SharpSeis™ Technology for Deghosting/Broadband Processing of High-Resolution Marine Seismic Data

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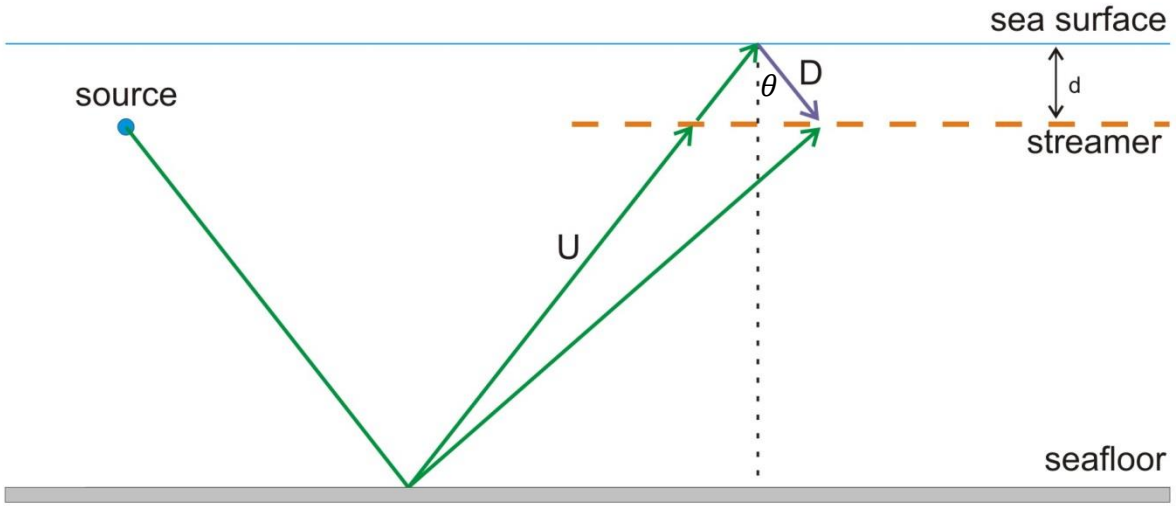
The ghost problem

Principle scheme of towed marine seismic survey



Ghost time delay: $\tau = \frac{2dcos\theta}{V}$

V – water velocity
d – streamer depth
θ – angle of incidence

The ghost problem

In frequency domain:

Original amplitude spectrum of the primary: $A(\omega)$;
Amplitude spectra of primary + ghost: $A(\omega)*2\sin(\omega\tau)$, where $\omega = 2\pi f$

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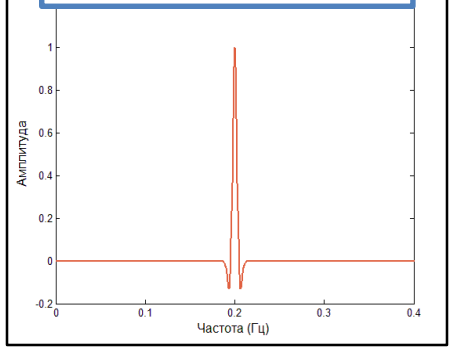
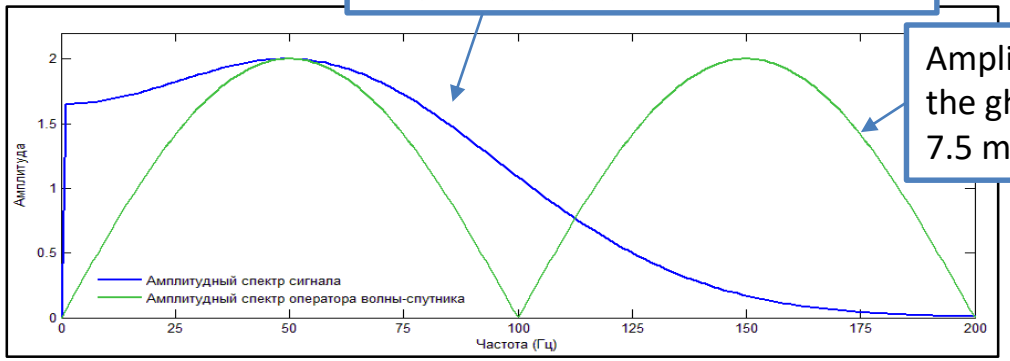
Ricker wavelet, 50 Hz



Amplitude spectrum of the wavelet

Amplitude spectrum of the ghost operator for 7.5 m towing depth



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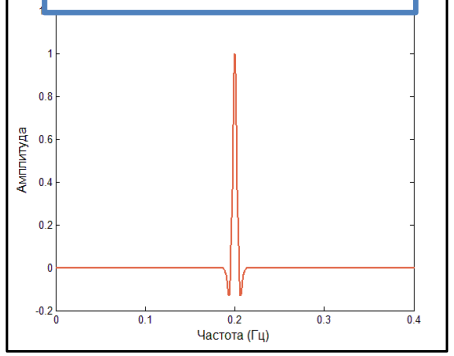

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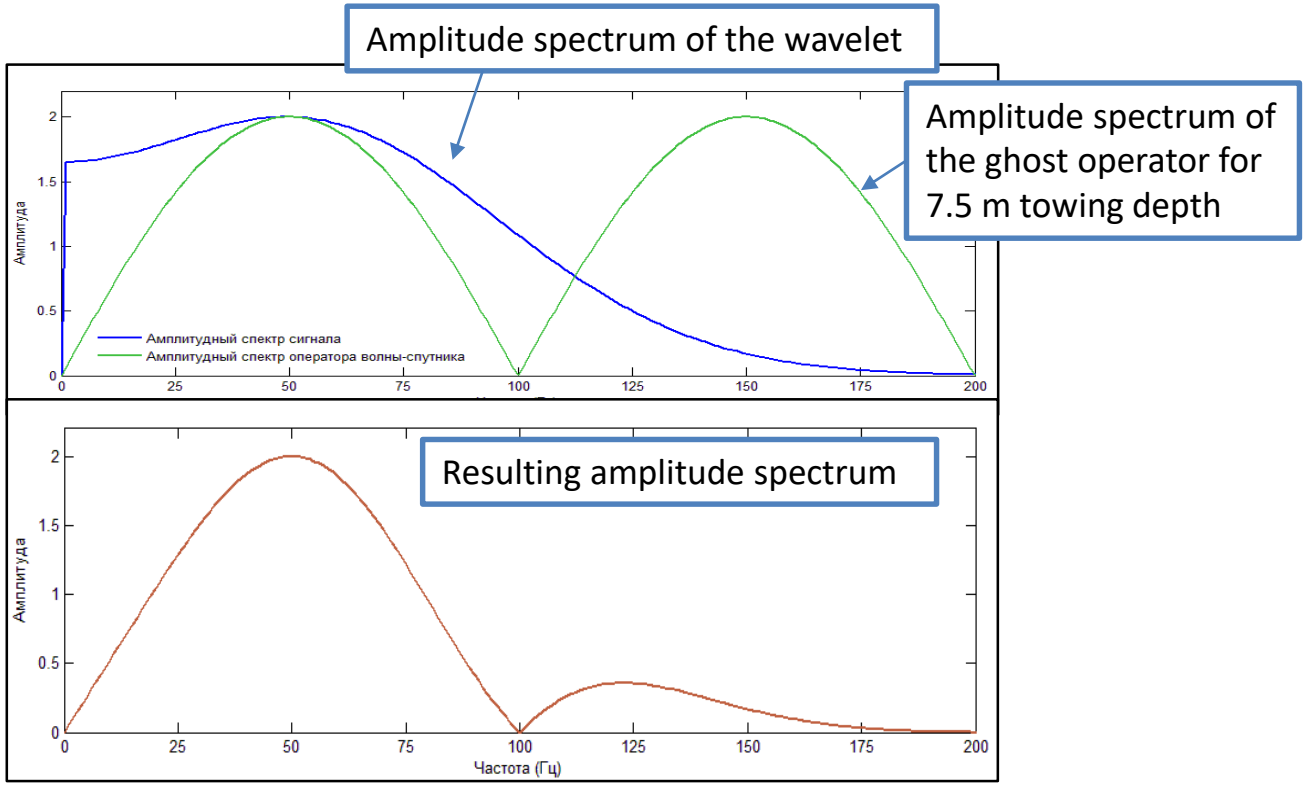
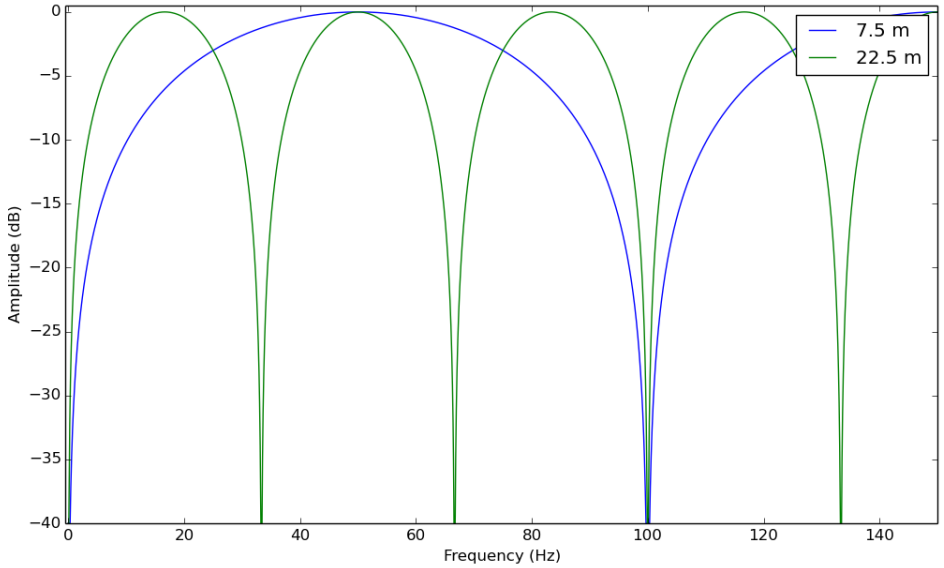


Resulting amplitude spectrum

The ghost problem

Shall we tow deeper?

Amplitude spectra of ghost operator for at 7.5 m and 22.5 m towing depths



notch frequencies : $\mathrm{F}nk = \frac{kV}{2d}$, where k=0, 1, 2…

Pros:	Cons:
Less noisy record, more lower frequencies can be registered	Notch frequencies appear earlier narrowing useful spectrum

The ghost problem

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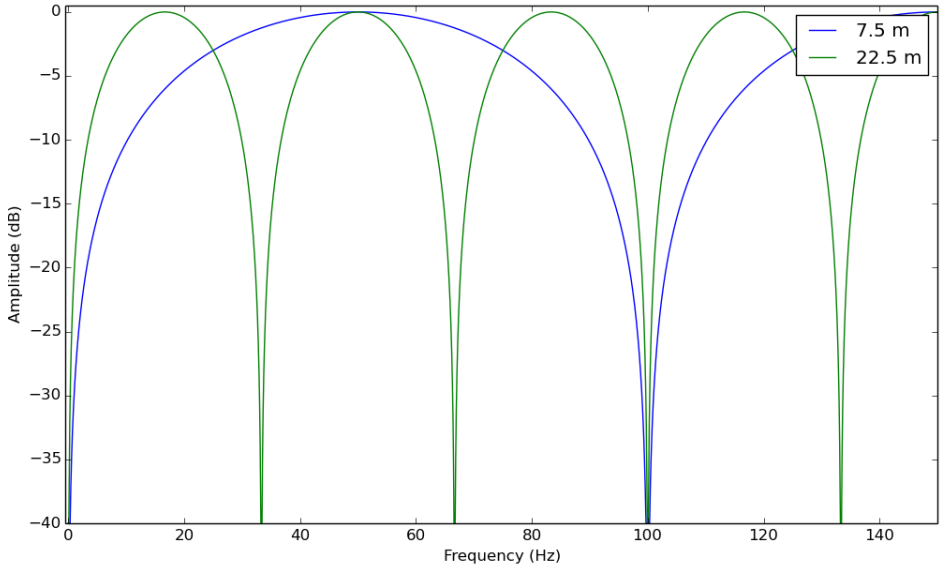
Amplitude spectra of ghost operator for at 7.5 m and 22.5 m towing depths



