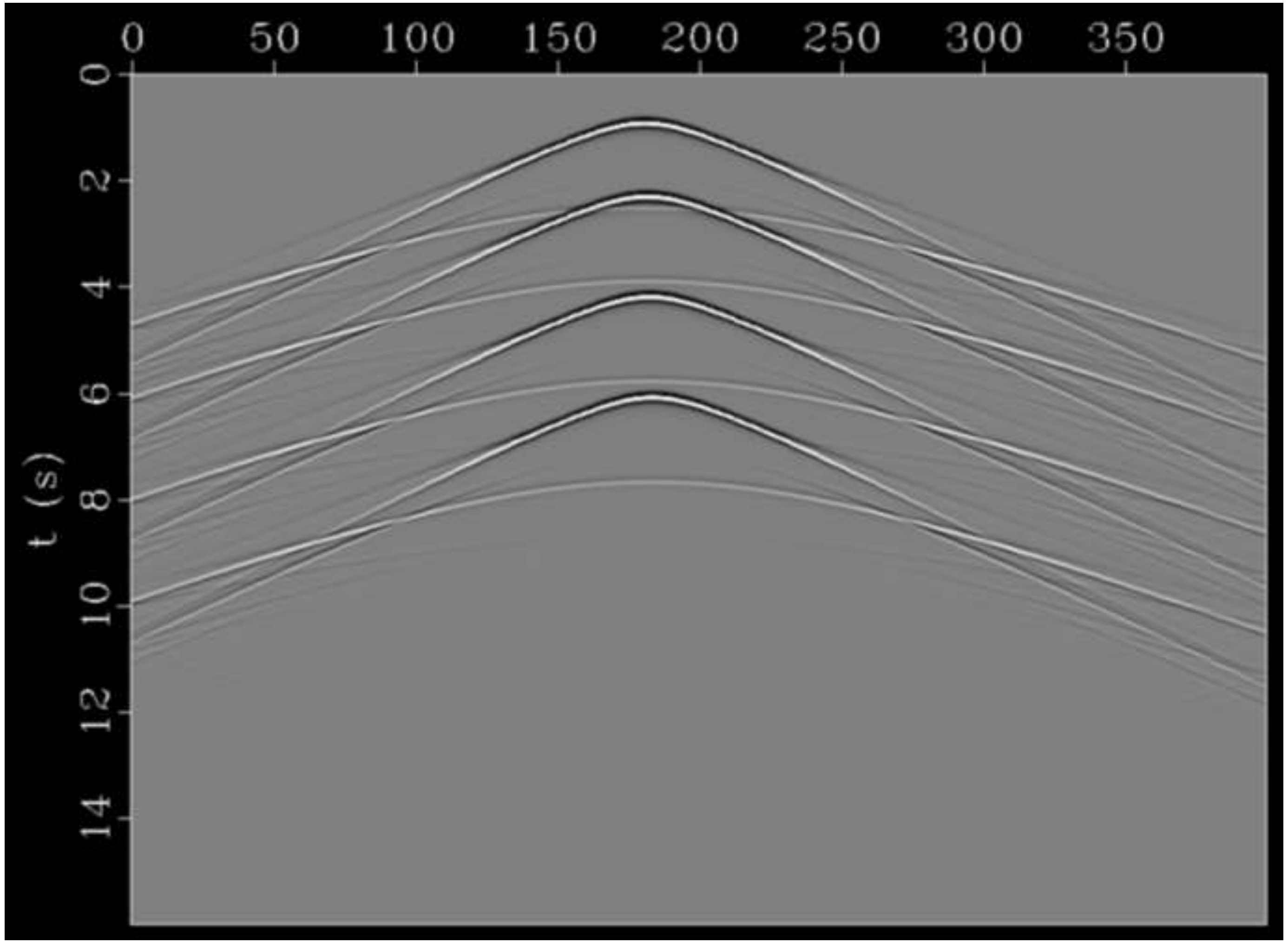
Where $T(.)$ is a sparsity-promoting operator (Threshold/Filtering)

Mahdad (2011)

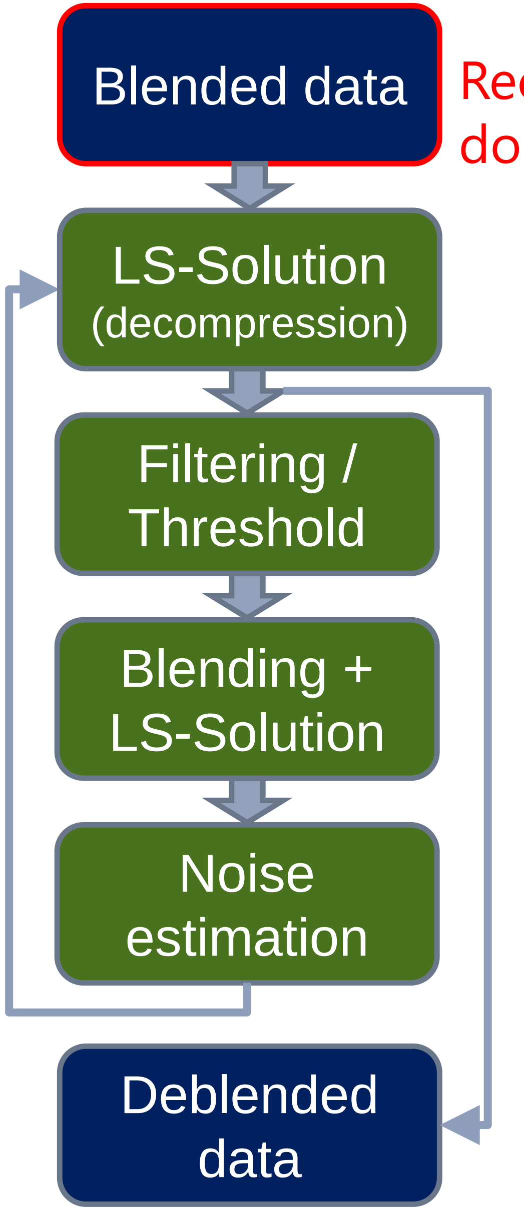
Deblending - Iterative Estimation And Subtraction



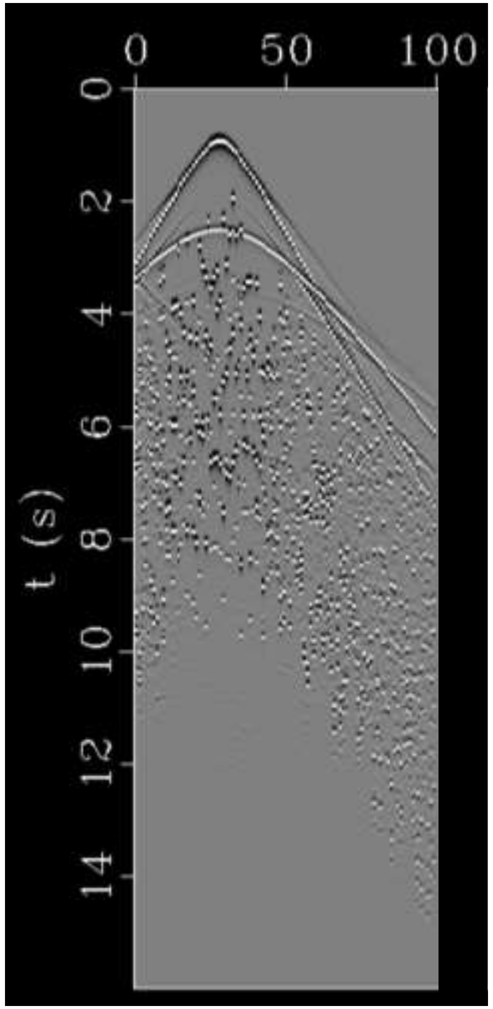
Shot domain



Deblending - Iterative Estimation And Subtraction



Receiver
domain



The method will be applied in the receiver domain

↓

Each receiver independently

↓

Natural domain to be parallelized

Deblending - Iterative Estimation And Subtraction

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Blended data

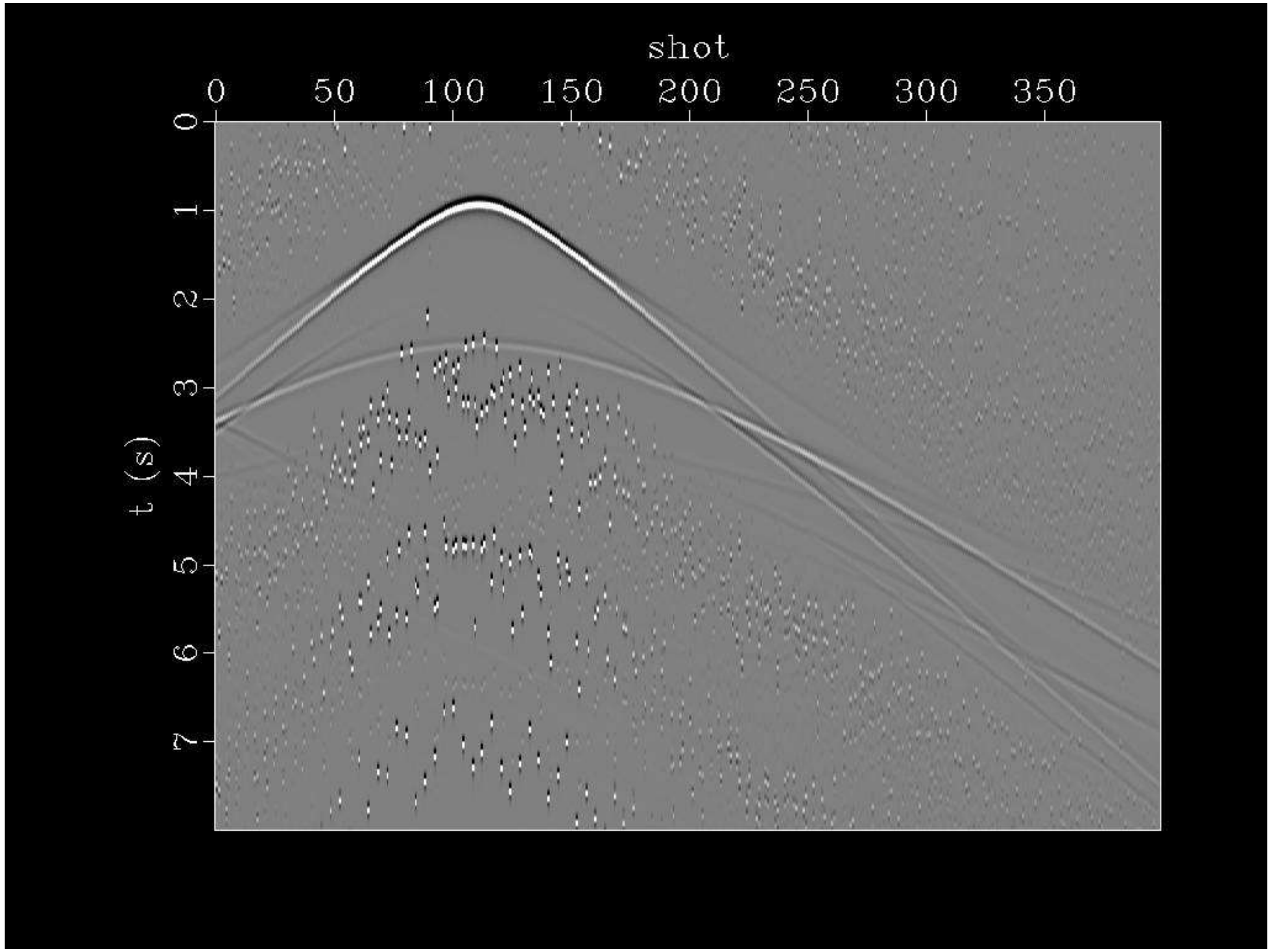
LS-Solution (decompression)

Filtering / Threshold

Blending + LS-Solution

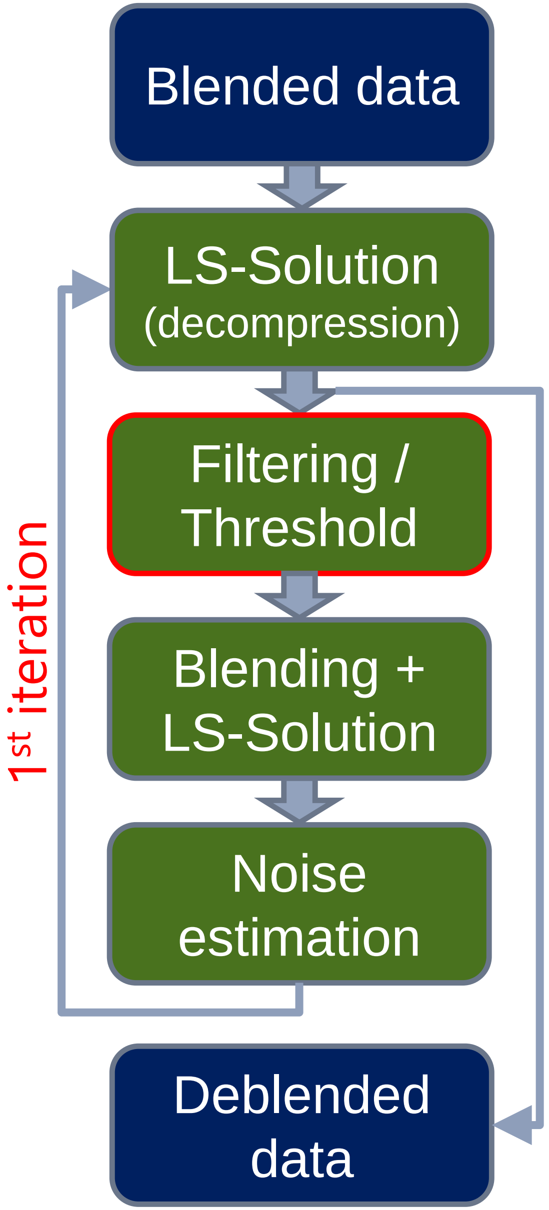
Noise estimation

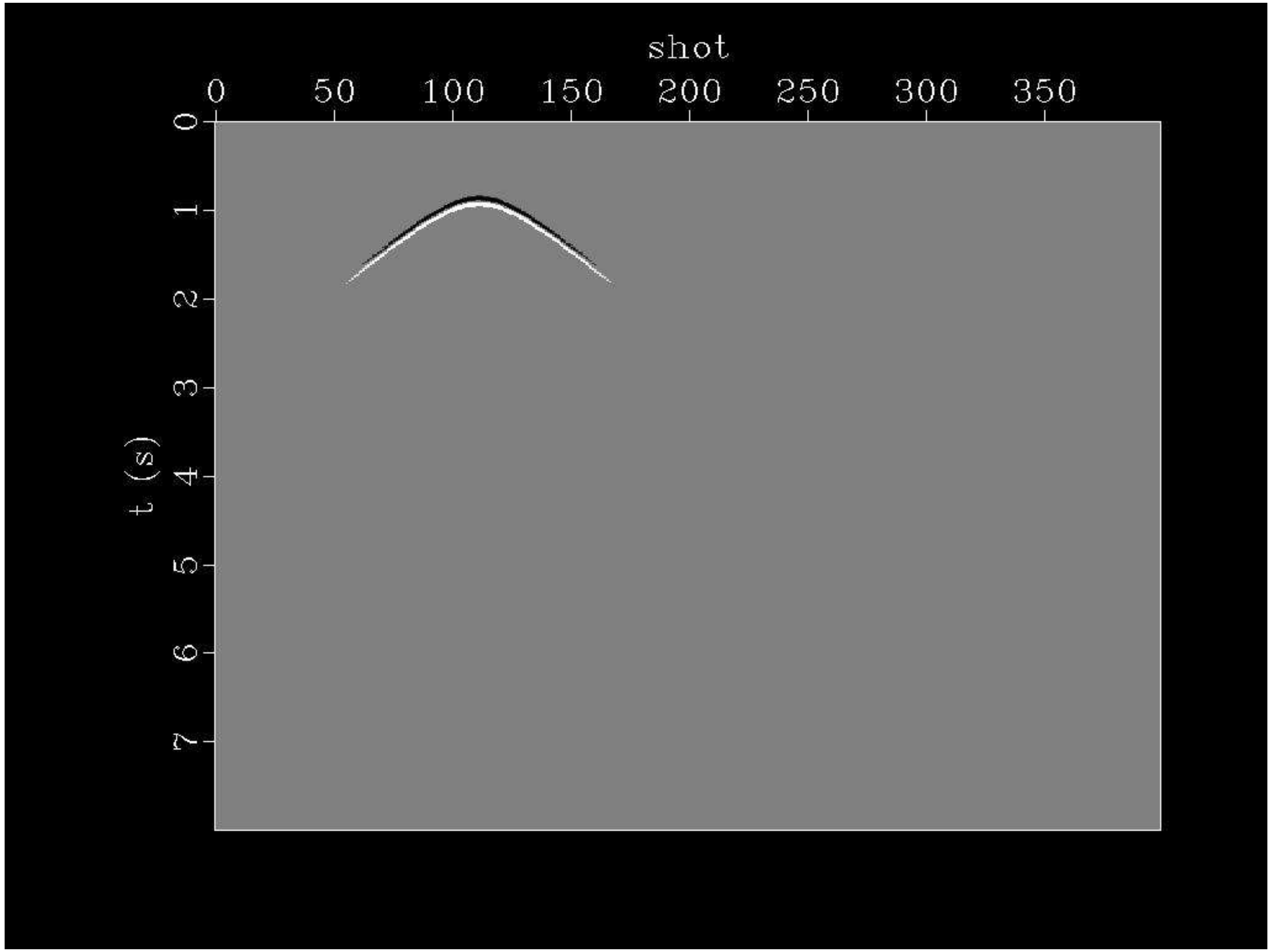
Deblended data



$$P_{i+1} = \Gamma^{\dagger}P' - [\Gamma^{\dagger}\Gamma - I]T(P_i)$$

Deblending - Iterative Estimation And Subtraction





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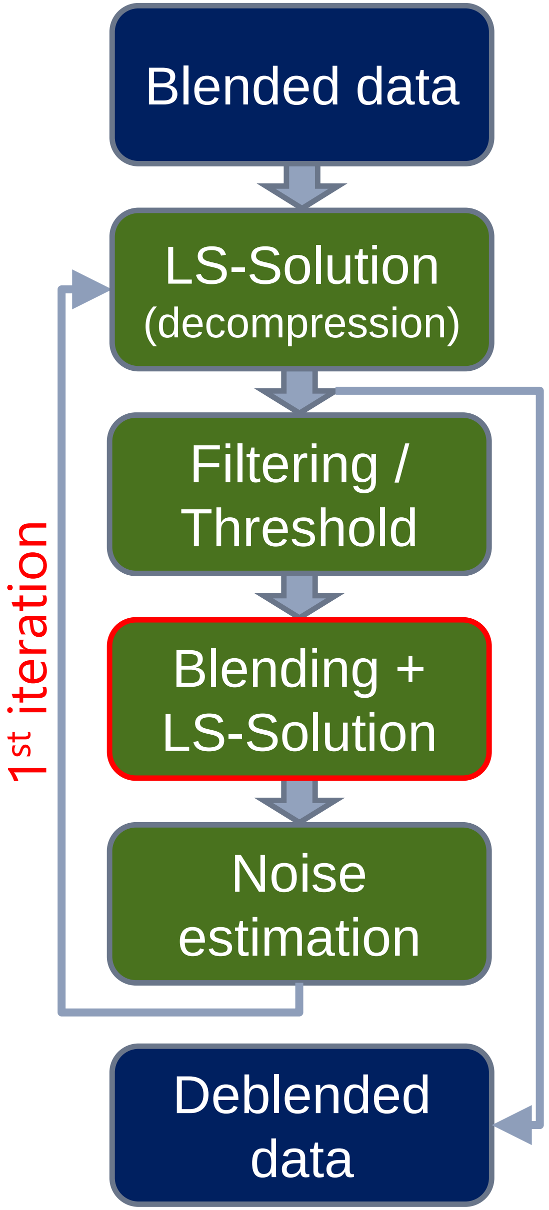

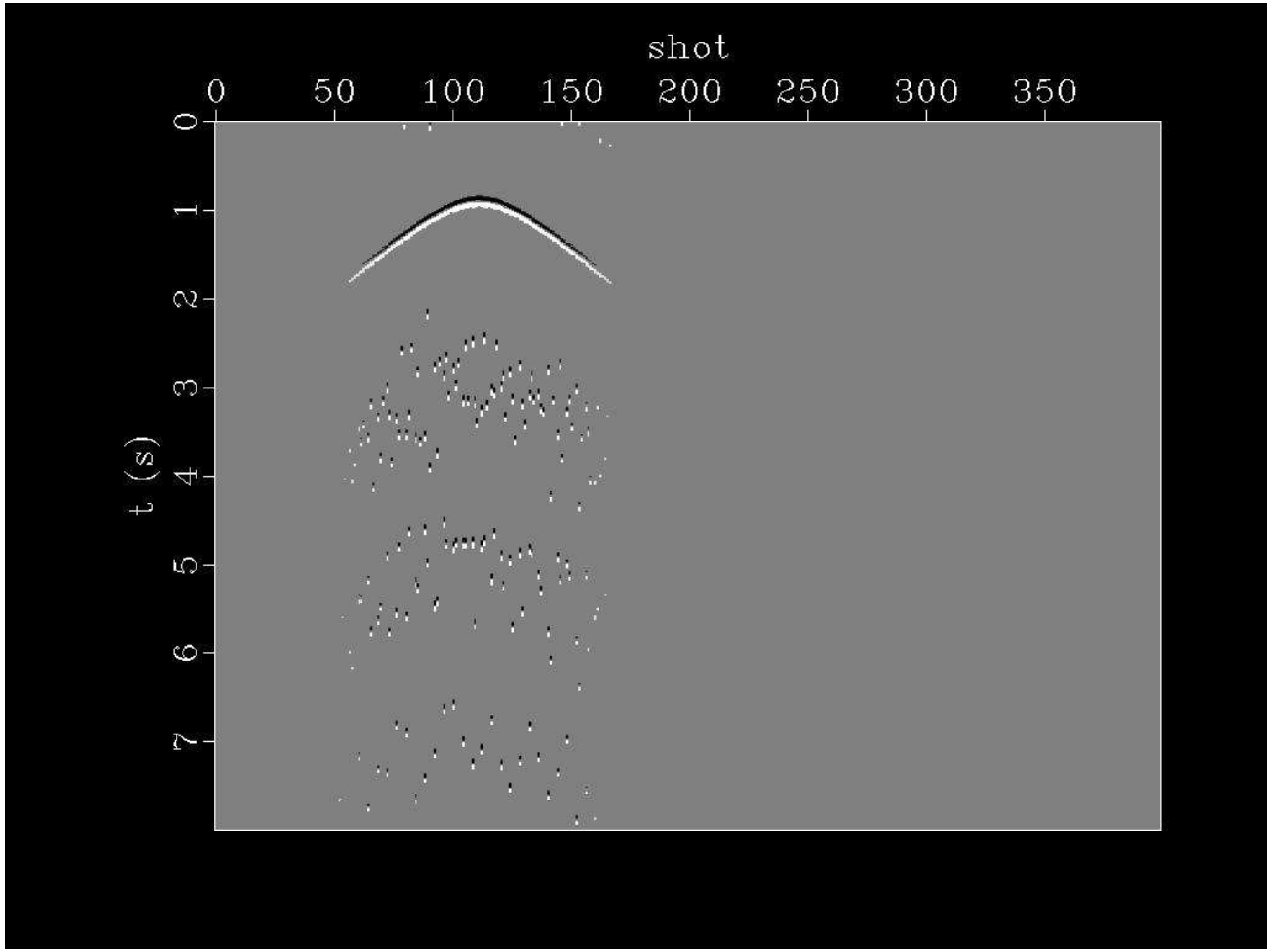

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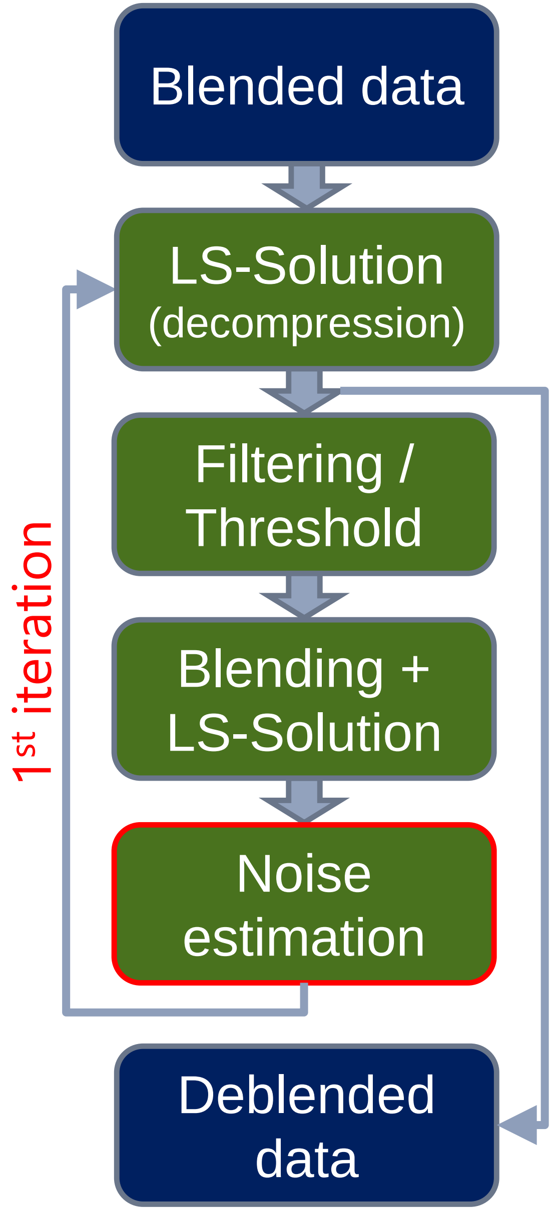
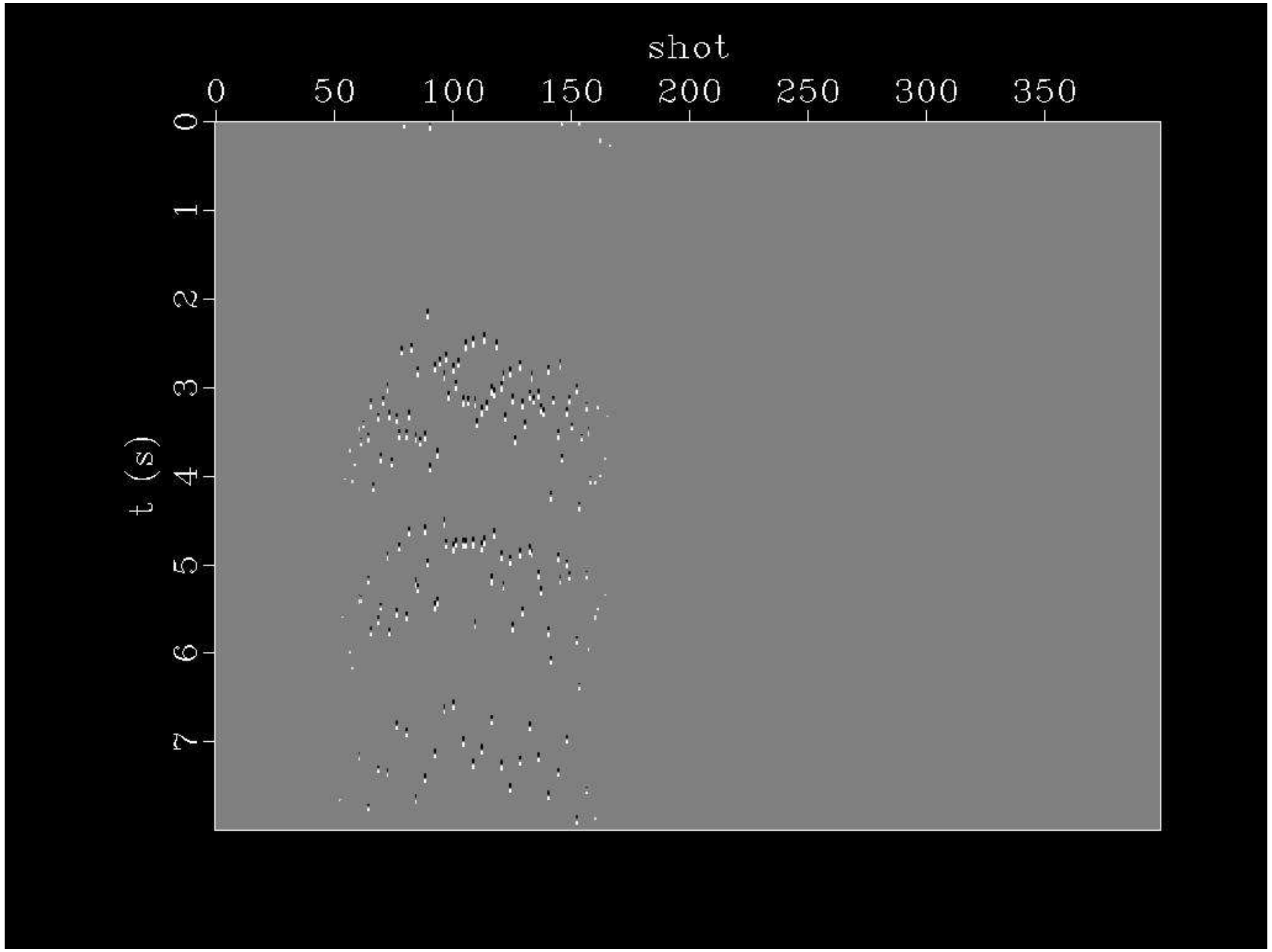
Deblending - Iterative Estimation And Subtraction

