Deblending with Radon operators I: the CMP domain

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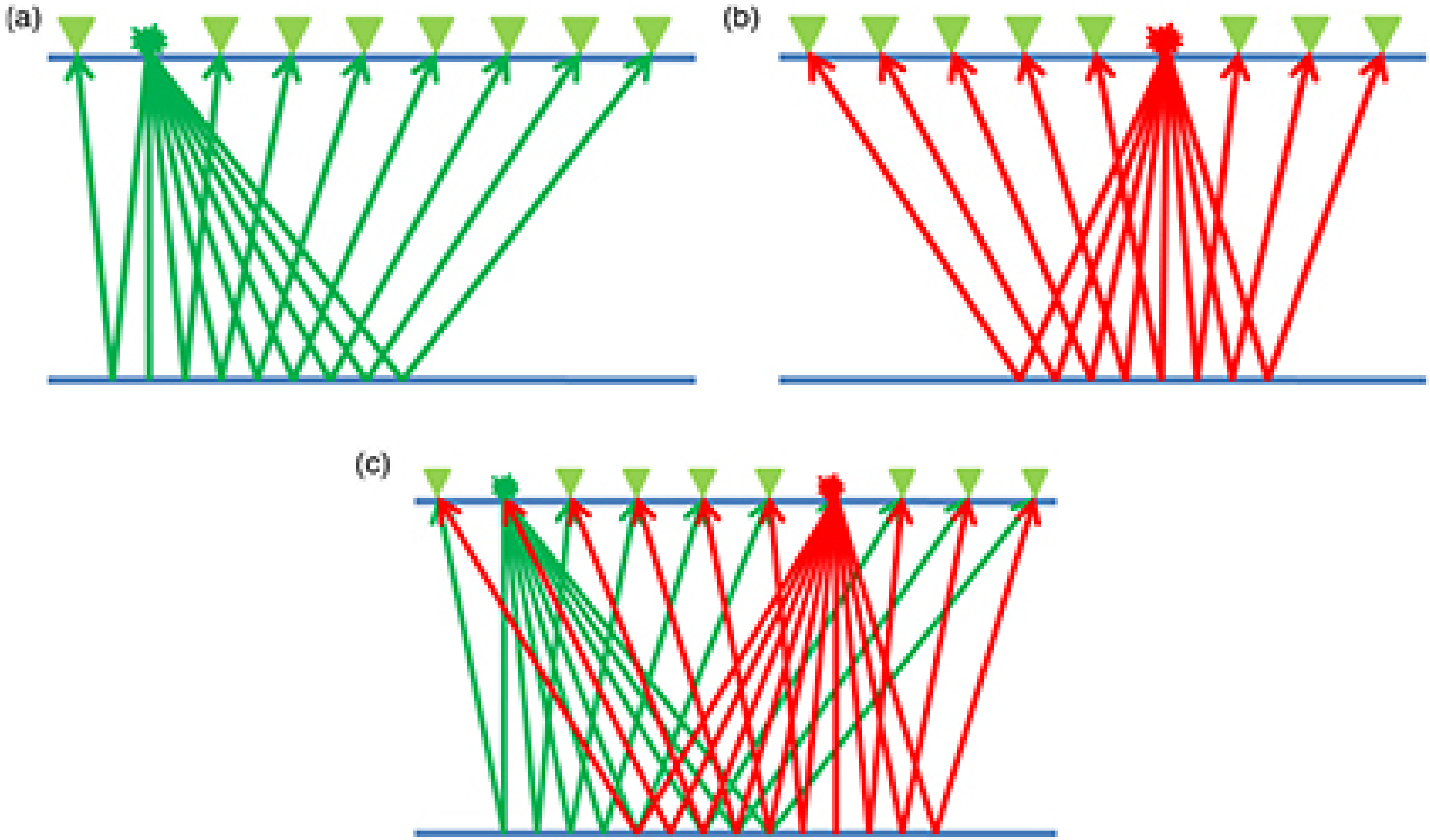
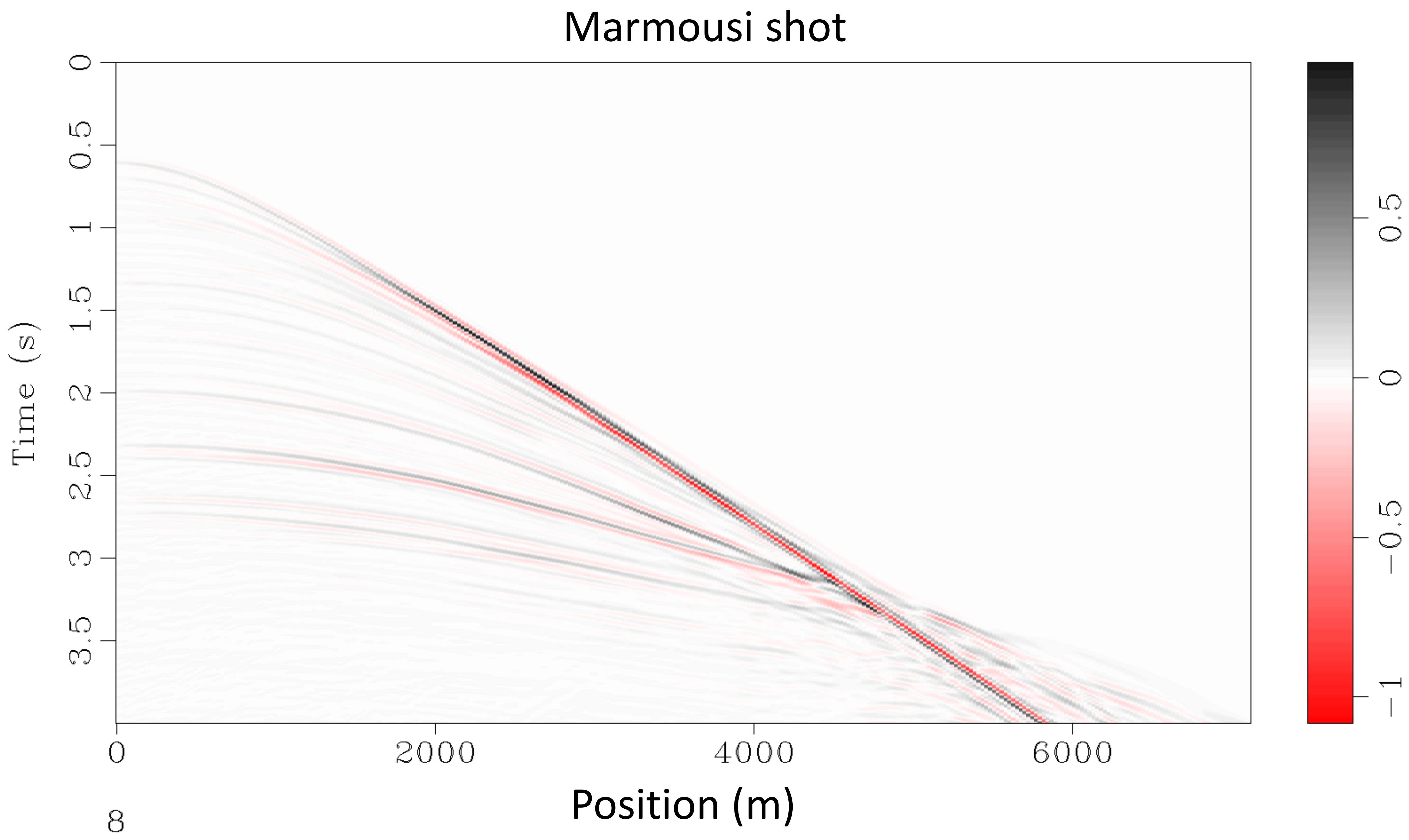
What is Blended data?

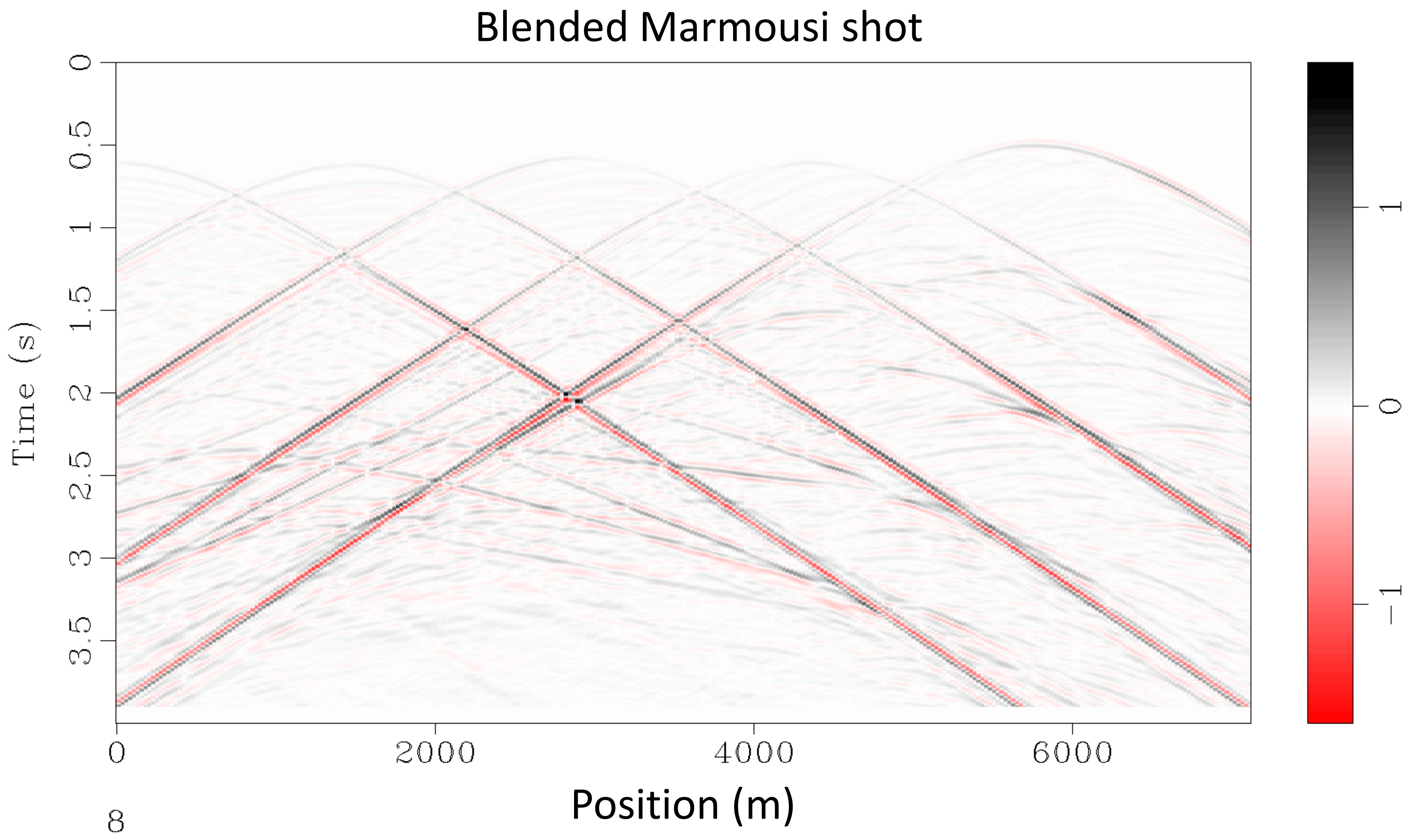


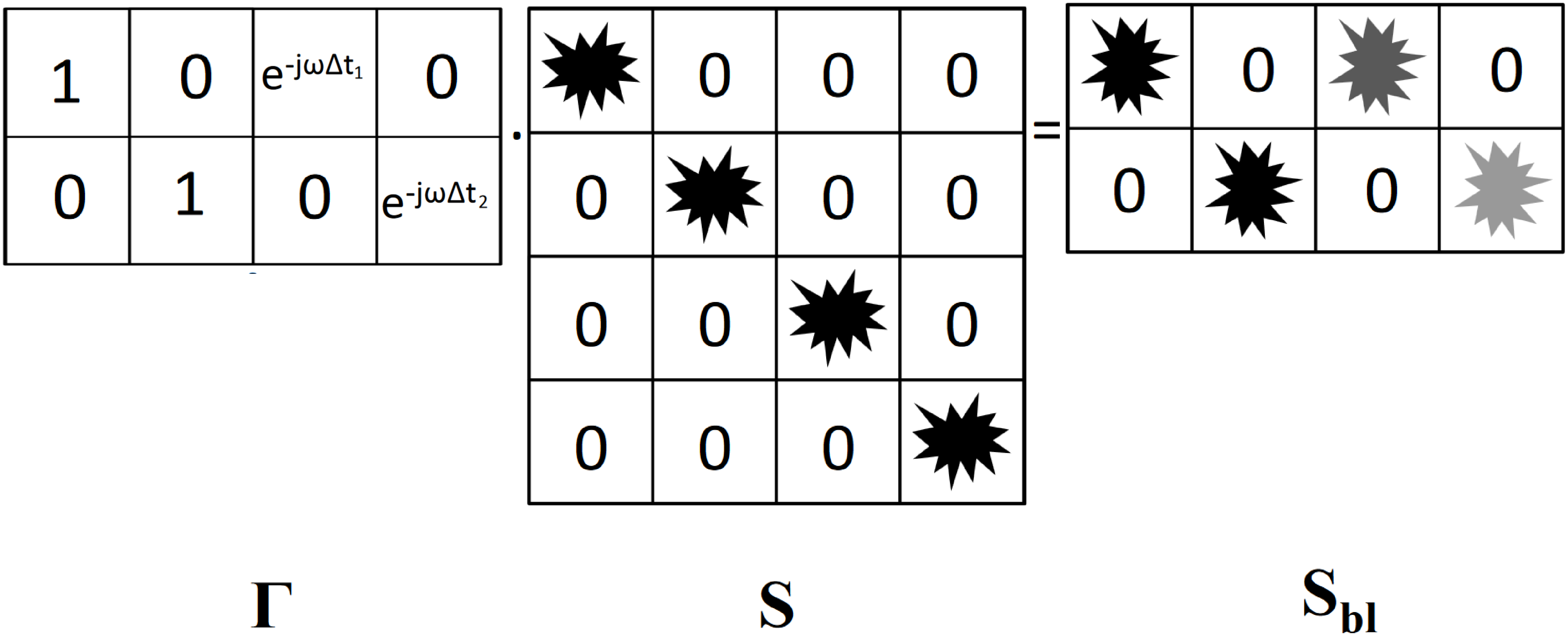
Journal of Geophysics and Engineering, Volume 12, Issue 2, April 2015, Pages 167–174, https://doi.org/10.1088/1742-2132/12/2/167

Standard acquisition



Blended acquisition





Urruticoechea, C. R., 2015, Seismic blending and deblending of crossline sources: M.Sc. thesis, Delft University of Technology. (modified)