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SharpSeis™ deghosting solution

Model of the trace:

$$z(t) = p(t) - p(t - \tau)$$

SharpSeis™ deghosting solution

Model of the trace:

$$z(t) = p(t) - p(t-\tau)$$

$$p(t) = z(t) + p(t-\tau)$$

SharpSeis™ deghosting solution

Model of the trace:

$$z(t) = p(t) - p(t-\tau)$$

$$p(t) = z(t) + p(t-\tau) =$$
$$= z(t) + z(t-\tau) + p(t-2\tau)$$

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$$z(t) = p(t) - p(t-\tau)$$

$$p(t) = z(t) + p(t-\tau) =$$
$$= z(t) + z(t-\tau) + p(t-2\tau) =$$
$$= z(t) + z(t-\tau) + z(t-2\tau) + p(t-4\tau) = \ldots$$

SharpSeis™ deghosting solution : recursive filtering

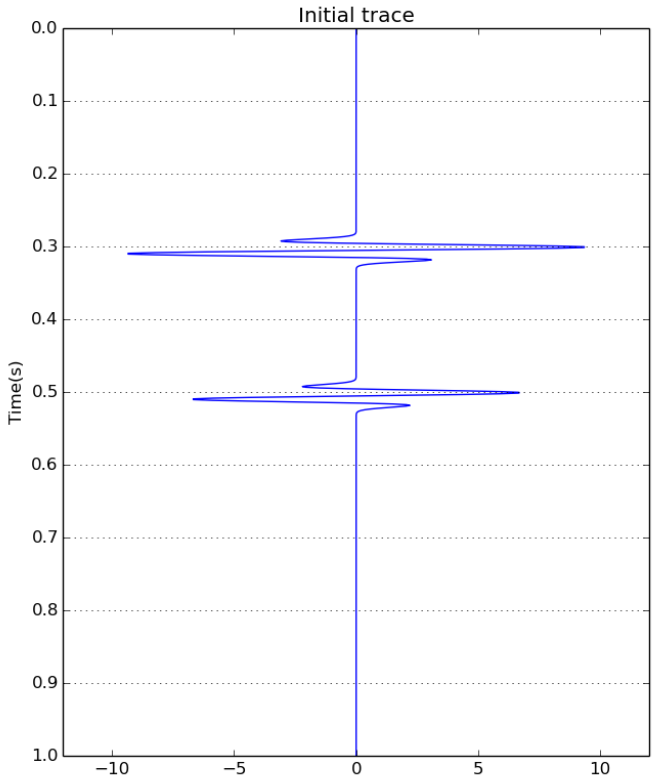
Model of the trace:

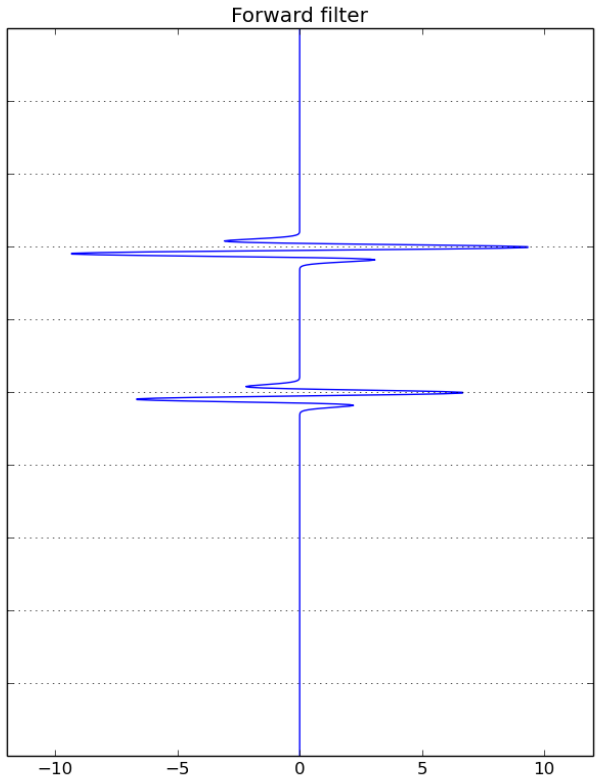
$$z(t) = p(t) - p(t-\tau)$$

Recursive filtering:

$$p(t) = z(t) + p(t-\tau) = z(t) + z(t-\tau) + p(t-2\tau) = \cdots$$

Iteration 0





SharpSeis™ deghosting solution : recursive filtering

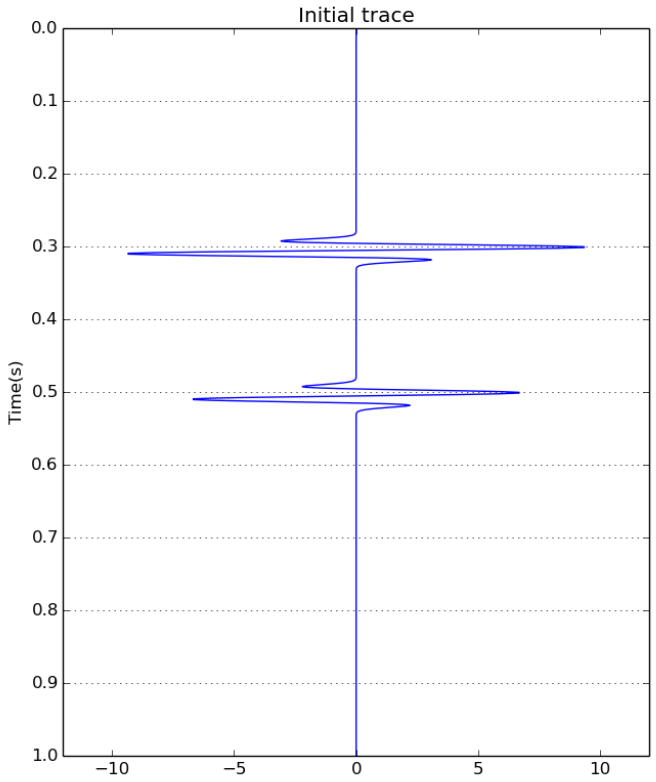
Iteration 1

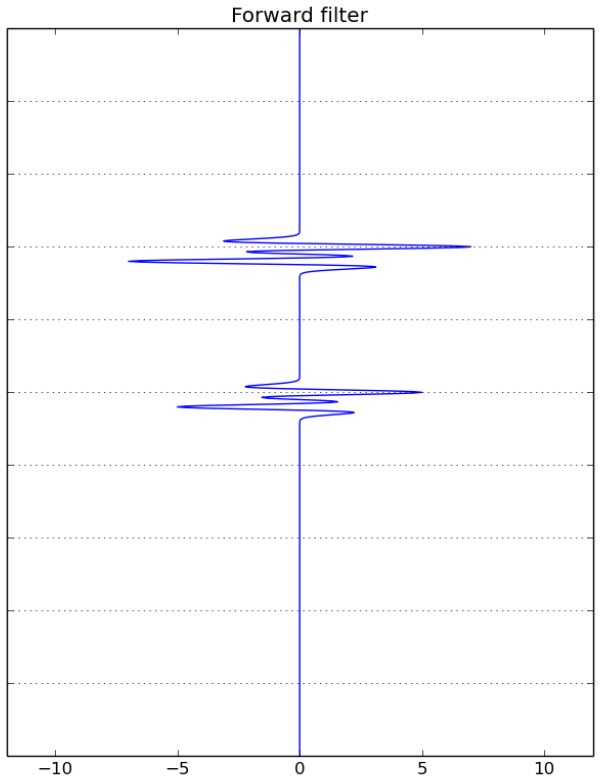
Model of the trace:

$$z(t) = p(t) - p(t - \tau)$$

Recursive filtering:

$$p(t) = z(t) + p(t - \tau) =$$
$$z(t) + z(t - \tau) + p(t - 2\tau) = \cdots$$





SharpSeis™ deghosting solution : recursive filtering

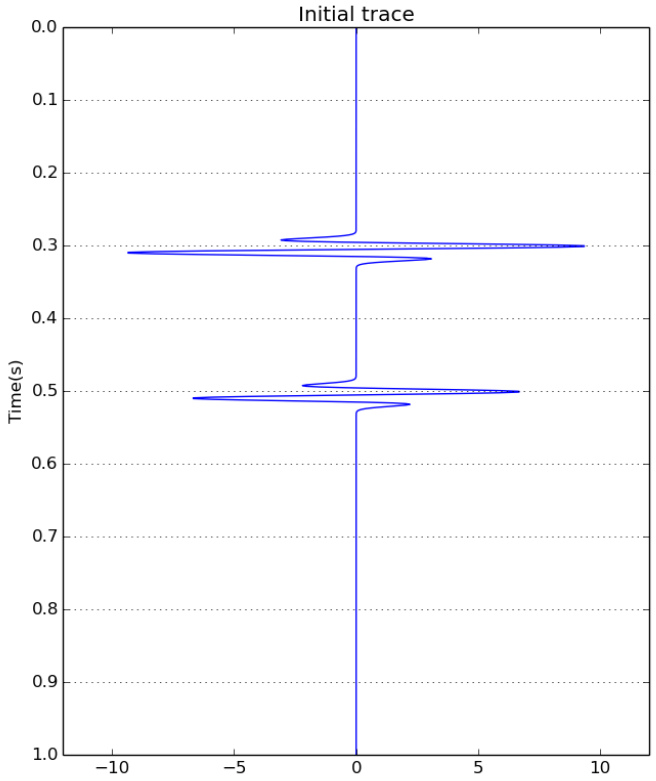
Iteration 2

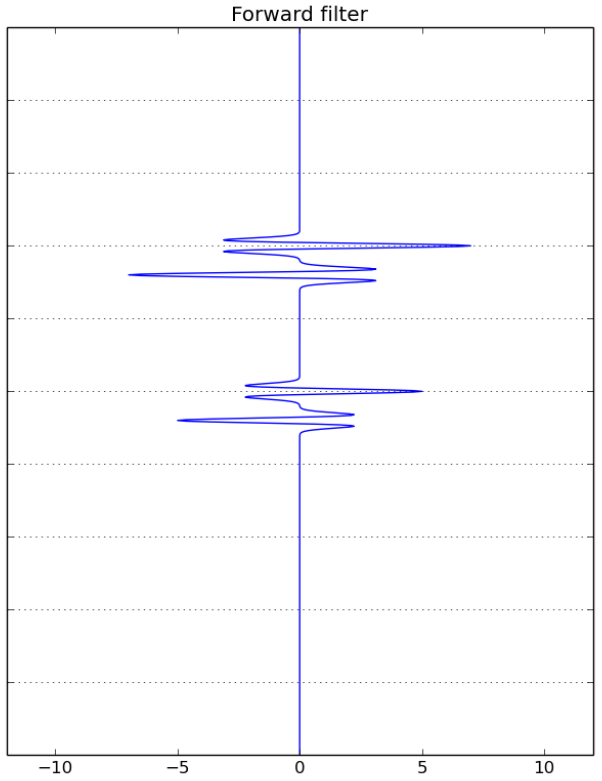
Model of the trace:

$$z(t) = p(t) - p(t-\tau)$$

Recursive filtering:

$$p(t) = z(t) + p(t-\tau) =$$
$$z(t) + z(t-\tau) + p(t-2\tau) = \cdots$$





SharpSeis™ deghosting solution : recursive filtering

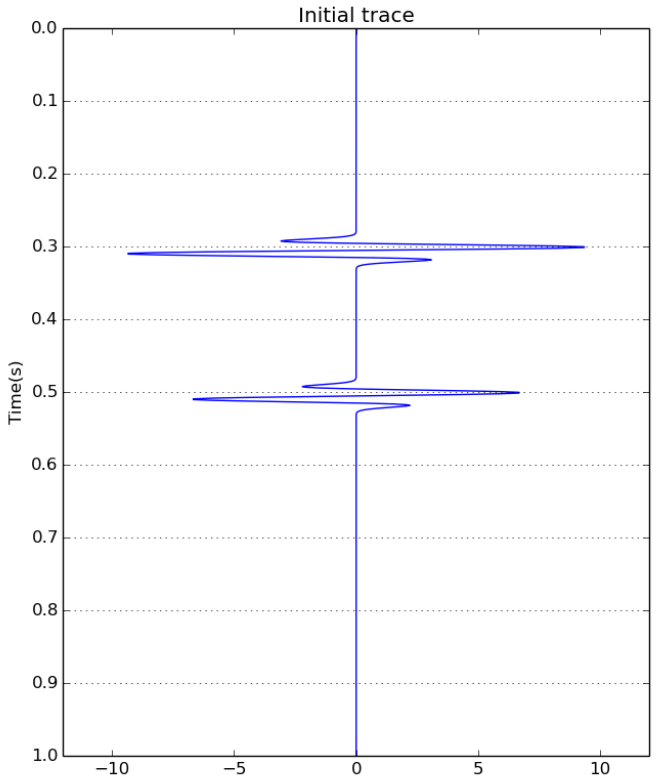
Iteration 3

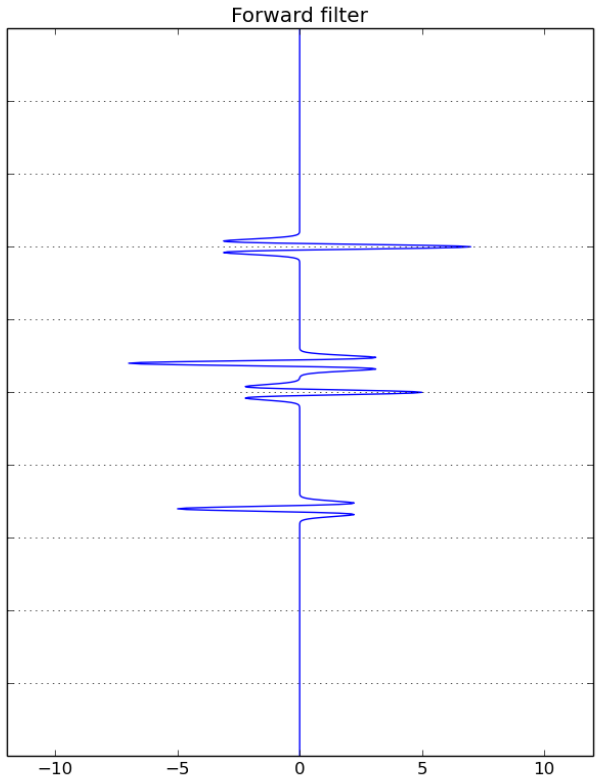
Model of the trace:

$$z(t) = p(t) - p(t-\tau)$$

Recursive filtering:

$$p(t) = z(t) + p(t-\tau) =$$
$$z(t) + z(t-\tau) + p(t-2\tau) = \cdots$$





SharpSeis™ deghosting solution : recursive filtering

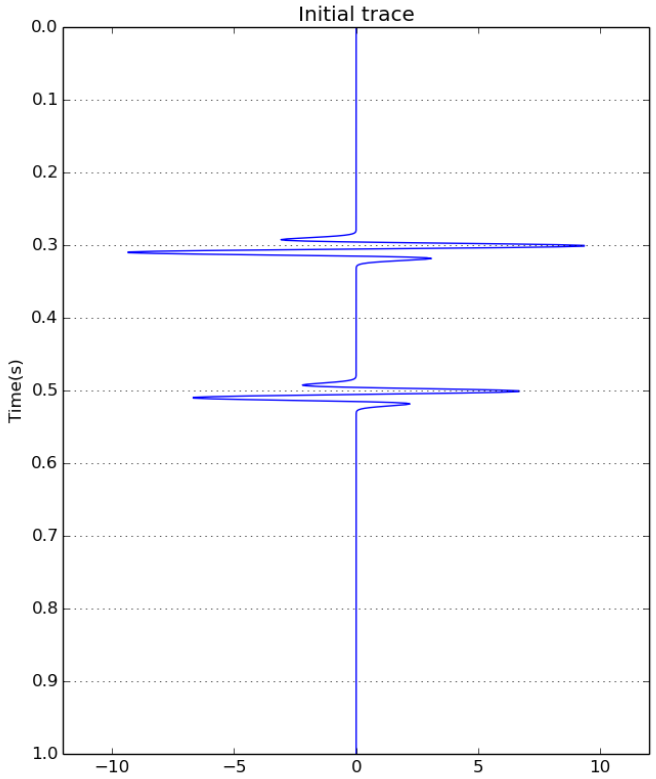
Iteration N

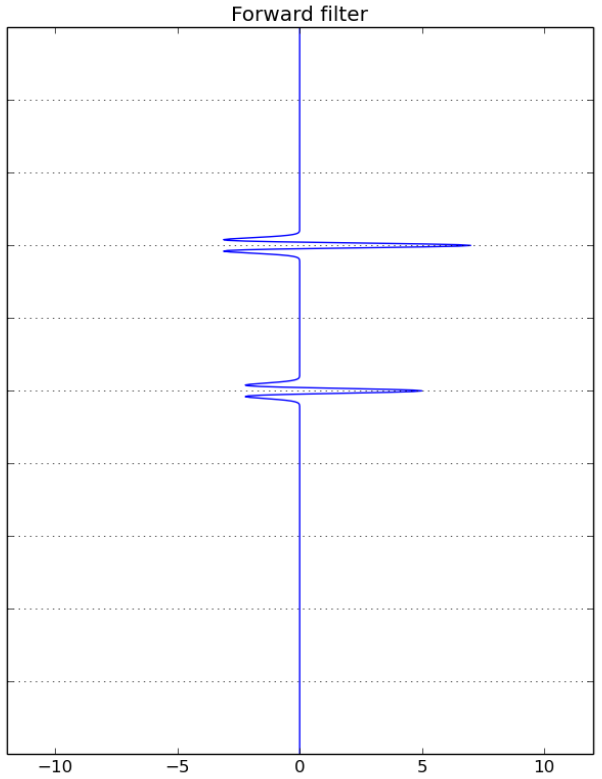
Model of the trace:

$$z(t) = p(t) - p(t - \tau)$$

Recursive filtering:

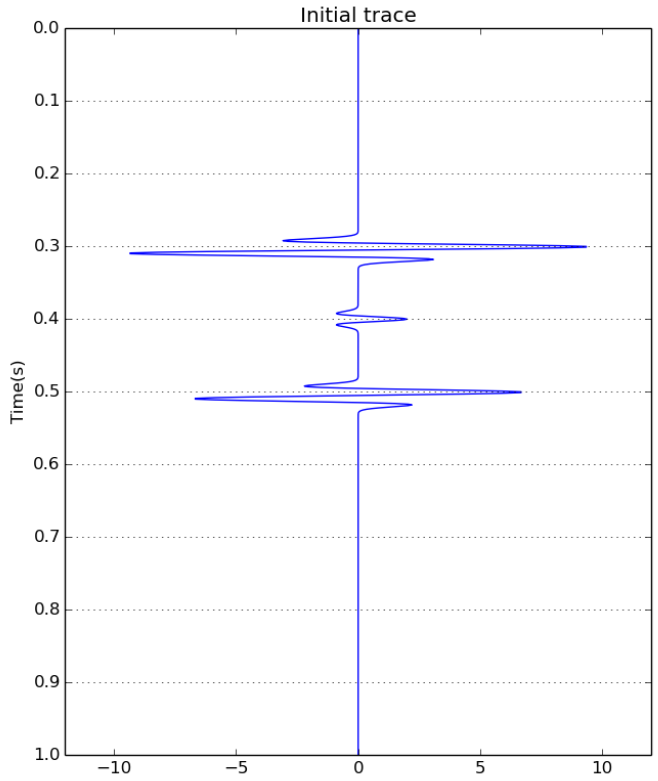
$$p(t) = z(t) + p(t - \tau) =$$
$$z(t) + z(t - \tau) + p(t - 2\tau) = \cdots$$





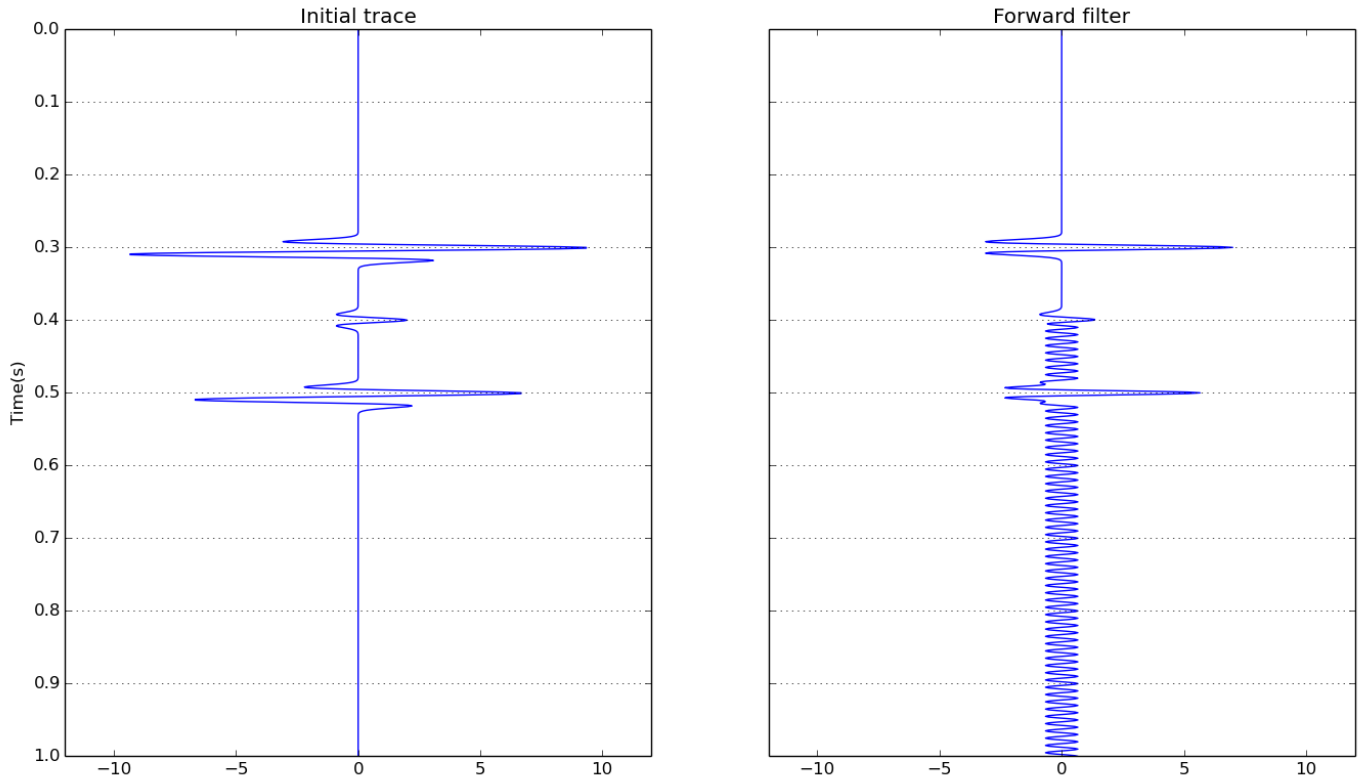
SharpSeis™ solution theory: recursive filtering

Additional noise – event without ghost



SharpSeis™ deghosting solution: recursive filtering

Additional noise creates infinite noise train pulse in direction of filtering:

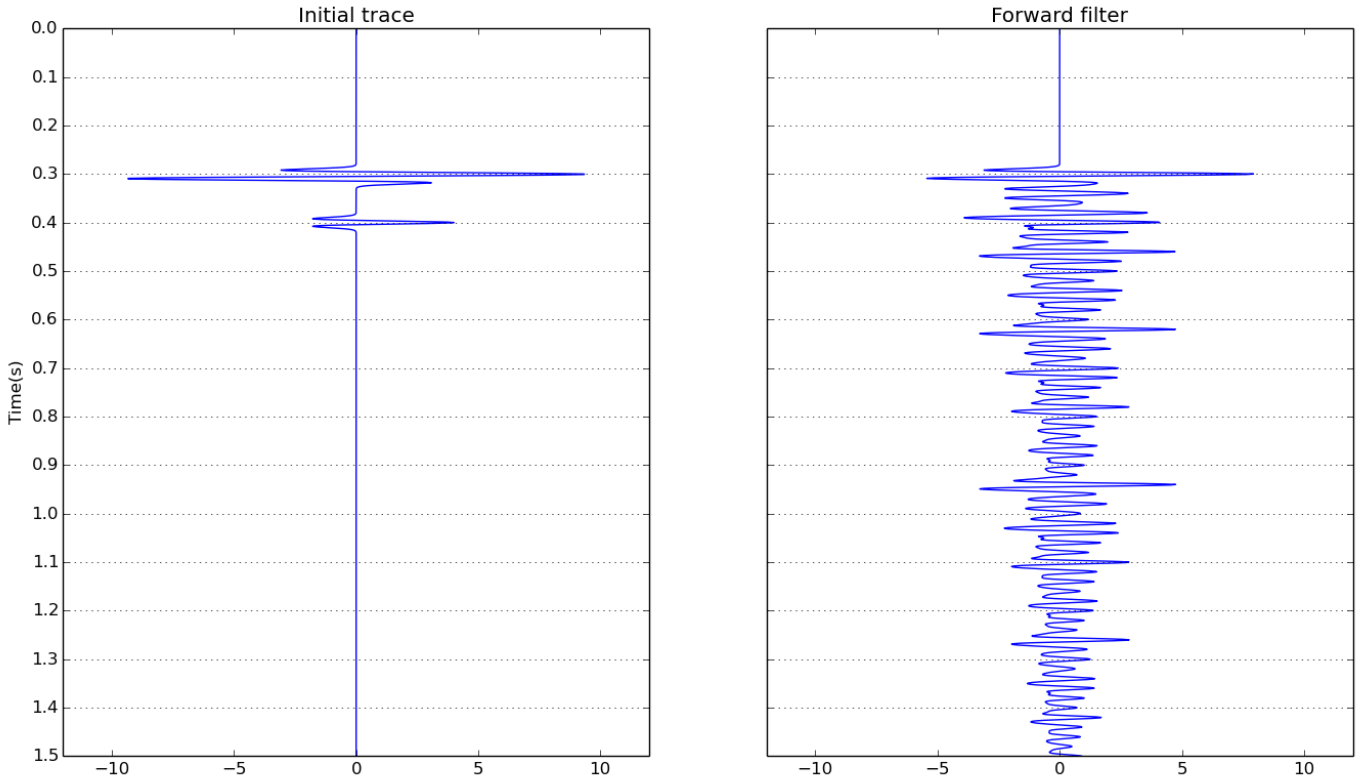


SharpSeis™ deghosting solution

Stabilizing the solution:

1. Damping factor:

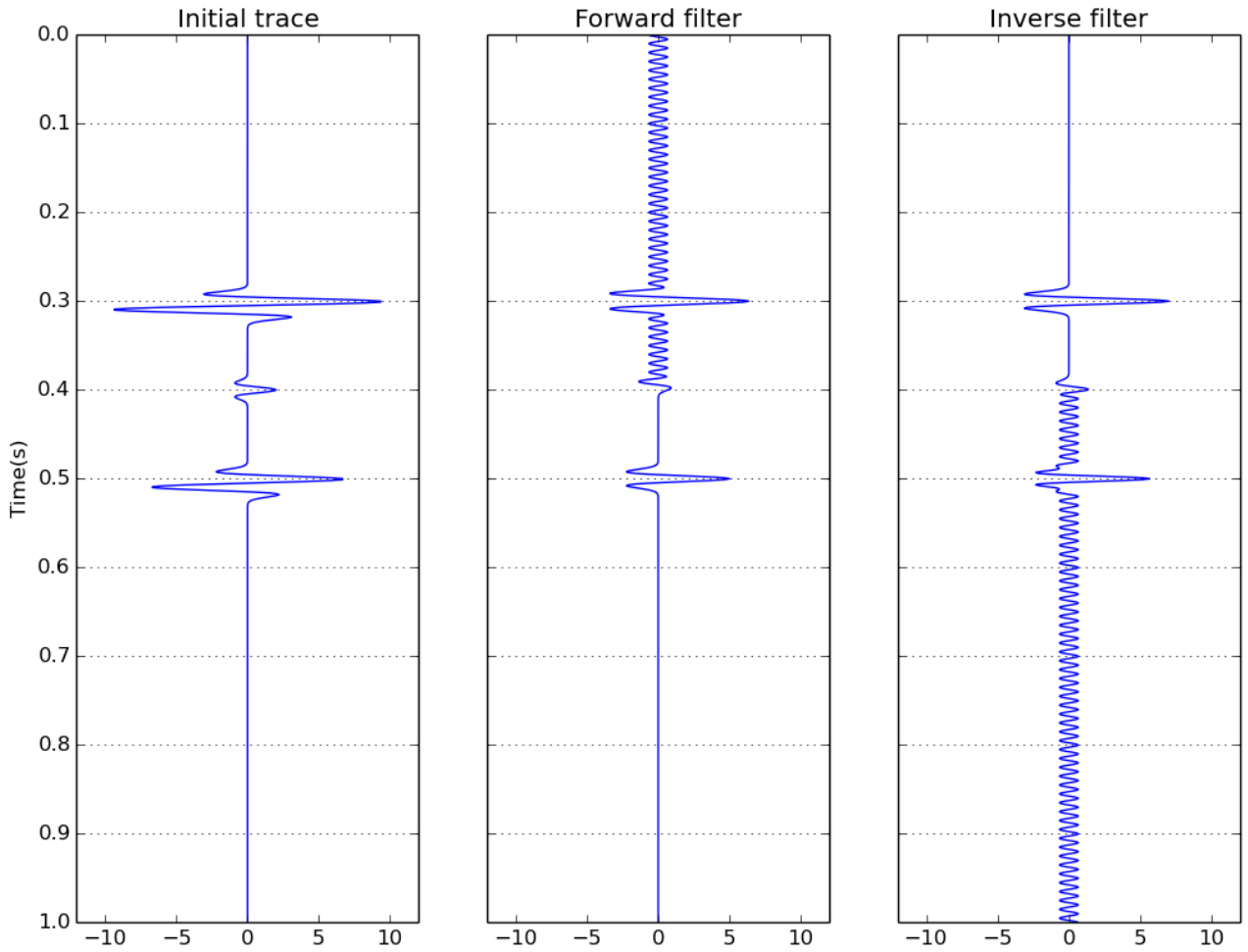
$$\vec{p}(t) = z(t) - q \cdot p(t - \tau),\ q<1$$



SharpSeis™ deghosting solution

Stabilizing the solution:

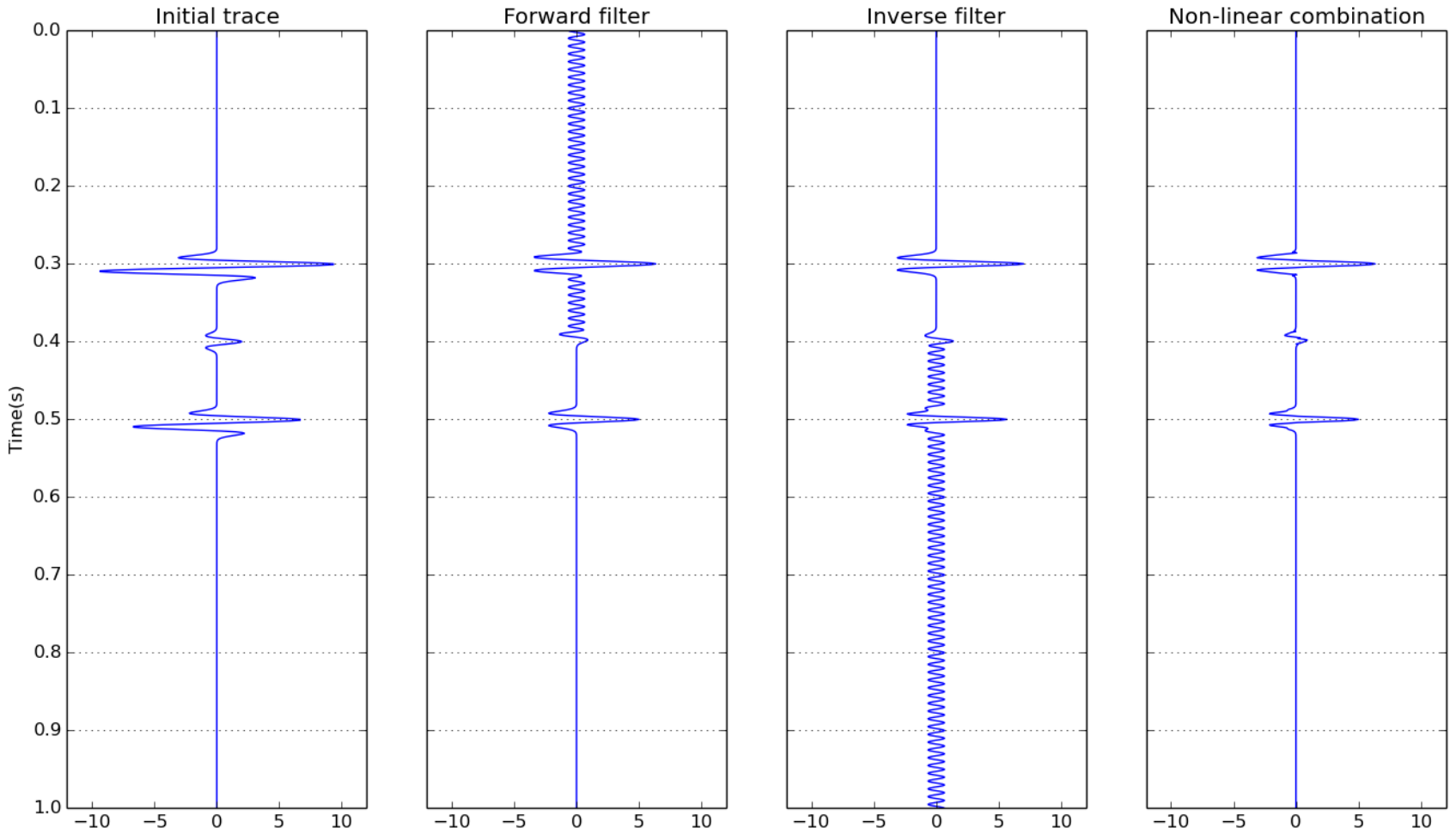
2. Filtering in both forward and reverse time:



SharpSeis™ deghosting solution

Stabilizing the solution:

3. Non-linear combination of forward and reverse filters



SharpSeis™ deghosting/broadband processing

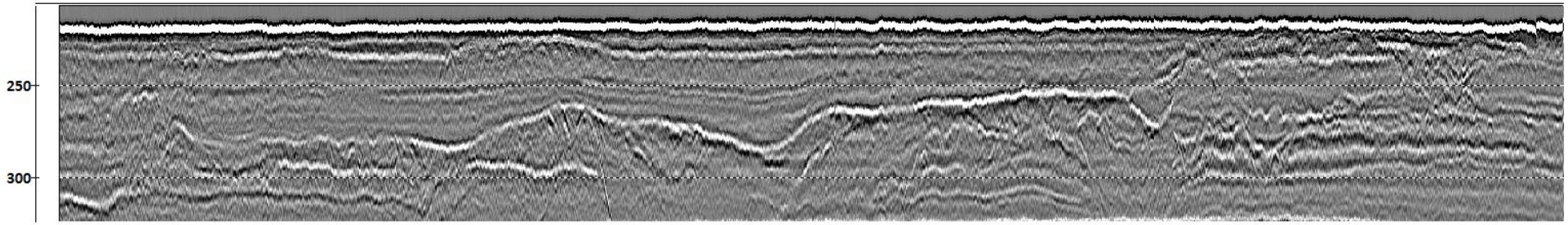
Summary:

1. Based on recursive filtering approach;
2. Stabilized with damping factor
3. Nonlinear combination of forward and reverse filtering result
4. Adaptive selection of filtering parameters (ghost delay and q)

SharpSeis™ processing of HR seismic data: one channel

(source towing depth – 2 m, receiver towing depth – around 3 m)

Raw data of one channel



Data courtesy of P-Cable 3D Seismic AS

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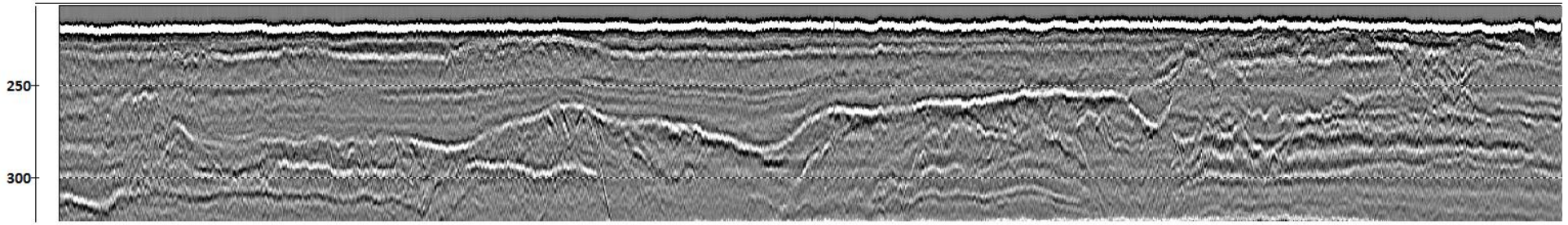
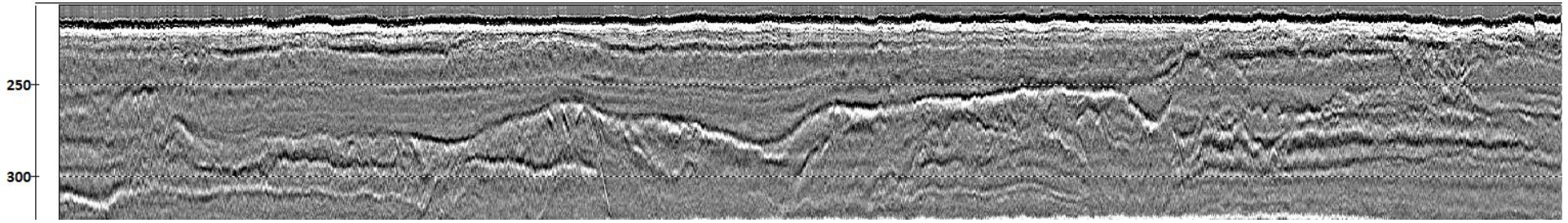


SharpSeis 1st iteration: receiver side ghost removed



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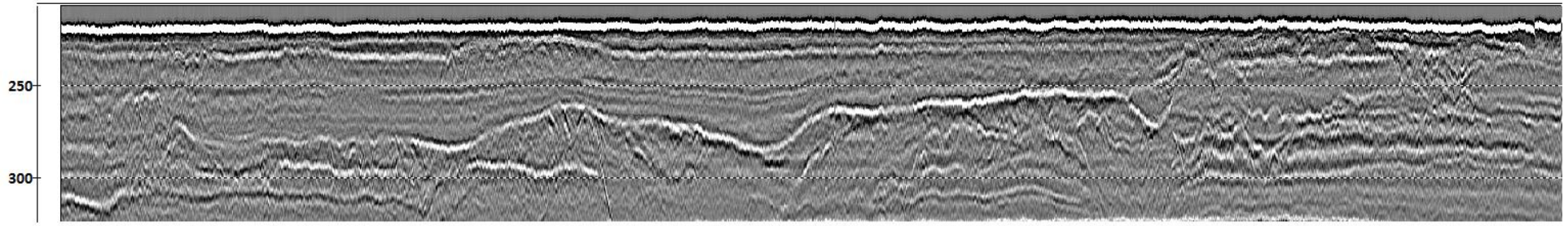

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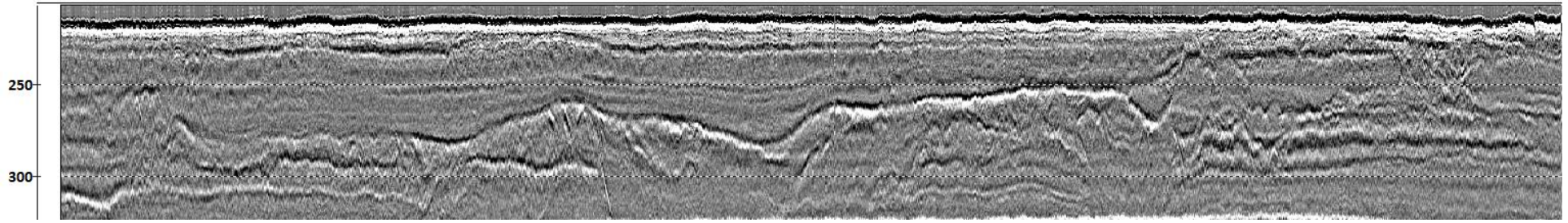
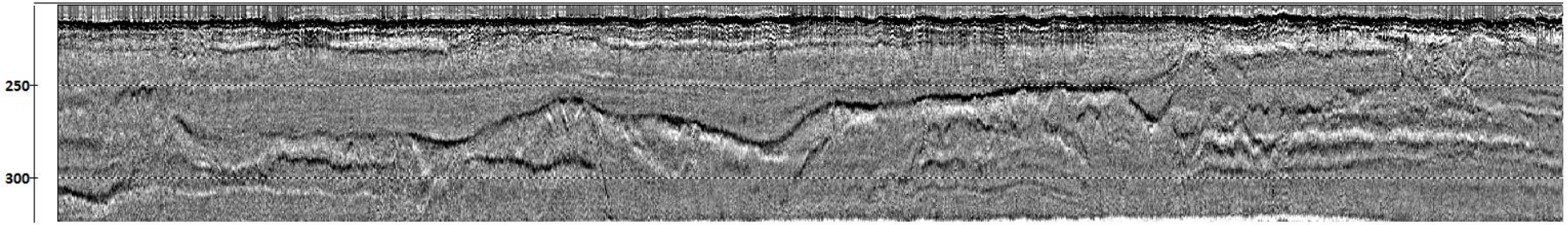


SharpSeis 2nd iteration: source side ghost removed



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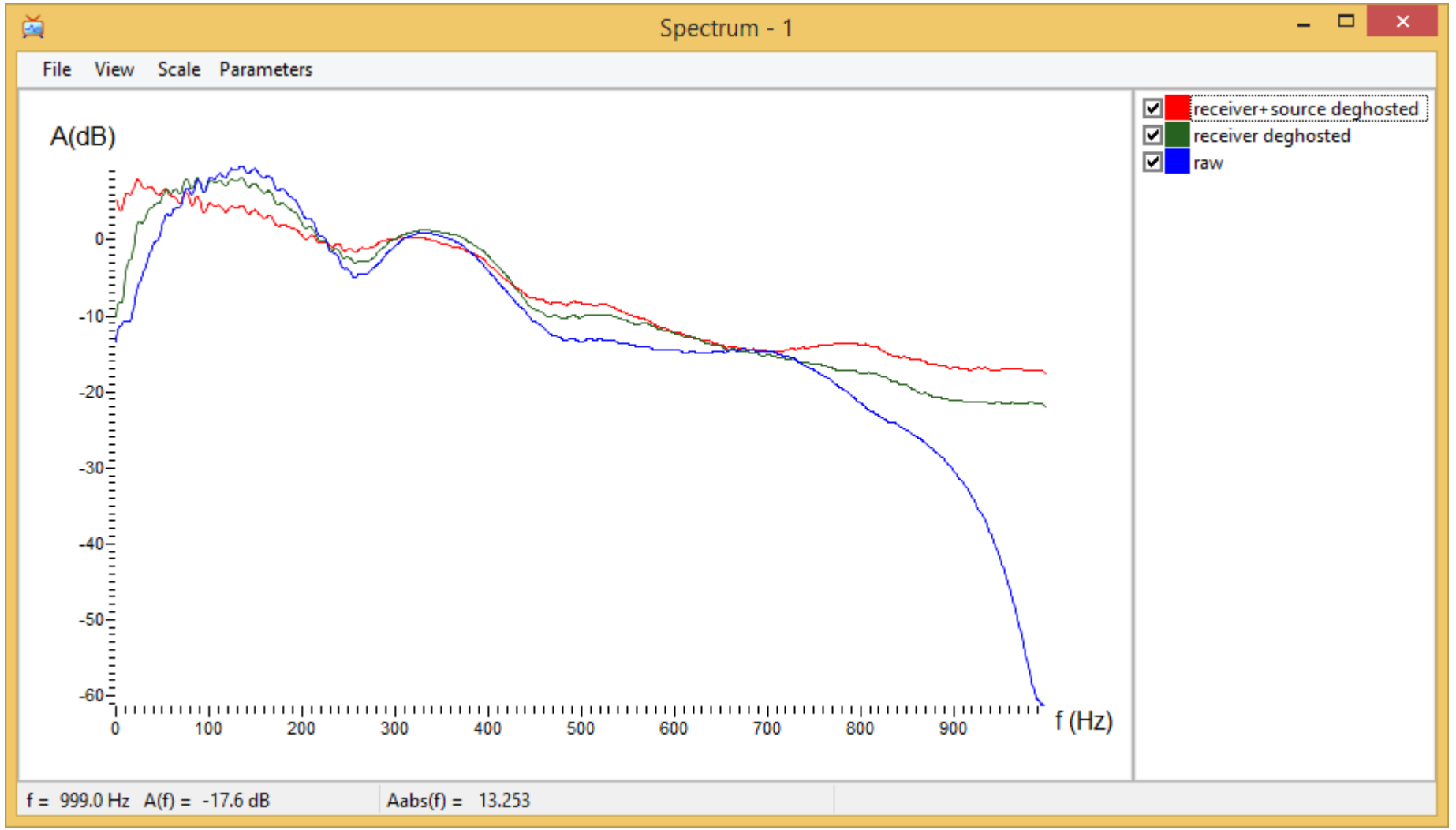
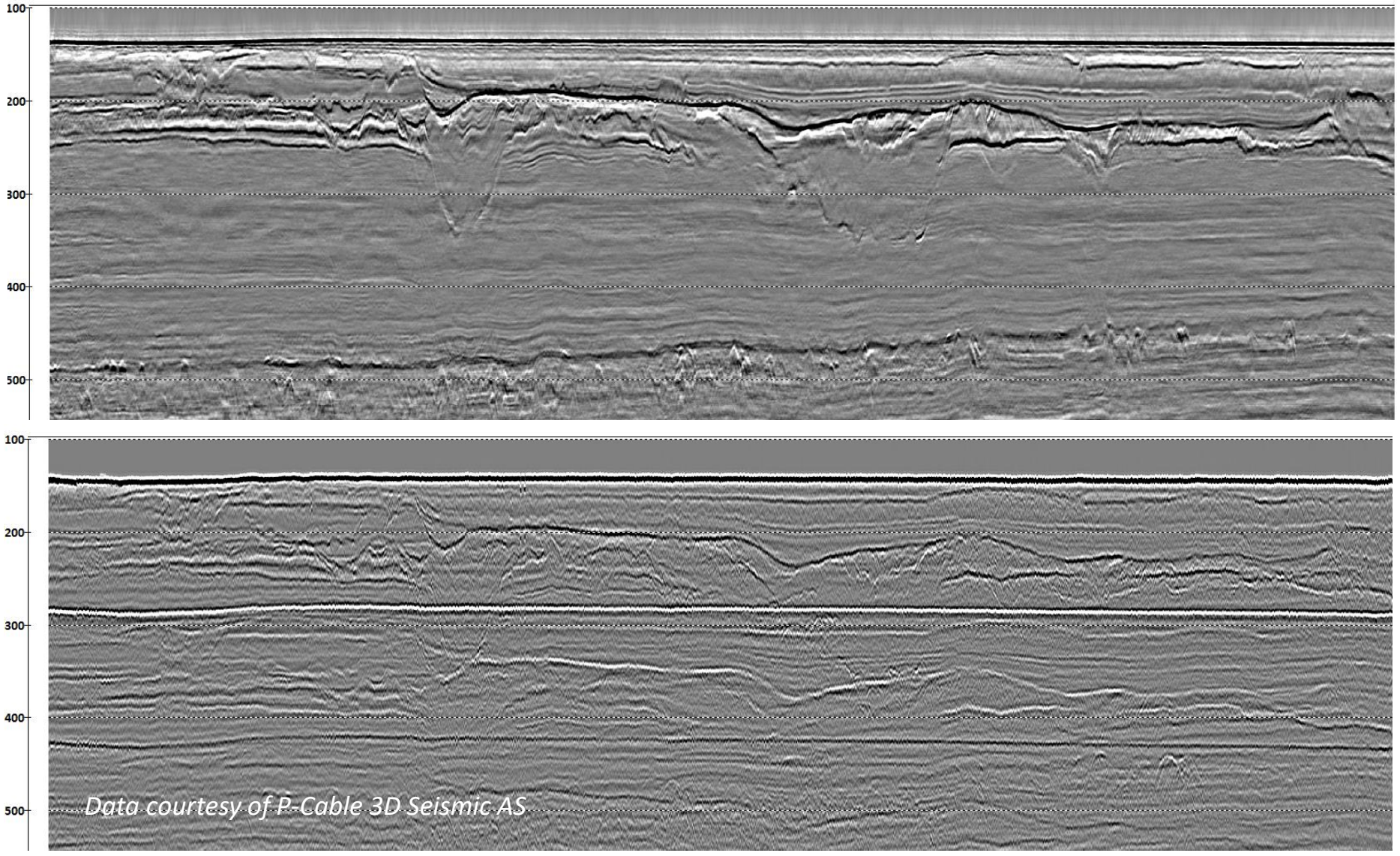