In pursuit of new ideas





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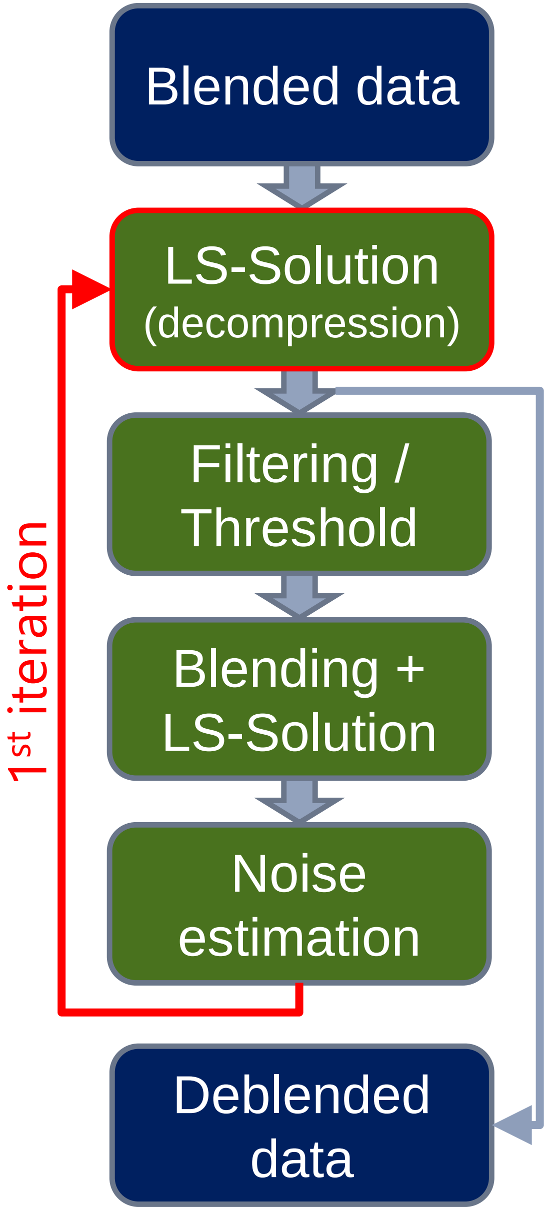
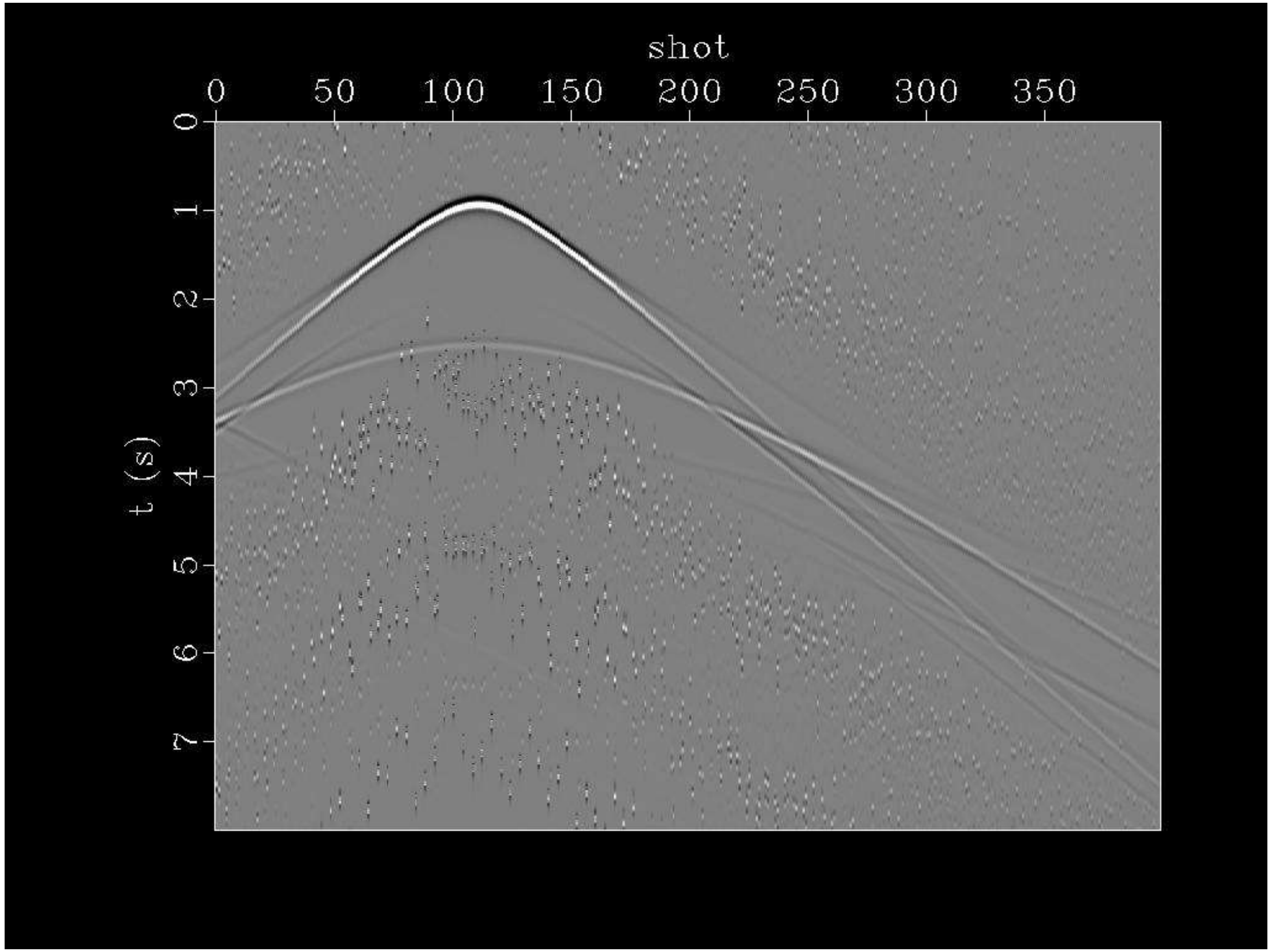
Deblending - Iterative Estimation And Subtraction





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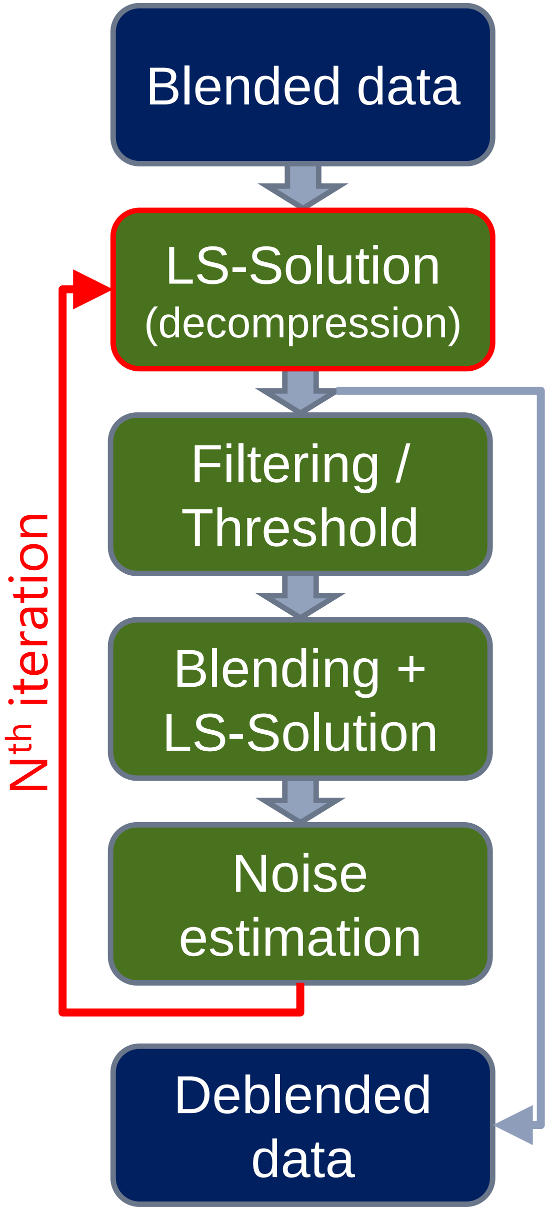
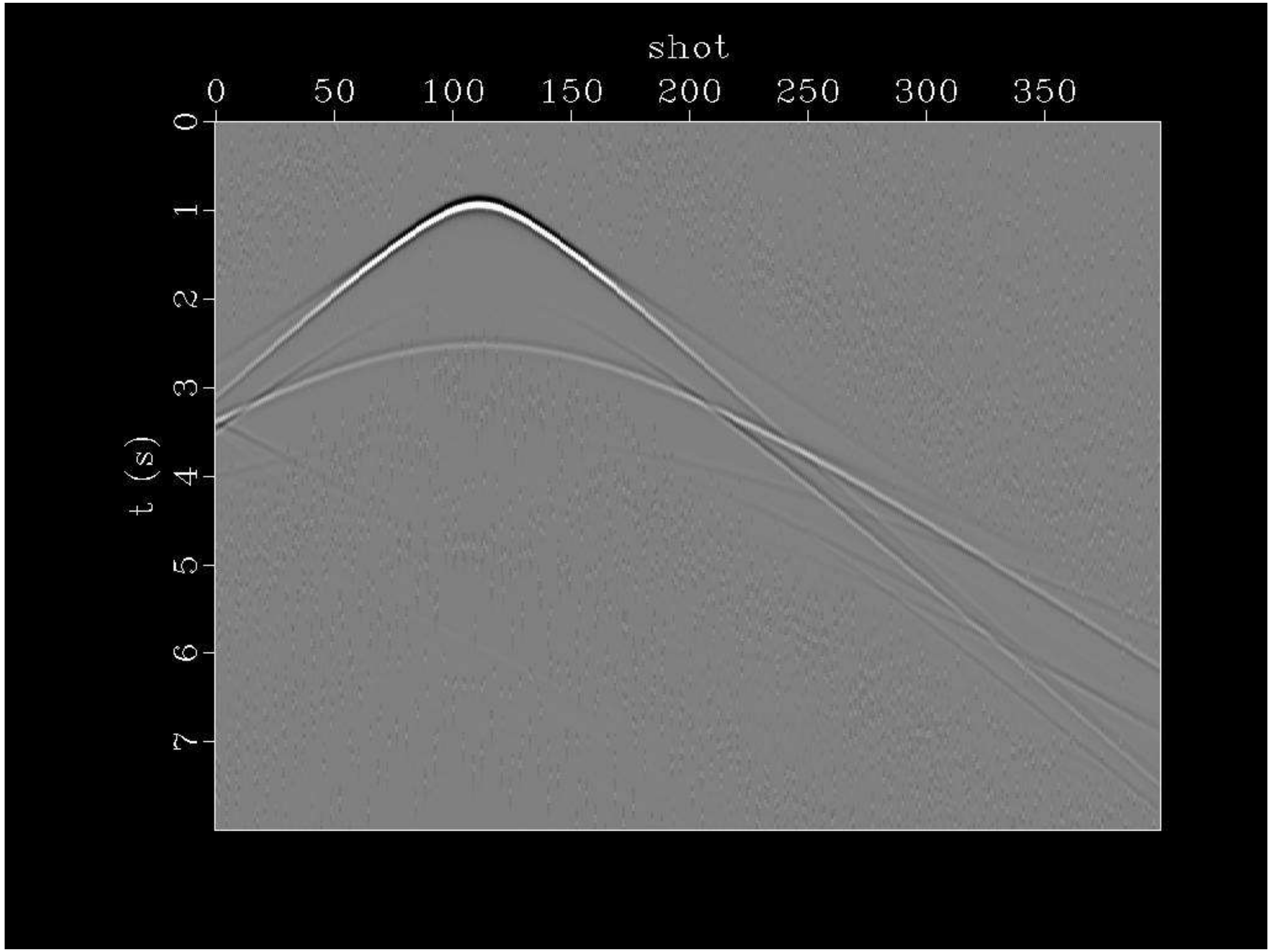
Deblending - Iterative Estimation And Subtraction





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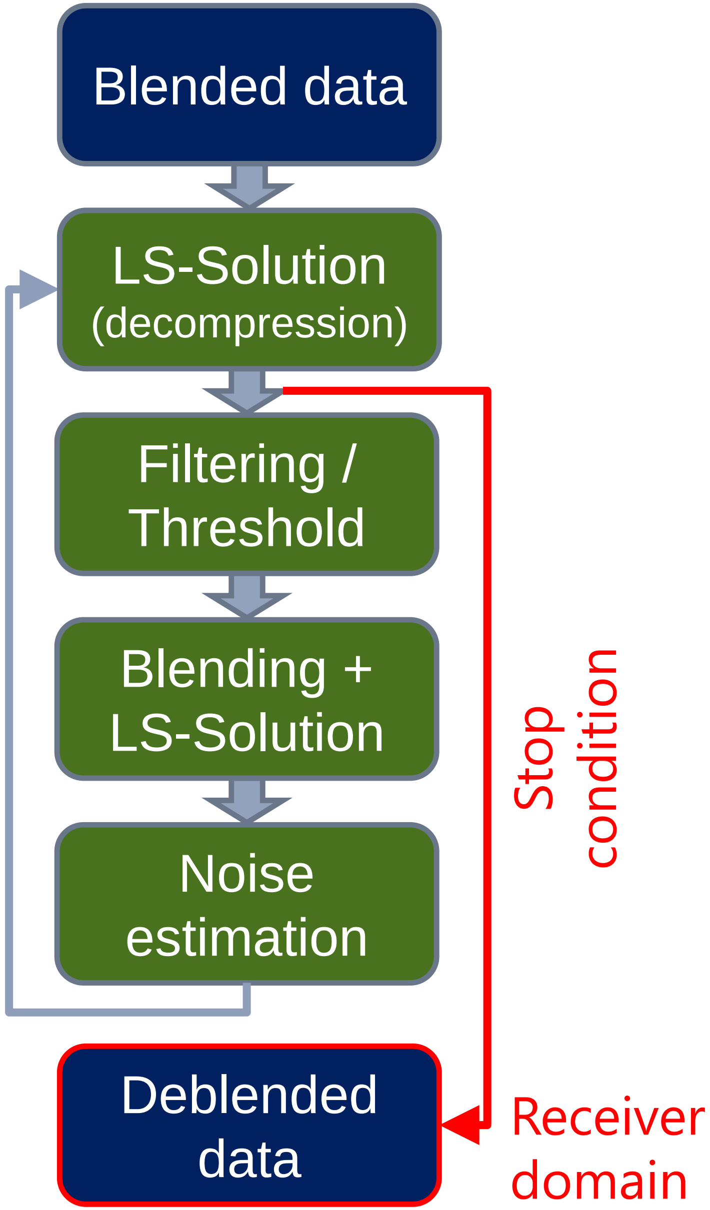
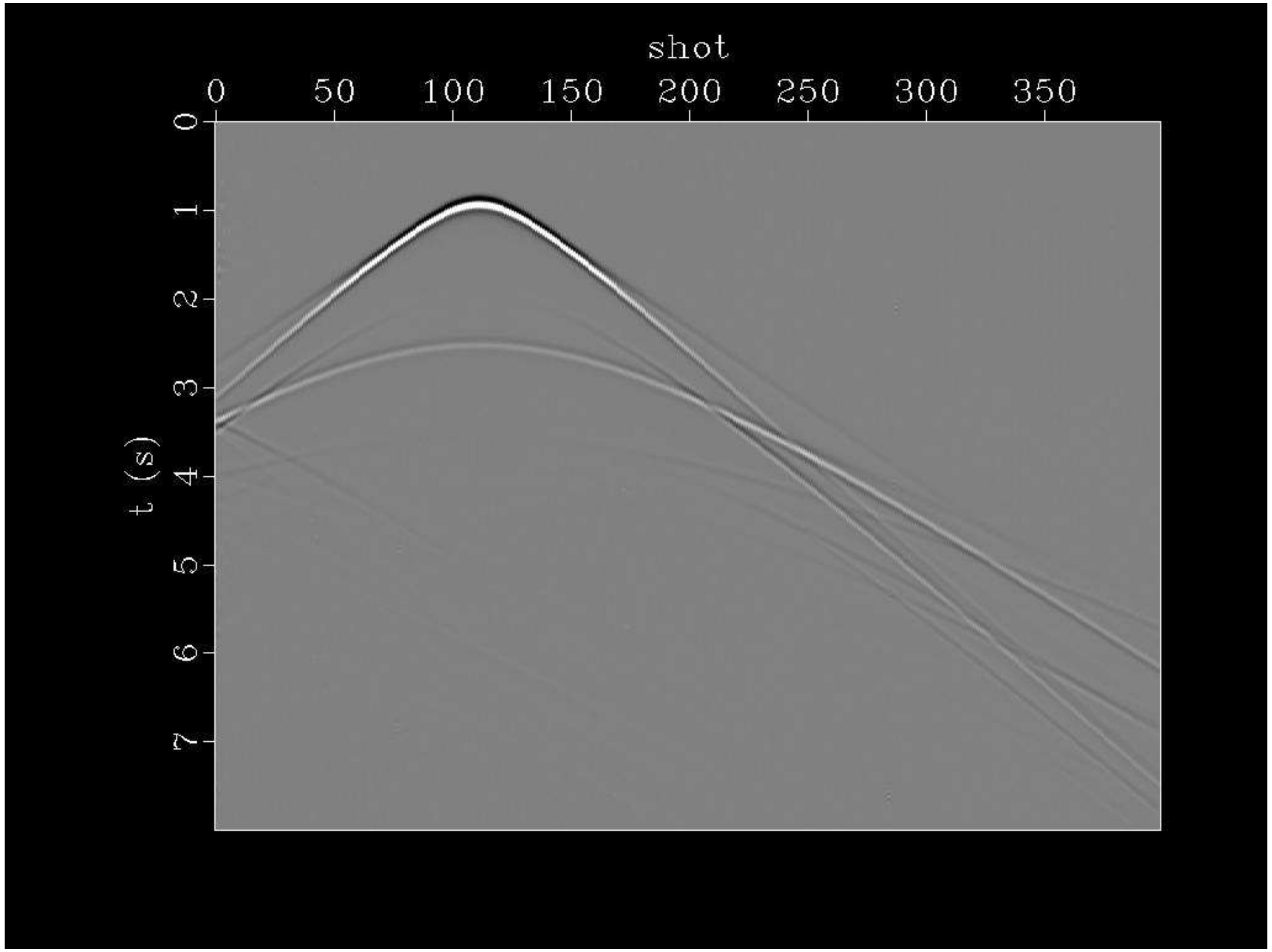
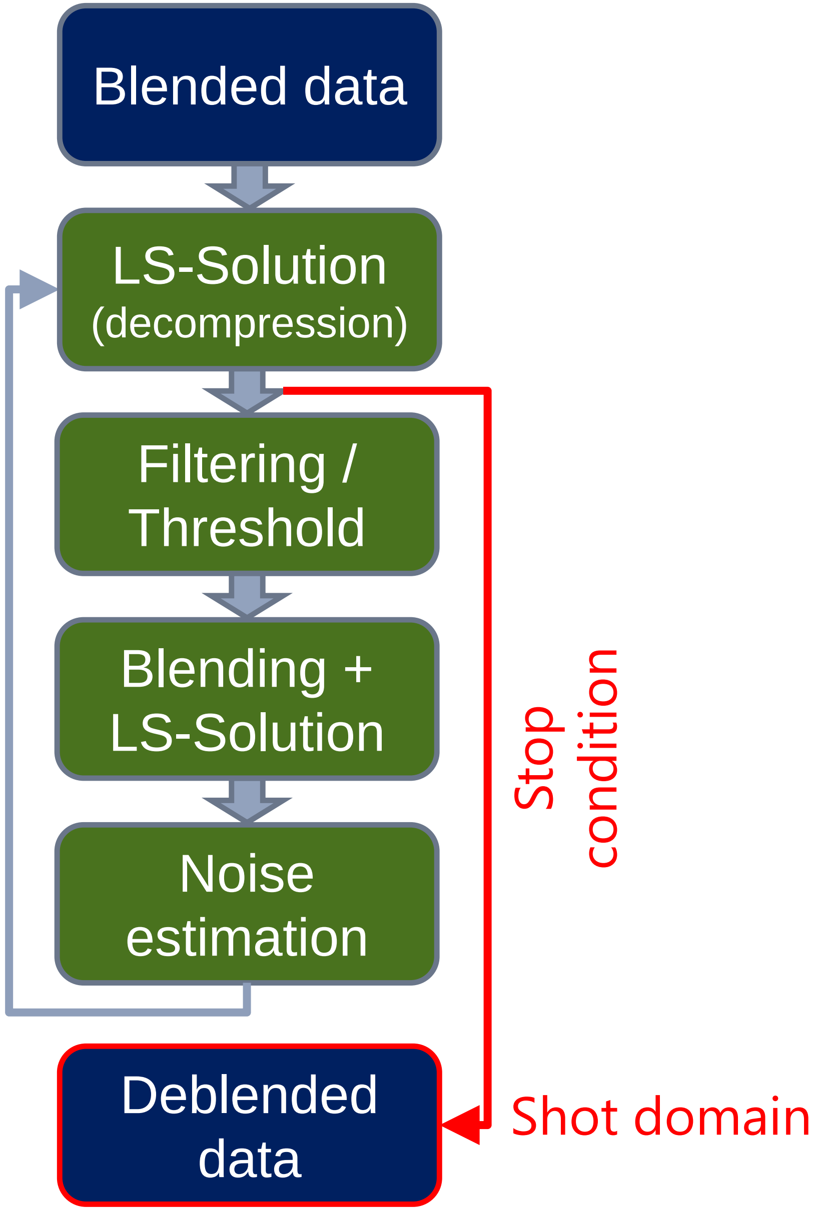
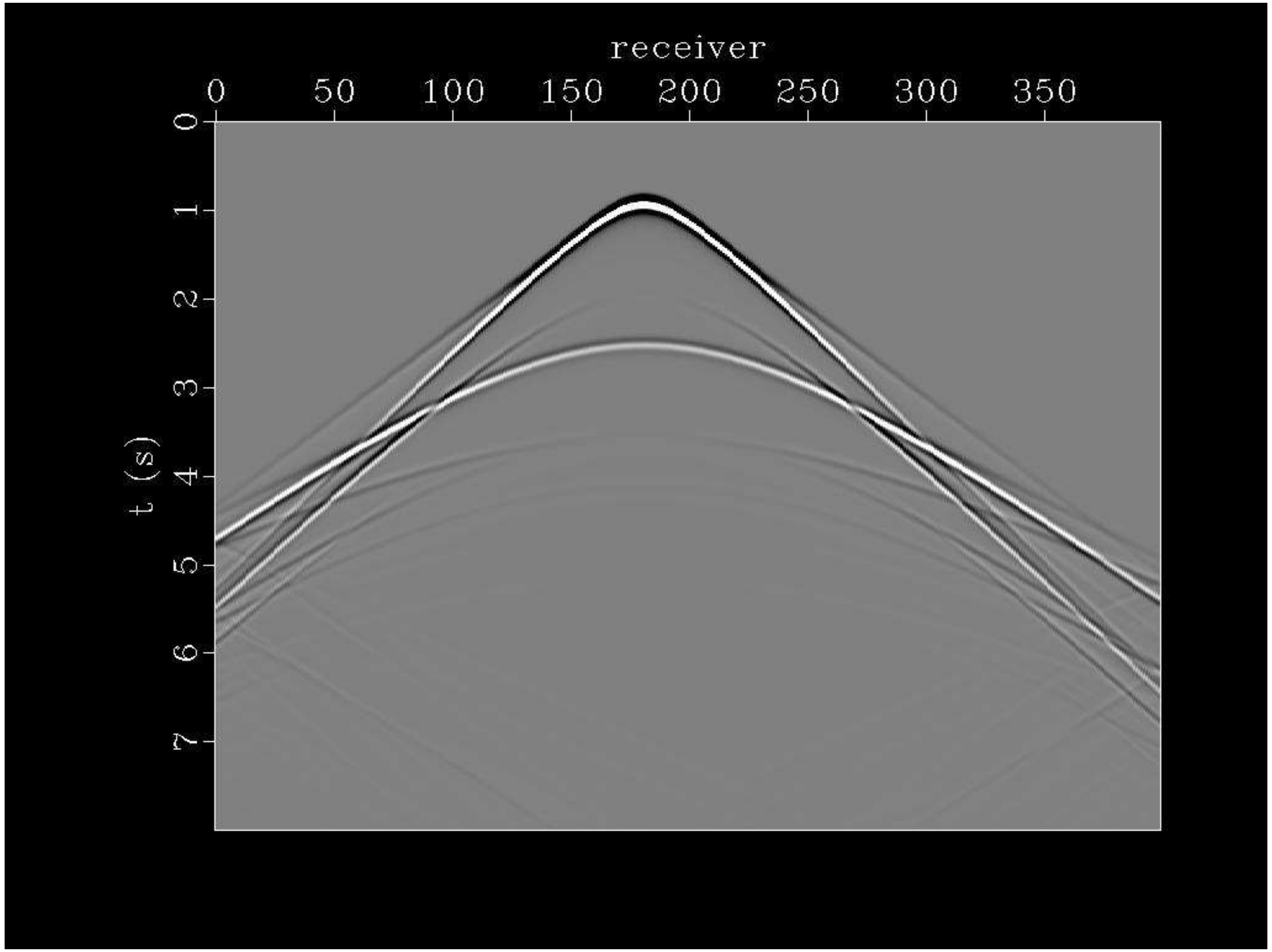


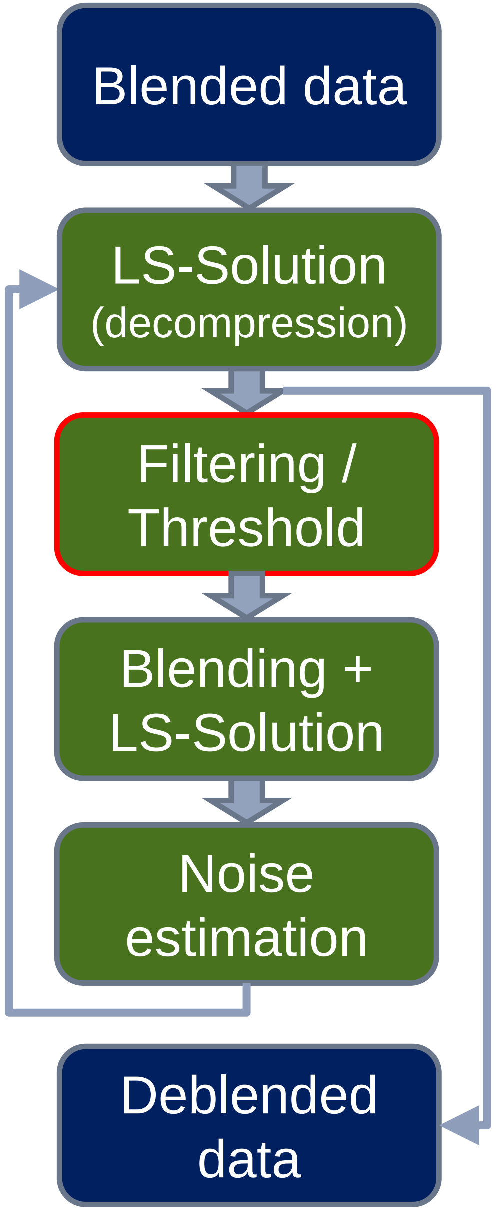


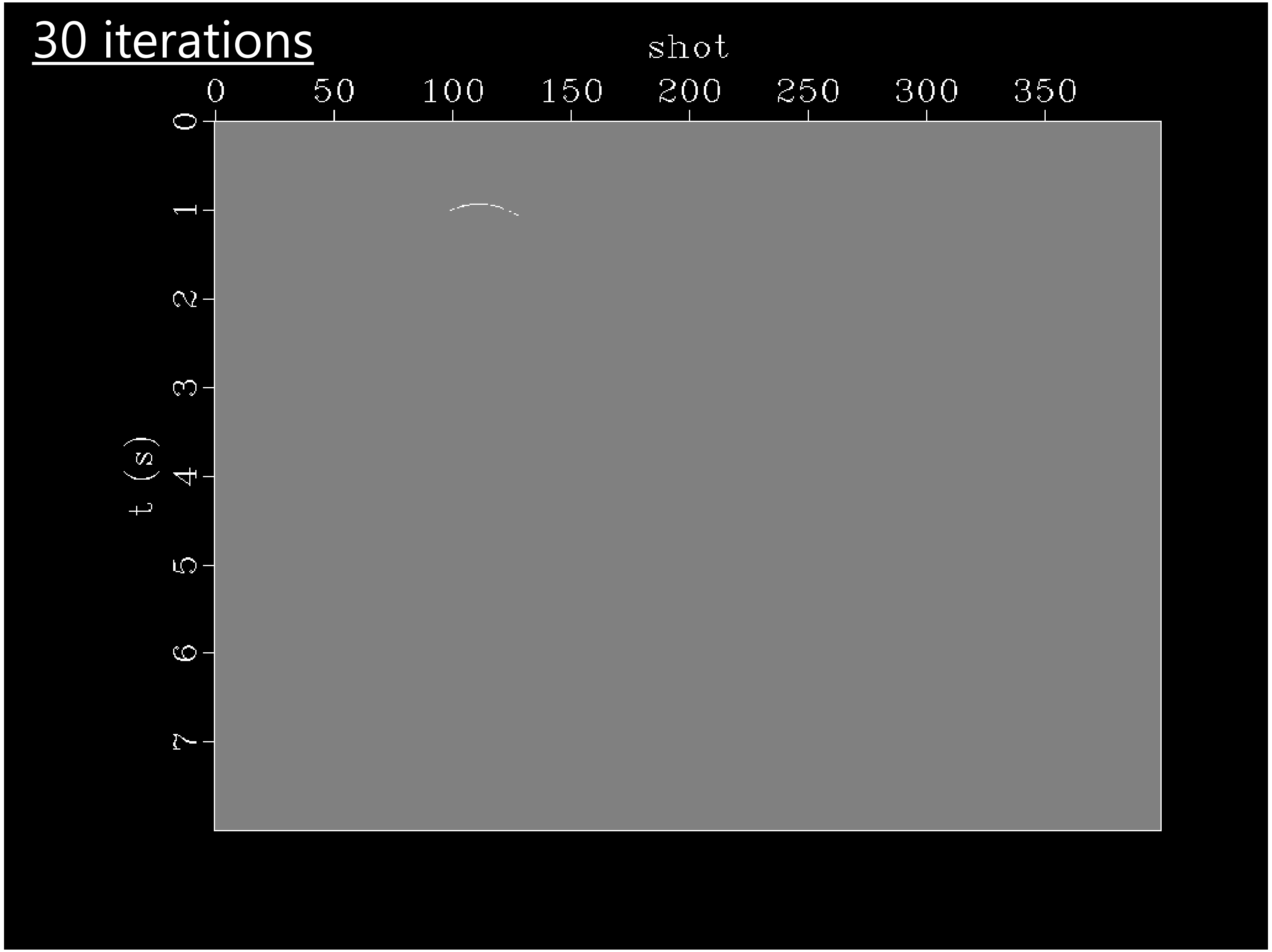
Deblending - Iterative Estimation And Subtraction