Deblending as Inversion

Forward model of Blending:

$$d = \Gamma m$$

Because the blending matrix Γ is underdetermined the direct inverse cannot be assessed

$$\mathrm{m} = (\Gamma^H \Gamma)^{-1} \Gamma^H d$$

Unfortunately, this problem is ill posed and therefore needs to re-formulated

Effects of Pseudo Deblending

$$\mathrm{m} = (\Gamma^H \Gamma)^{-1} \boxed{\Gamma^H d}$$

Pseudo-deblending

$$S_{pdb} = \boxed{\Gamma^H S_{bl}},$$ Where $$S_{bl} = \Gamma S,$$

Therefore Pseudo deblending can be considered an operation on the pre-blended dataset:

$$S_{pbl} = \Gamma^H \Gamma S.$$

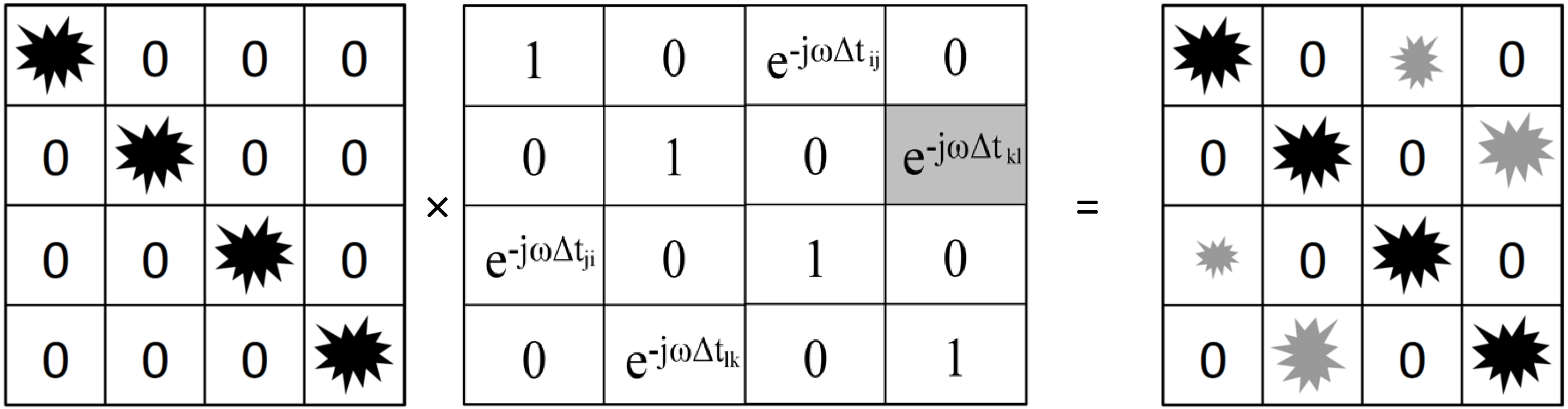
Effect of Pseudo Deblending

$$S_{pbl} = S\boxed{\Gamma^H\Gamma}.$$

$$\begin{bmatrix} e^{-j\omega\Delta t_i} & 0 \\ 0 & e^{-j\omega\Delta t_k} \\ e^{-j\omega\Delta t_j} & 0 \\ 0 & e^{-j\omega\Delta t_l} \end{bmatrix} \cdot \begin{bmatrix} e^{+j\omega\Delta t_i} & 0 & e^{+j\omega\Delta t_j} & 0 \\ 0 & e^{+j\omega\Delta t_k} & 0 & e^{+j\omega\Delta t_l} \end{bmatrix} = \begin{bmatrix} 1 & 0 & e^{-j\omega\Delta t_{ij}} & 0 \\ 0 & 1 & 0 & e^{-j\omega\Delta t_{kl}} \\ e^{-j\omega\Delta t_{ji}} & 0 & 1 & 0 \\ 0 & e^{-j\omega\Delta t_{lk}} & 0 & 1 \end{bmatrix}$$

$$\Gamma^{\mathbf{H}} \quad \times \quad \Gamma \quad = \quad \Gamma^{\mathbf{H}}\Gamma$$

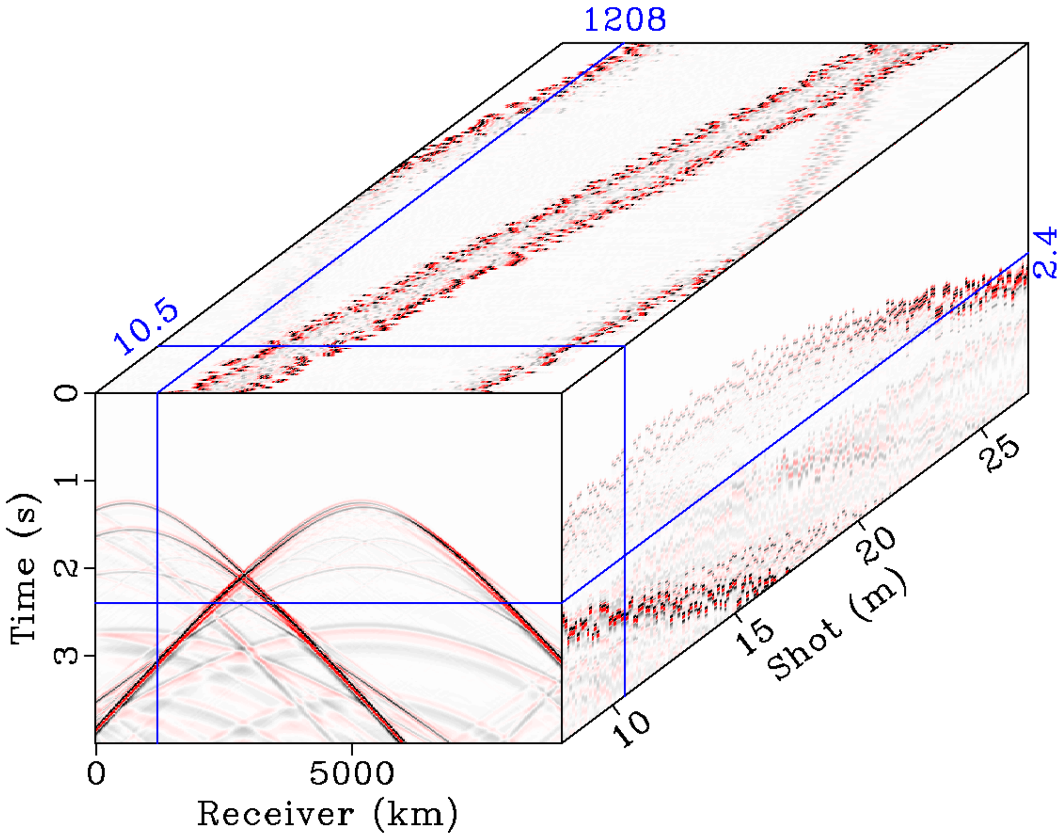
Urruticoechea, C. R., 2015, Seismic blending and deblending of crossline sources: M.Sc. thesis, Delft University of Technology.



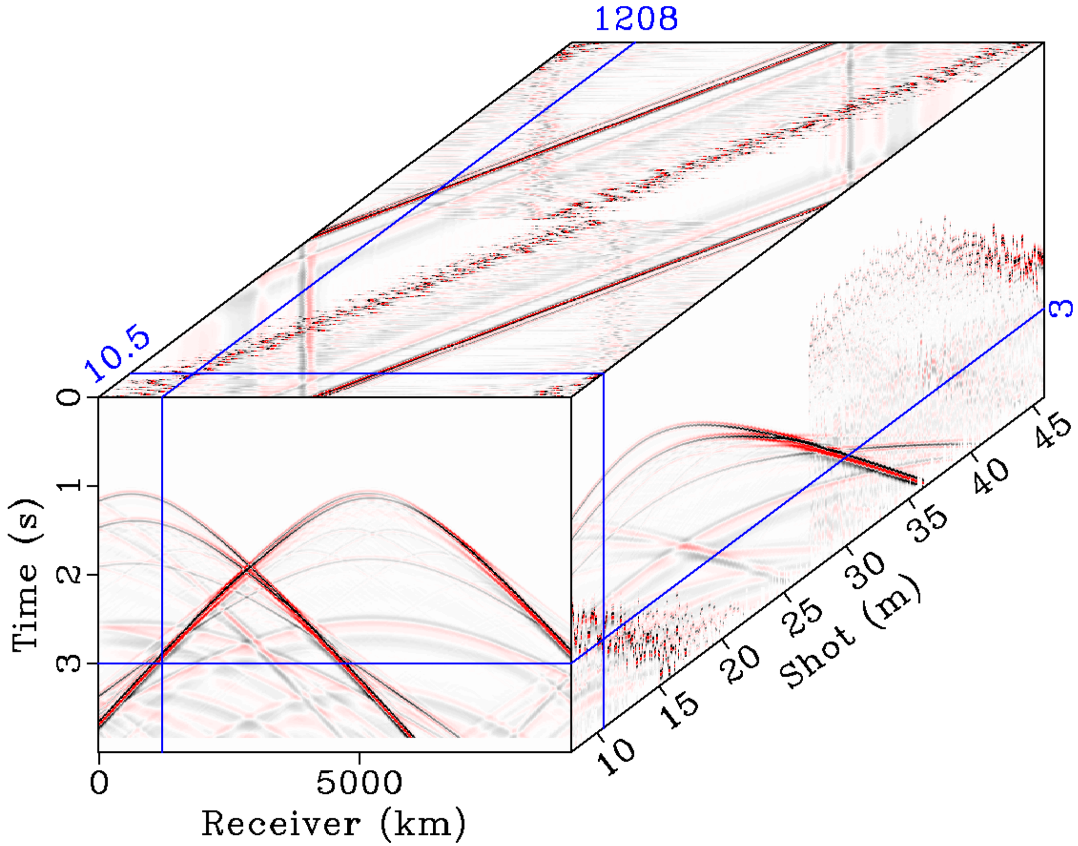
$$S\ \Gamma^H\Gamma = S_{pbl}$$

Urruticoechea, C. R., 2015, Seismic blending and deblending of crossline sources: M.Sc. thesis, Delft University of Technology.

Blended Data



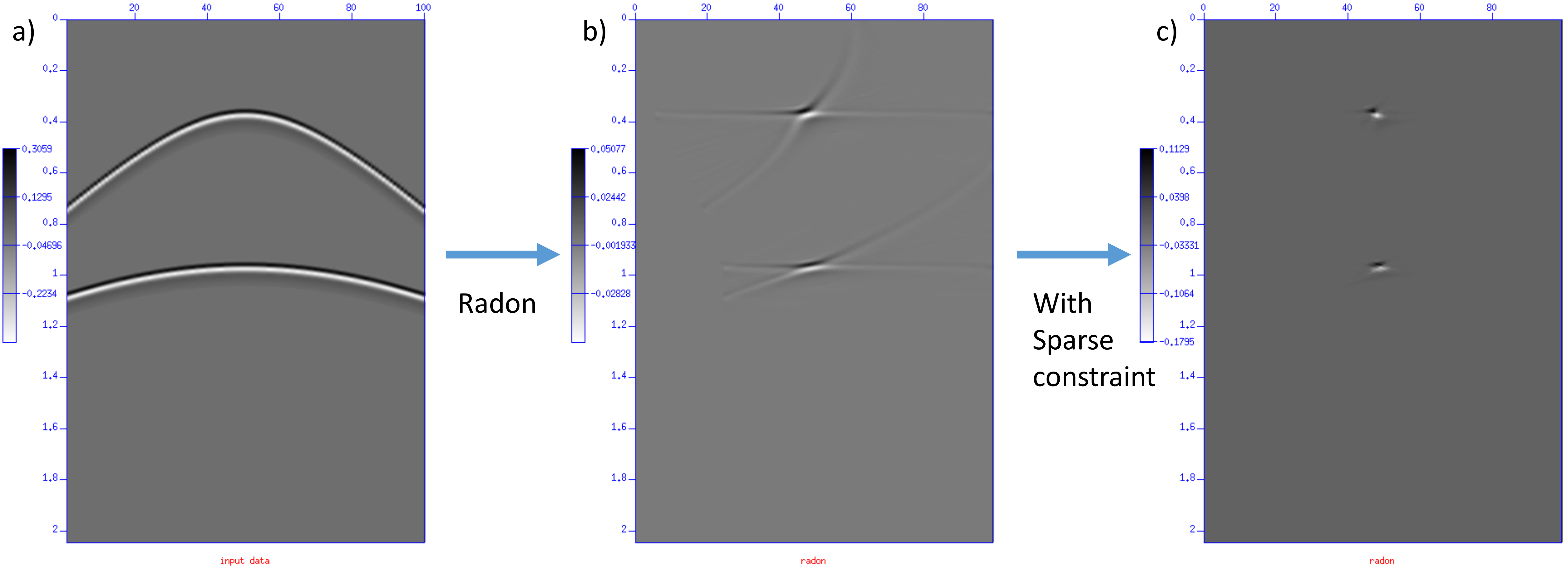
Pseudo Deblended Data



Sparse Hyperbolic Radon Transform

$$u(p,\tau) = \int_{h_1}^{h_2} d(h, t = \sqrt{\tau^2 + p^2h^2})dh$$

where u(p,t) is the radon space data, p is the slowness, t is the two way travel time, <u>h1</u> is the upper offset limit, <u>h2</u> the lower offset limit, and d is the data space to be transformed. The slowness p is then defined as the inverse of velocity 1/V.



Radon Denoising

$$\boxed{S_{pdb}} = \boxed{S_{bl}}\boxed{\Gamma}^{H}$$

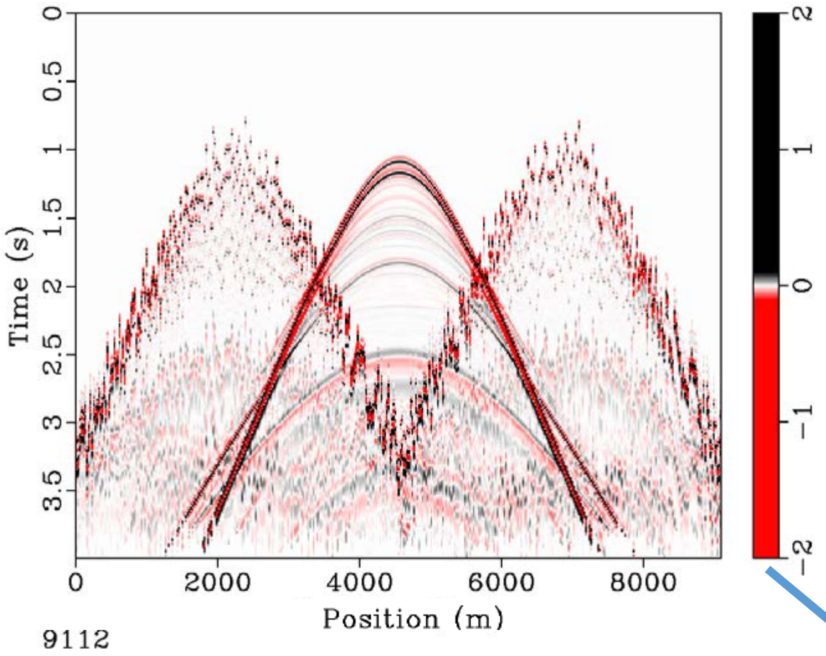
$$||\boxed{S_{pdb}} - \boxed{R}m||_2^2 + \mu||m||_1^1$$

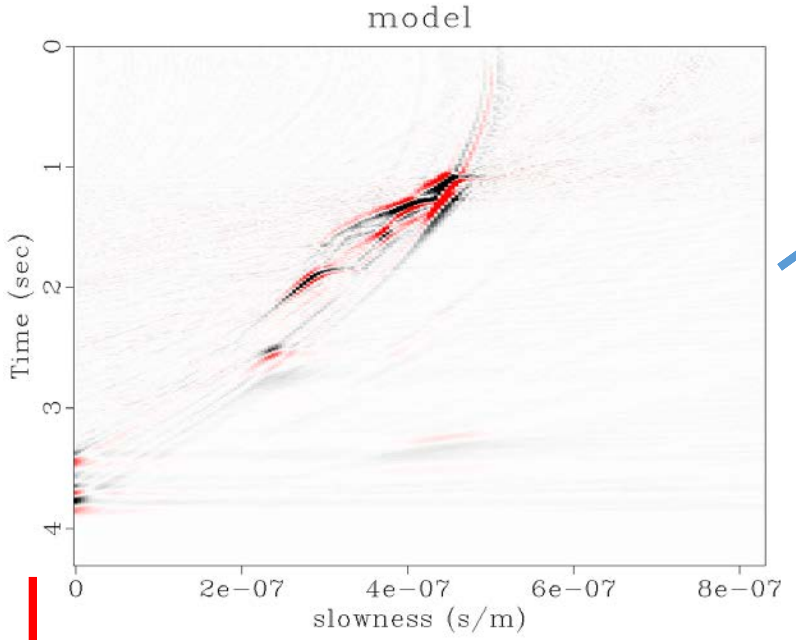
Radon Inversion

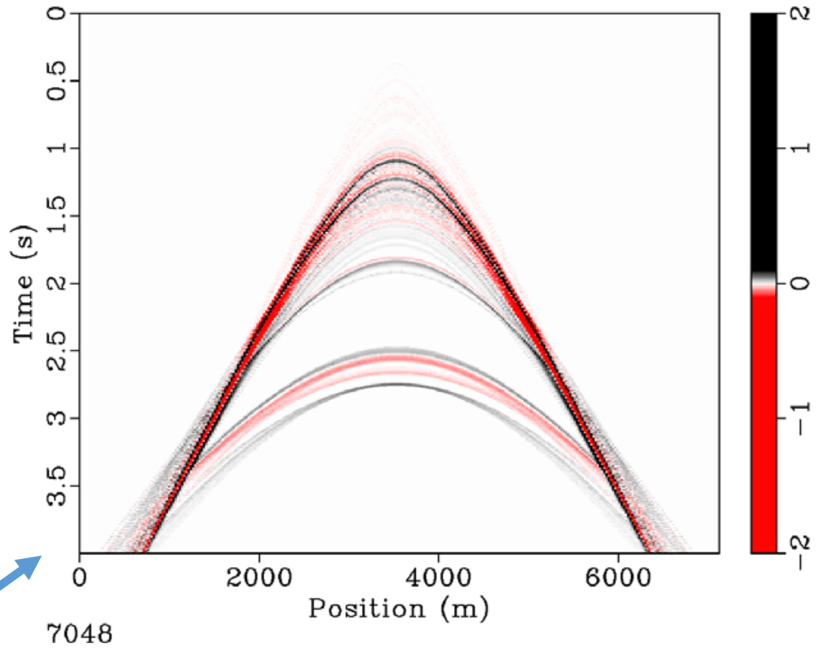
$$||\boxed{S_{bl}} - \boxed{\Gamma}\boxed{R}m||_2^2 + \mu||m||_1^1$$