Data courtesy of P-Cable 3D Seismic AS

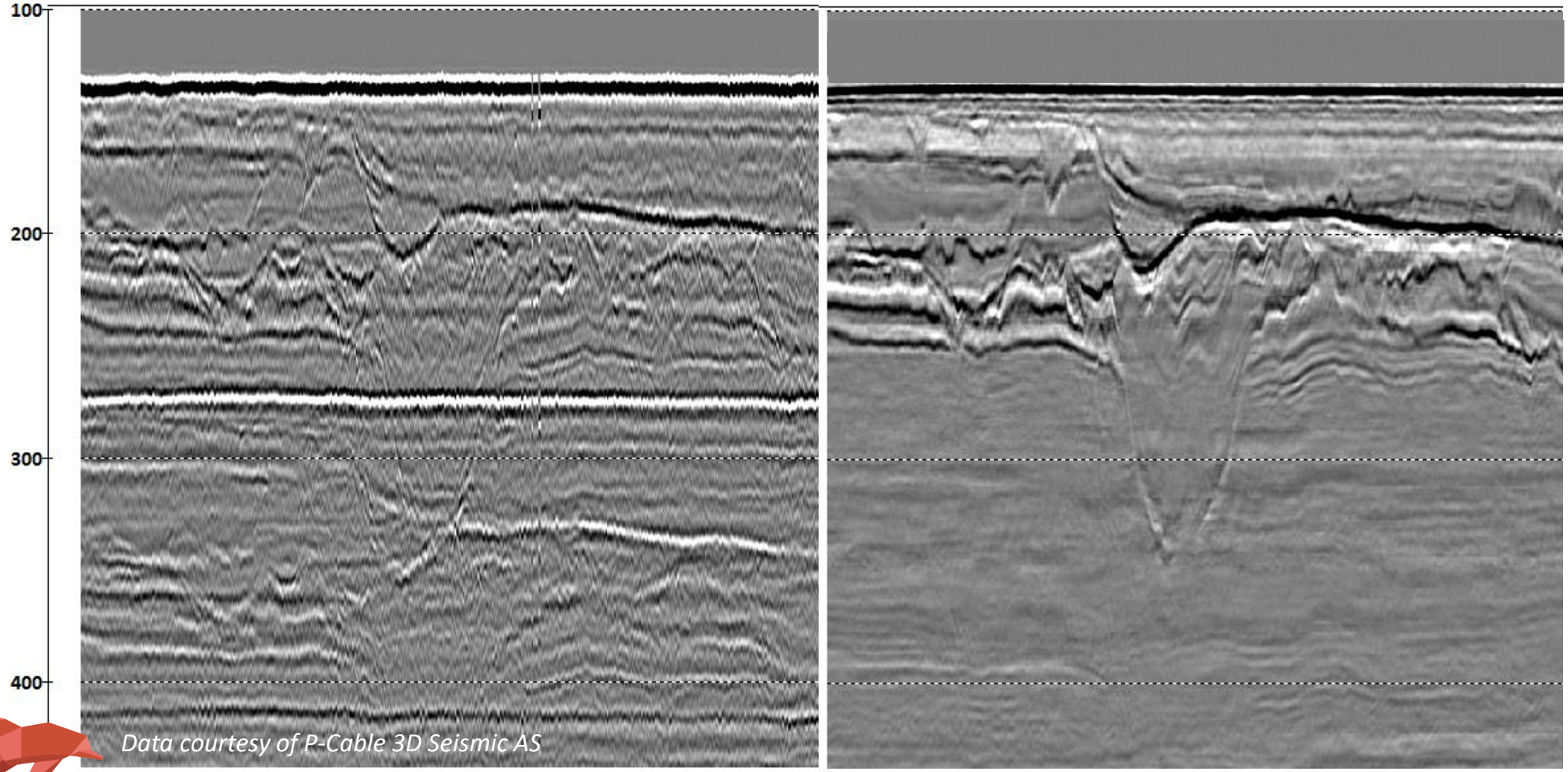
SharpSeis™ processing of HR seismic data: final stack