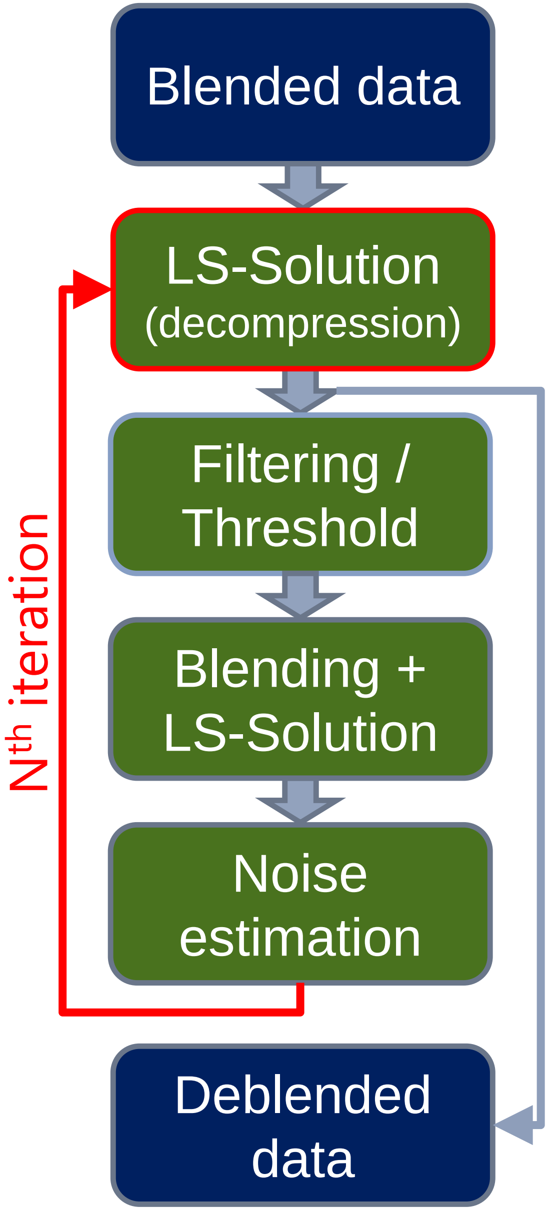


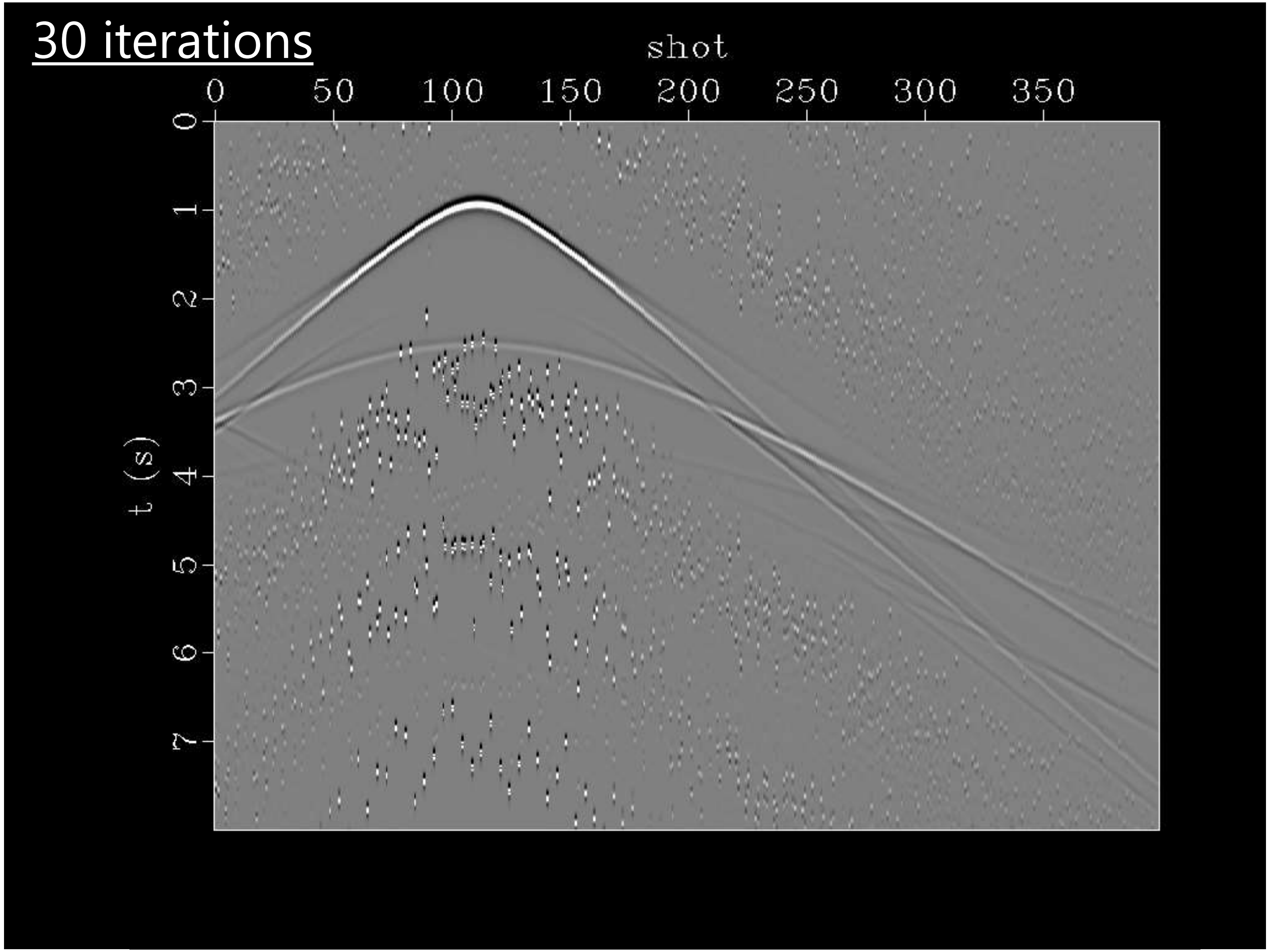
Deblending – Iterative estimation and subtraction





Deblending – Iterative estimation and subtraction





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In pursuit of new ideas

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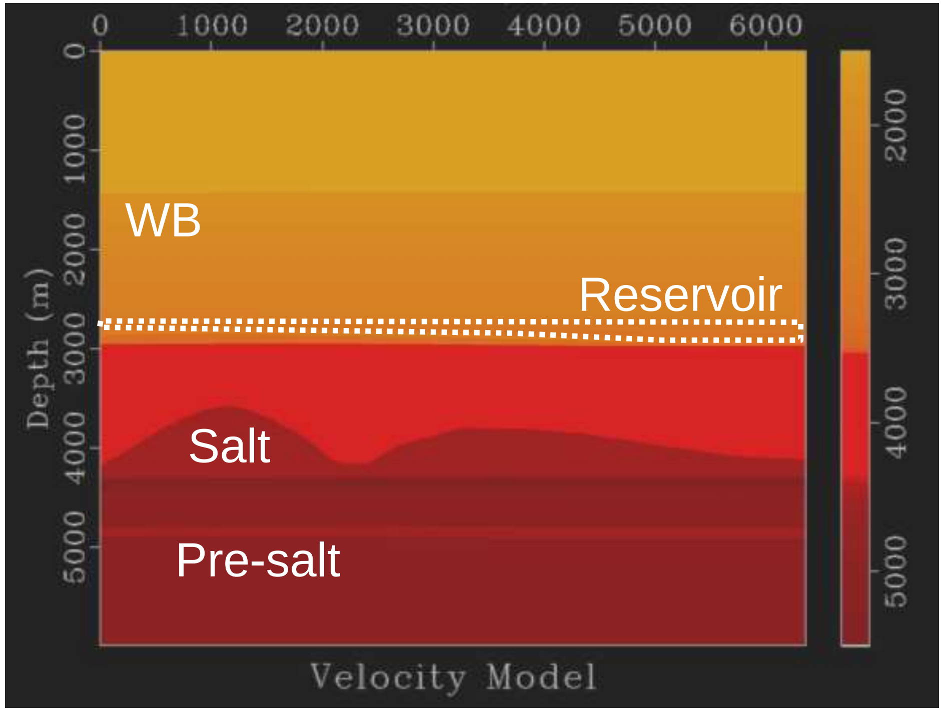
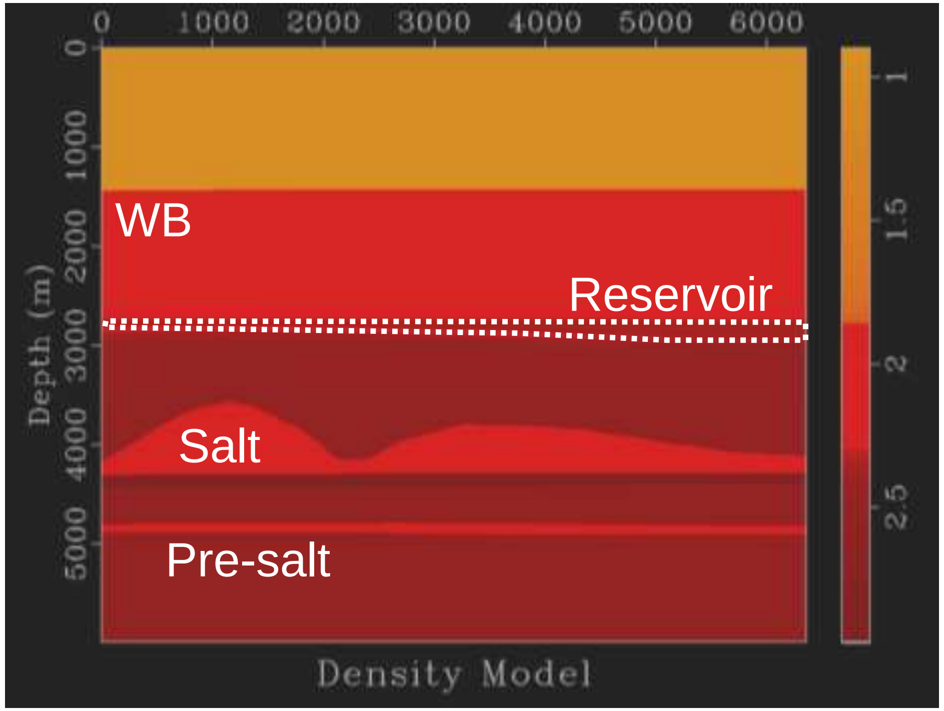
Results – Synthetic data (Modeling)

RCP
In pursuit of new ideas

2D Synthetic model with Jubarte field properties





Simulation:

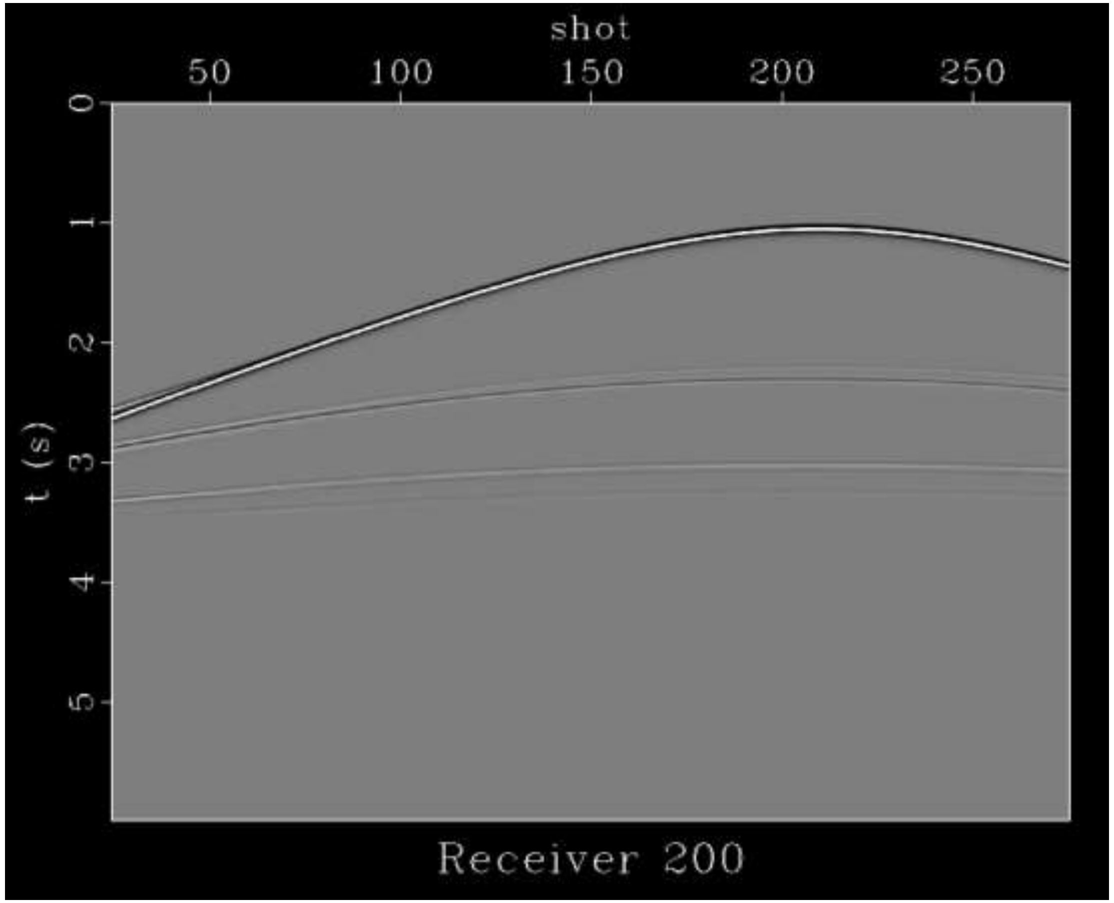
- **N˚ of sources/record** = 4
- **Shot int.** = 25 m
- **Source depth** = 10 m
- **Rec. depth** = 1430 m
- **Record length** = 10 sec
- **Firing int.** = 2.5 ± 0.4 sec
- **Wavelet freq** = 25 Hz

Assumptions:

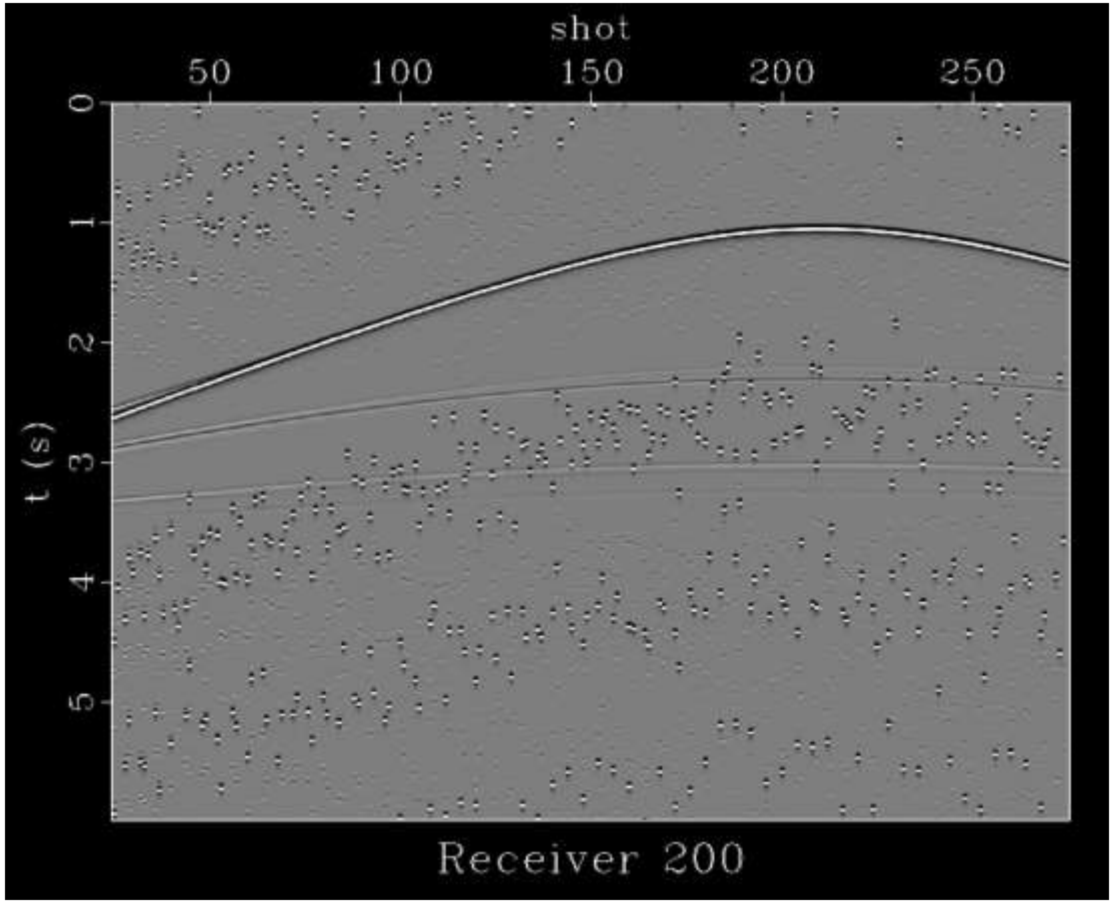
- **Noise free!**
- **Blending neighbor shots → one source ship with increased speed**

Comparative Analysis in the Receiver Domain

Results – Synthetic data (Receiver domain)

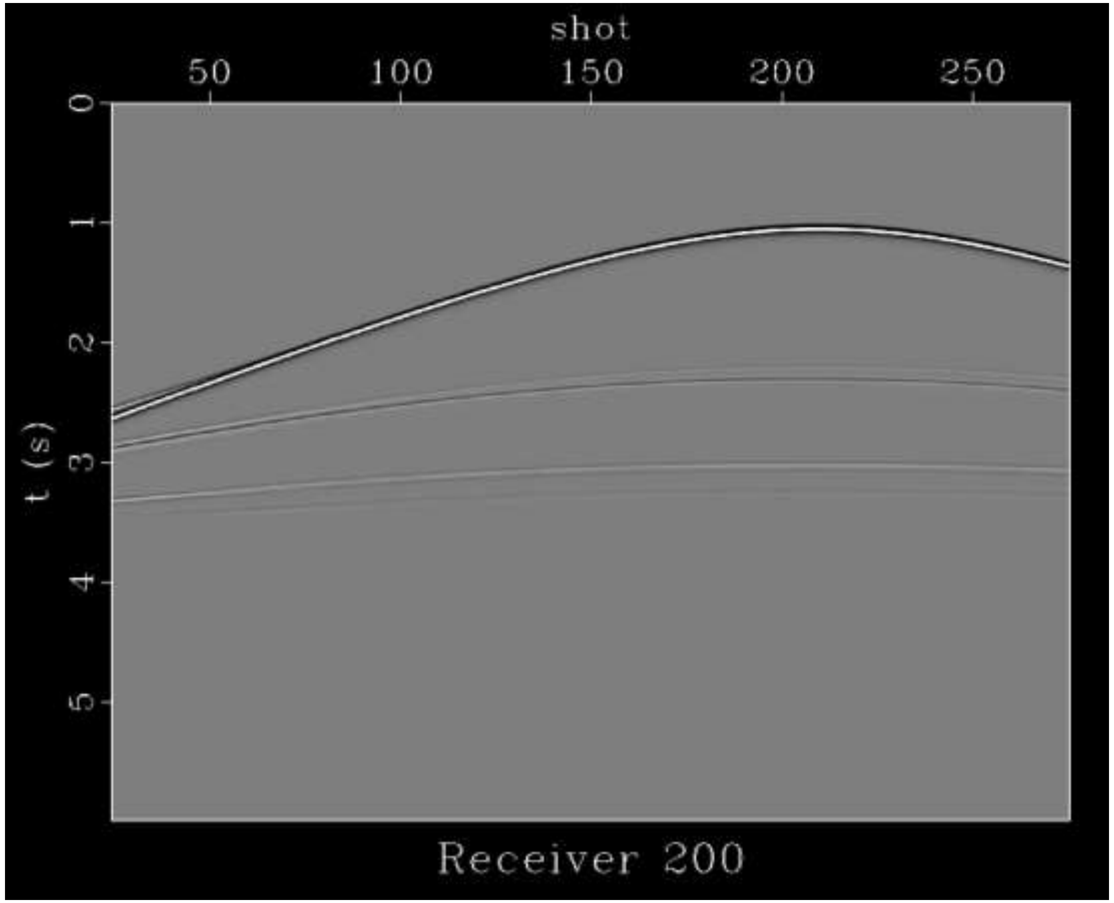


Original unblended data

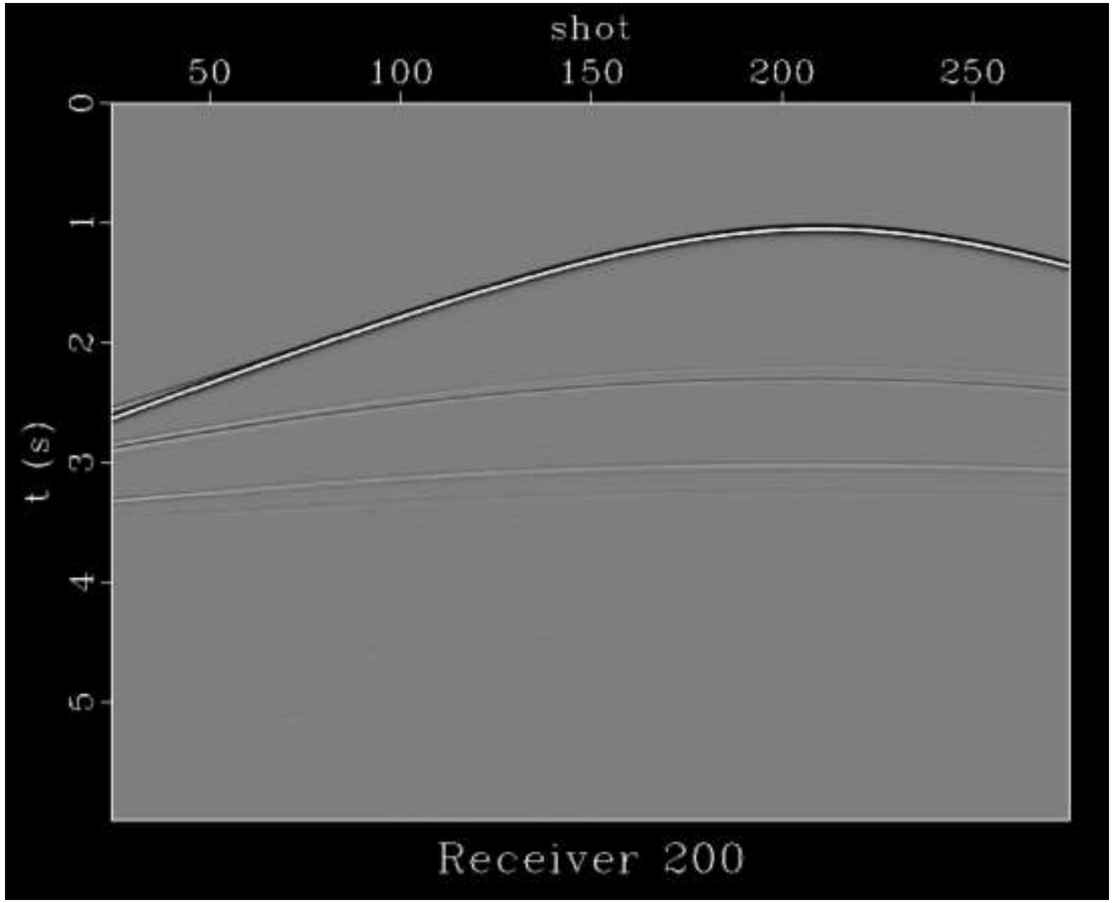


Data after LS-solution

Results – Synthetic data (Receiver domain)