Denoising – sparse radon transform

$$\left|\left|S_{pdb} - \boxed{R}m\right|\right|_2^2 + \mu||m||_1^1$$





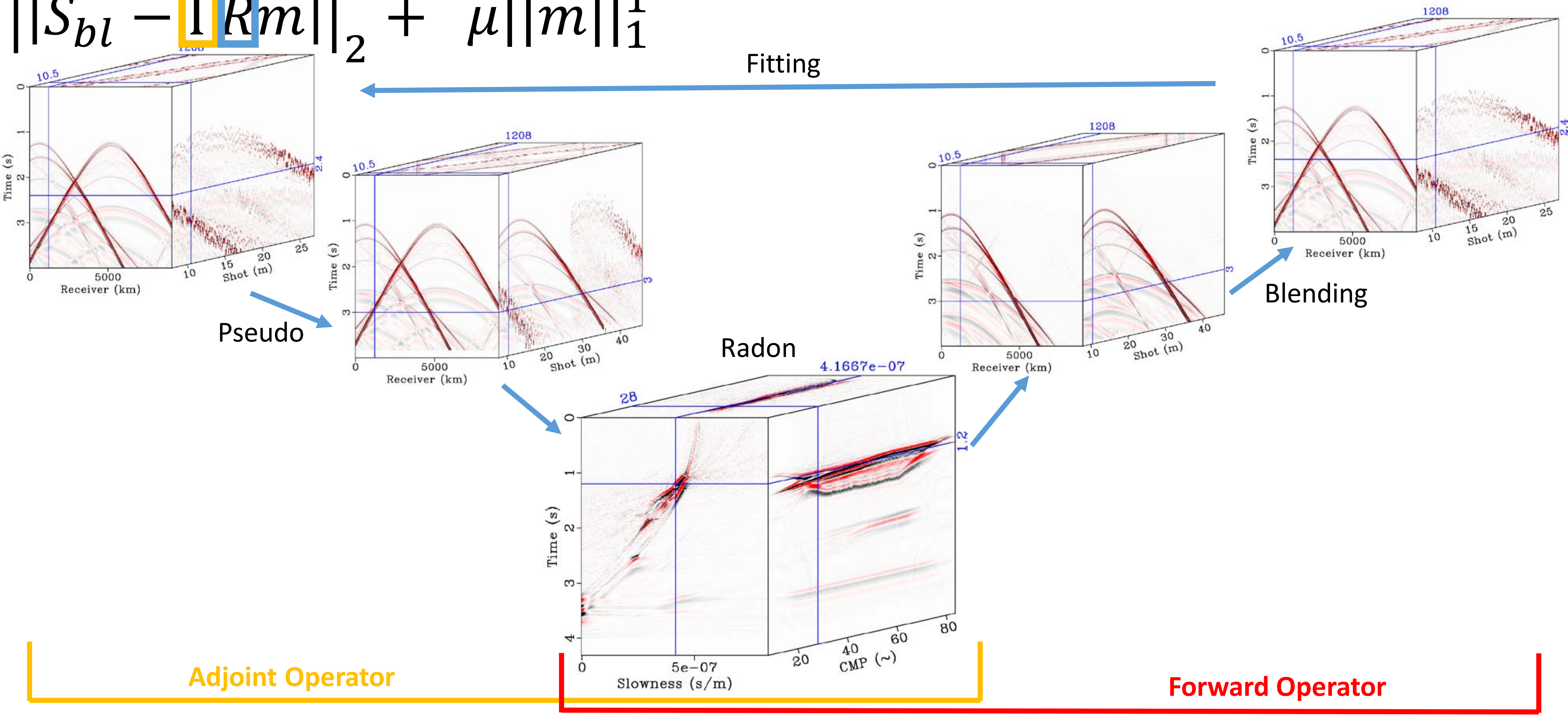


Adjoint Operator

Forward Operator

Sparse Inversion

$$||S_{bl} - \boxed{\Gamma}\boxed{R}m||_2^2 + \mu||m||_1^1$$



Advantages of CMP domain

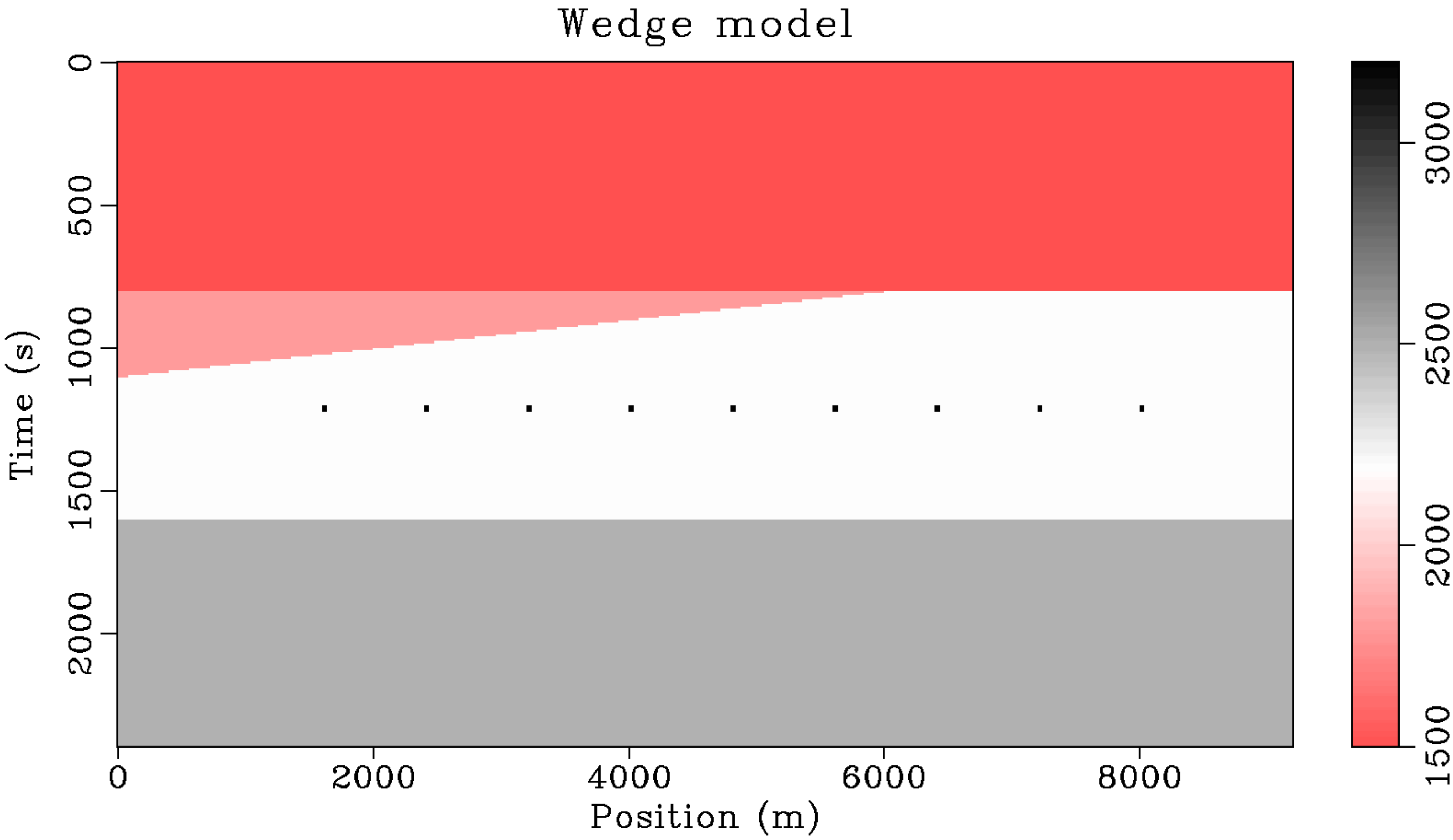
- Events are centered
  - Dipping and complex geometries are centered for the most part with no shifted apexes
- Radon operator
  - Relatively simpler, just hyperbolic instead of apex shifted
    - Reduces computational time

- 3D data is normally sorted into CMP bins for processing

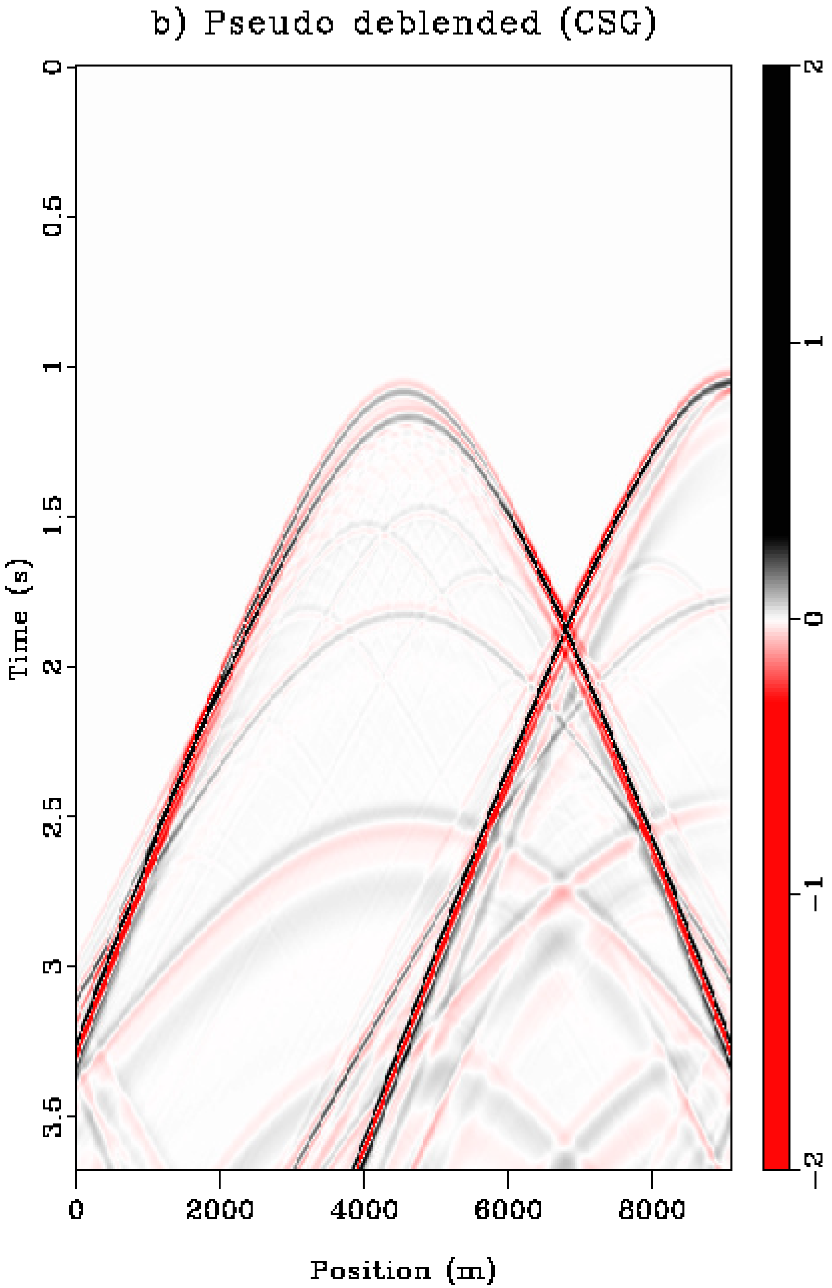
Drawbacks of CMP domain

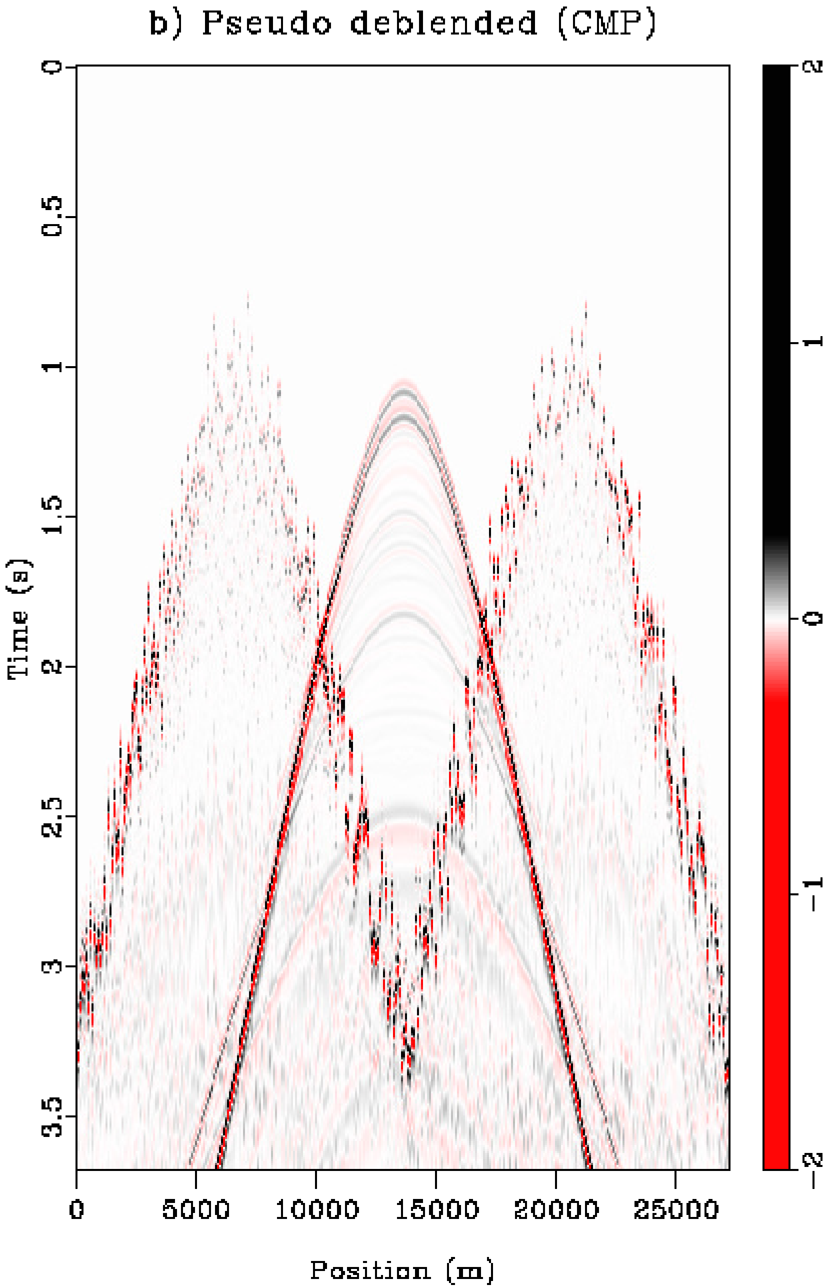
- Traces per CMP not consistent
  - Traces per CMP varies based on location within survey
  - Very few traces at the edges
- Aliasing
  - CMP domain has half the sampling interval compared to receiver/domain
  - High likelihood events will be aliased