SharpSeis™ processing of HR seismic data: final stack

Original brute stack

Deghosted stack



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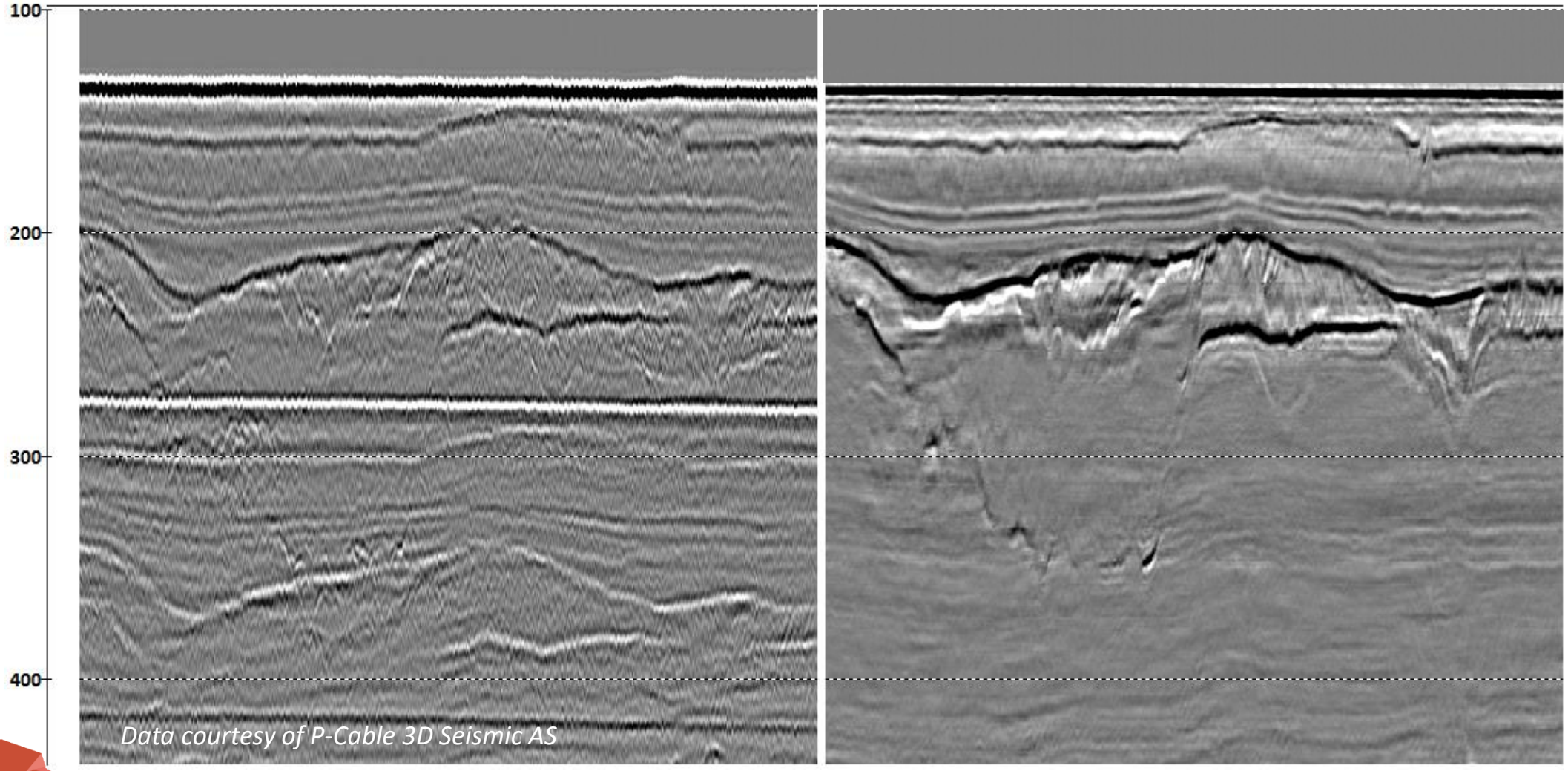
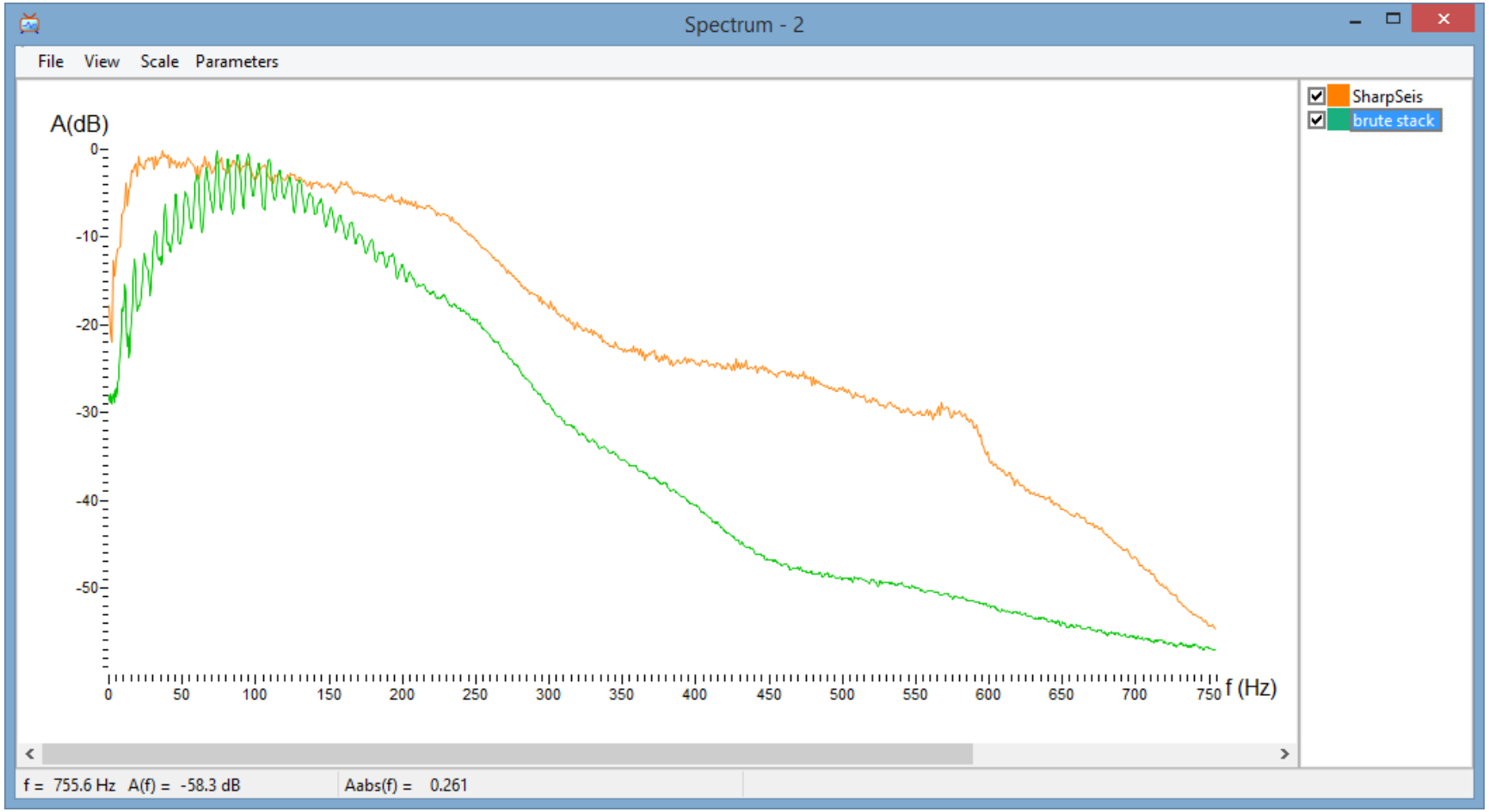
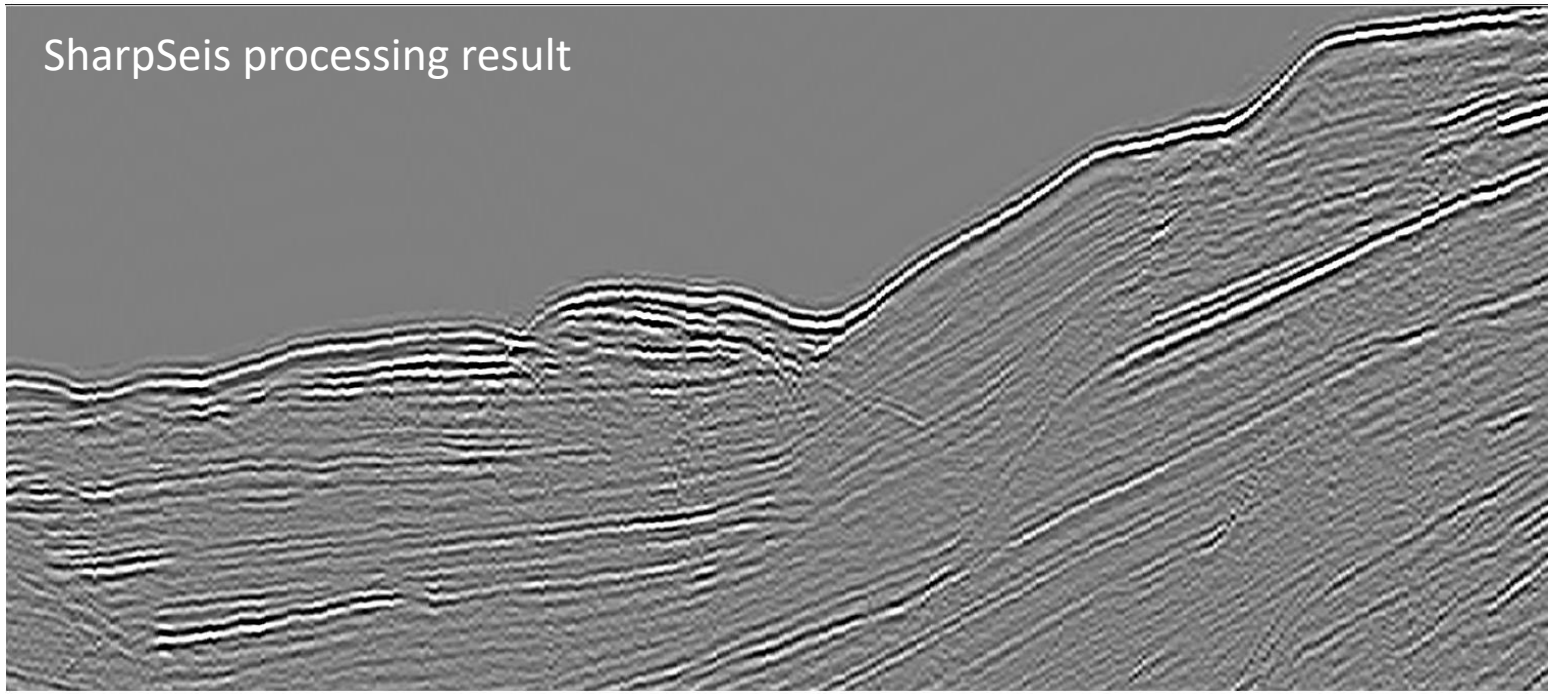
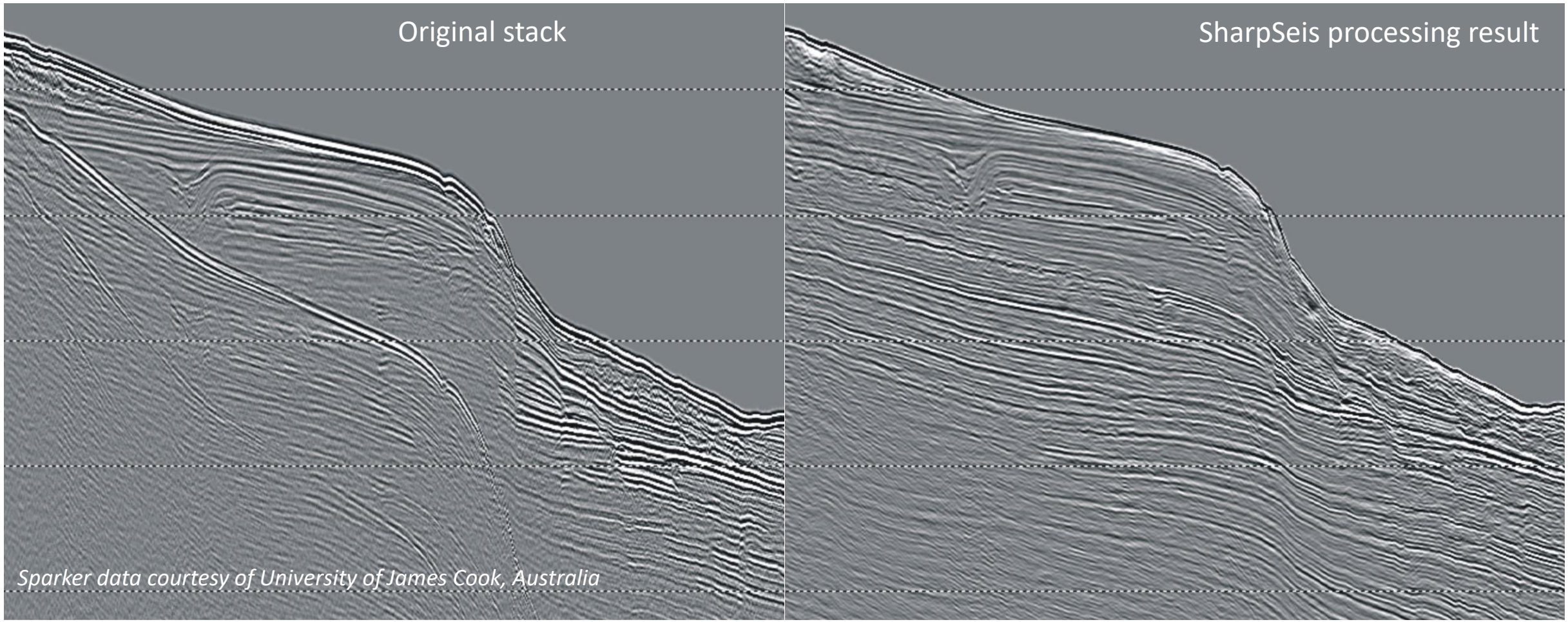


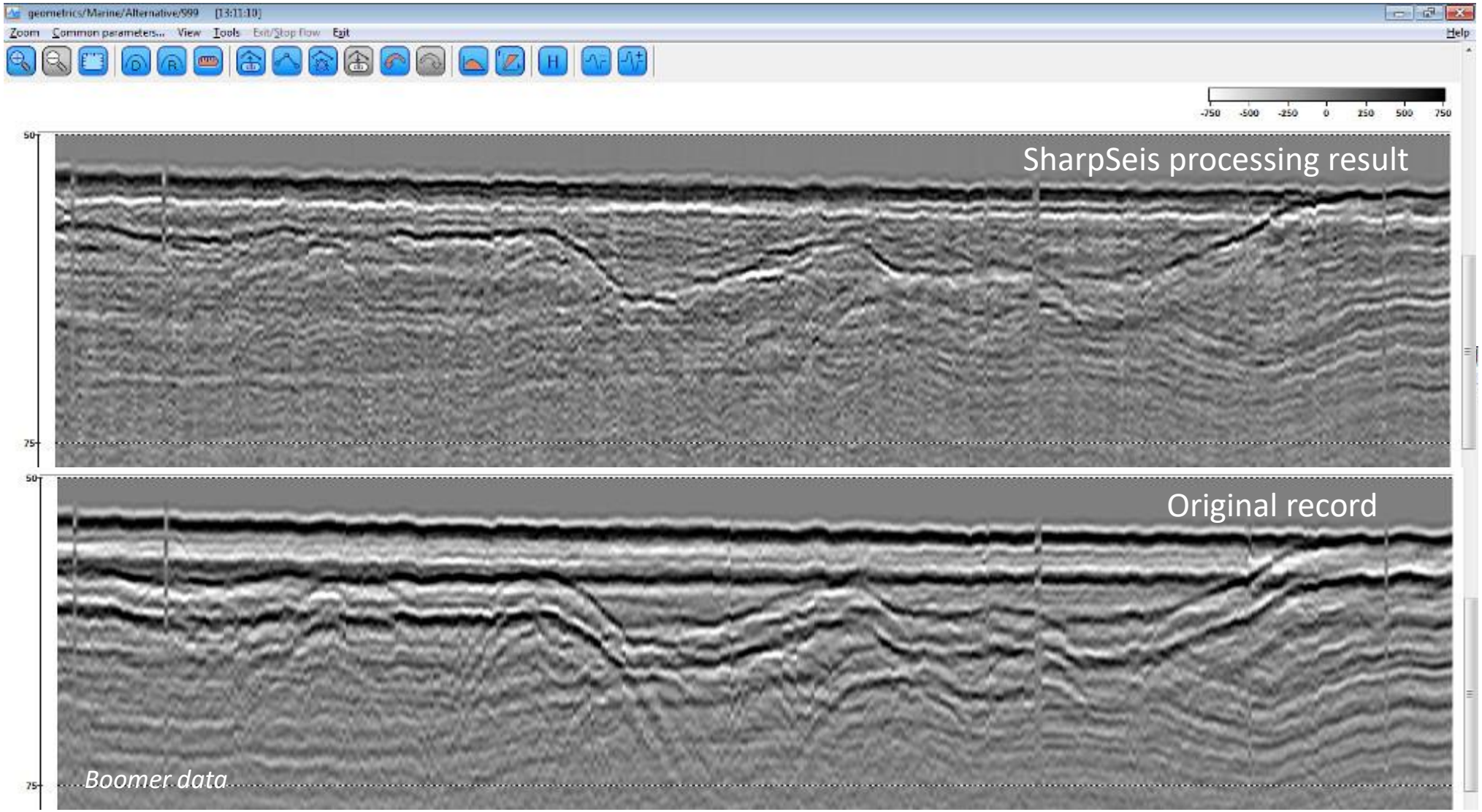
SharpSeis™ processing of HR seismic data: final stack