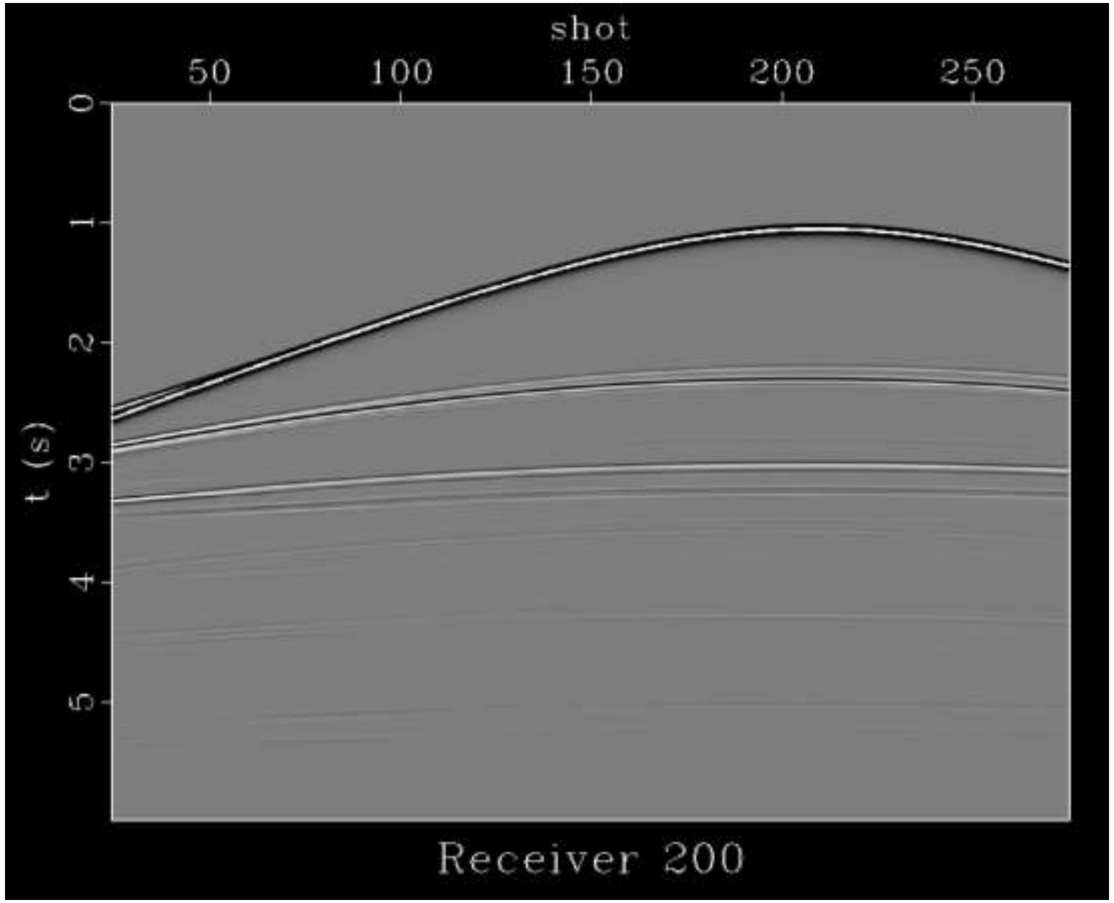


Original unblended data

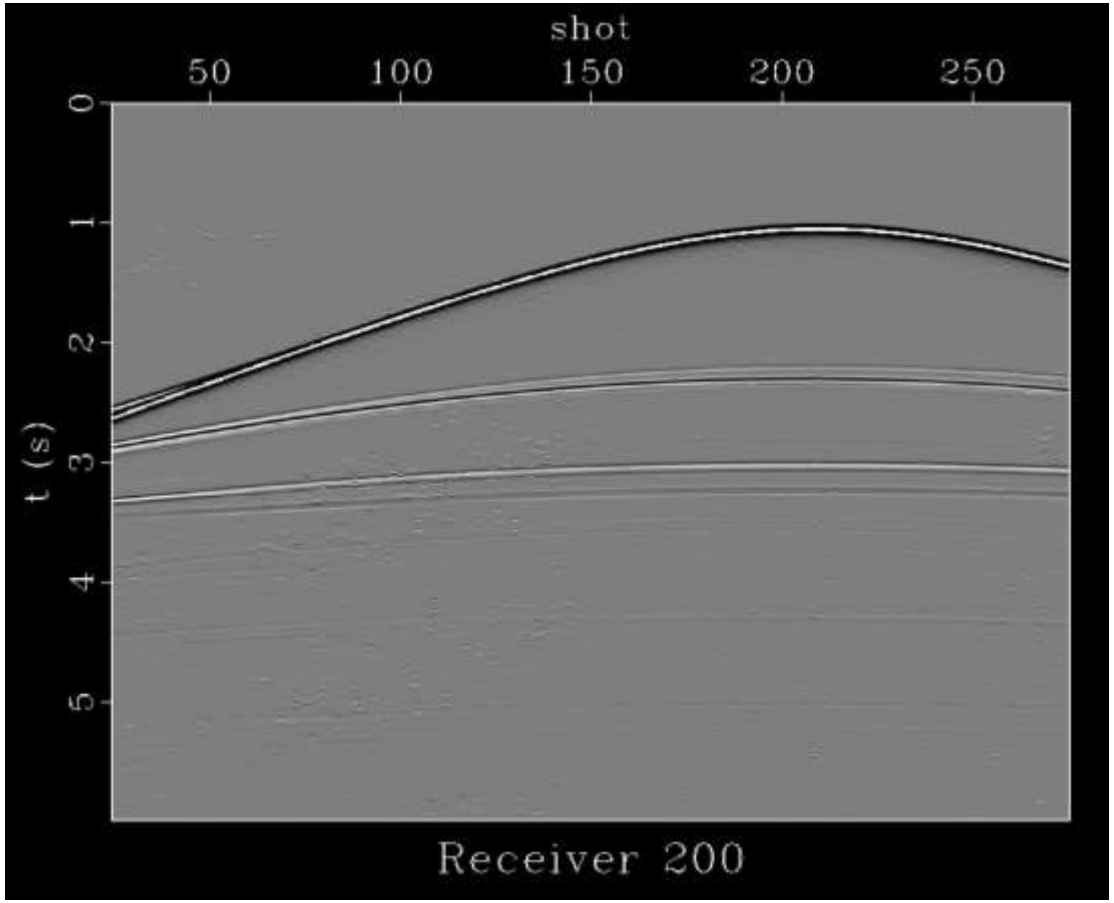


Deblended data after 30 iterations

Results – Synthetic data (Receiver domain)



Original unblended data
(with CLIPPING)



Deblended data after 30 iterations
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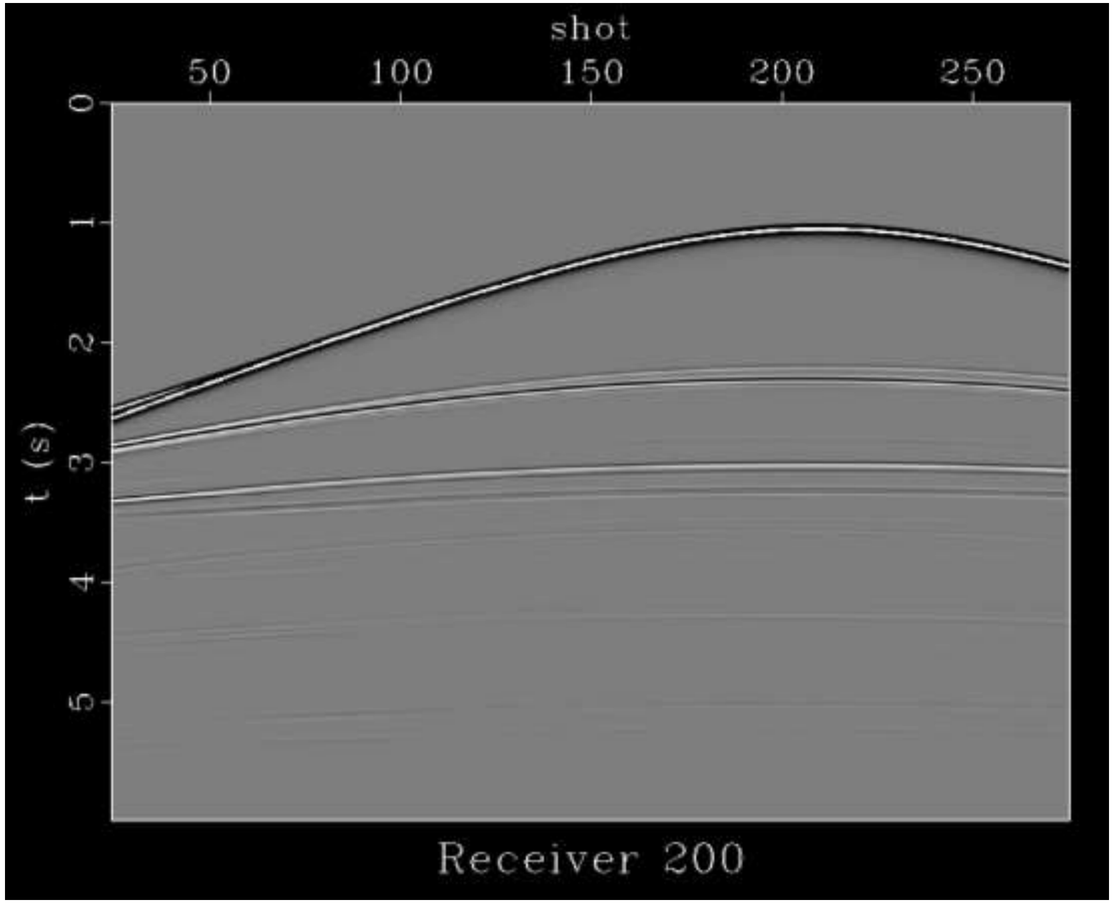
Results – Synthetic data (Receiver domain)



Original unblended data
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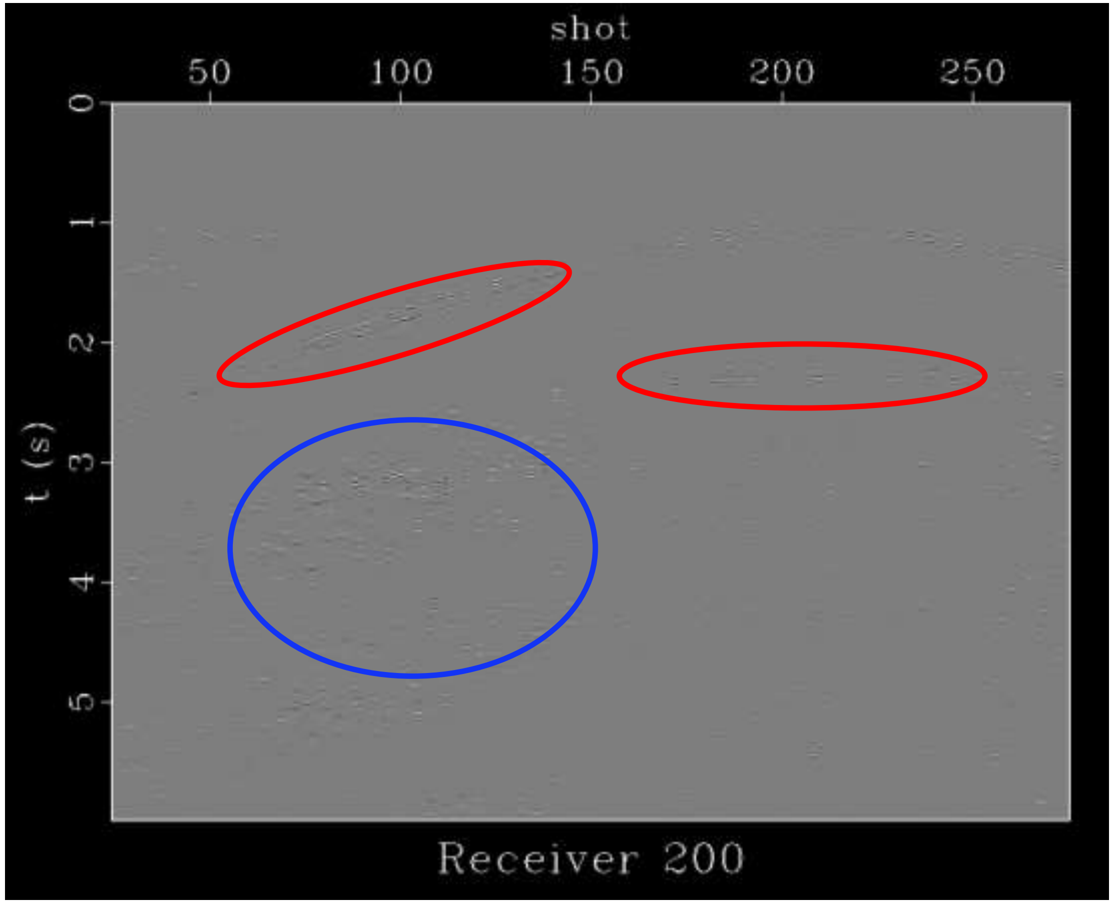
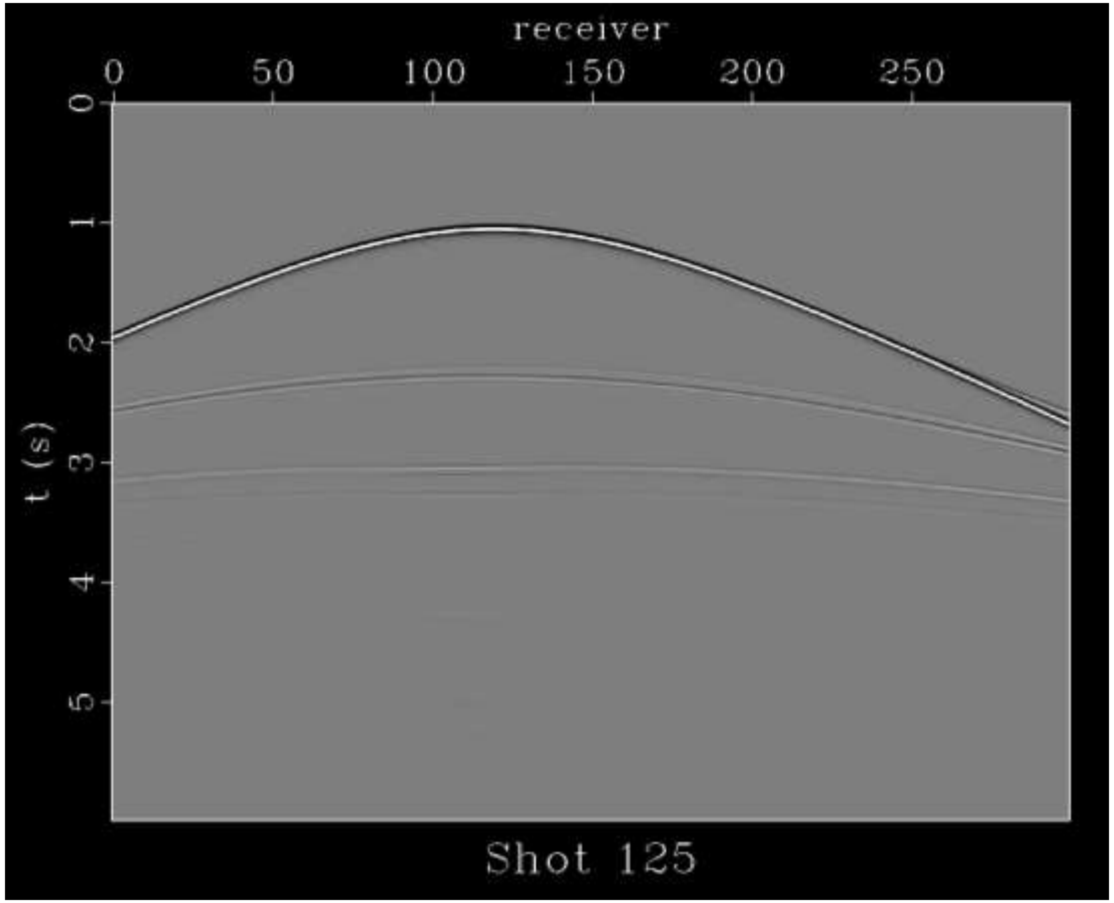


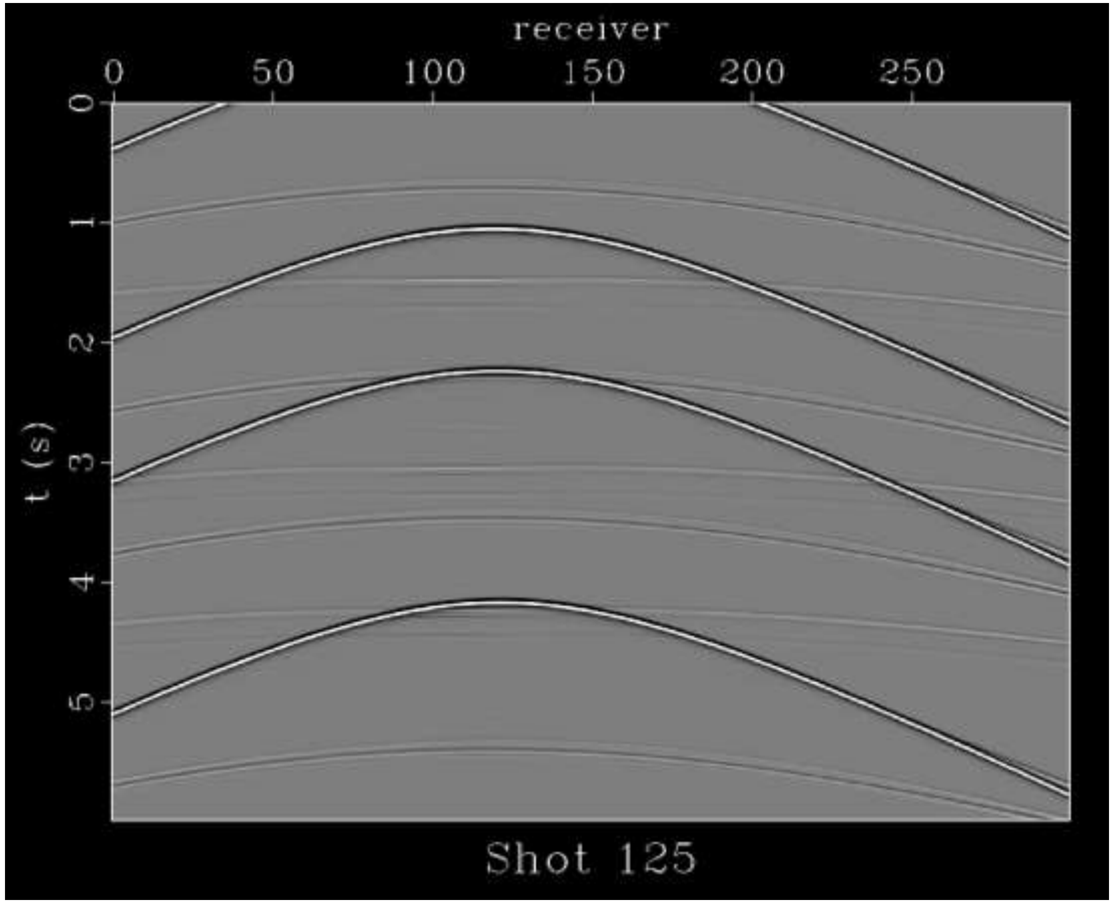
Deblending ERROR
(with CLIPPING)

Comparative Analysis in the Shot Domain

Results – Synthetic data (Shot domain)

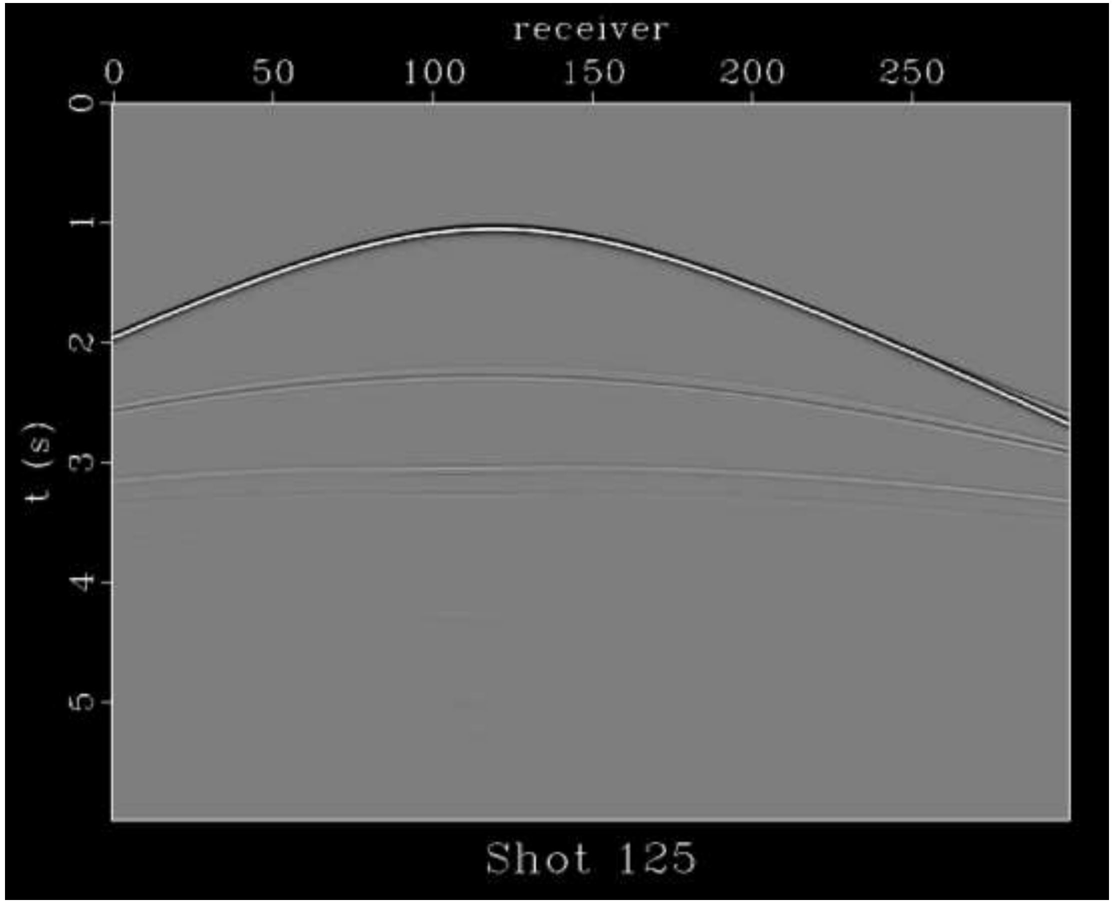


Original unblended data



Data after LS-solution

Results – Synthetic data (Shot domain)



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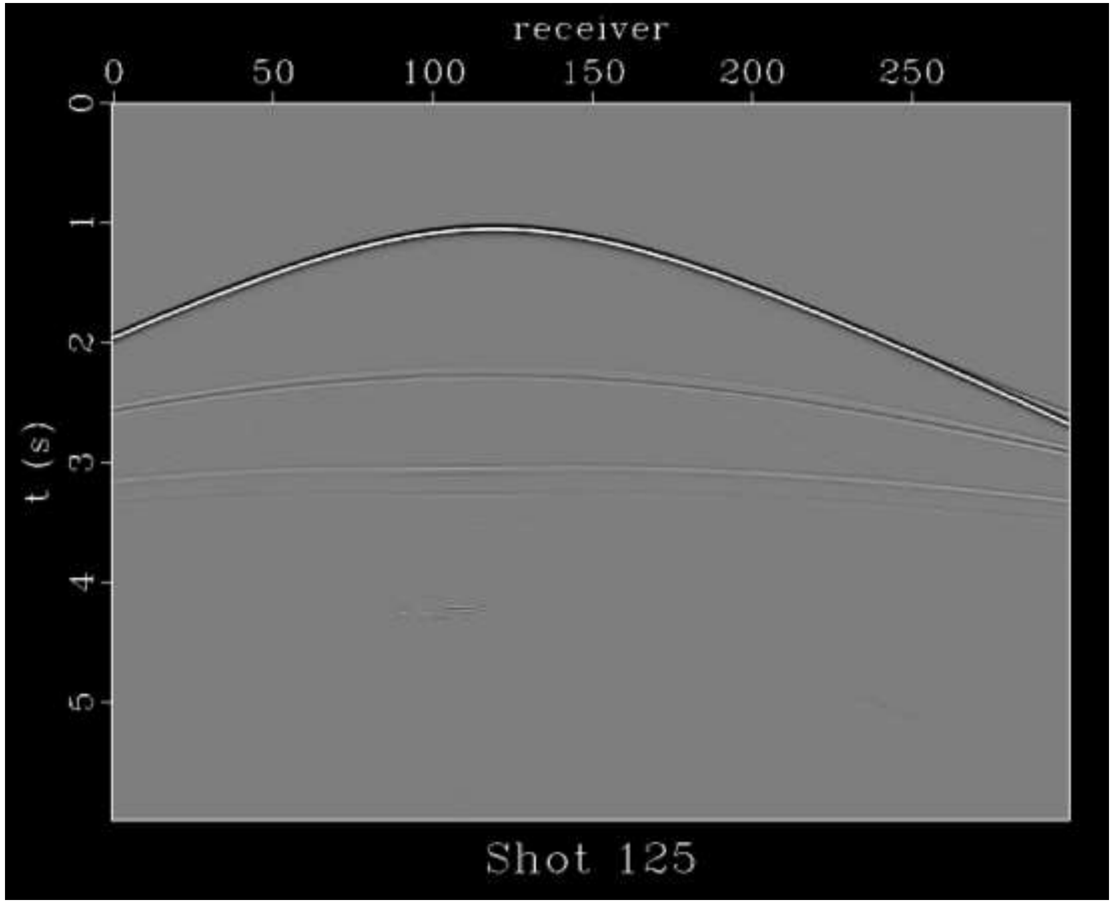
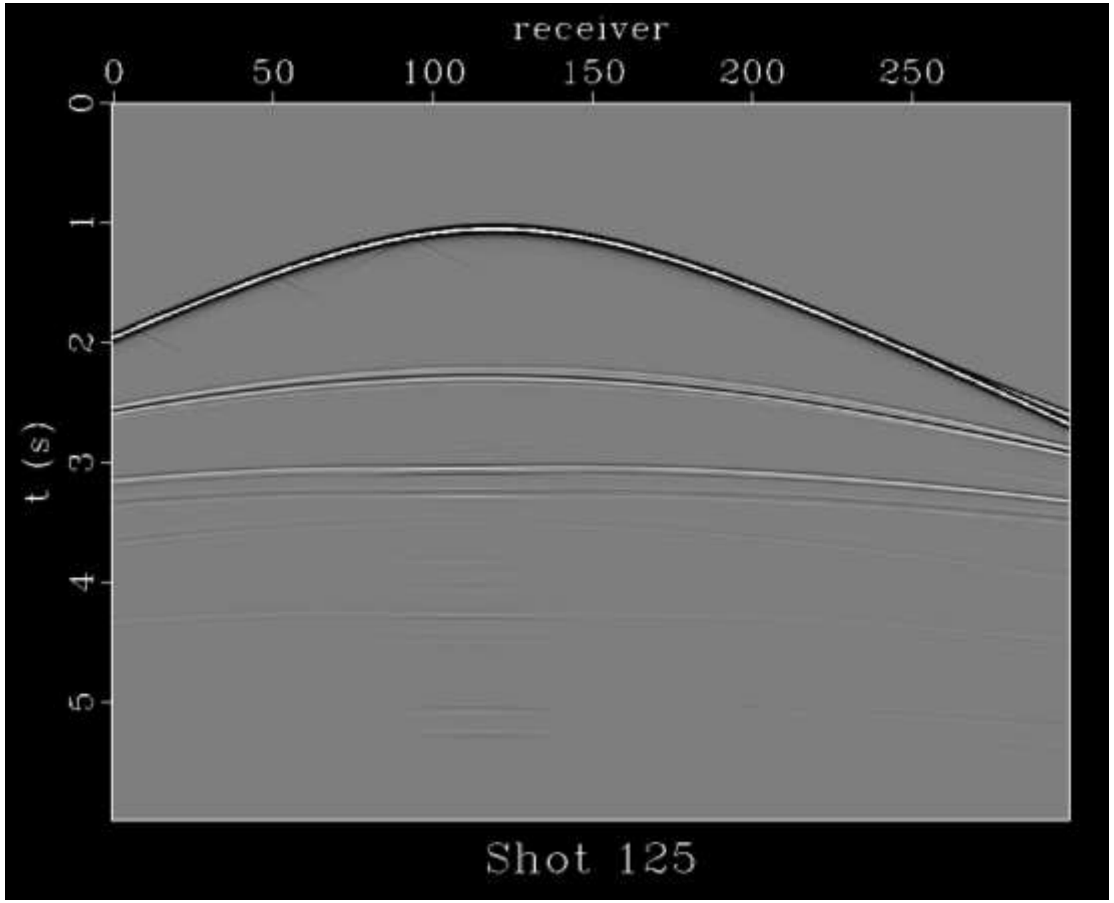
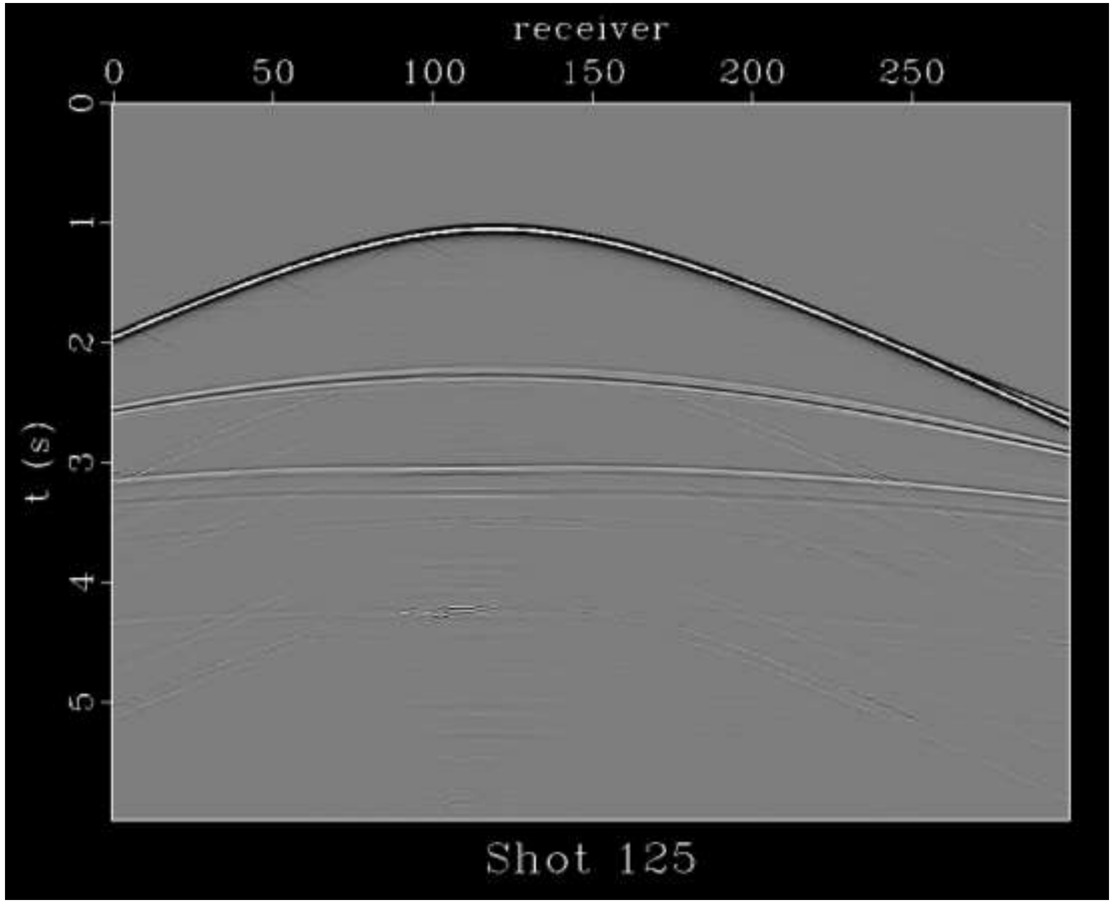