Results – Wedge Model



Results


b) Pseudo deblended (CSG)
Time (s)
0
0.5
1
1.5
2
2.5
3
3.5
0
2000
4000
6000
8000
Position (m)
2
1
0
−1
−2


b) Pseudo deblended (CMP)
Time (s)
0
0.5
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1.5
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2.5
3
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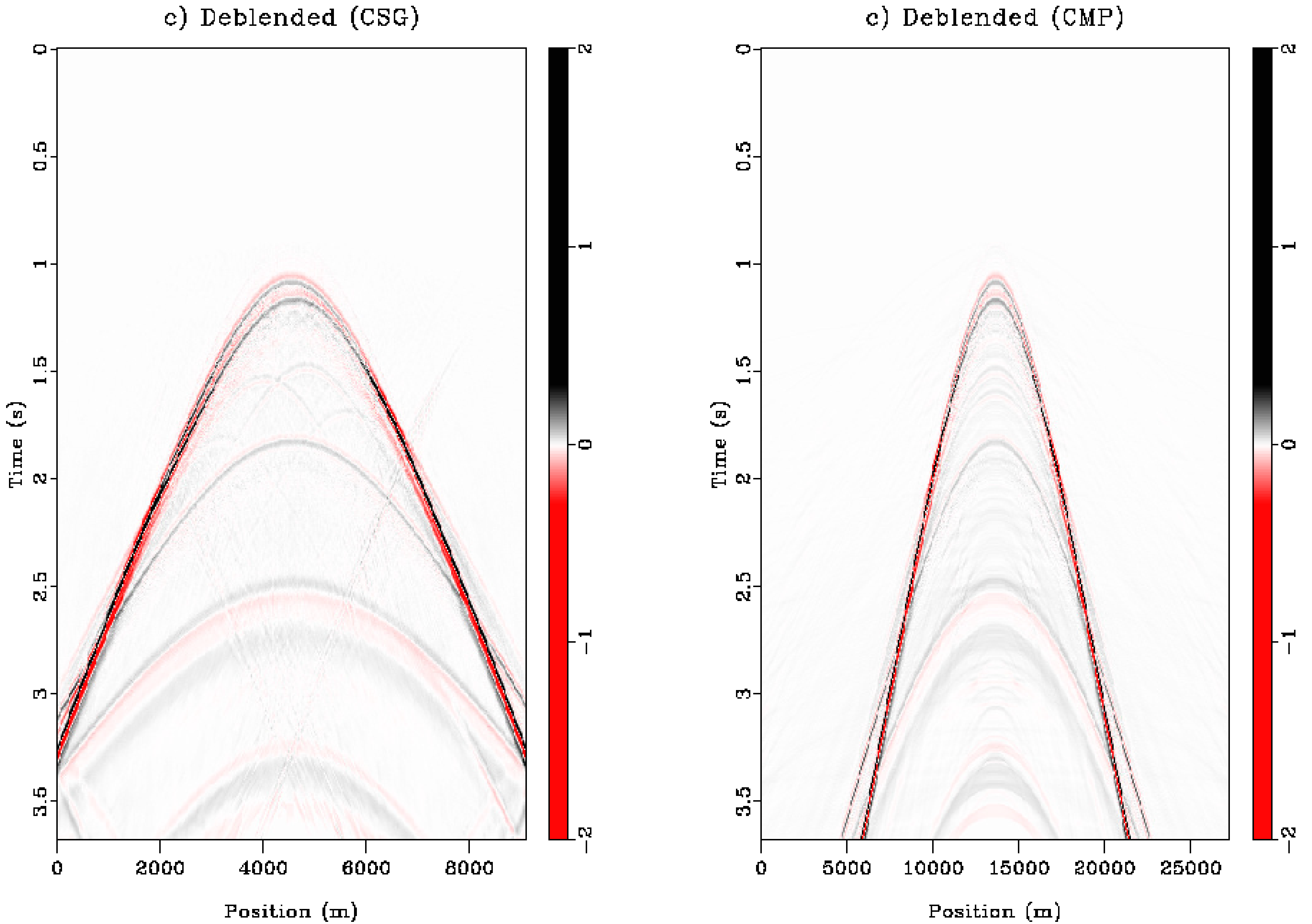
5000
10000
15000
20000
25000
Position (m)
2
1
0
−1
−2


c) Deblended (CSG)
c) Deblended (CMP)
Time (s)
Position (m)
0
0.5
1
1.5
2
2.5
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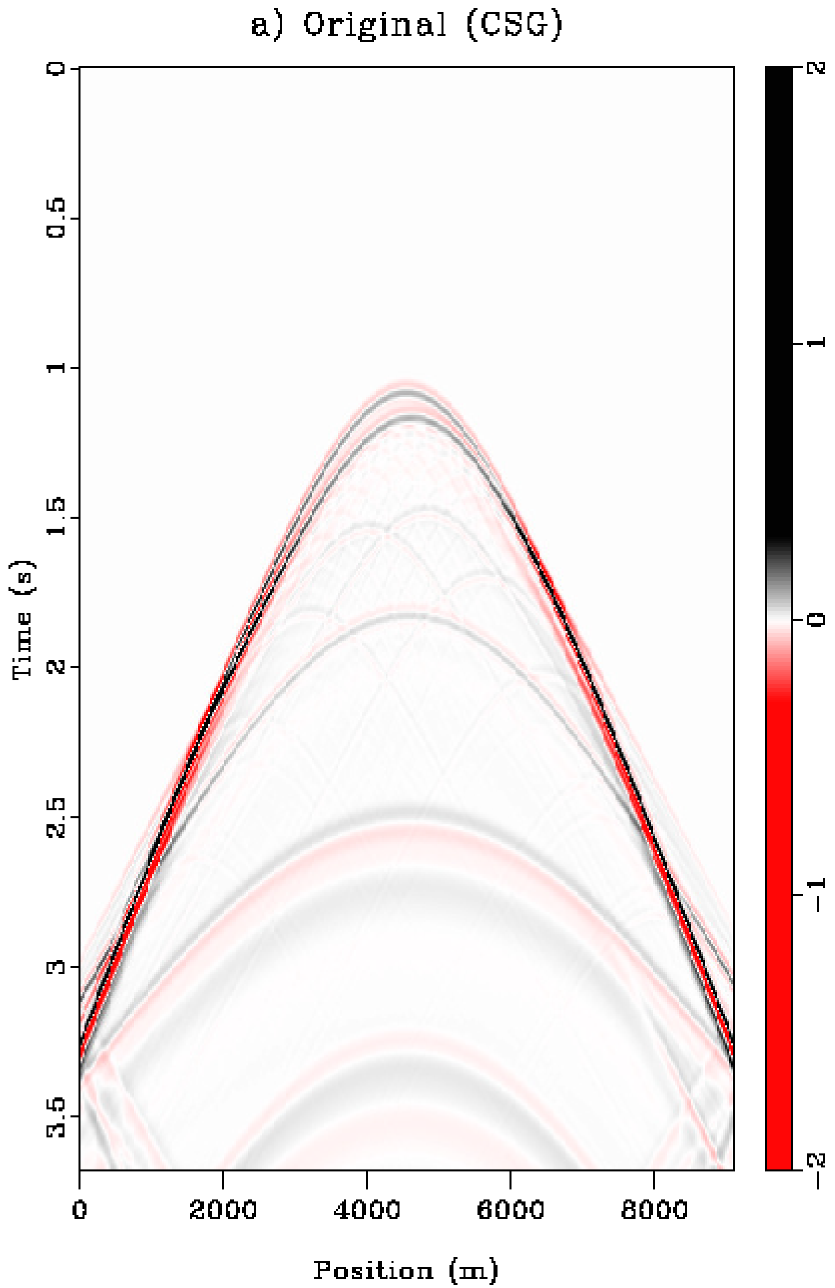
3.5
0
2000
4000
6000
8000
5000
10000
15000
20000
25000
2
1
0
−1
−2


a) Original (CSG)
Time (s)
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4000
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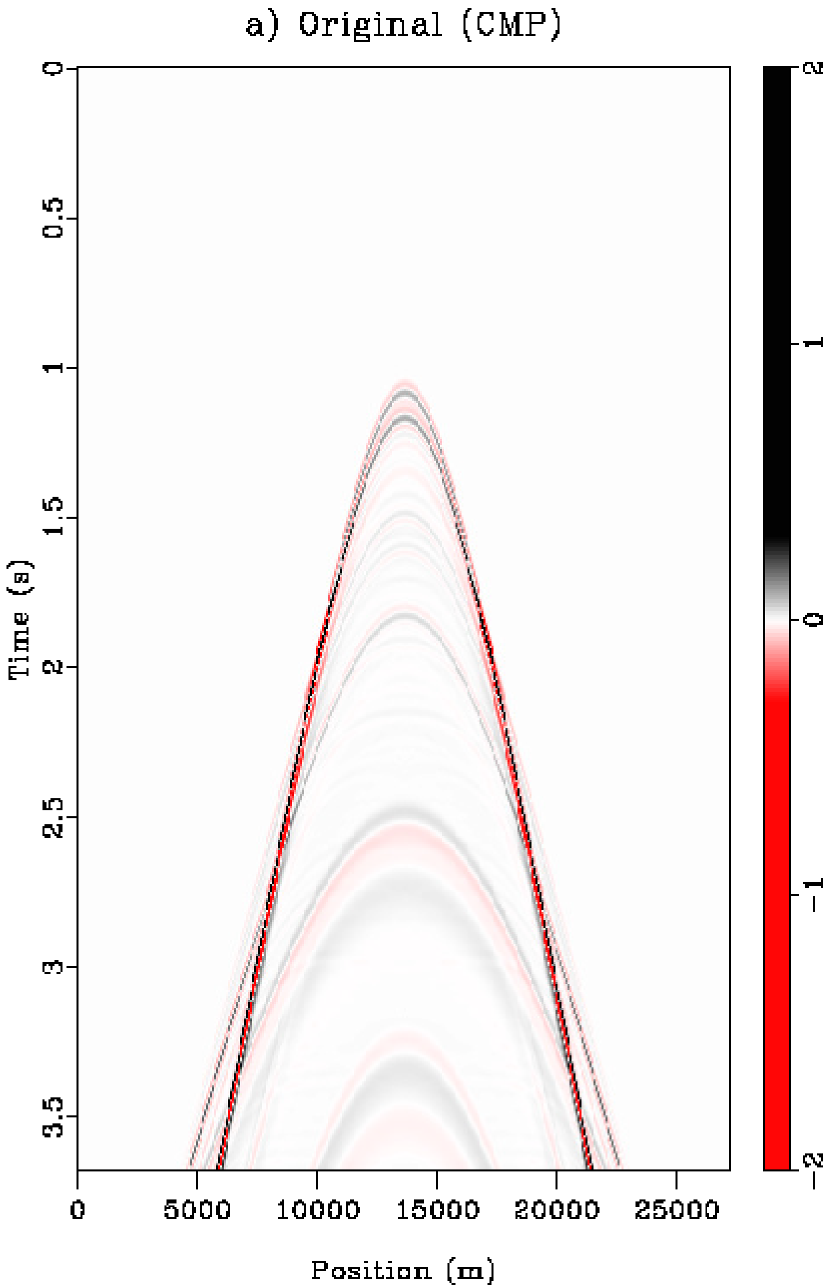
8000
Position (m)
2
1
0
−1
−2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10000
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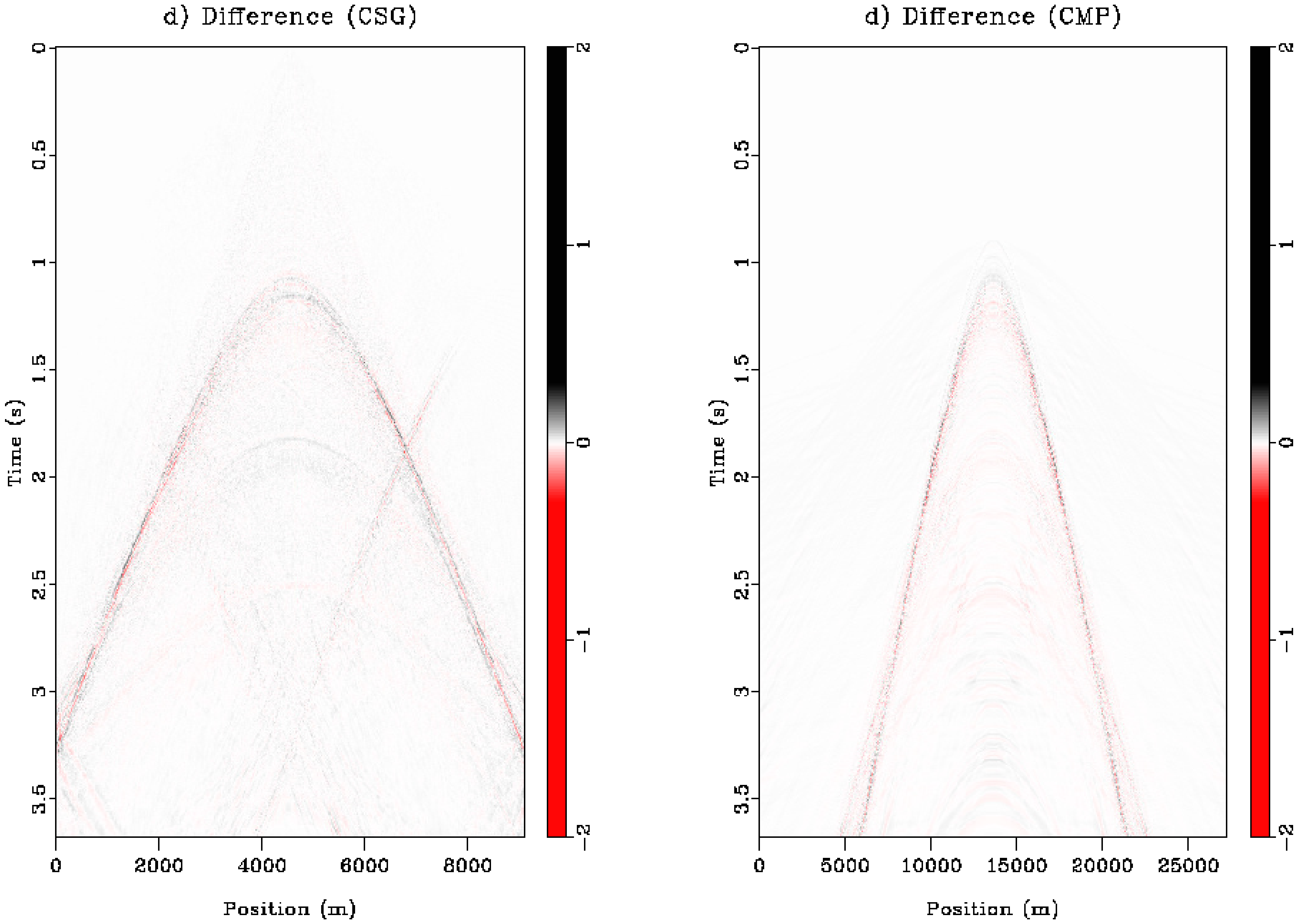
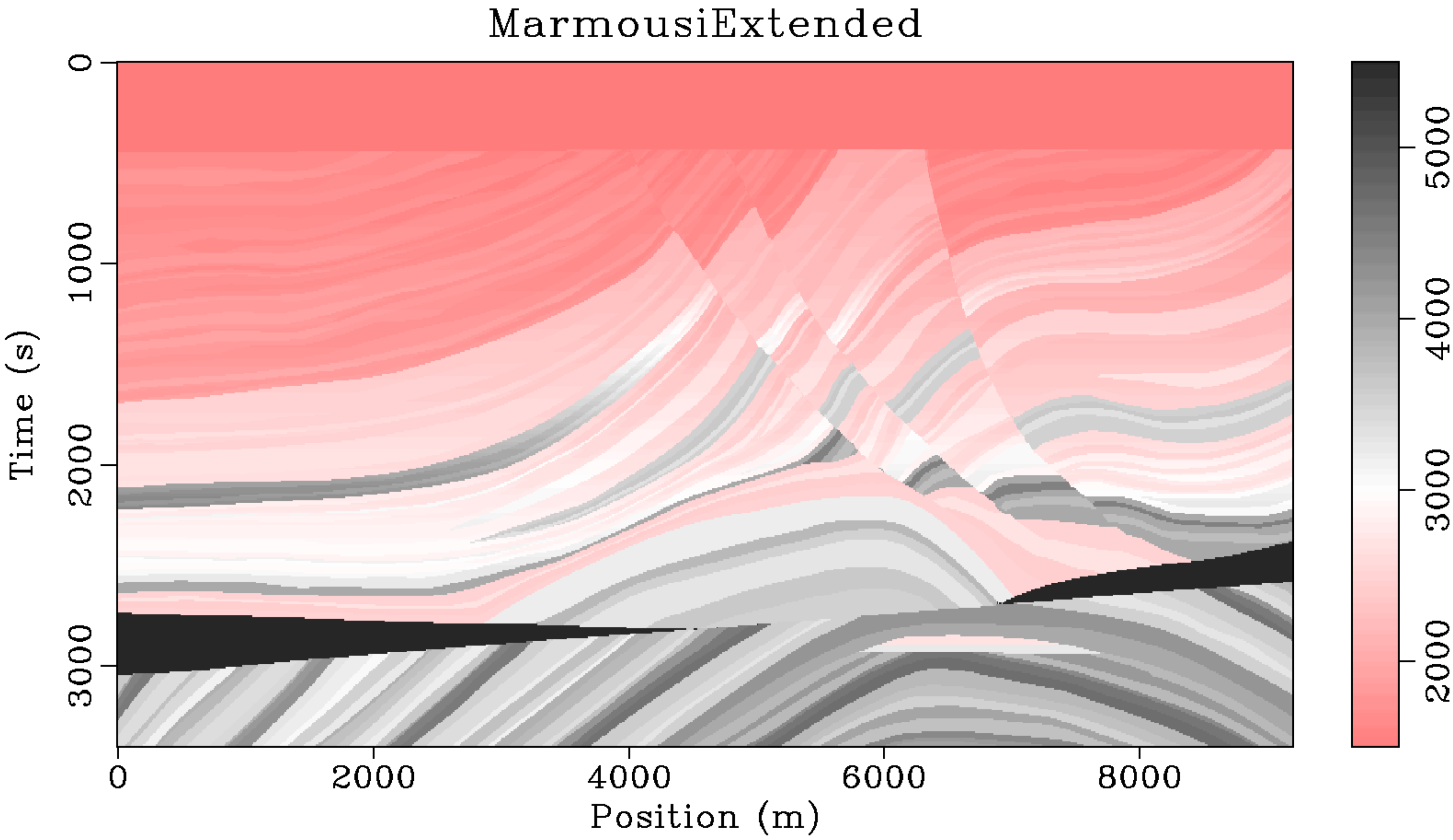
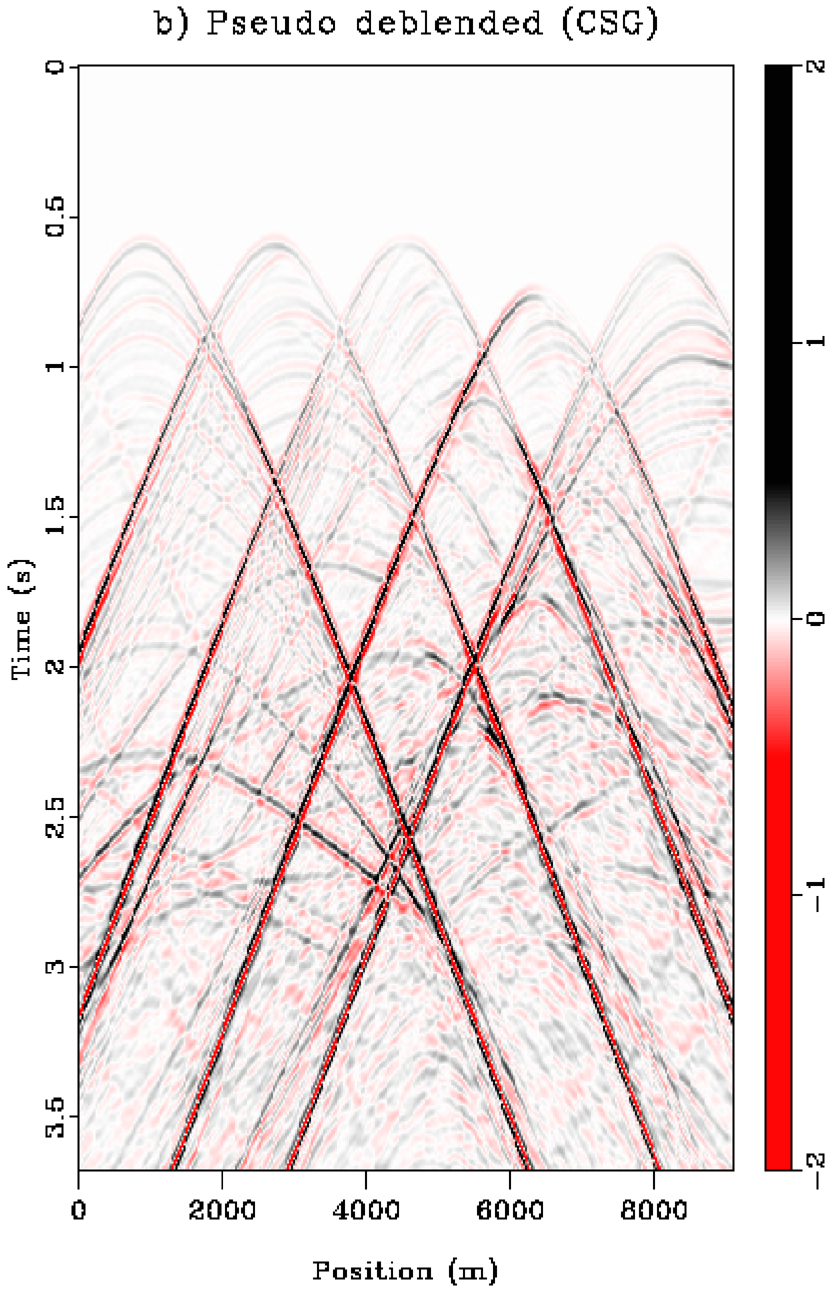
20000
25000
Position (m)
2
1
0
−1
−2