SharpSeis processing result


Original stack
Airgun data courtesy University of Napoli

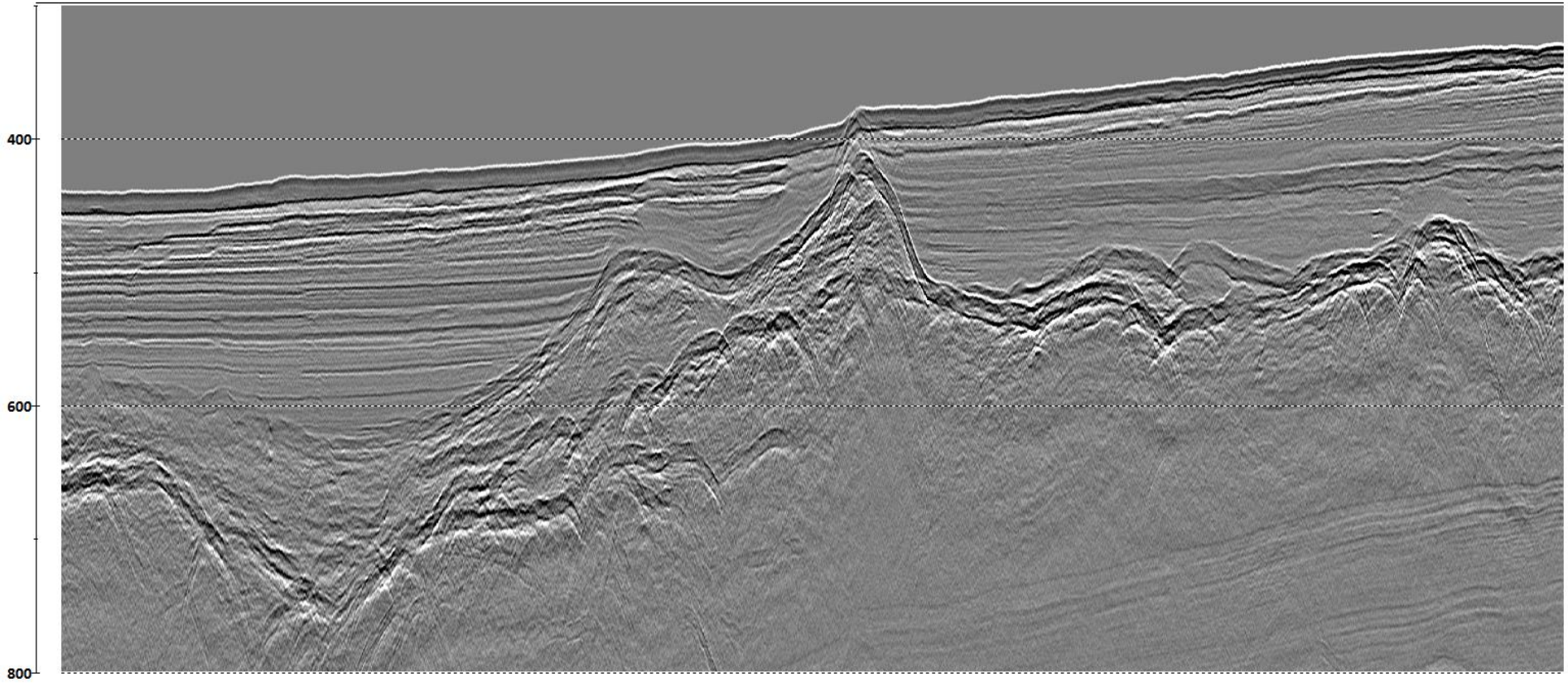

Original stack
SharpSeis processing result
Sparker data courtesy of University of James Cook, Australia


geometrics/Marine/Alternative/999 [13:11:10]
Zoom Common parameters... View Tools Exit/Stop Flow Exit Help
-750 -500 -250 0 250 500 750
50
75
SharpSeis processing result
50
75
Original record
Boomer data

What about deep-tow?

Deep-tow HR seismic

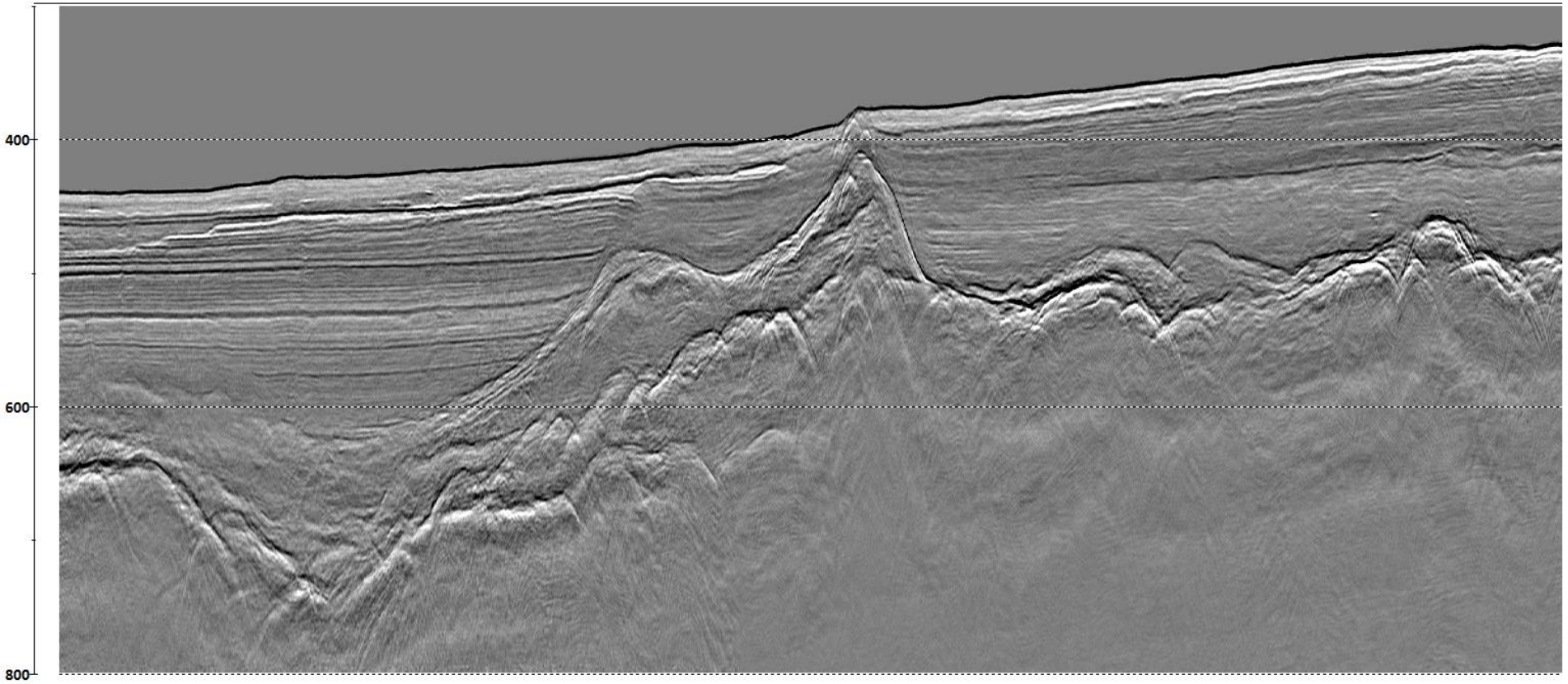
One channel, raw



P-Cable data courtesy University of Tromsø

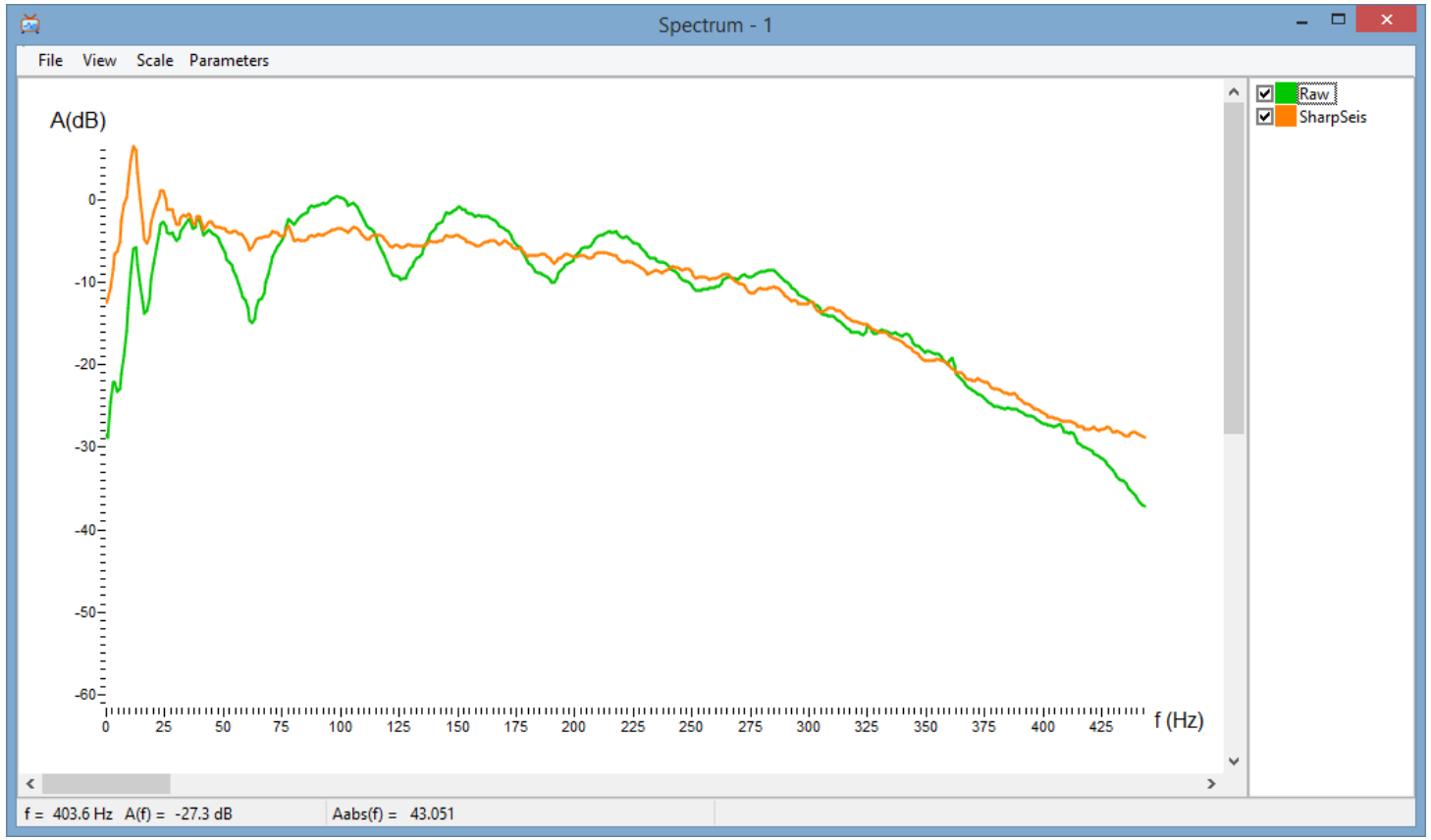
Deep-tow HR seismic

One channel, processed with SharpSeis™



P-Cable data courtesy University of Tromsø

Deep-tow HR seismic



P-Cable data courtesy University of Tromsø

Conclusions

- SharpSeis™ deghosting technique implemented in RadExPro seismic software was proved to be efficient for broadband processing of HR marine seismic data.
- It is capable to significantly increase data resolution and detail.
- The technique can be applied to both conventional and deep-tow data, providing a way to benefit from higher SNR potentially associated with deep-tow data acquisition.