Deblended data after 30 iterations

Results – Synthetic data (Shot domain)

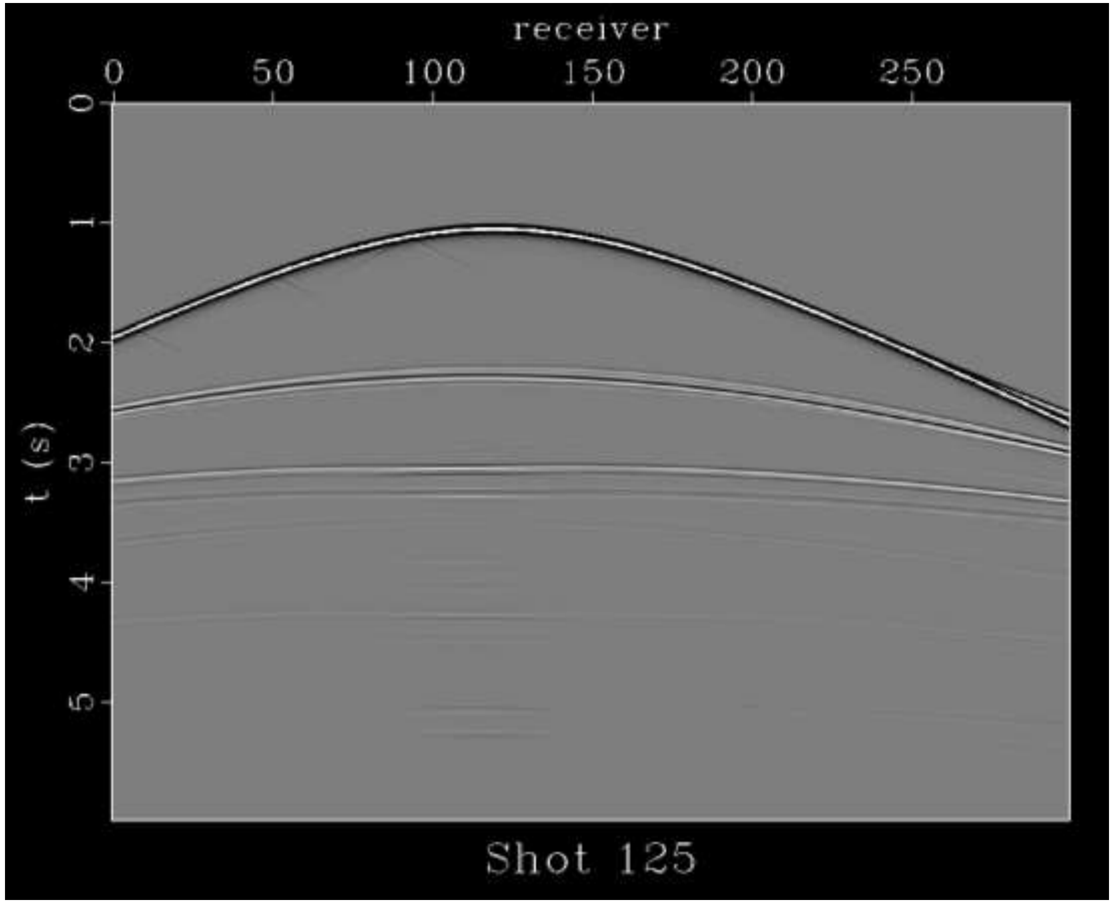


Original unblended data
(with CLIPPING)

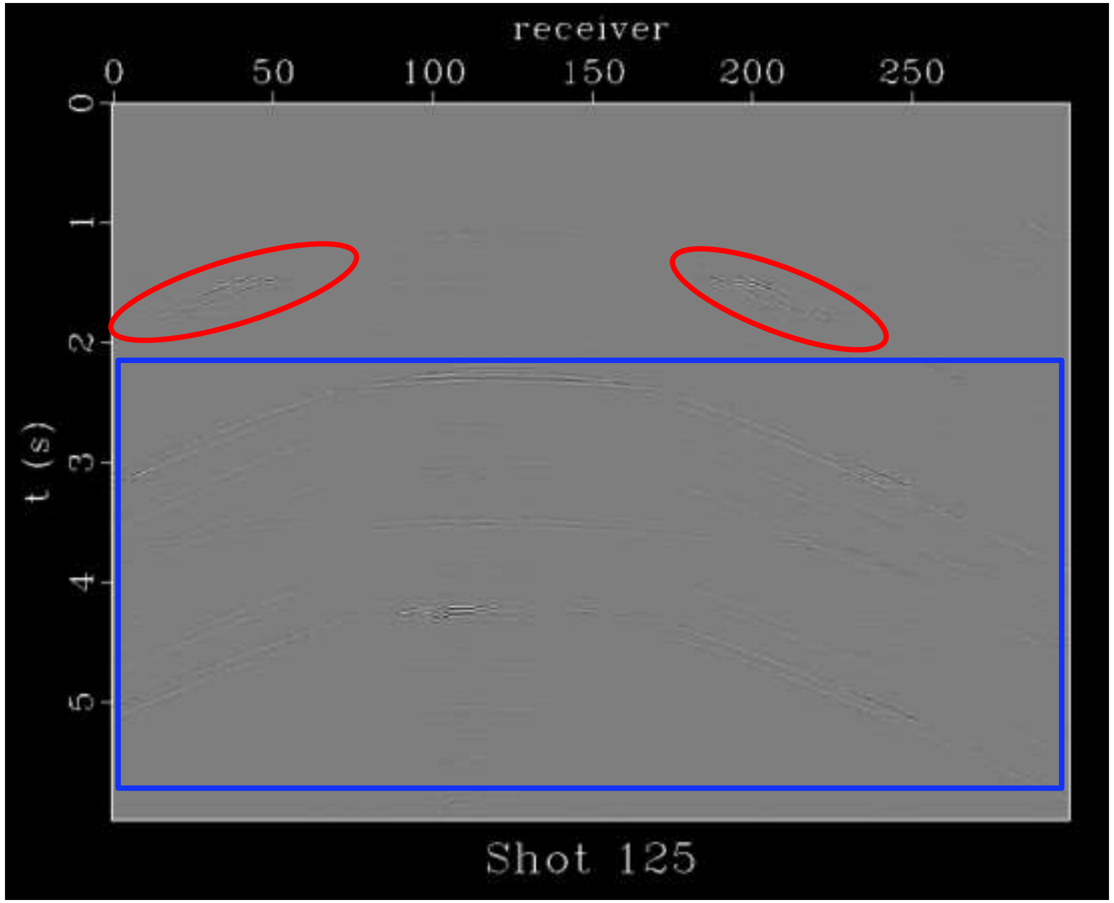


Deblended data after 30 iterations
(with CLIPPING)

Results – Synthetic data (Shot domain)



Original unblended data
(with CLIPPING)

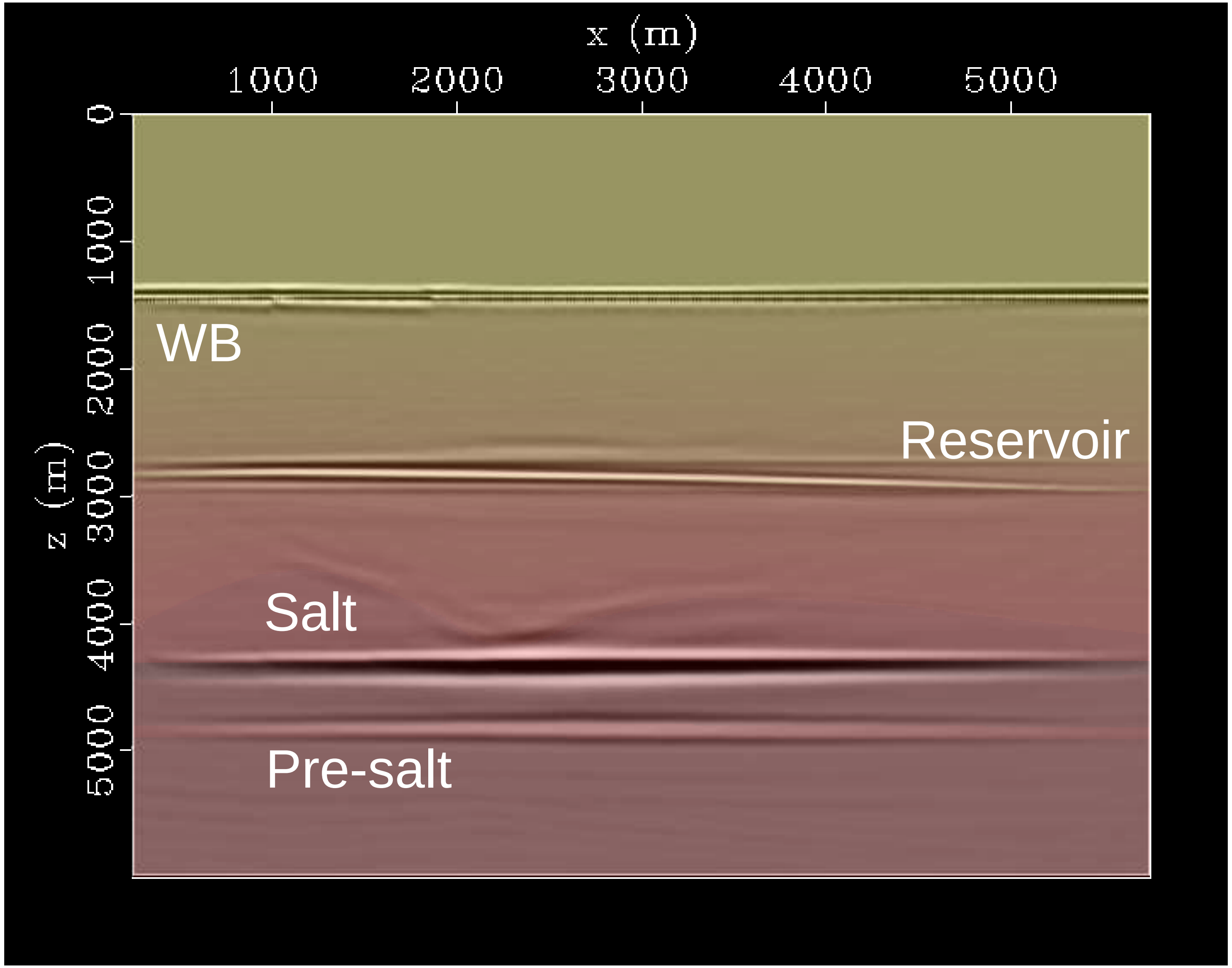


Deblending ERROR
(with CLIPPING)

In pursuit of new ideas

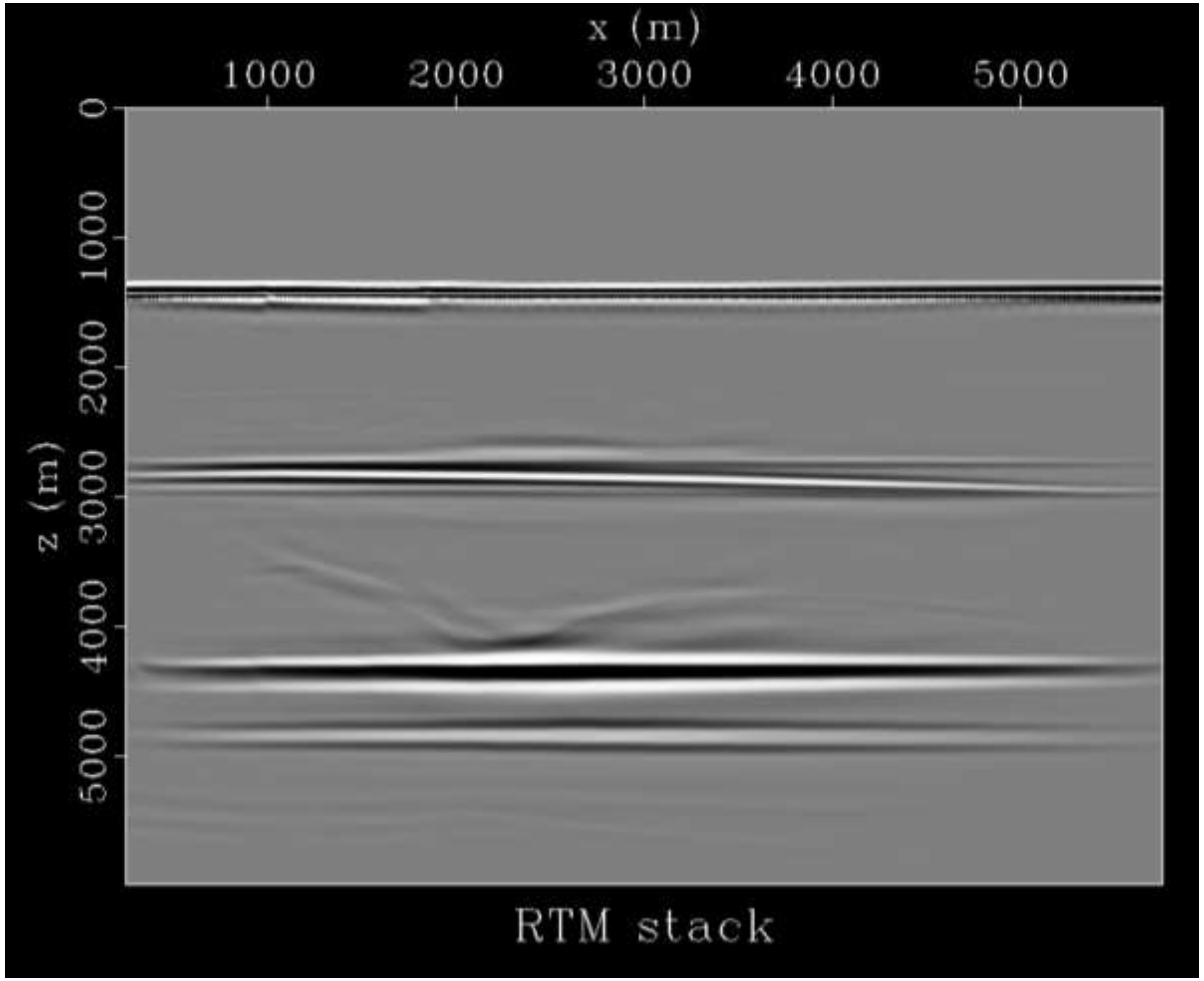
Comparative Analysis in the Image Domain – RTM (Quantitative analysis)

Results – Synthetic data (RTM & Velocity overlay)

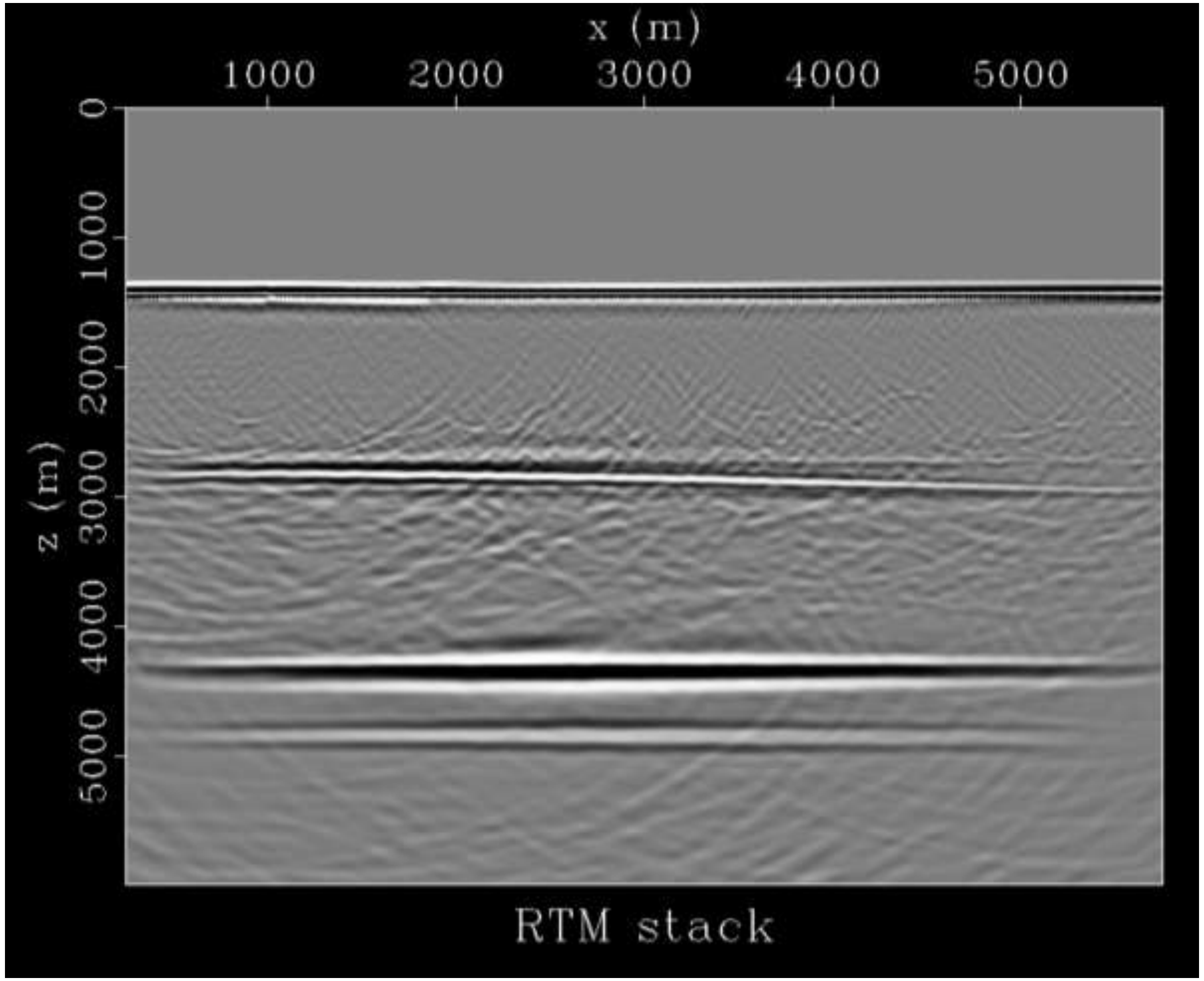


Results – Synthetic data (RTM)

RCP
In pursuit of new ideas

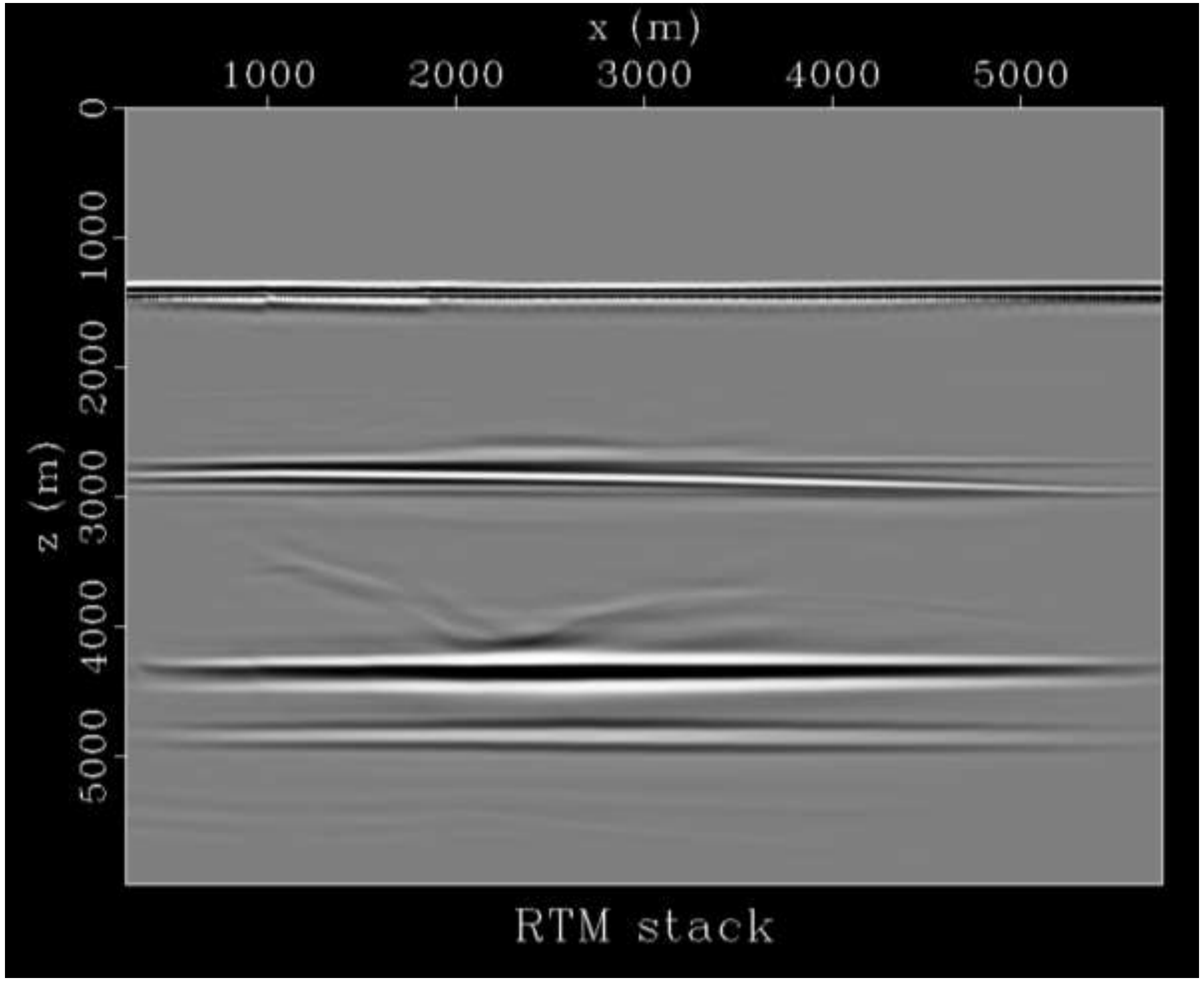


Original unblended data

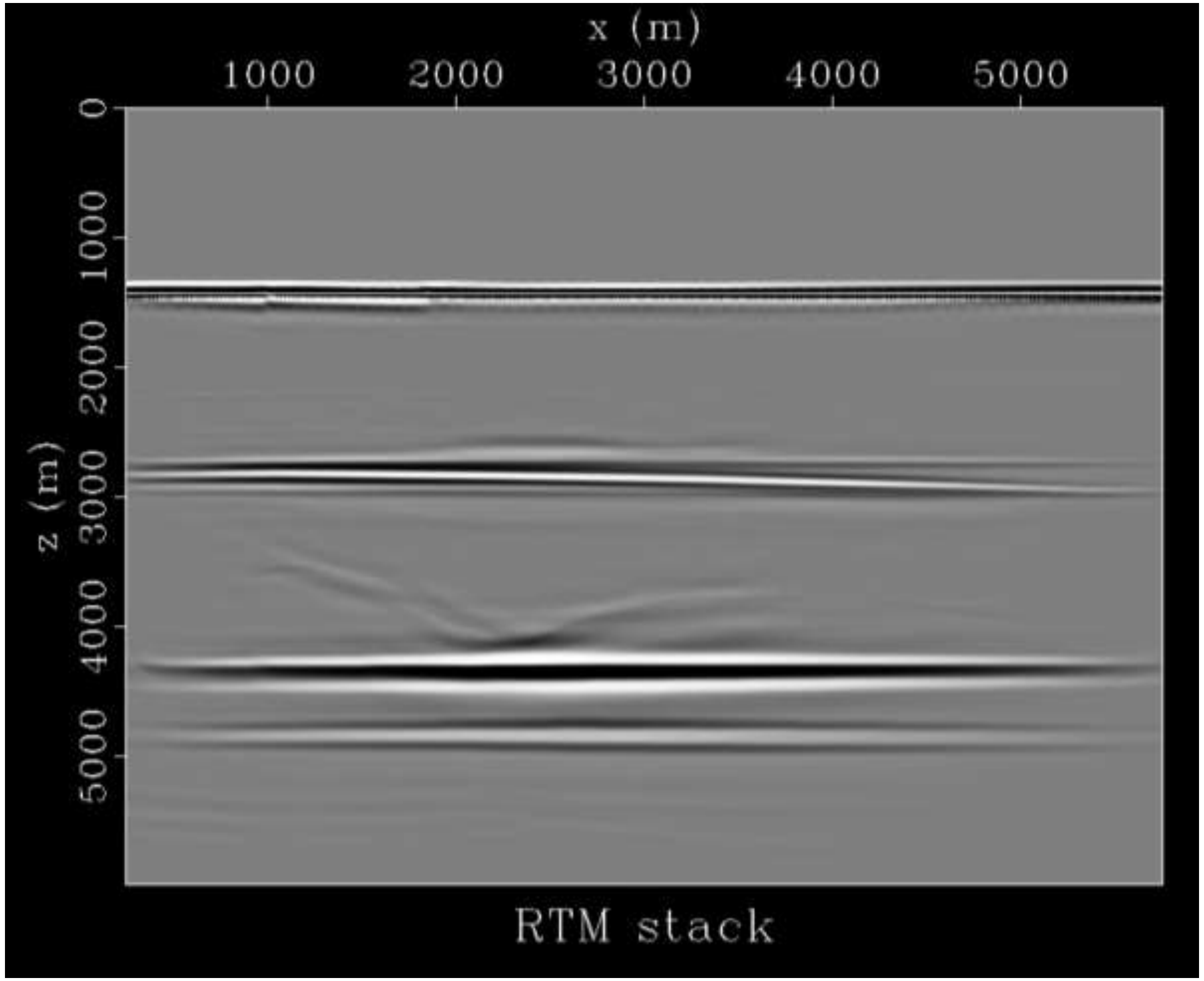


Data after LS-solution

Results – Synthetic data (RTM)