d) Difference (CSG)
Time (s)
Position (m)
0
2000
4000
6000
8000
0.5
1
1.5
2
2.5
3
3.5
−2
−1
0
1
2
d) Difference (CMP)
Time (s)
Position (m)
5000
10000
15000
20000
25000

Results - Marmousi




b) Pseudo deblended (CSG)
Time (s)
0
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Position (m)
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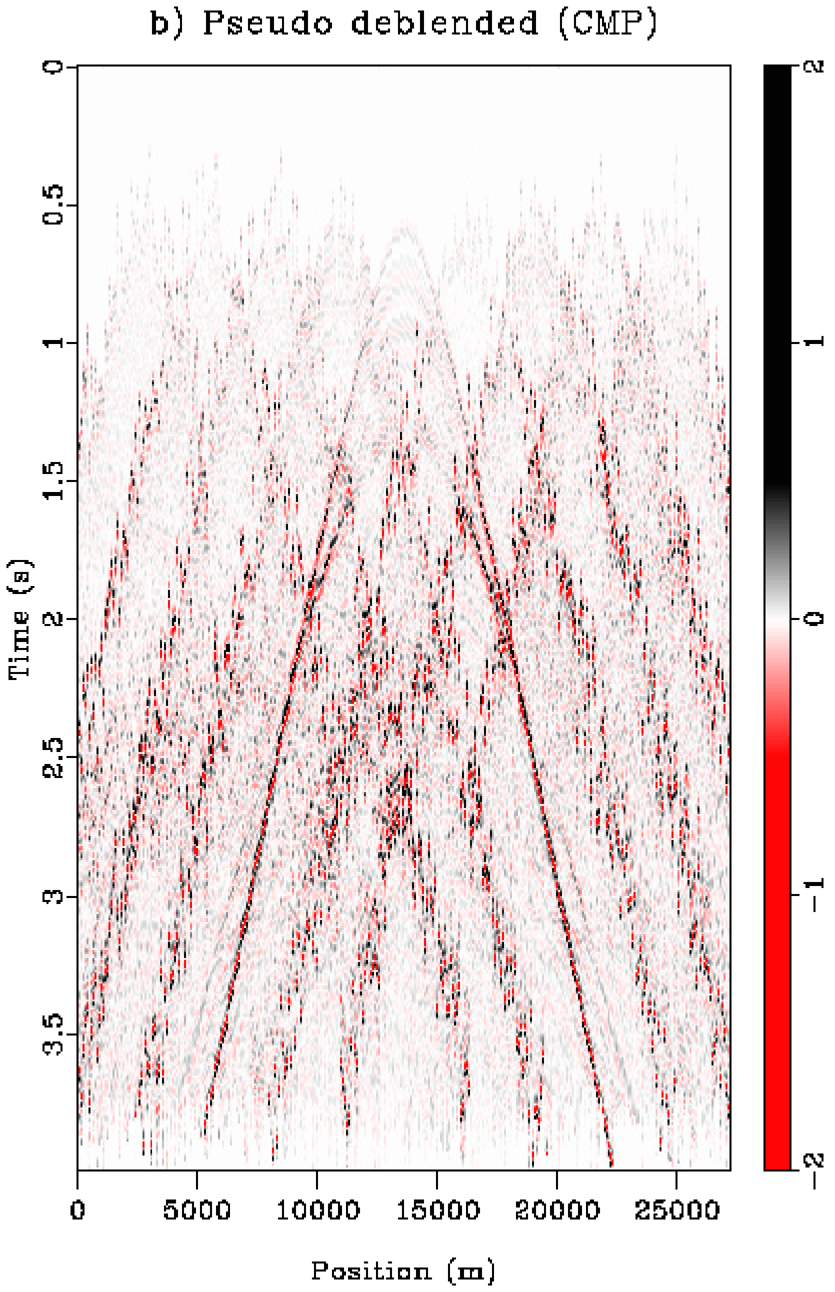
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Position (m)
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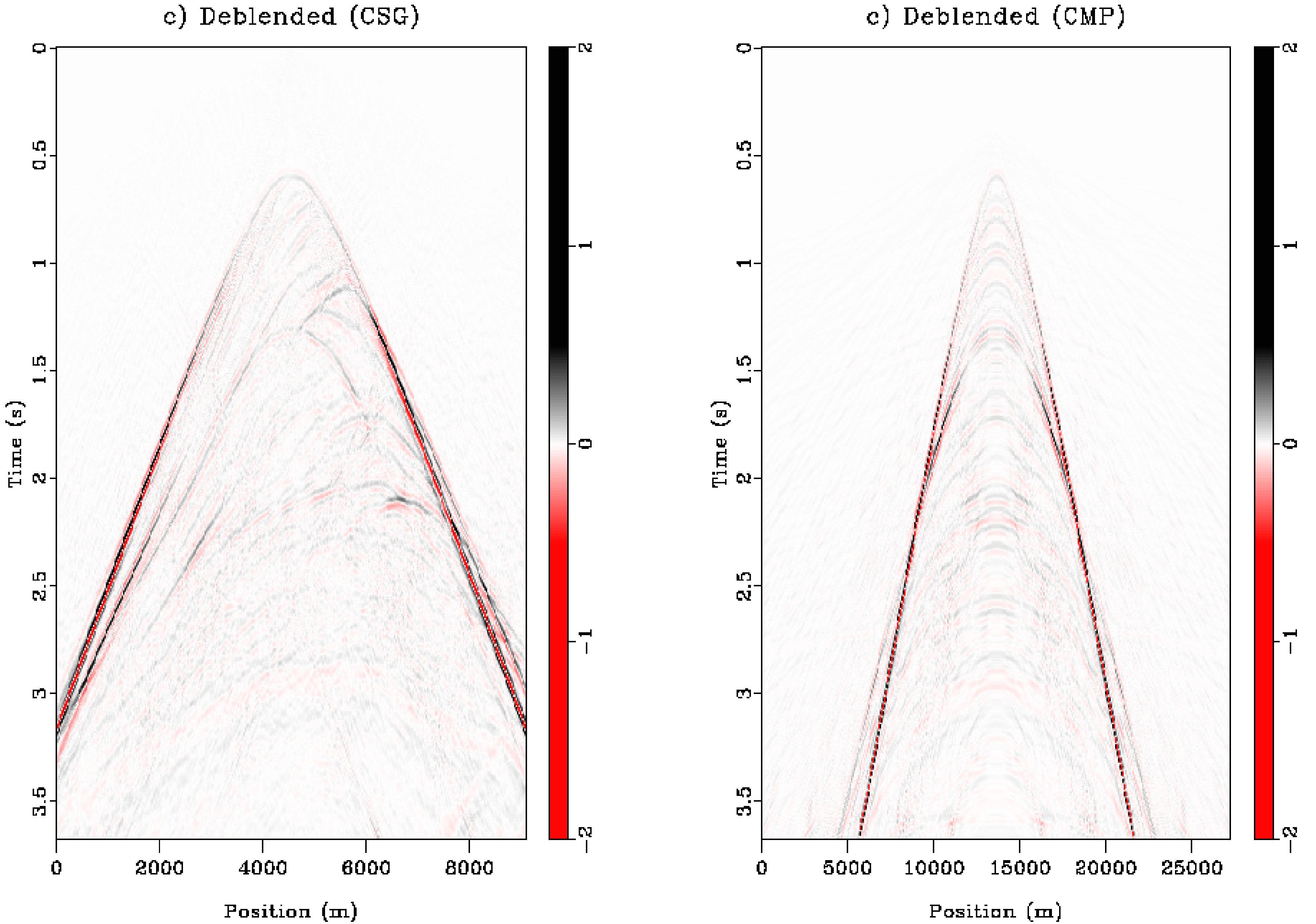
c) Deblended (CSG)
Time (s)
Position (m)
0
0.5
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4000
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8000
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1
0
−1
−2
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Position (m)
0
0.5
1
1.5