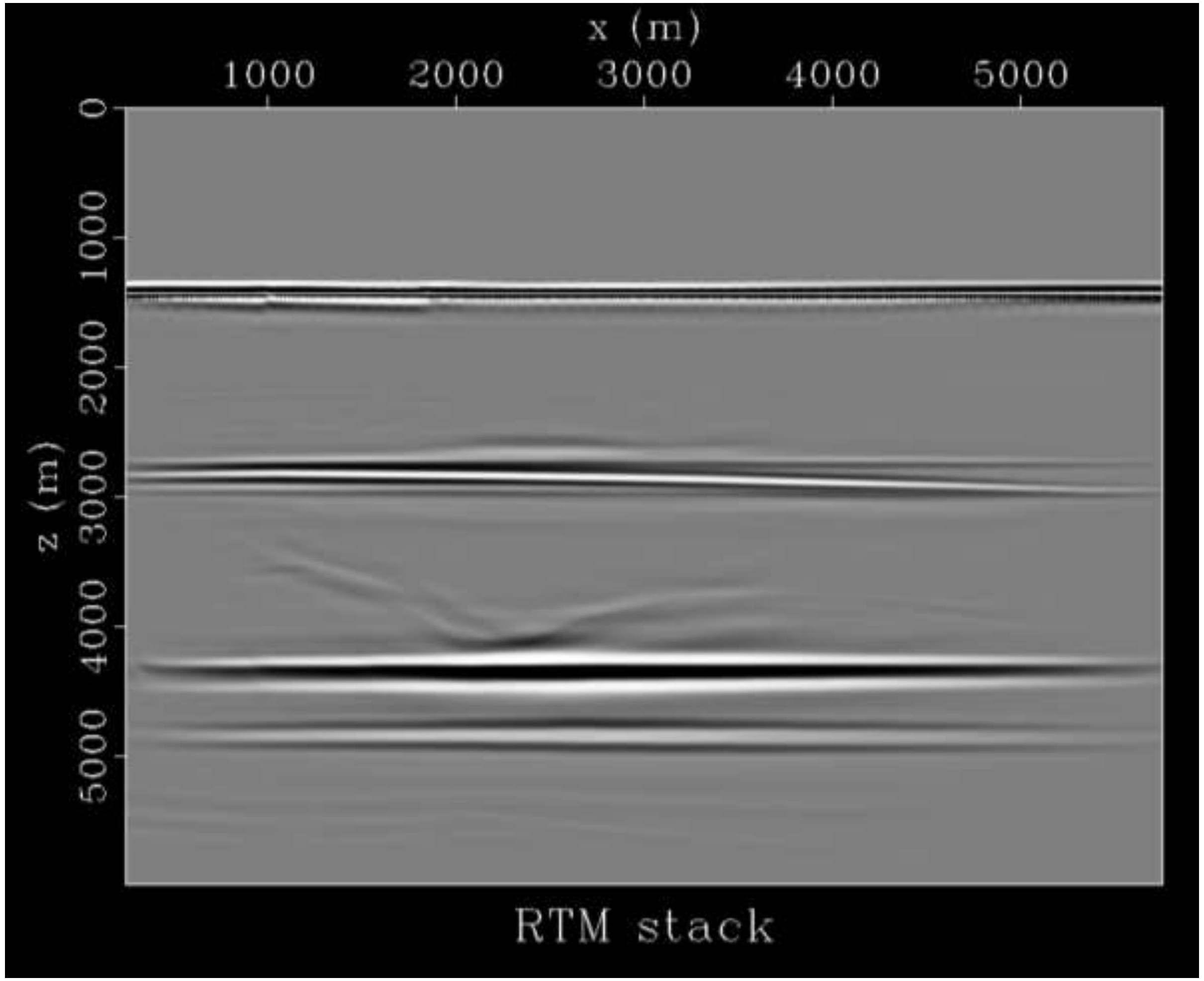


Original unblended data

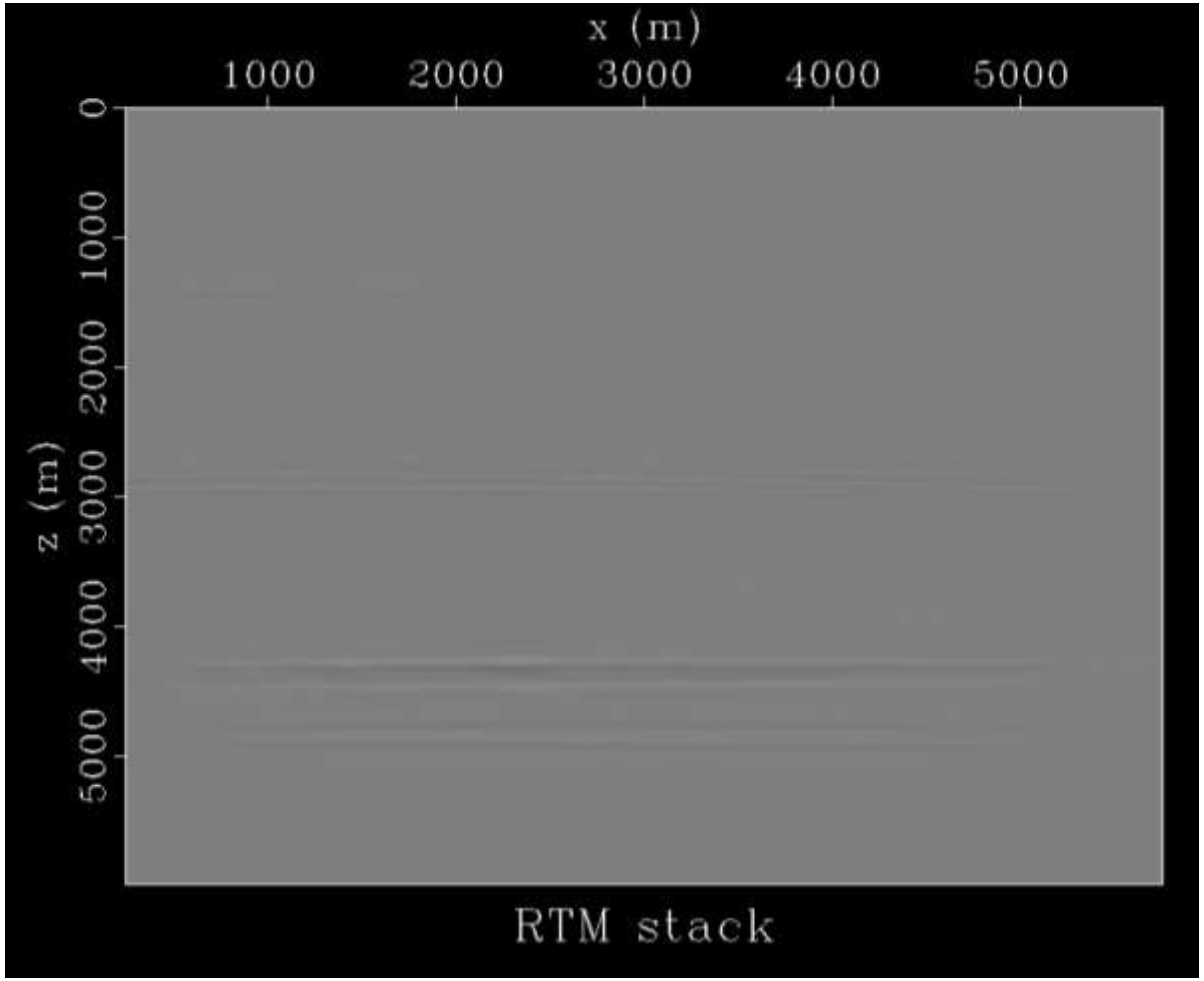


Deblended data after 30 iterations

Results – Synthetic data (RTM)

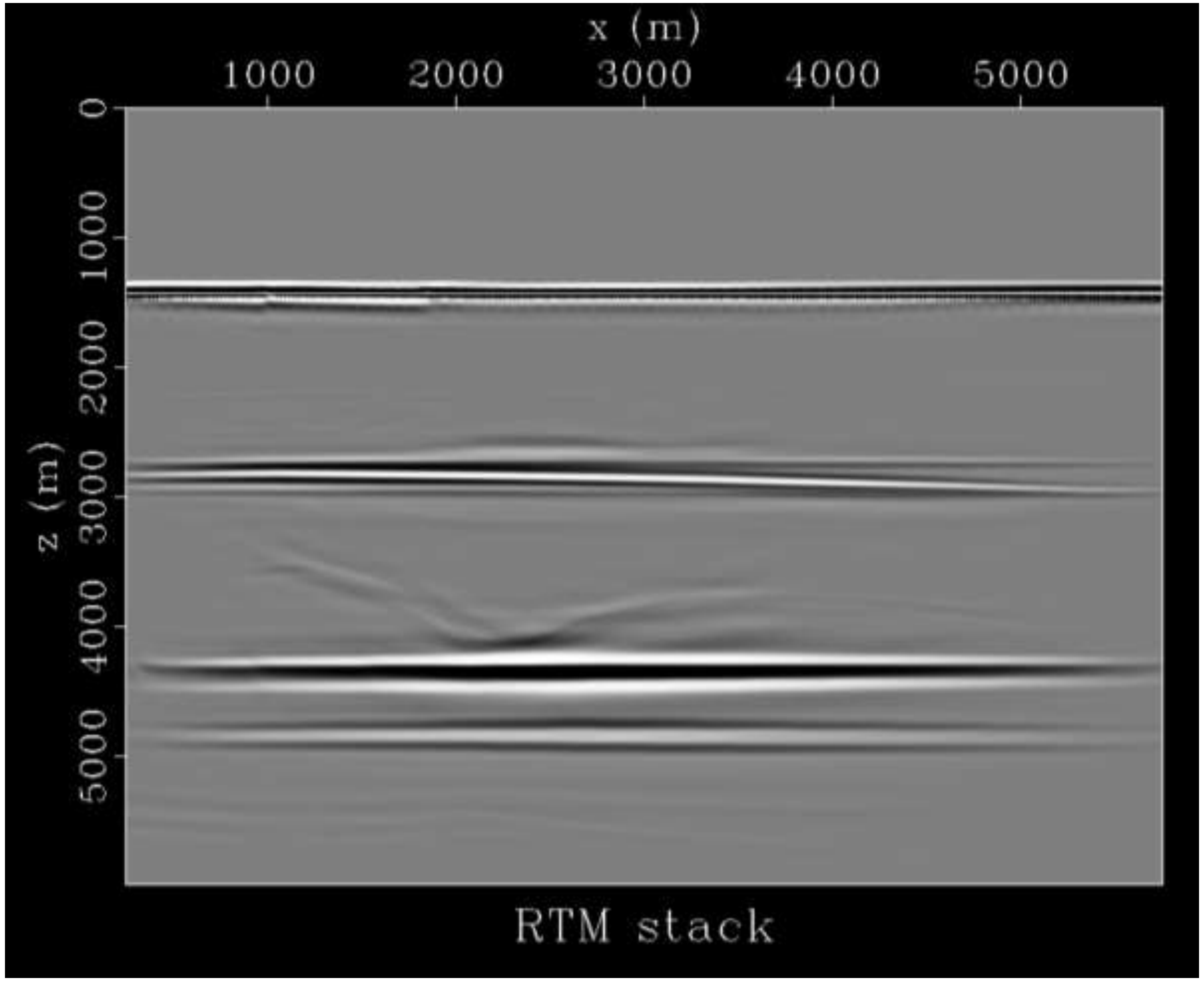


Original unblended data

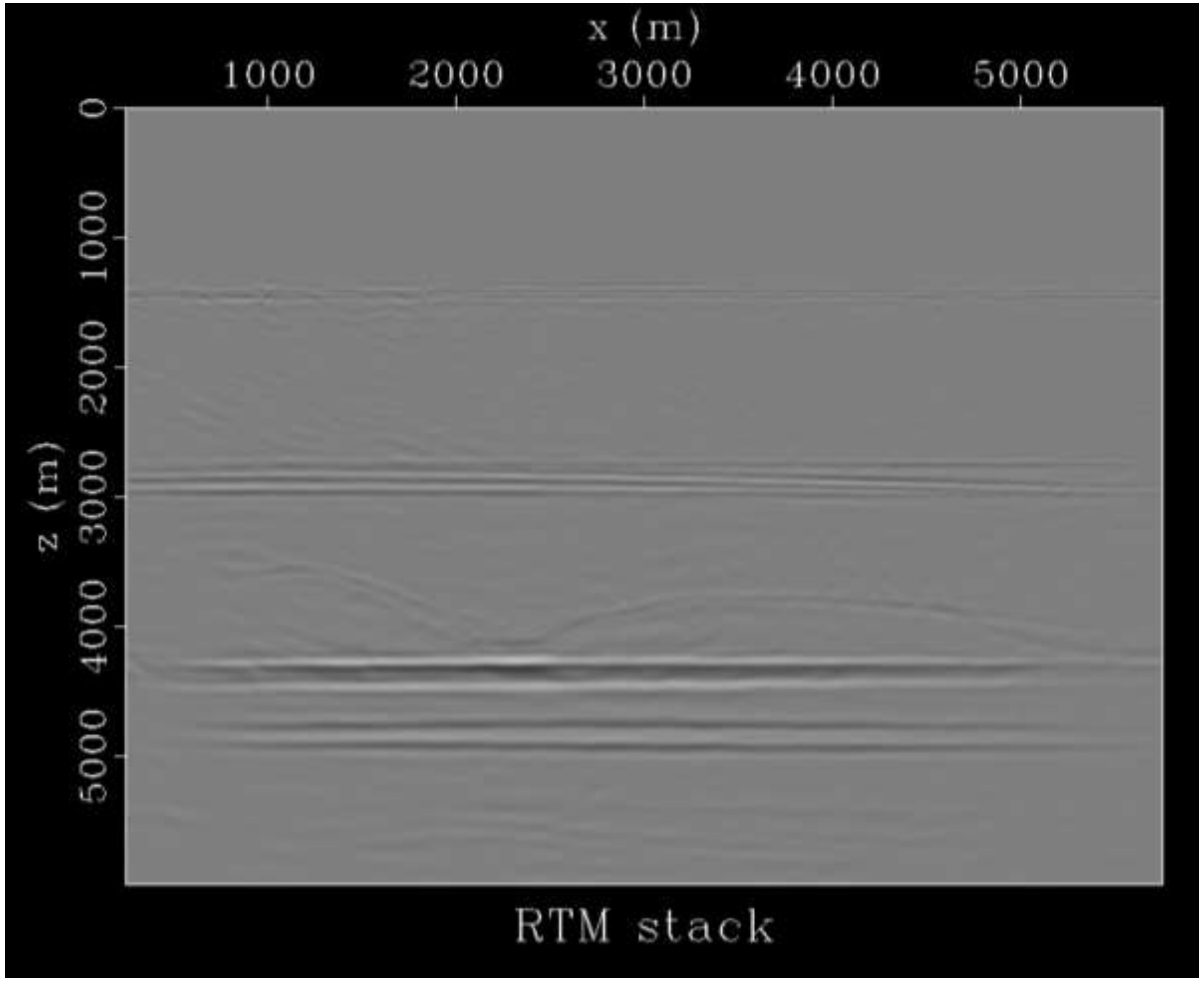


Deblending ERROR

Results – Synthetic data (RTM)



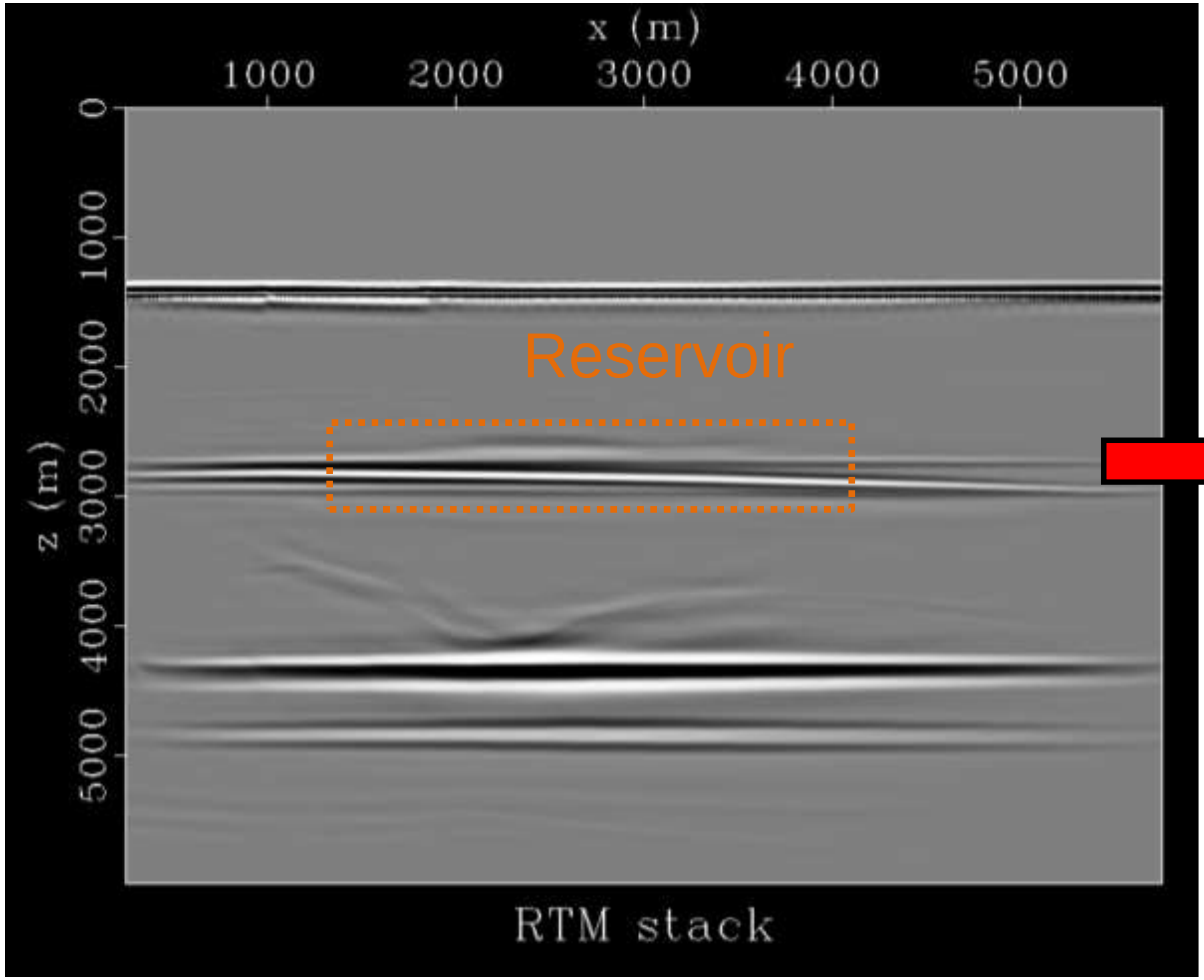
Original unblended data

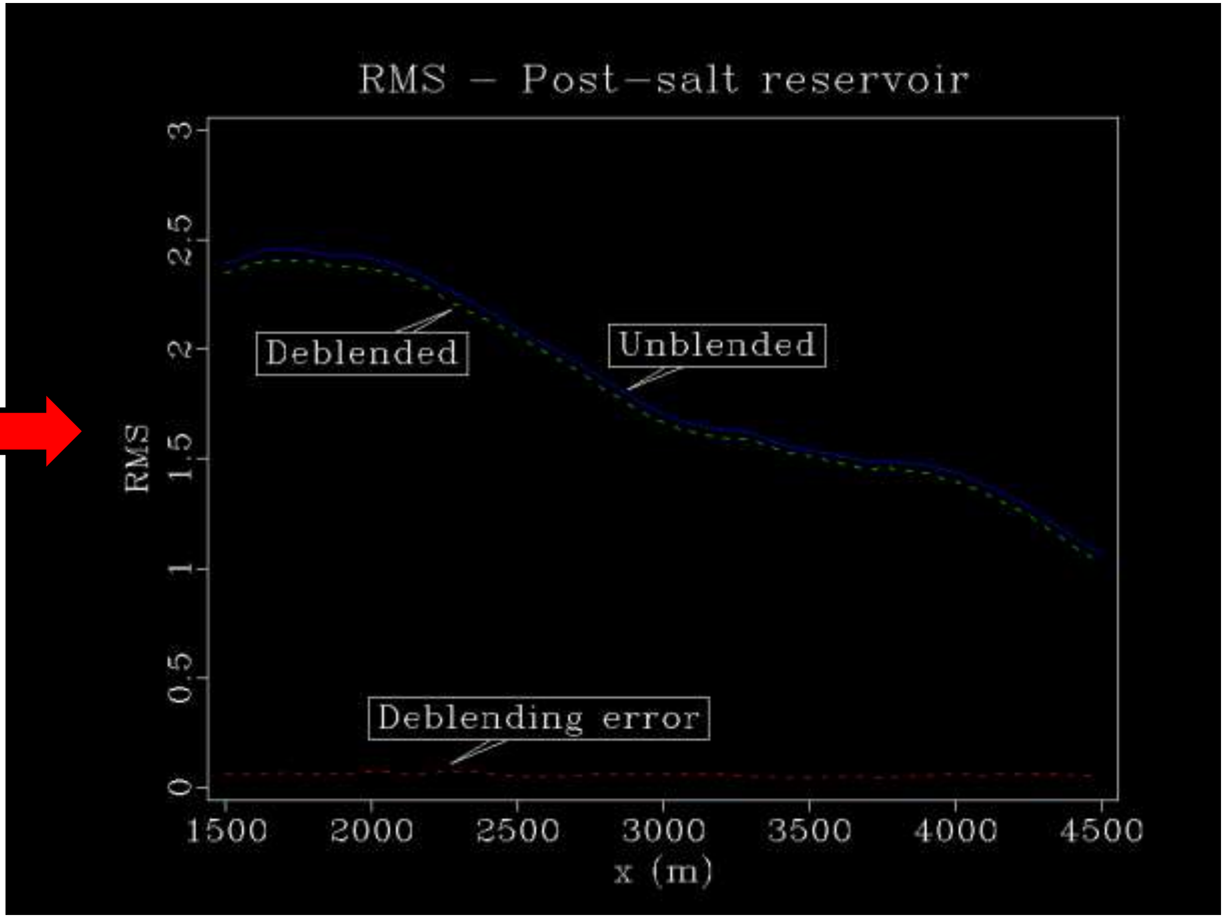


Deblending ERROR
(with GAIN 5x)

Results – Synthetic data – Quantitative analysis

RCP
In pursuit of new ideas

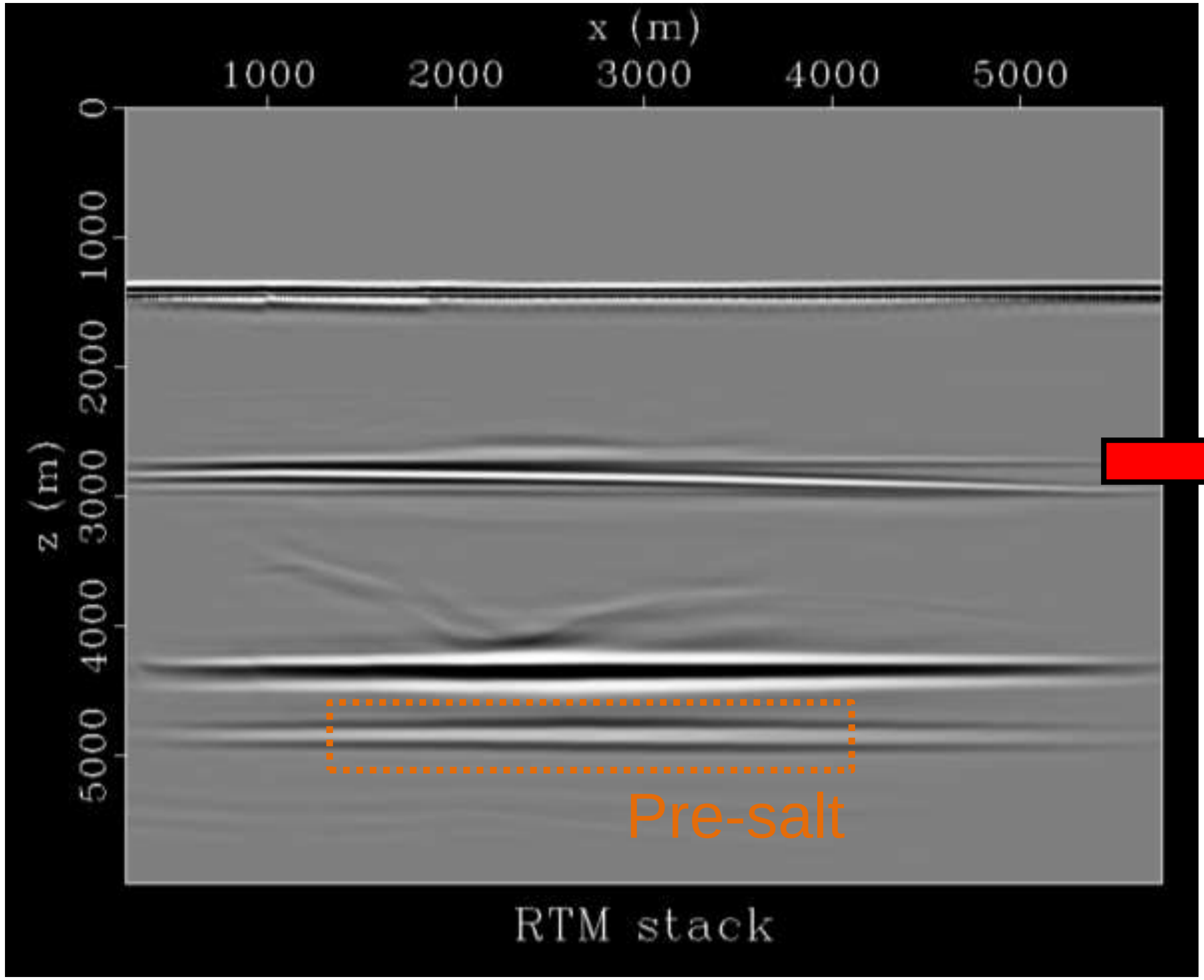


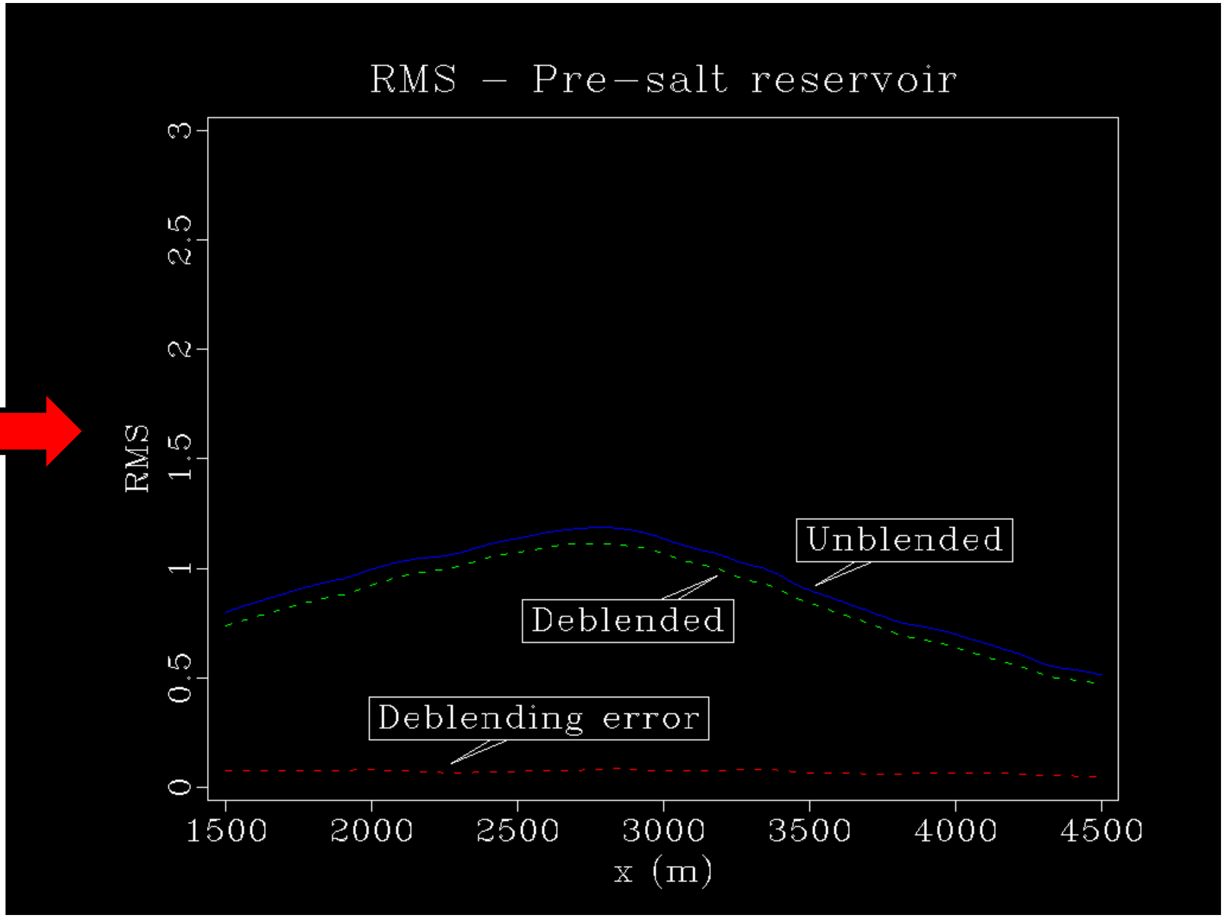


$$RMS = \frac{\sqrt{\sum_{i=1}^{n} x_i^2}}{n}$$

Results – Synthetic data – Quantitative analysis

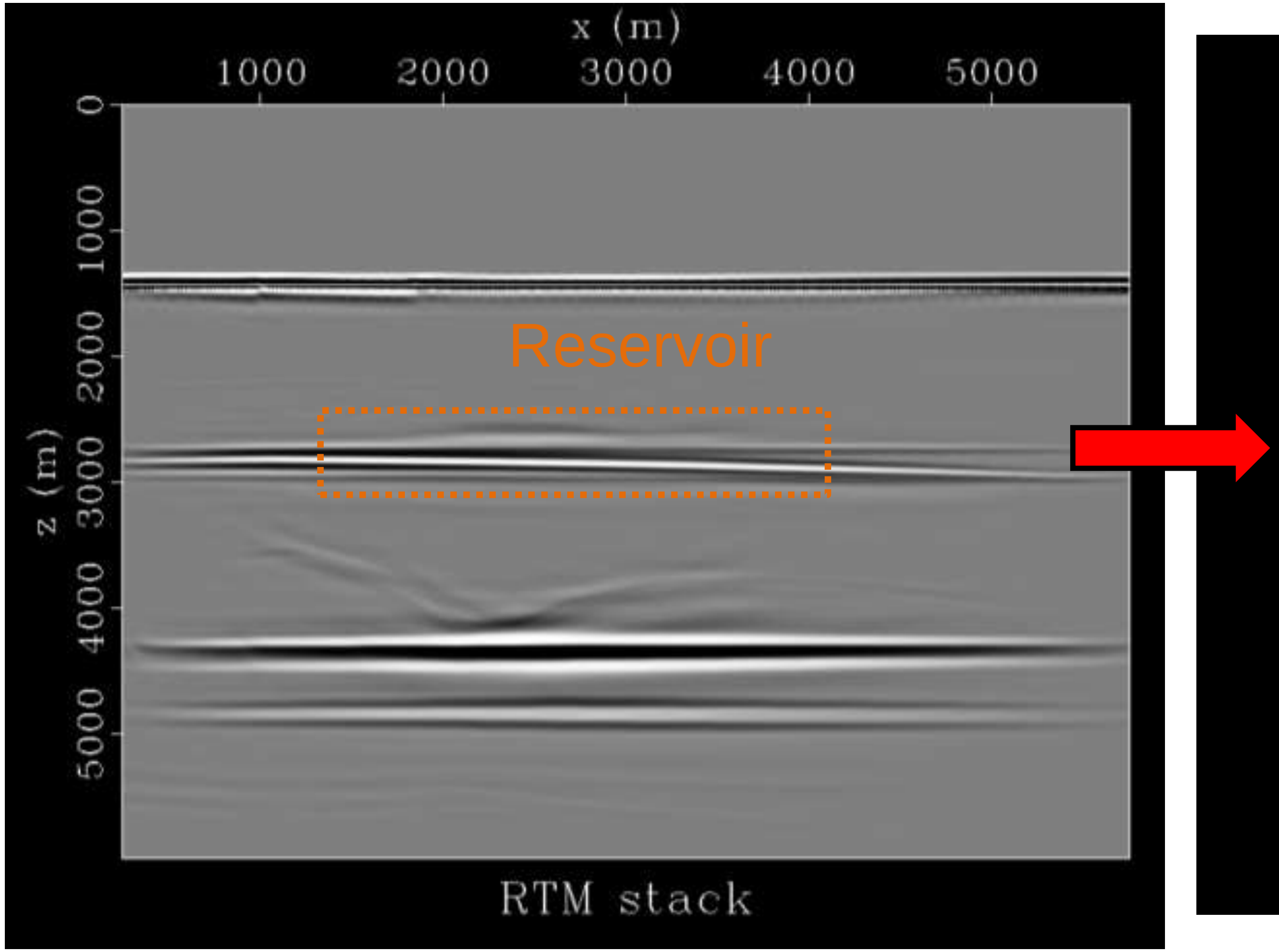
RCP
In pursuit of new ideas

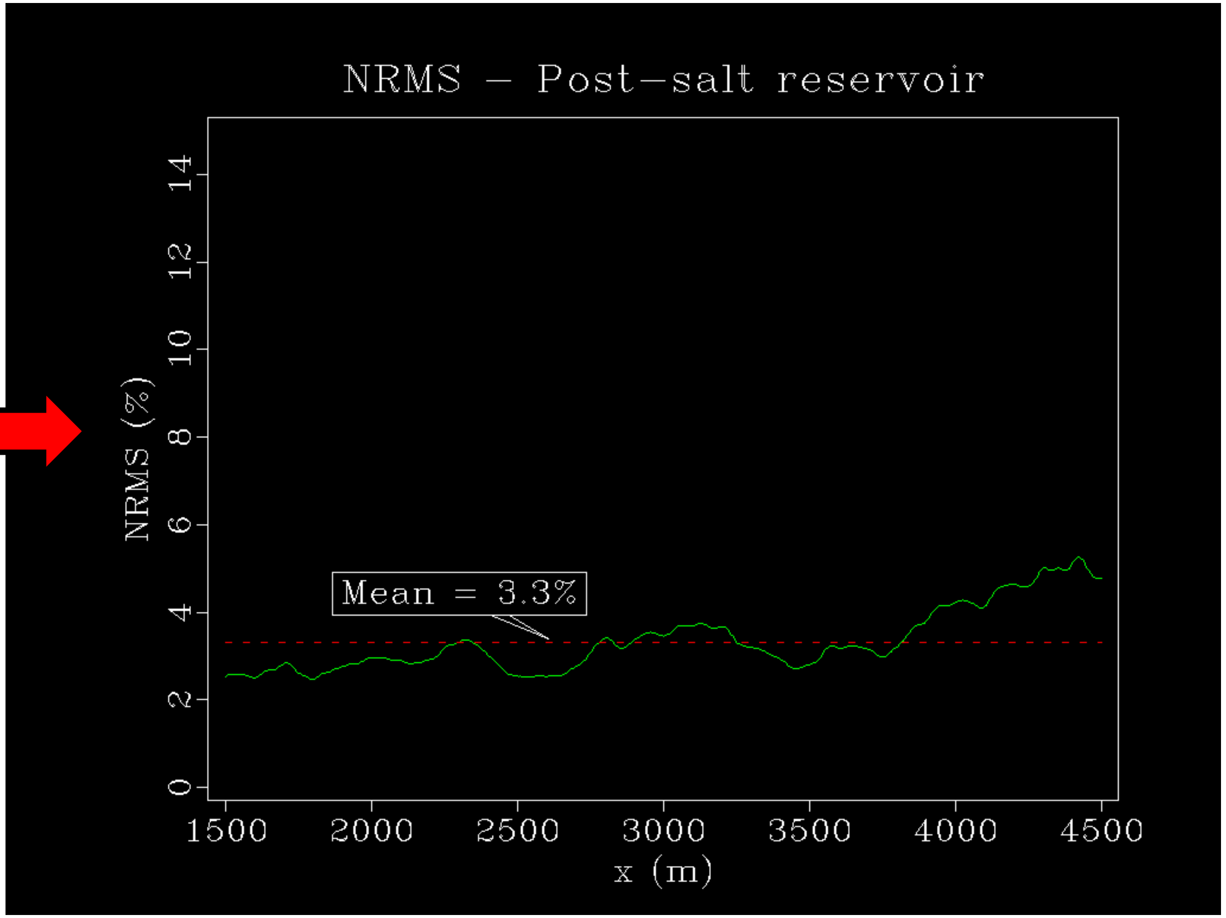




$$RMS = \frac{\sqrt{\sum_{i=1}^{n} x_i^2}}{n}$$

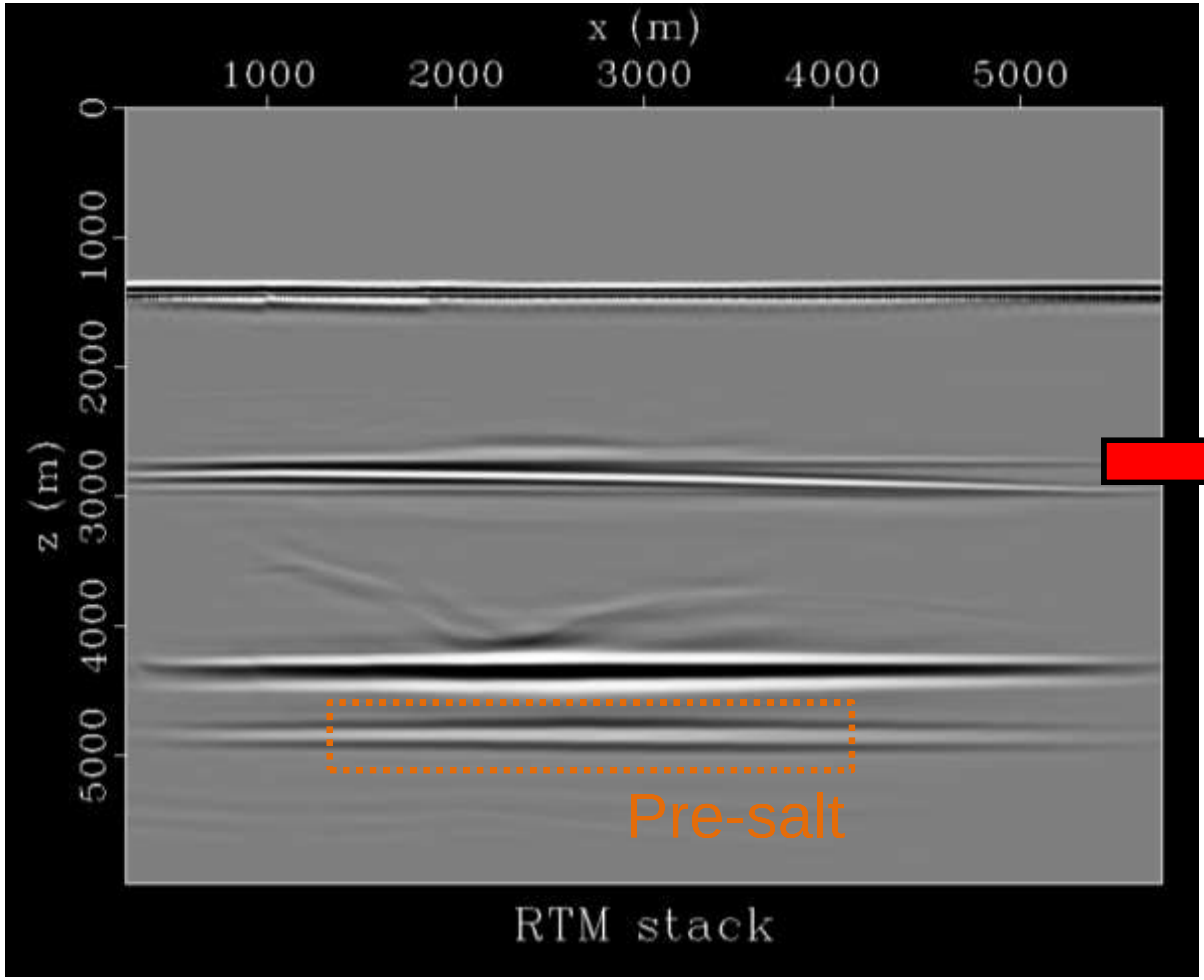
Results – Synthetic data – Quantitative analysis

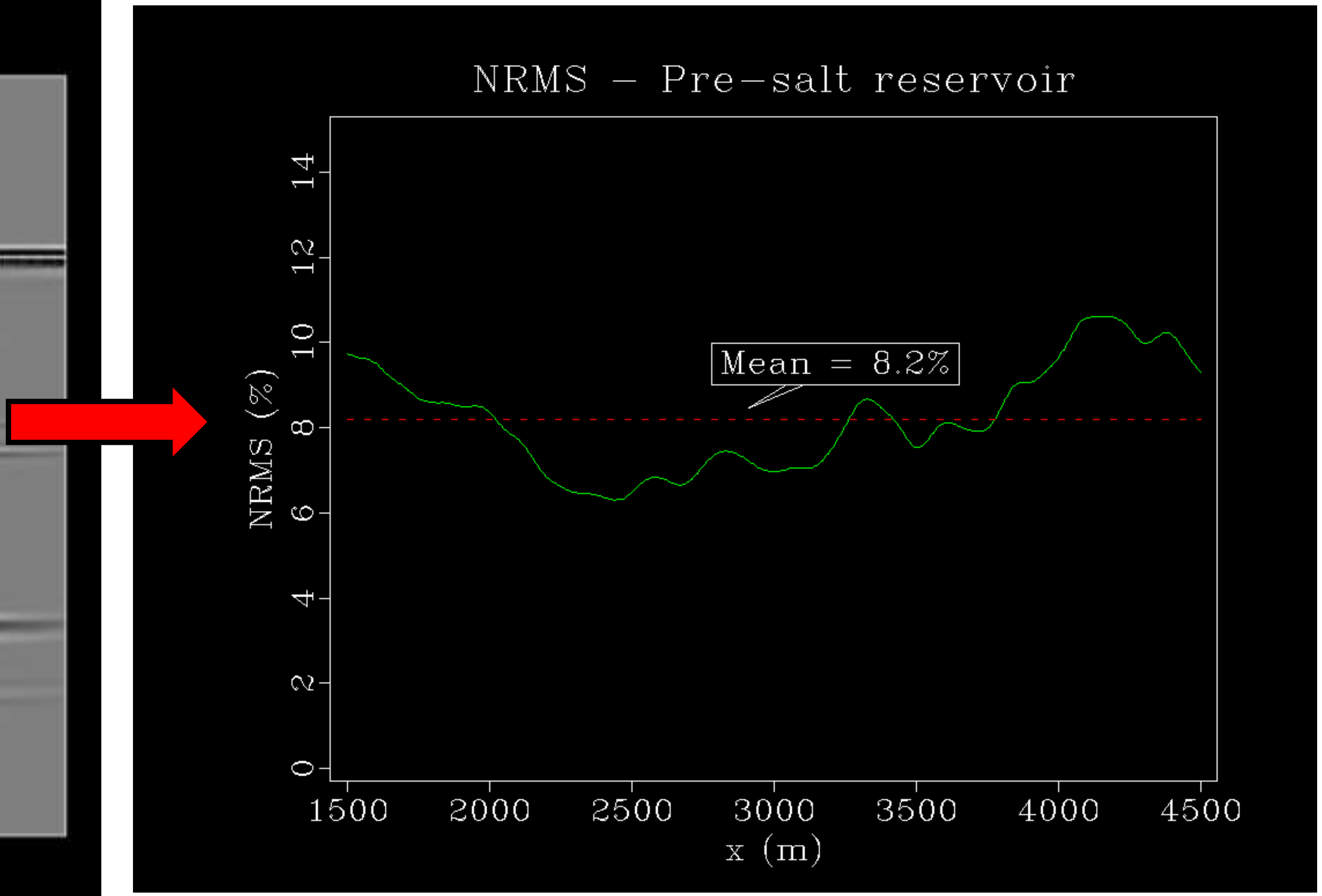




$$NRMS = 200 \times \frac{RMS_{(Unbl-Debl)}}{RMS_{Unbl} + RMS_{Debl}}$$

Results – Synthetic data – Quantitative analysis





$$NRMS = 200 \times \frac{RMS_{(Unbl-Debl)}}{RMS_{Unbl} + RMS_{Debl}}$$

Outline

- Objective
- Theoretical background
  - Blending
  - Deblending
- Results
  - Synthetic data
  - Field data (preliminary results)
- Final remarks
- Next steps

Results – Field data – Jubarte PRM (Base survey)

RCP In pursuit of new ideas

General Acquisition Parameters:

Shot Survey Area = 11km x 11km

Shot grid = 25m x 25m

Shots per sail-line = 440

Receiver patch = 3km x 3km

Receiver grid = 300m x 50m

N° receivers = 712

Record Length = 10,240 ms

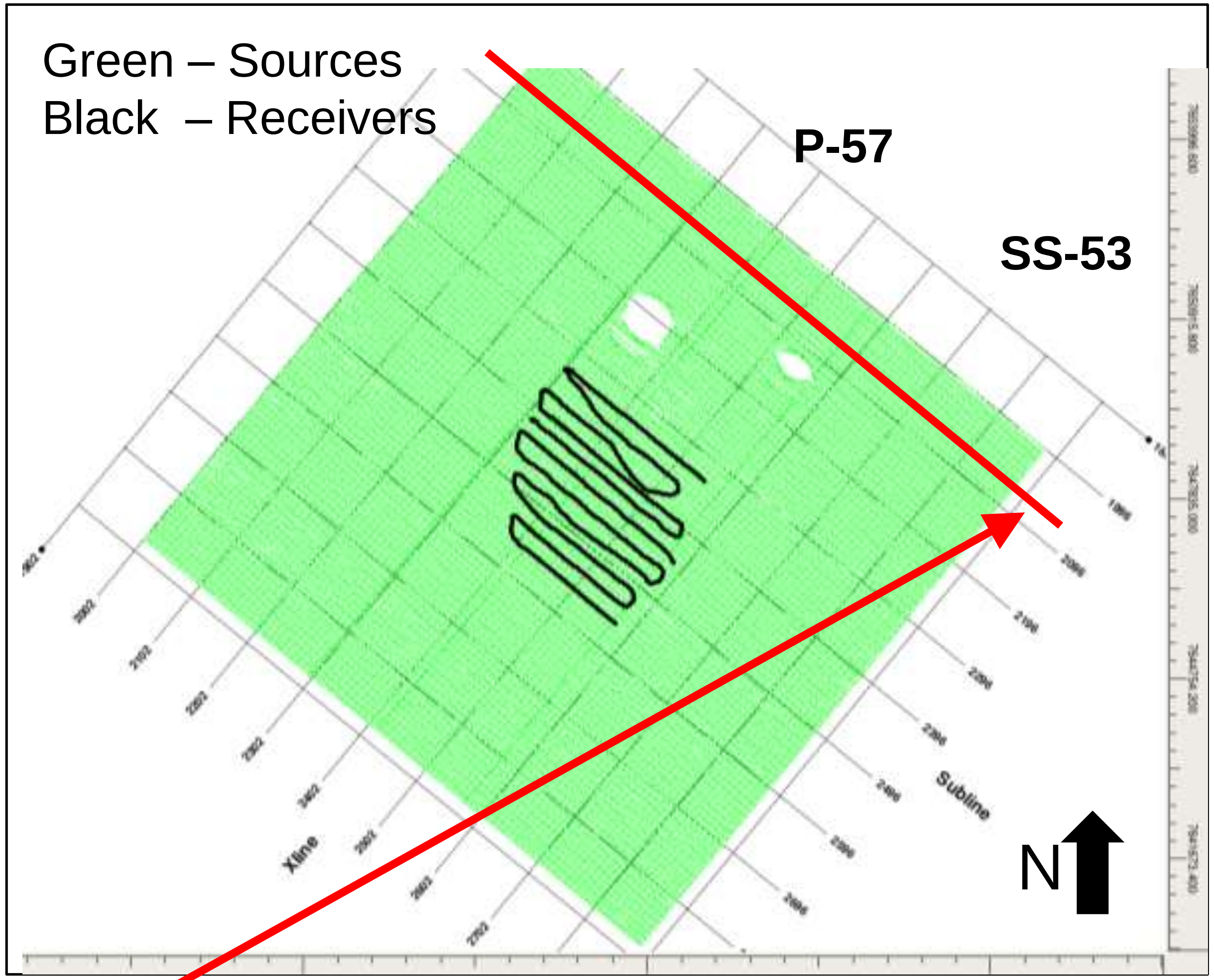
Blending simulation:

N° of sources/record = 4

Blending neighbor shots

Firing int. = 2.5 ± 0.4 sec

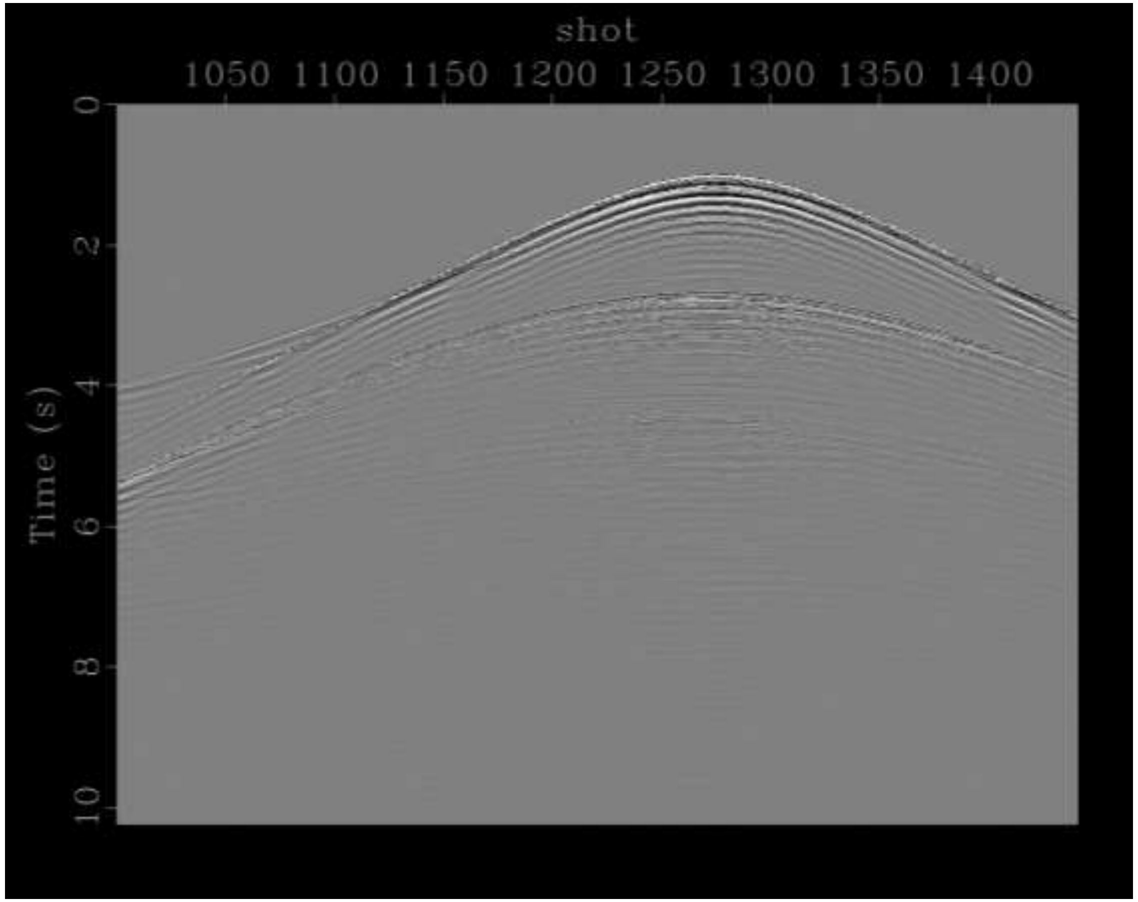
Source Position Post-Plot



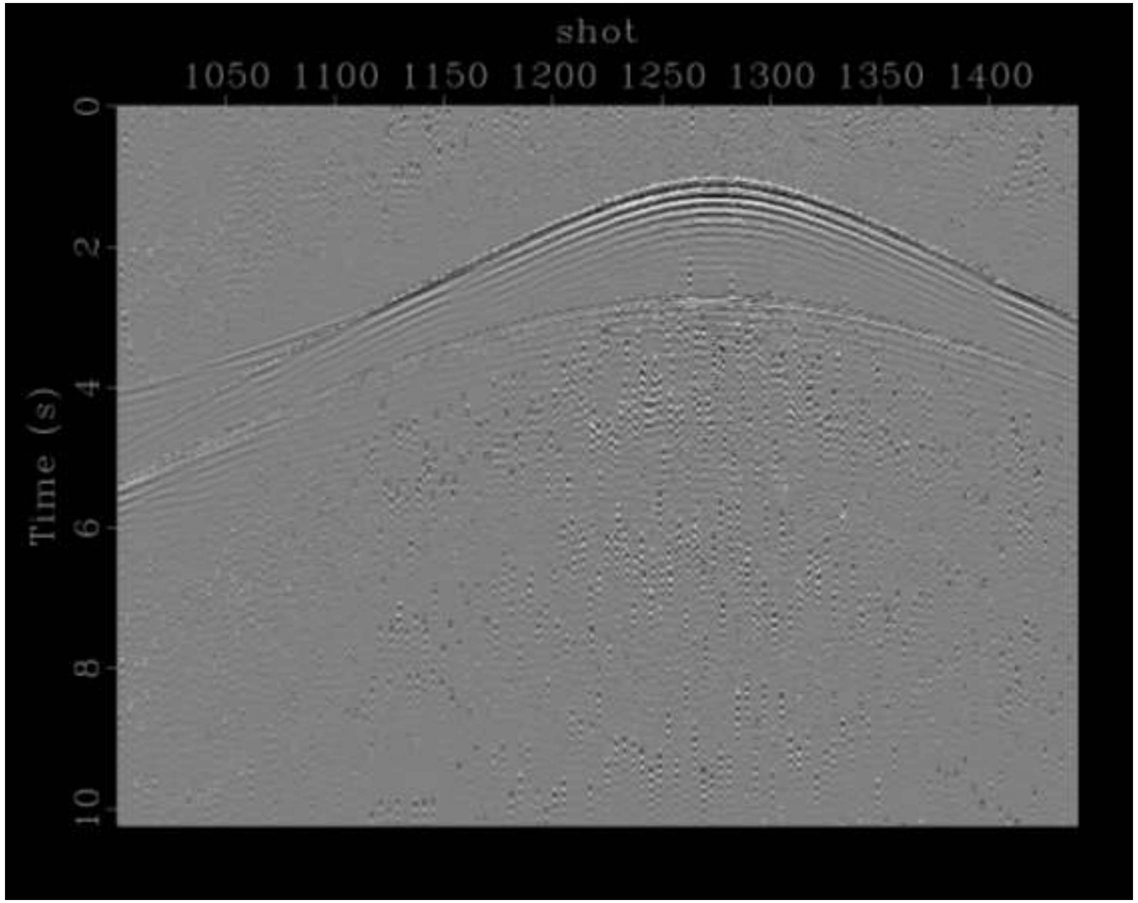
Sail-line
used in the

Comparative Analysis in the Receiver Domain

Results – Field data (Receiver domain)

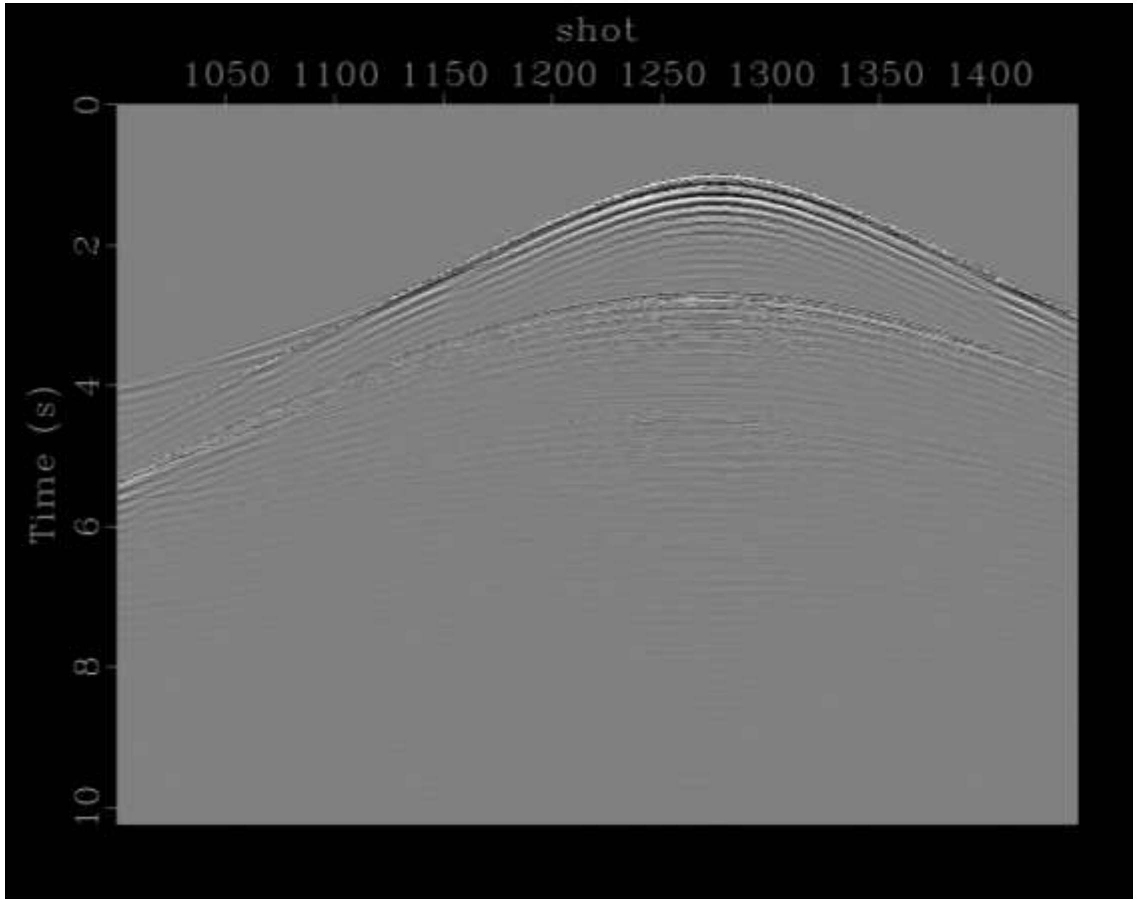


Original unblended data

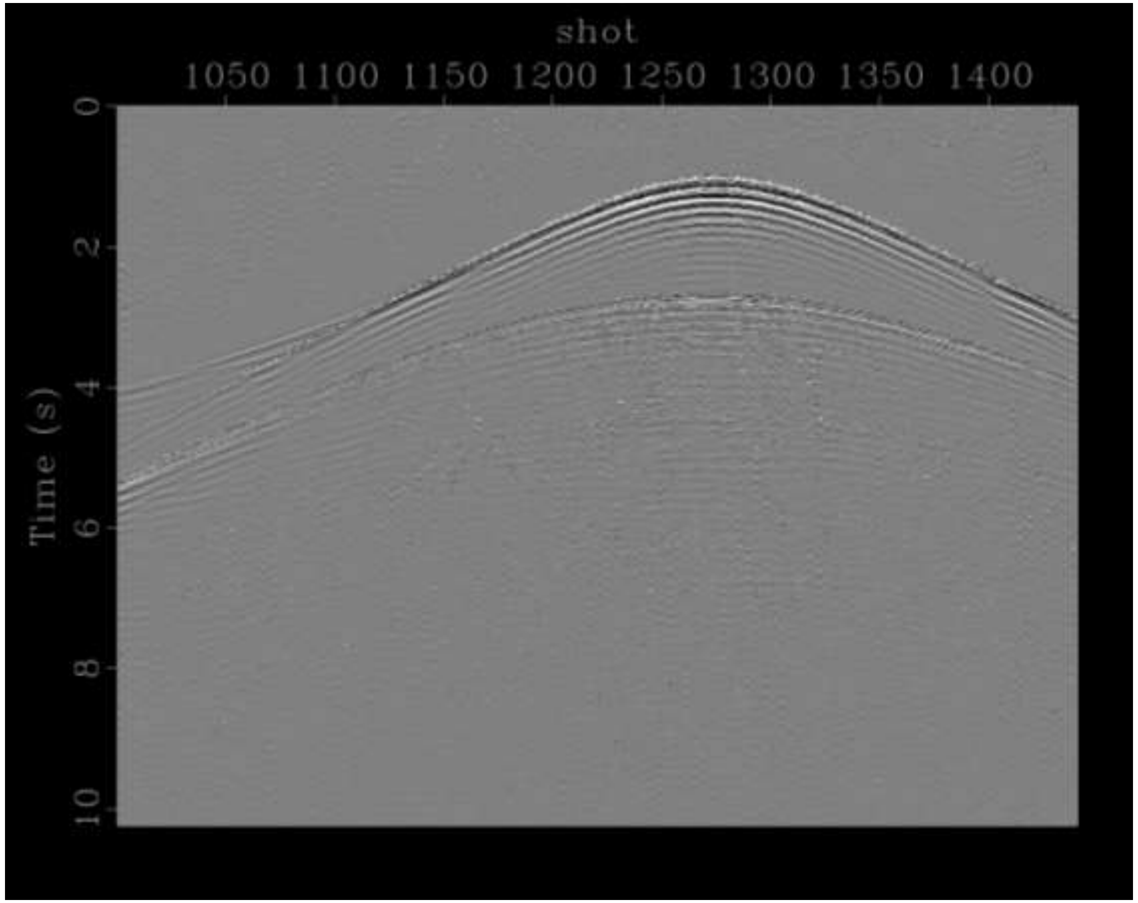


Data after LS-solution

Results – Field data (Receiver domain)