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3.5
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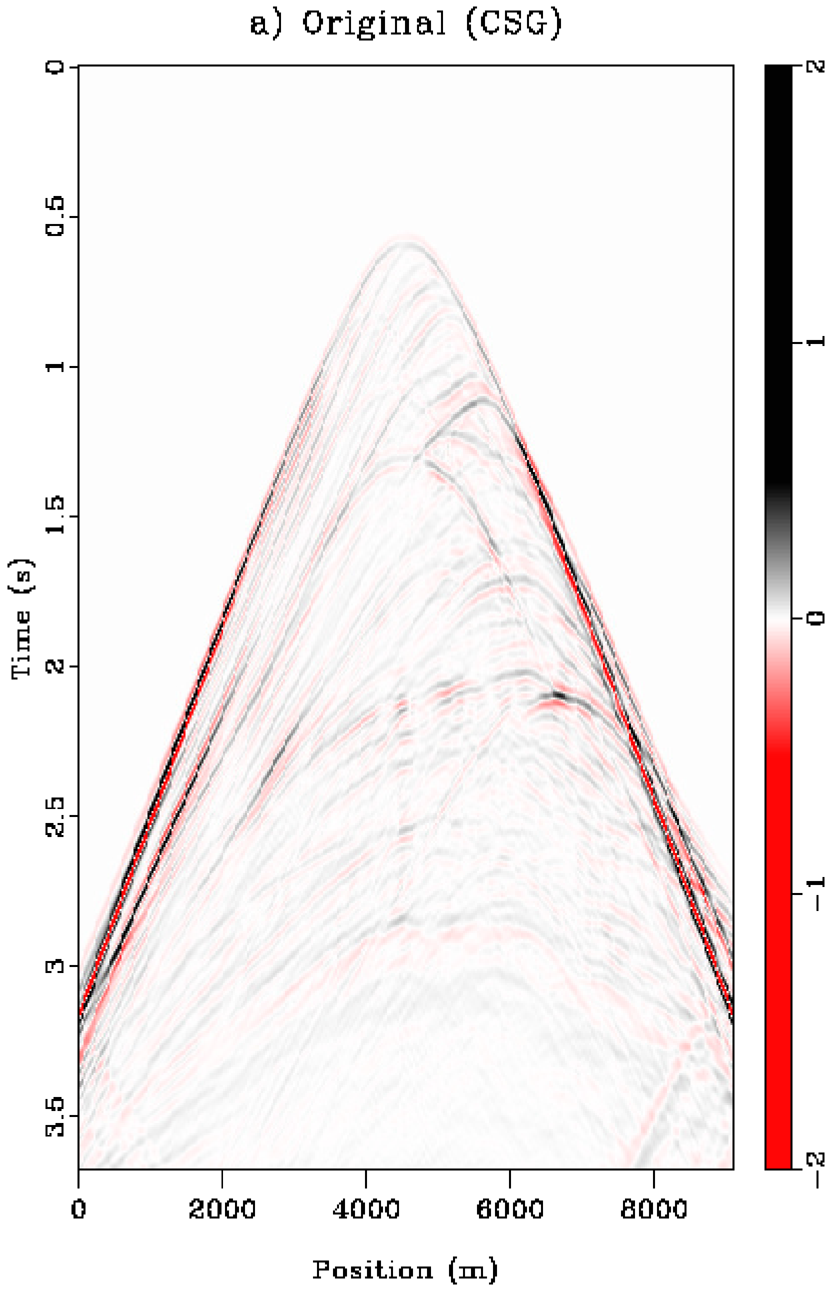
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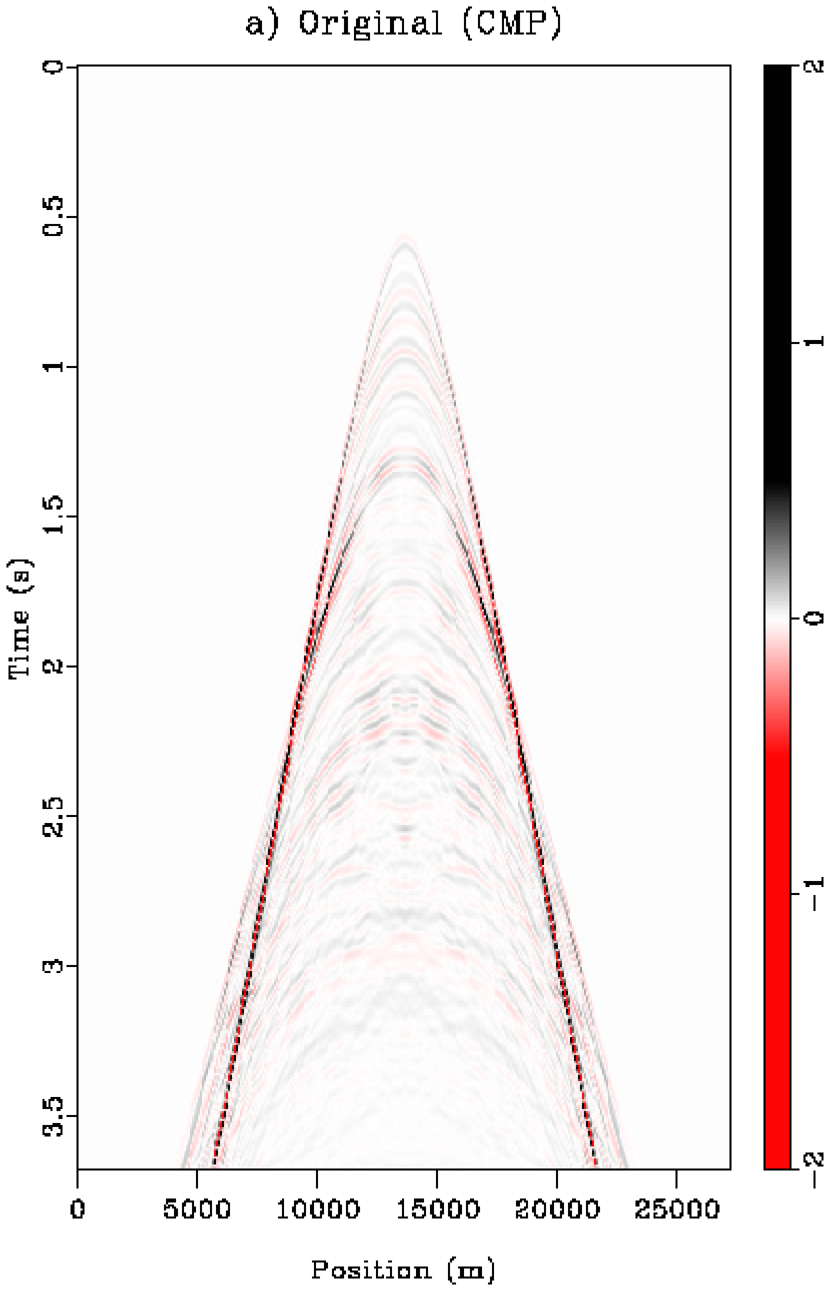
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Position (m)
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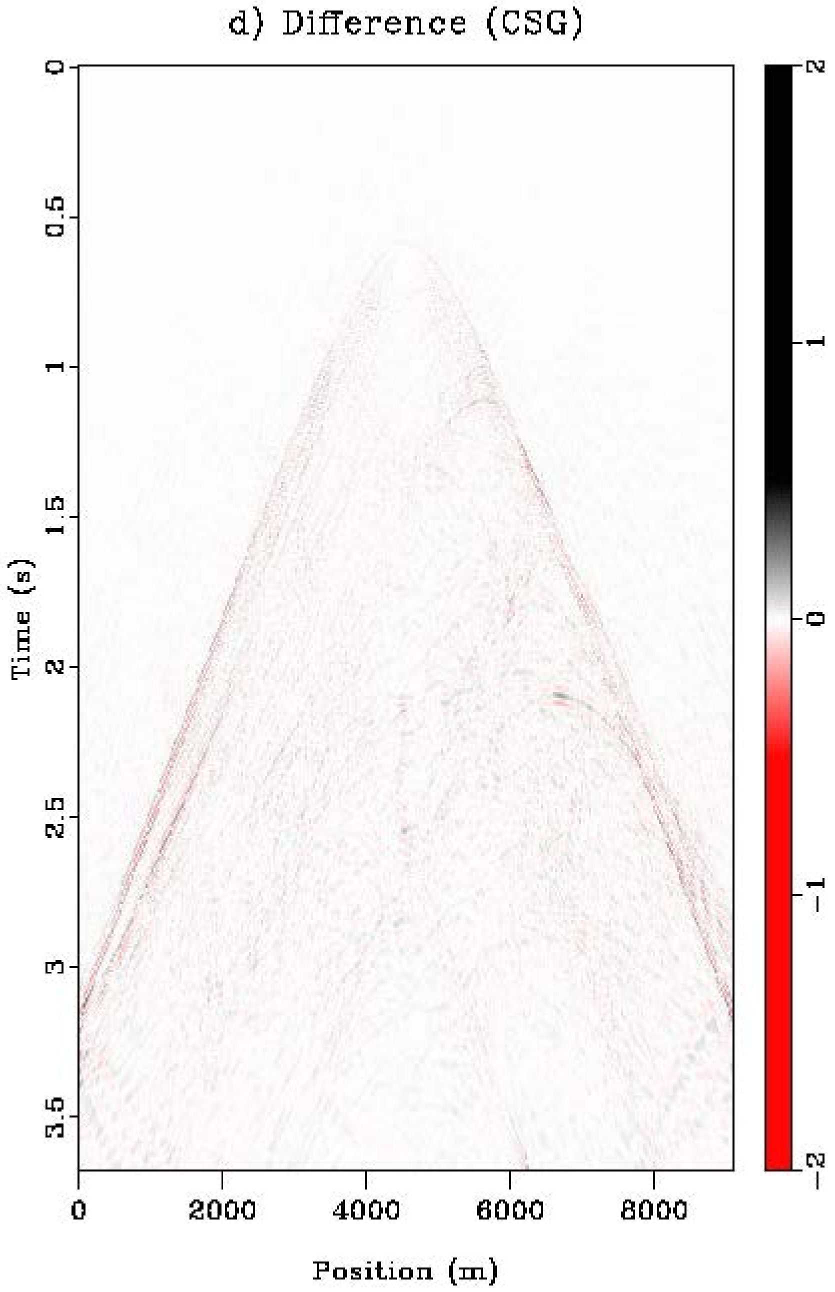
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Position (m)
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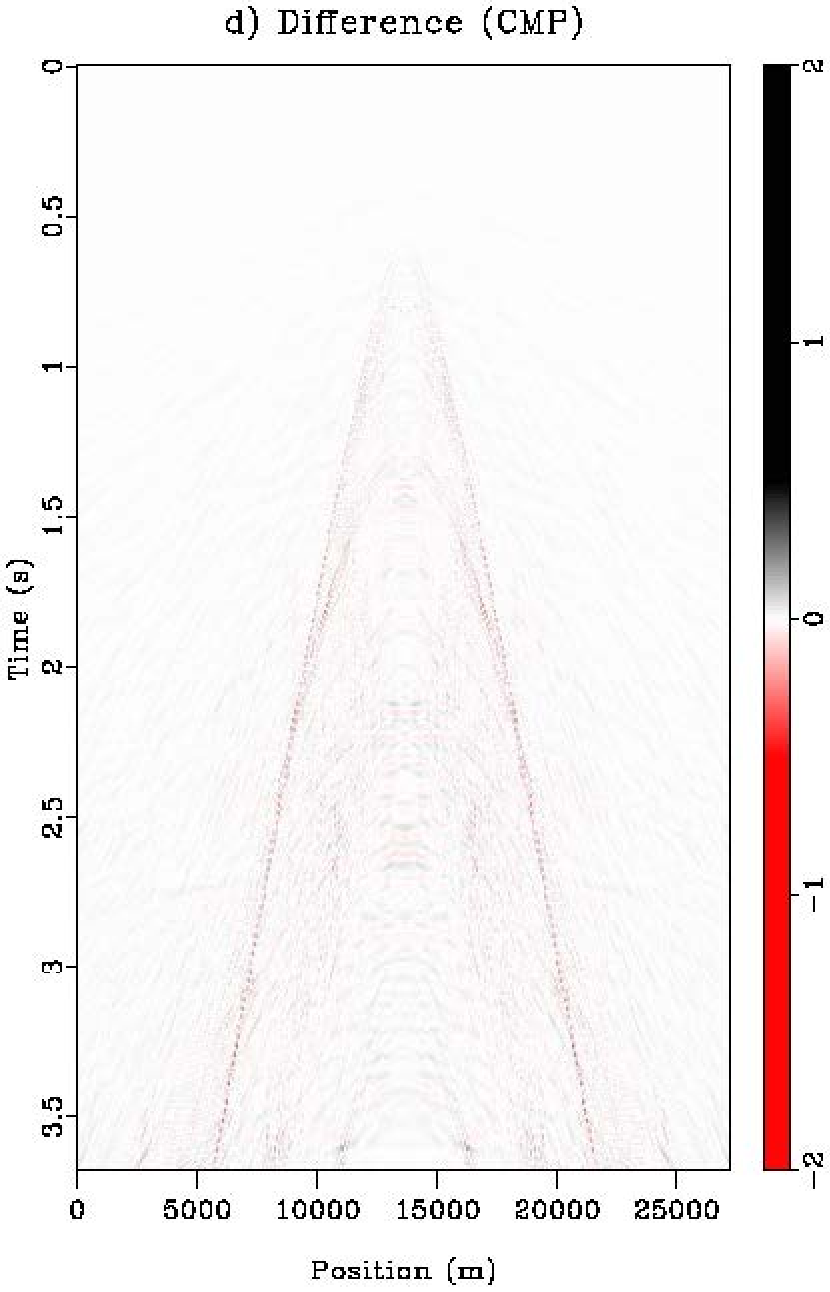
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0
0.5
1
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0
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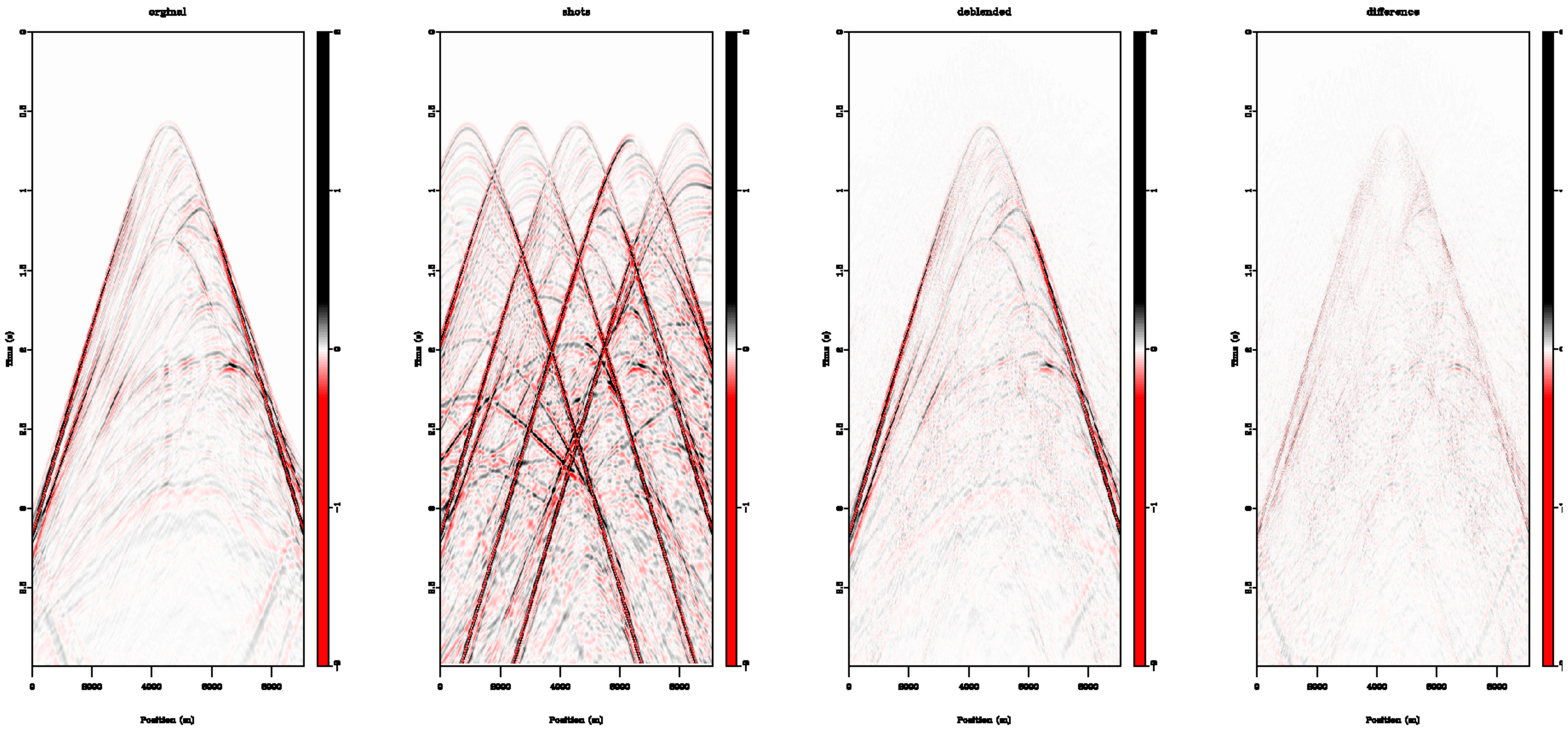
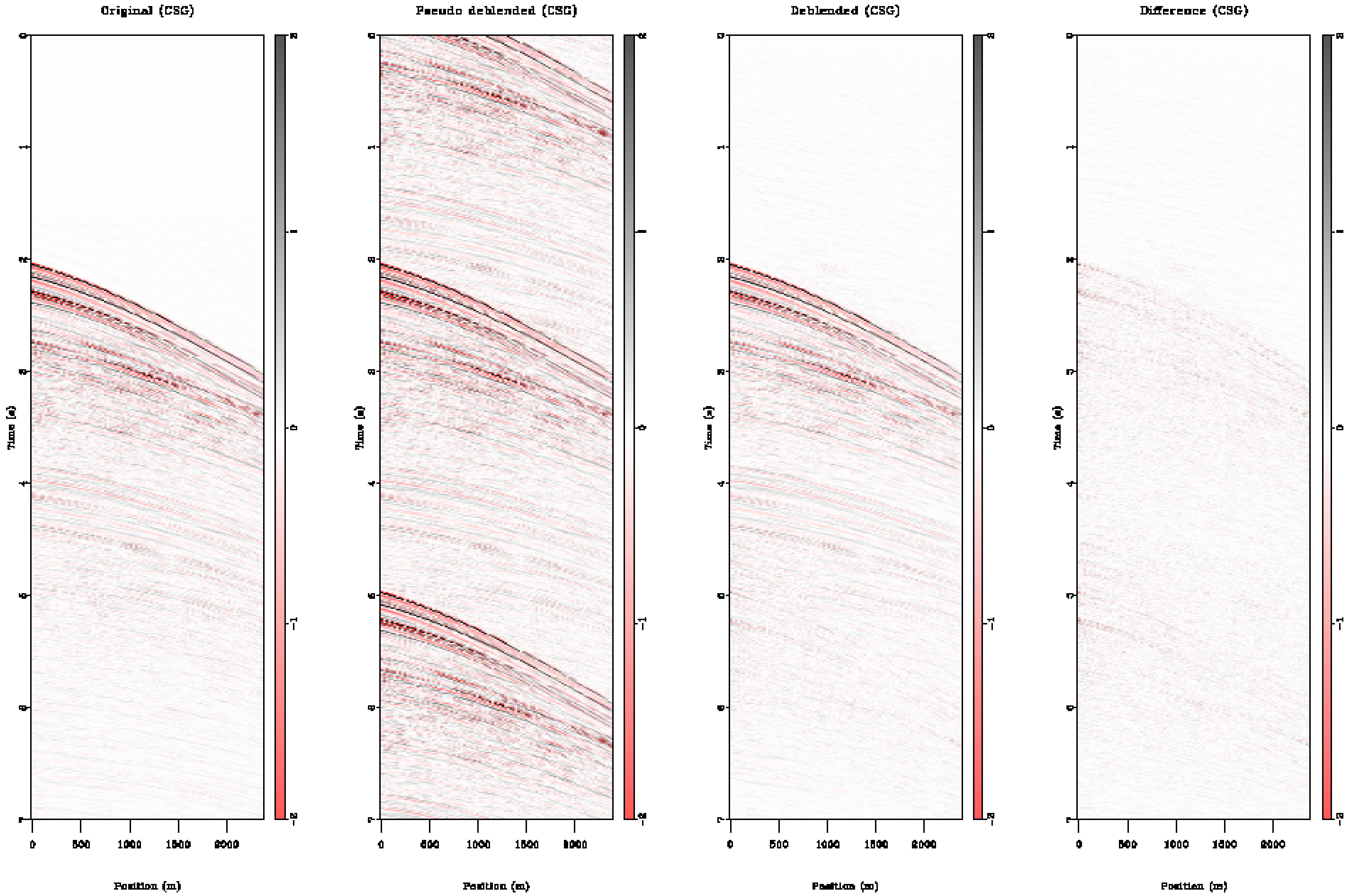
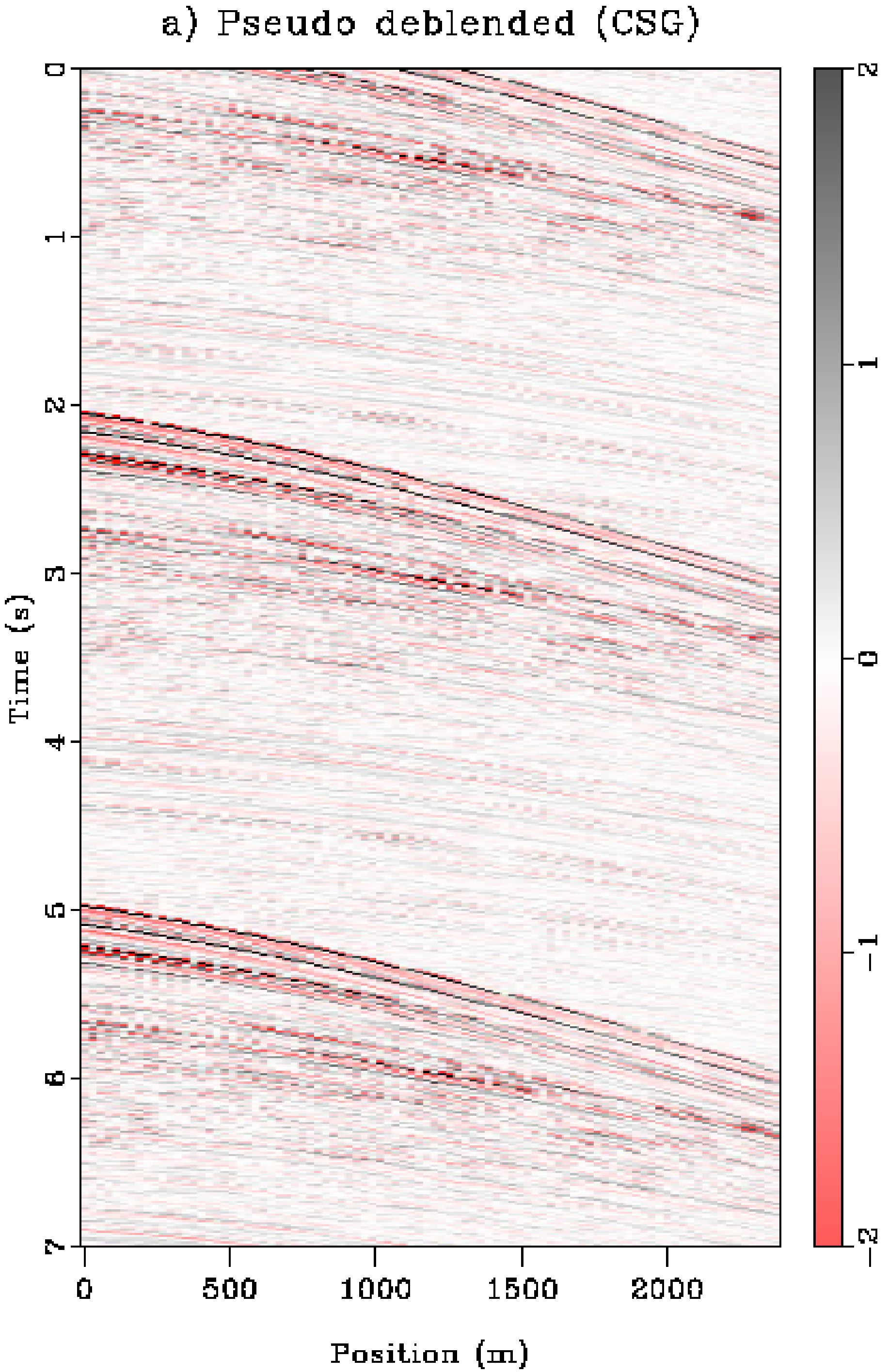
−2