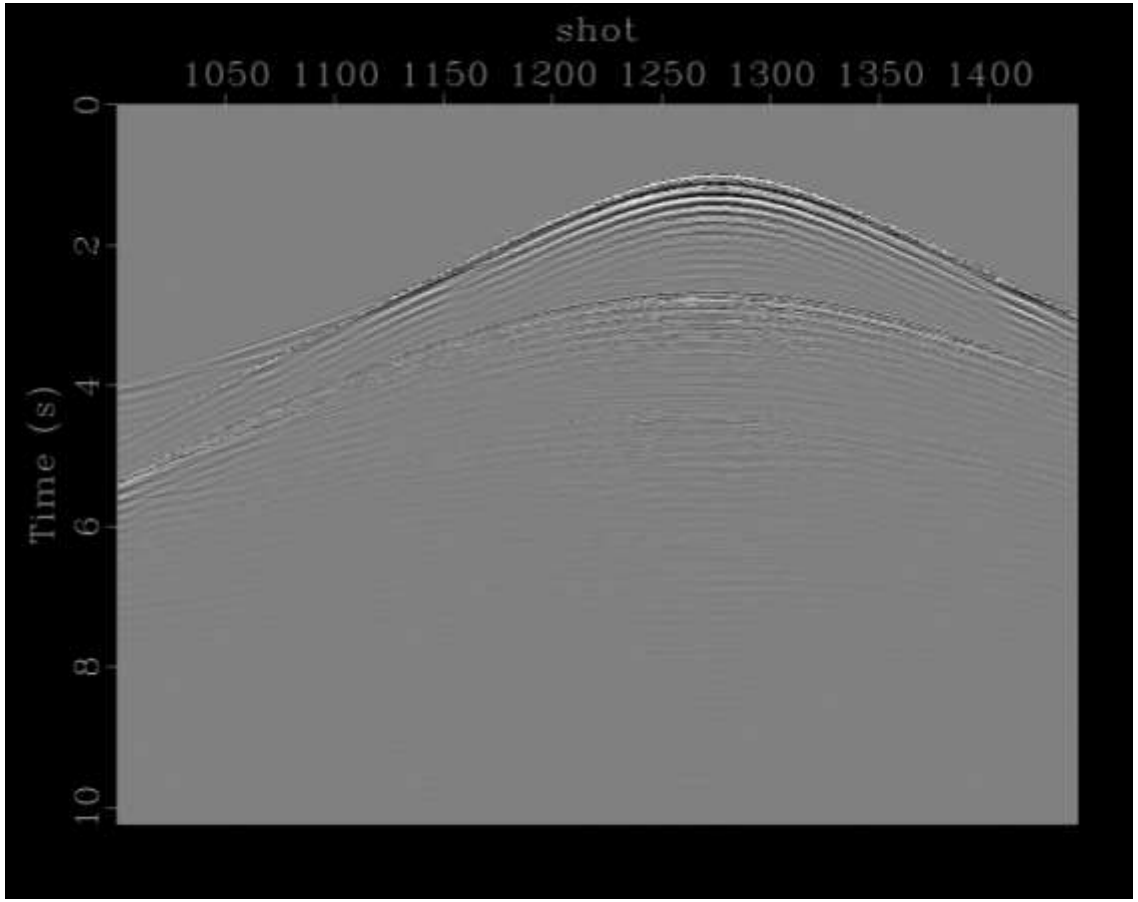


Original unblended data



Deblended data after 20 iterations

Results – Field data (Receiver domain)

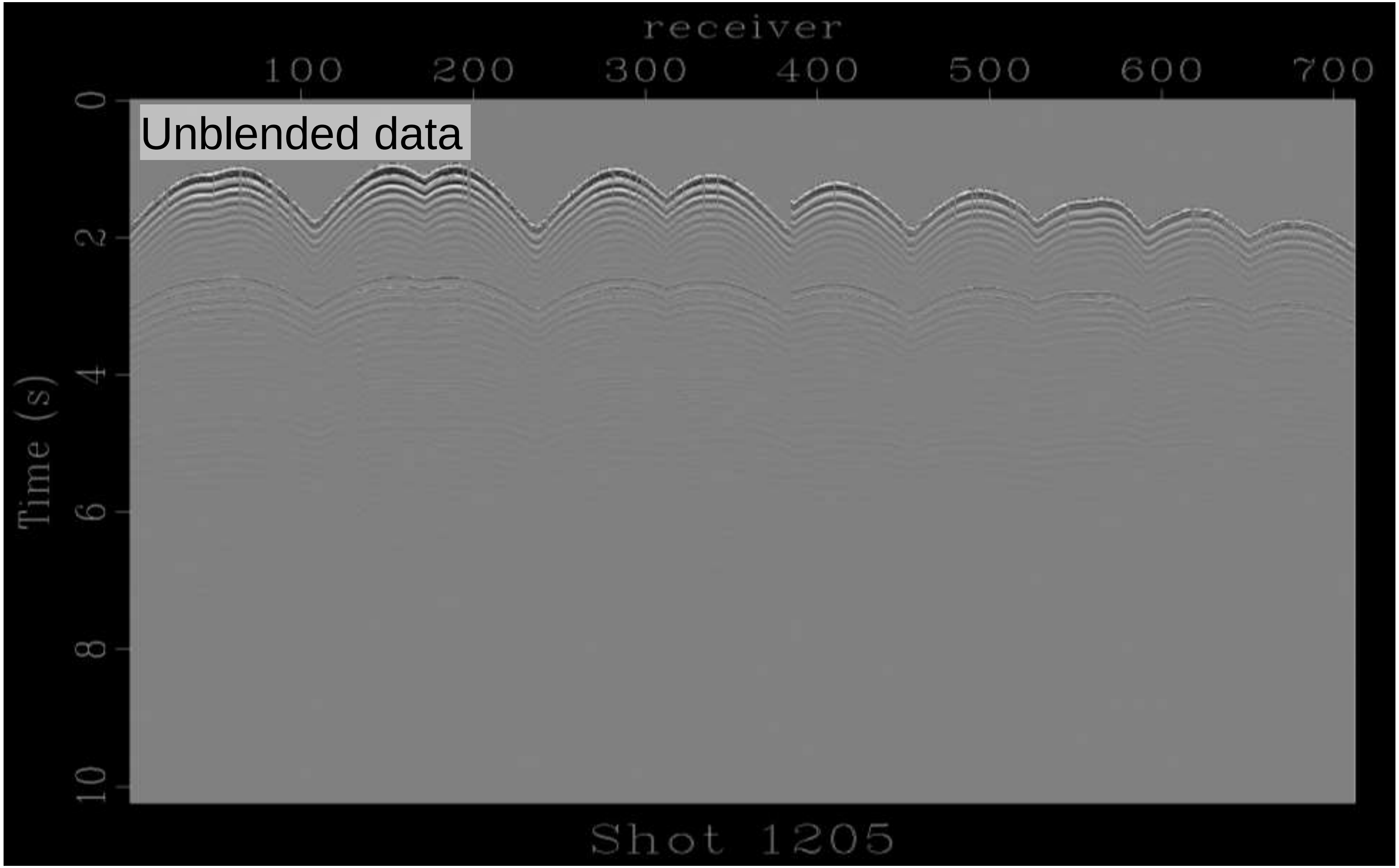


Original unblended data

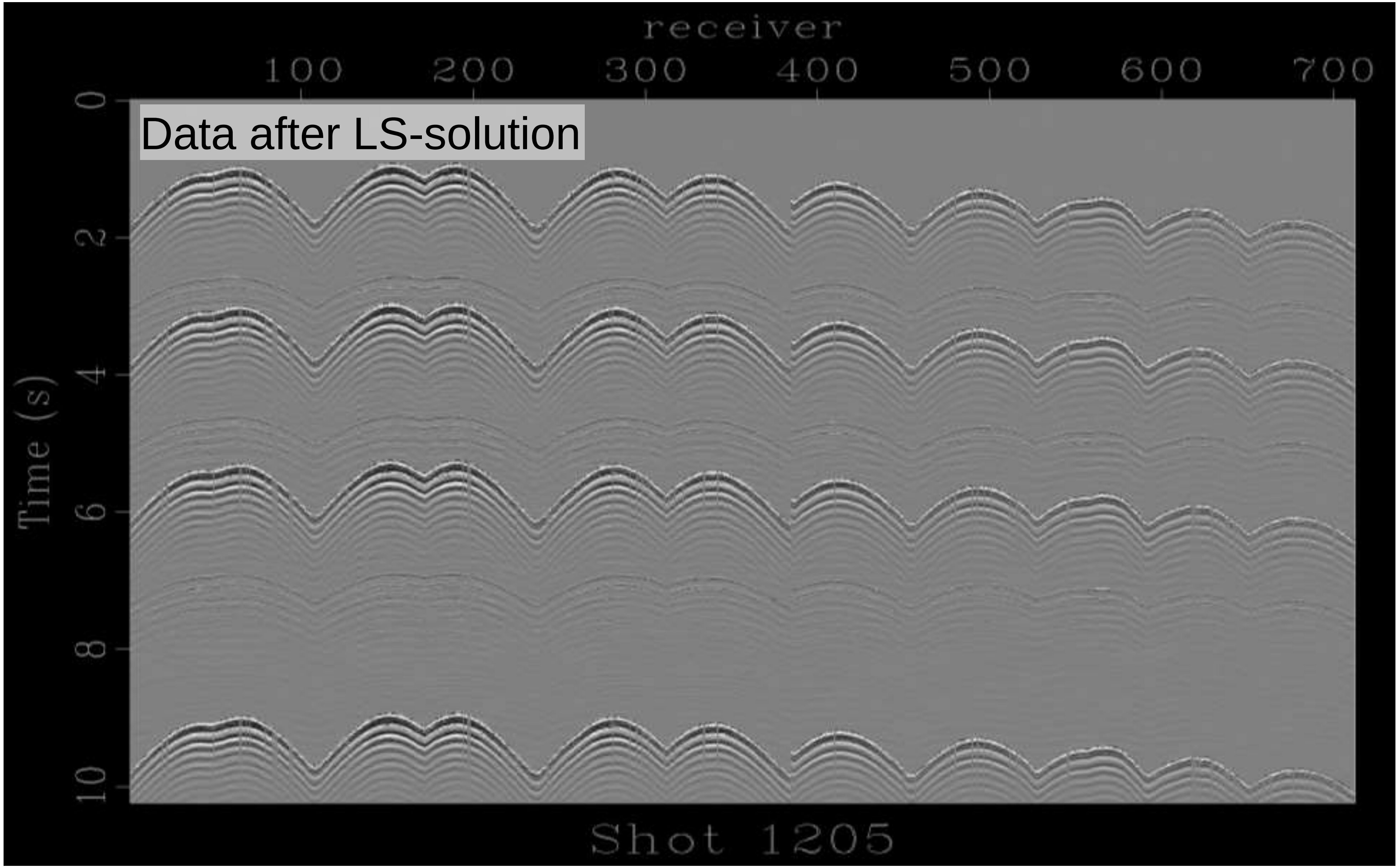
Deblending ERROR

Comparative Analysis in the Shot Domain

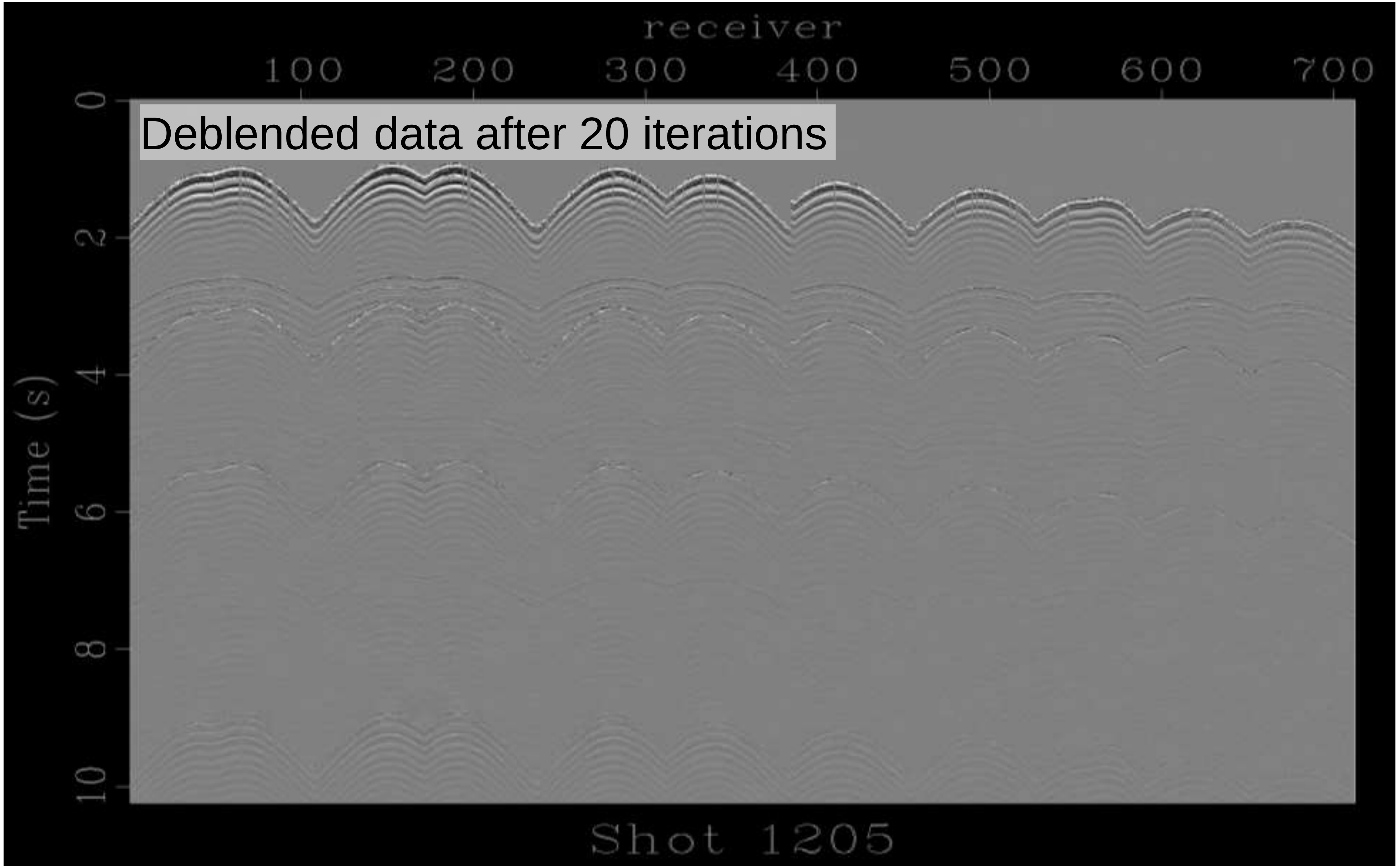
Results – Field data (Shot domain)



Results – Field data (Shot domain)



Results – Field data (Shot domain)



Results – Field data (Shot domain)

Outline

- Objective
- Theoretical background
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  - Deblending
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  - Synthetic data
  - Field data
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Final remarks

- Blended acquisitions are a very effective way to acquire seismic data at lower costs;

- Although mathematically simple, the iterative deblending method (with a good filtering operator) can provide satisfactory results;

- Quantitative analysis (using RMS and NRMS attributes) is essential to numerically validate deblending results.

Outline

RCP In pursuit of new ideas

- Objective
- Theoretical background
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  - Deblending
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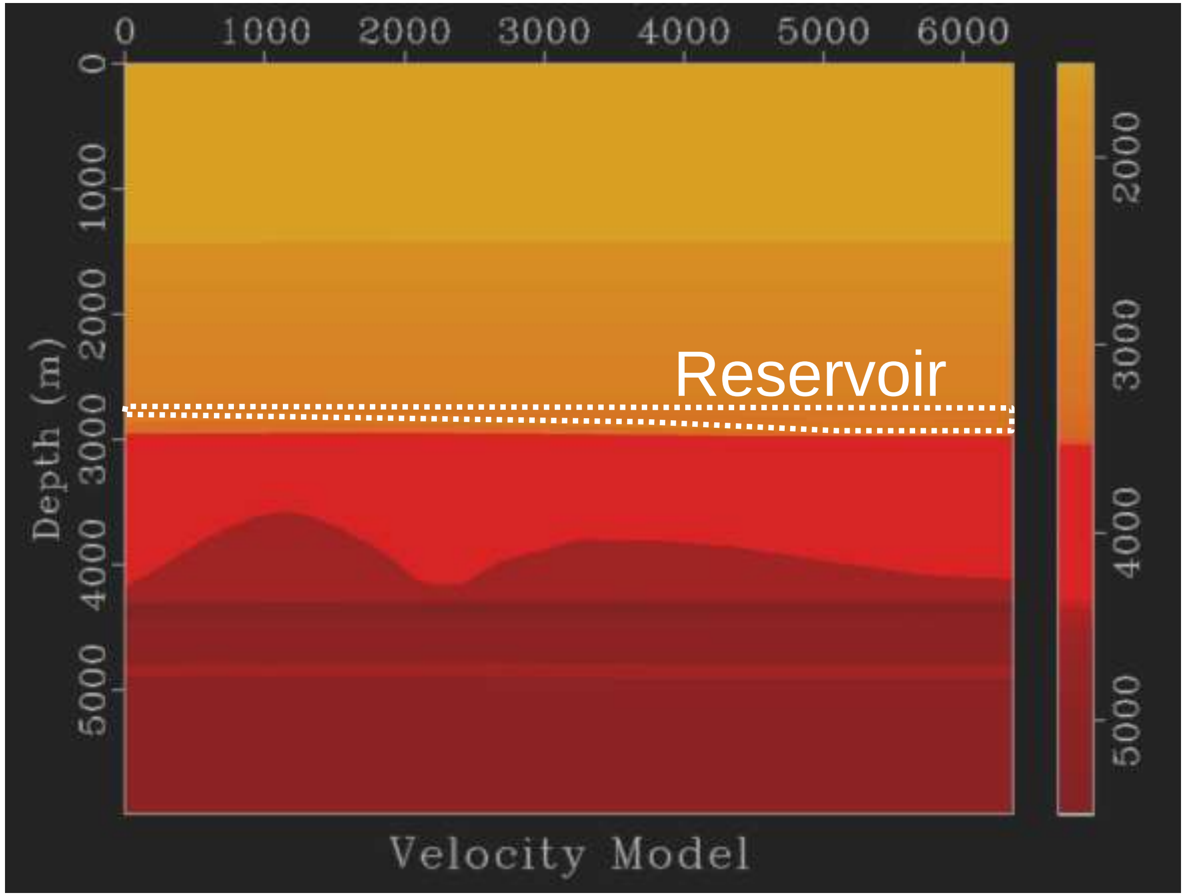
Next steps

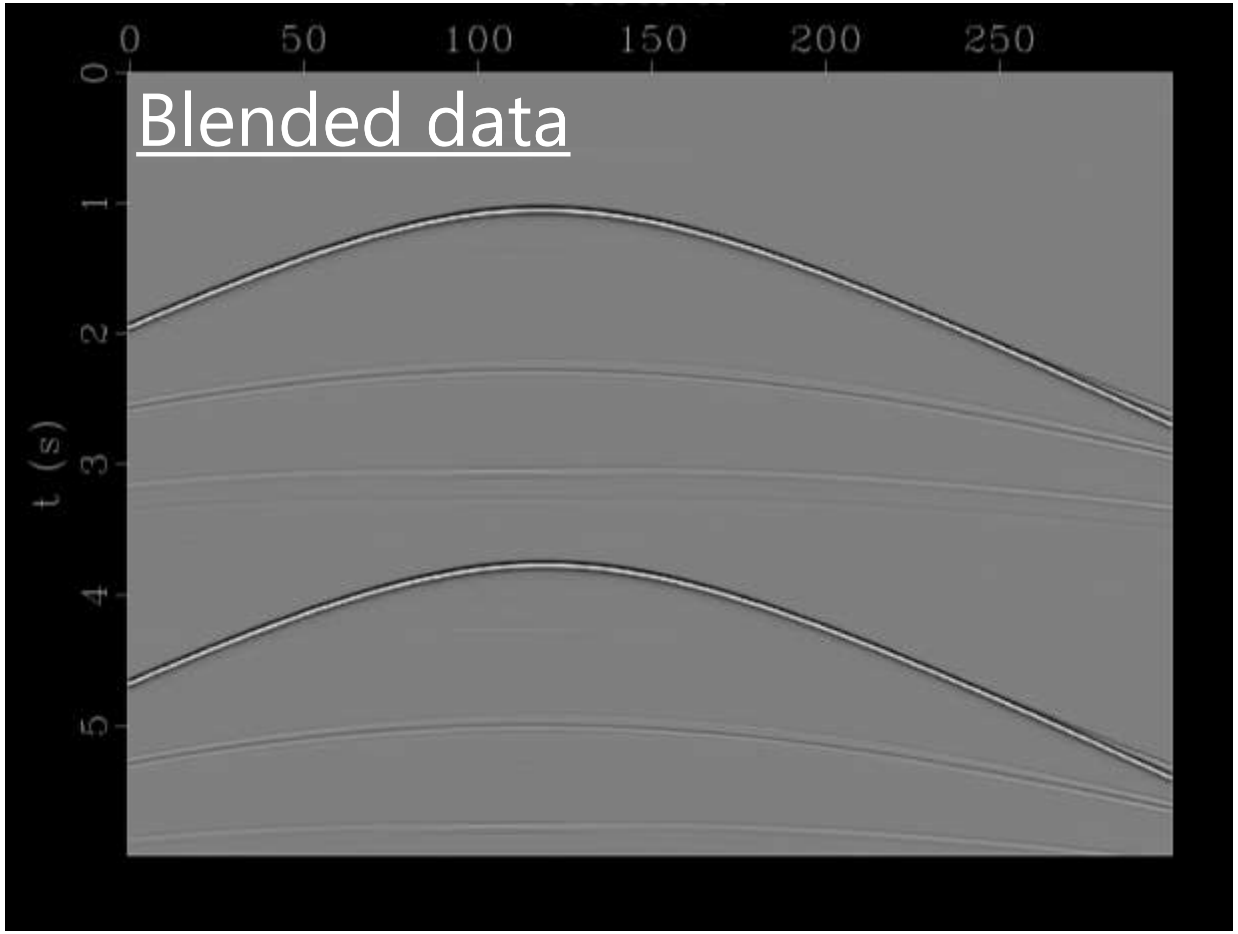
- Improve the iterative deblending results in field data;

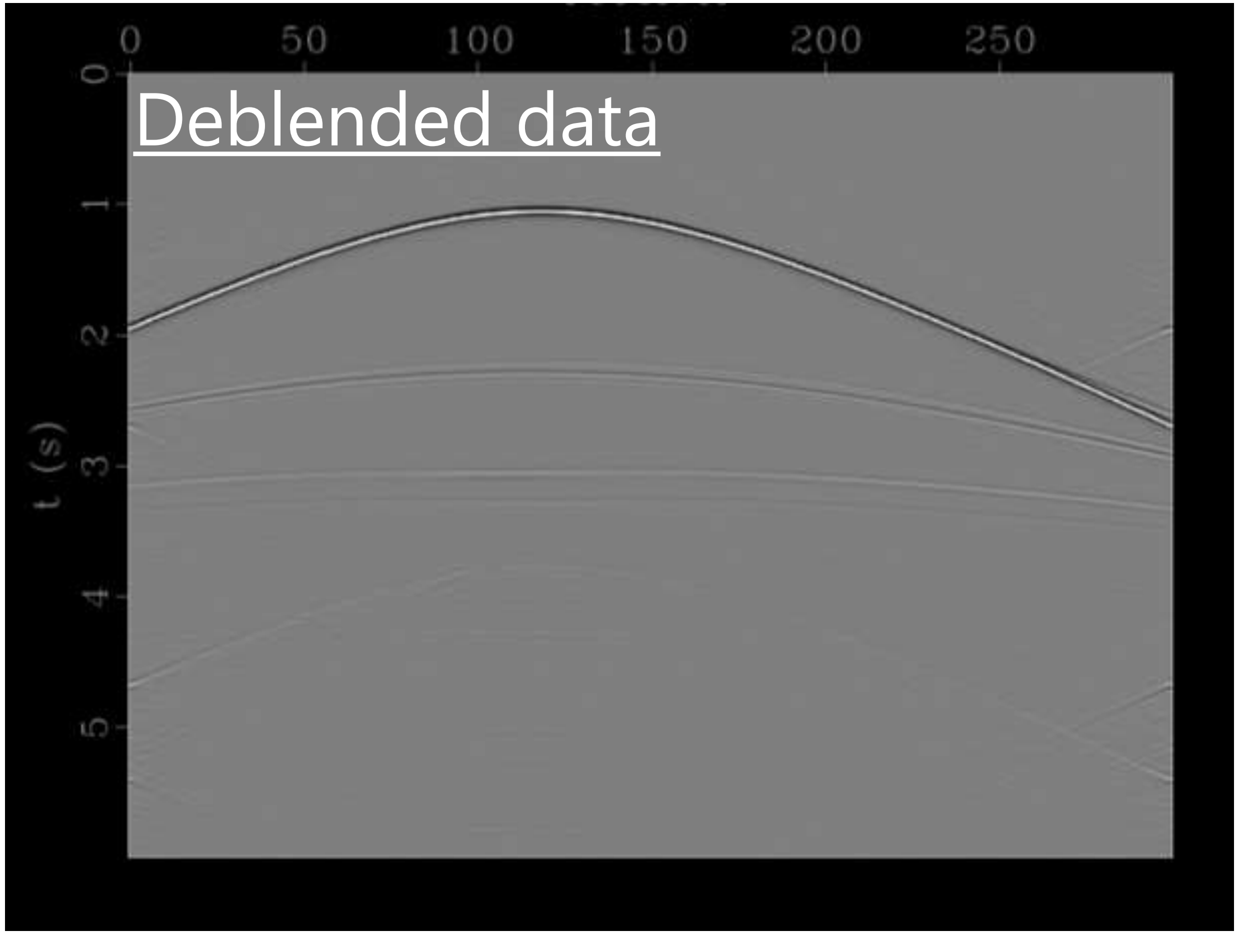
- Model a new synthetic seismic data **simulating production effects** and analyze how blending and deblending procedures will affect the 4D signal;



Next steps

- Deblending by “Compressive sensing”.





AFL

Anadarko Petroleum Corporation

Apache

CGG

Chevron

CIMAREX

CNOOC

DAWSON Dawson Geophysical Company

devon

drillinginfo better, faster decisions

eog resources

ExxonMobil

Great Western OIL & GAS COMPANY

HALLIBURTON Landmark

HighPoint RESOURCES

شركة نفط الكويت Kuwait Oil Company

ikon Science

LUMINA

Lundin Petroleum

NANOSEIS

OptaSense®

OXY

OIL AND GAS INSTITUTE - National Research Institute

PDC ENERGY

PENN VIRGINIA CORPORATION

PIONEER NATURAL RESOURCES

REPSOL

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WHITING

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