Results - Marmousi



Gulf of Mexico Dataset




a) Pseudo deblended (CSG)
Time (s)
Position (m)
0
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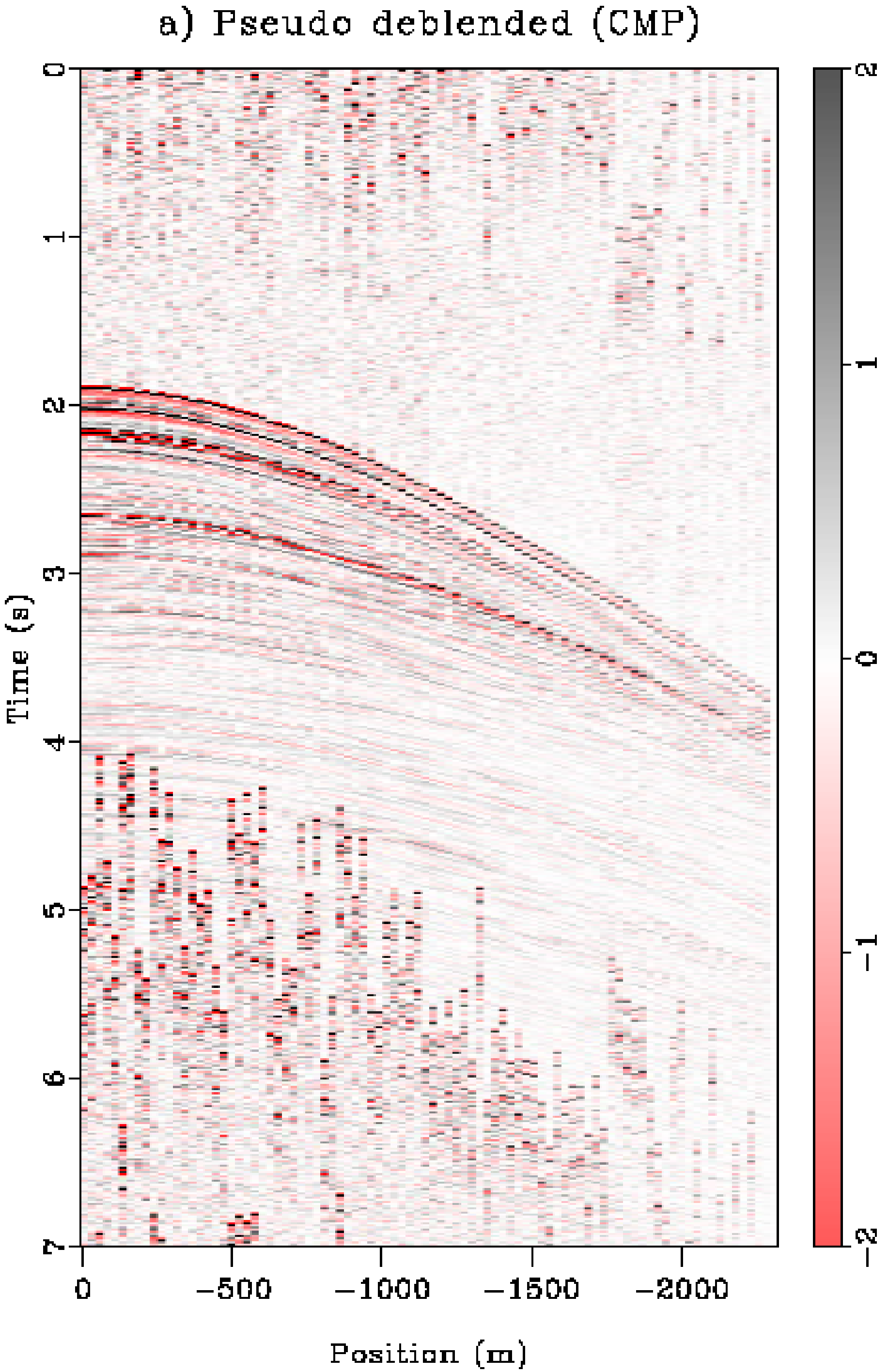
a) Pseudo deblended (CMP)
Time (s)
Position (m)
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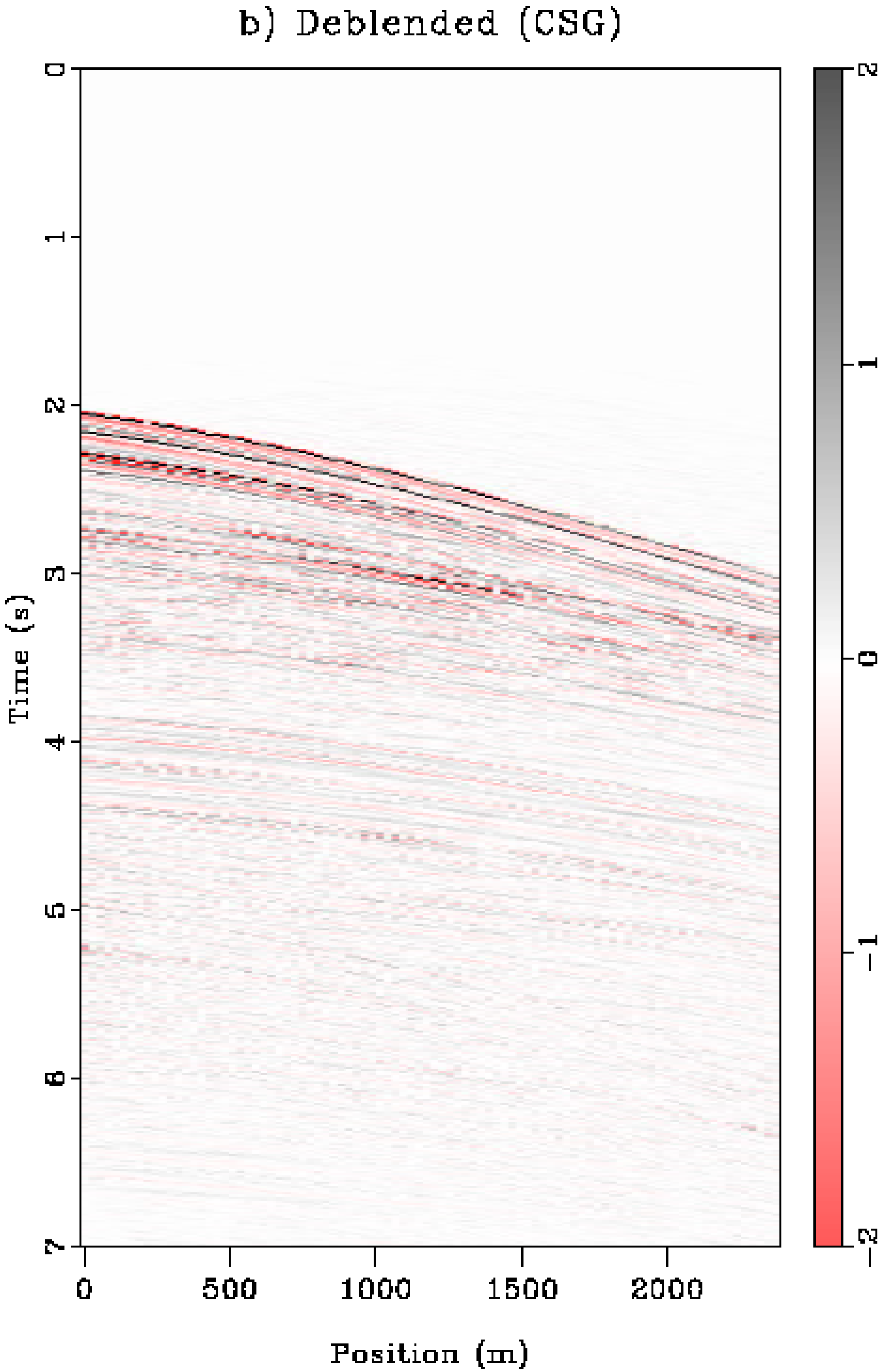
b) Deblended (CSG)
Time (s)
Position (m)
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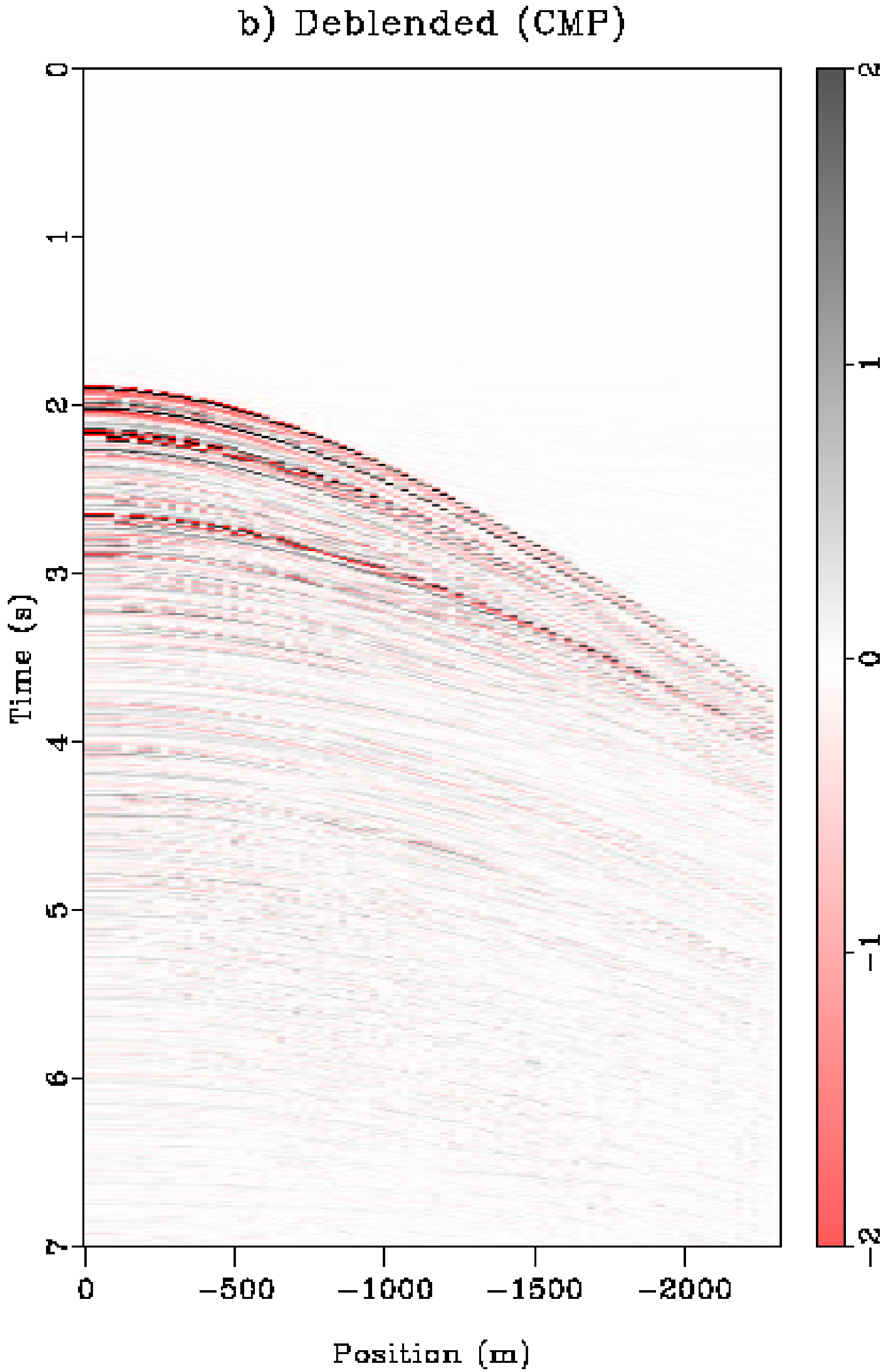
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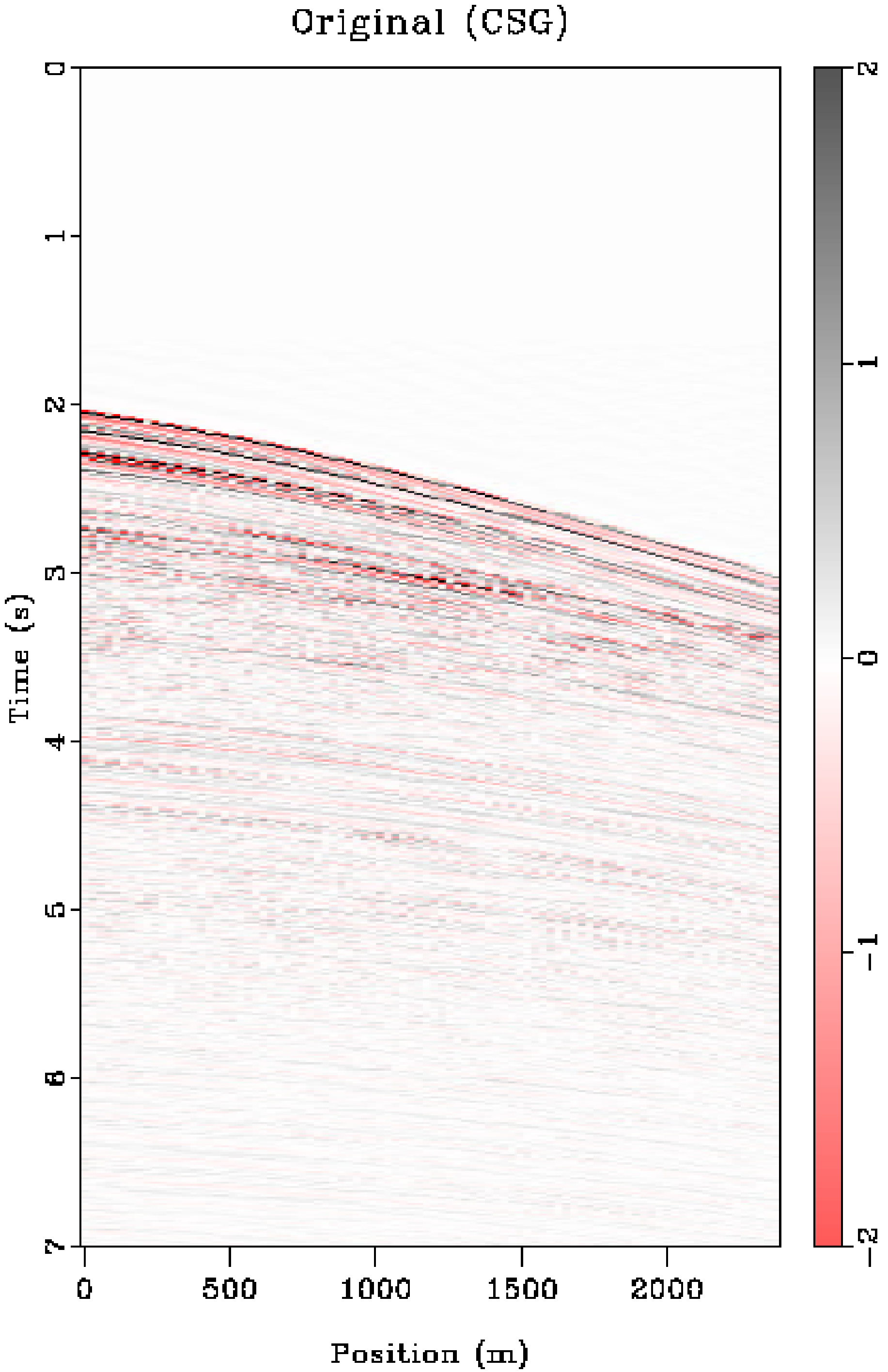
Original (CSG)
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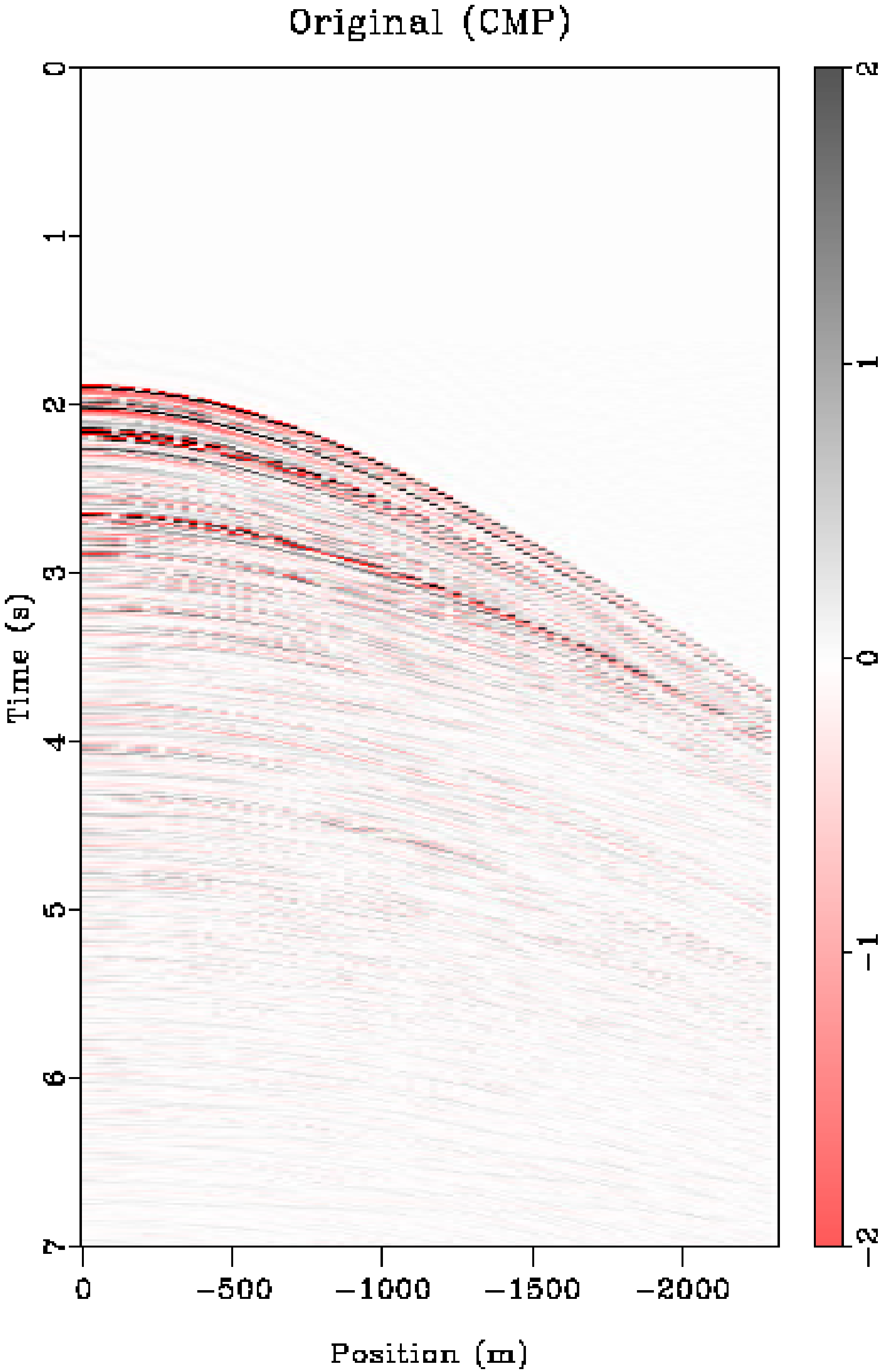
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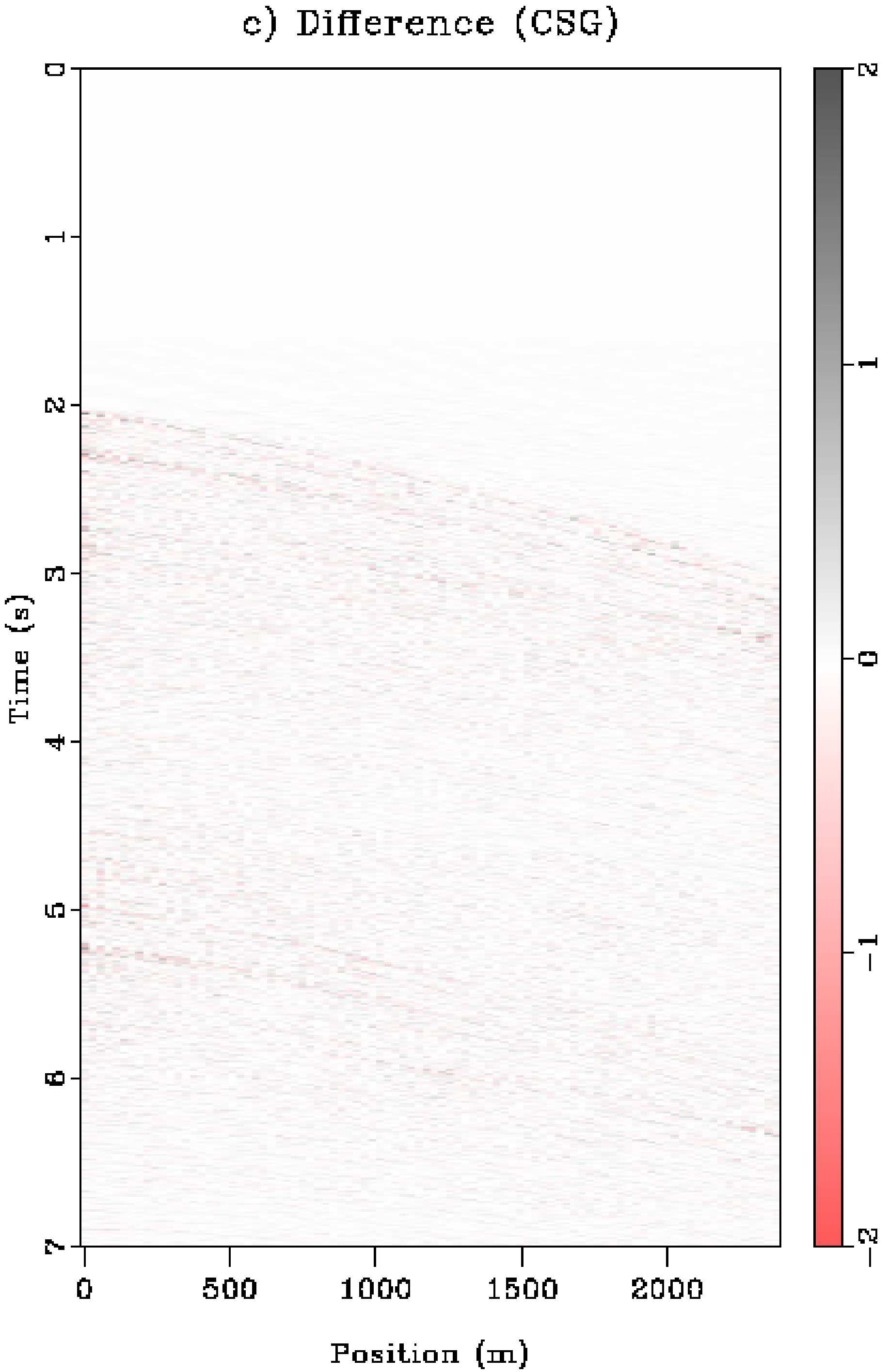
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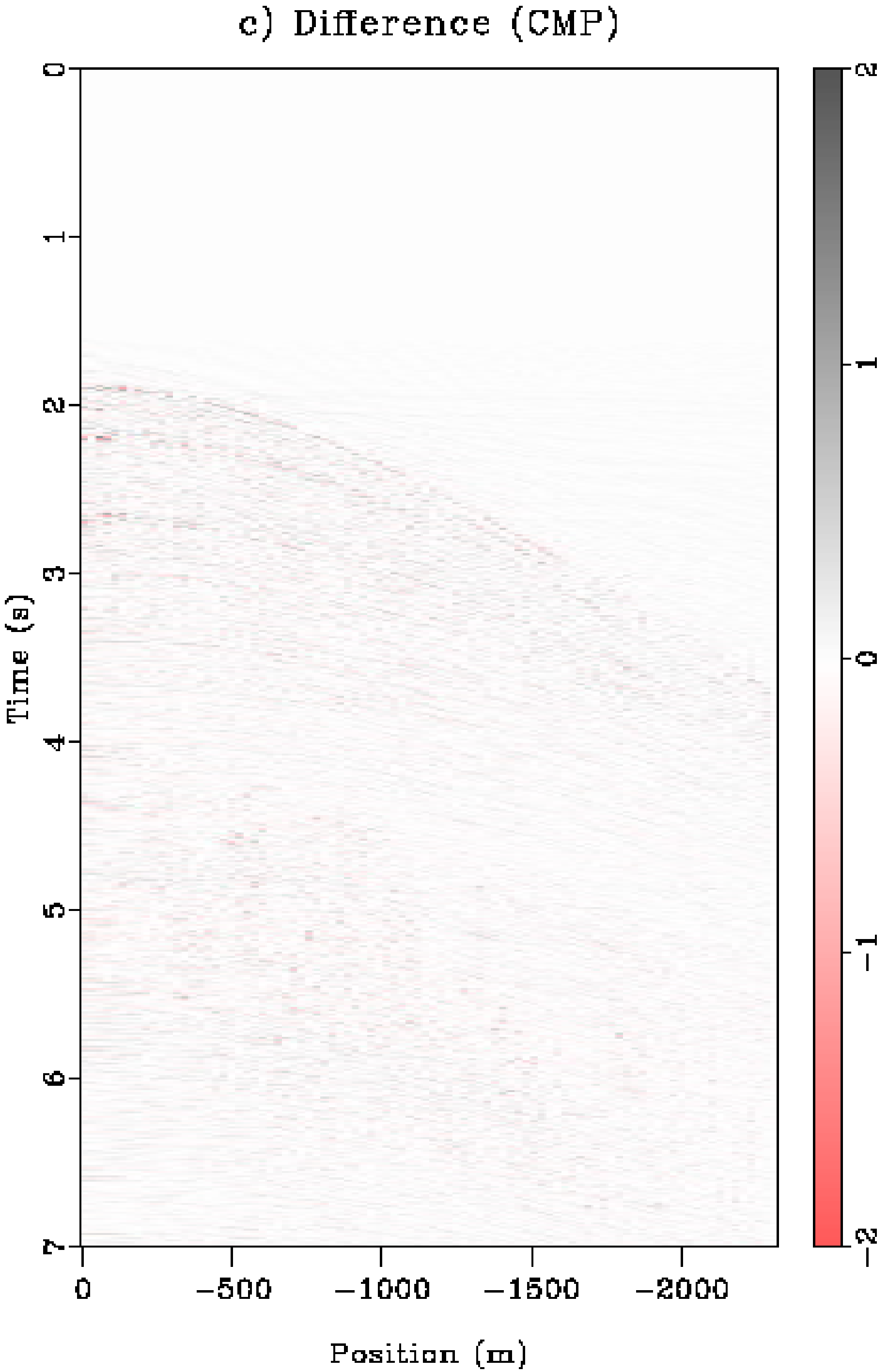
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Time (s)
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2
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0
−1
−2

Future Work

Extend Radon deblending to 3D applications

First need to find best high efficiency operator outlined below

Hybrid Radon transform

Using a hybrid linear-hyperbolic radon to map ground roll and direct arrivals as well as reflections for separation

Local windowing using linear radon

To deal with amplitude issues with diffractions using local instead of global helps preserve low amplitude events

acknowledgement

We thank the sponsors of CREWES for continued support. This work was funded by CREWES industrial sponsors, and NSERC (Natural Science and Engineering Research Council of Canada) through the grant CRDPJ 461179-13.