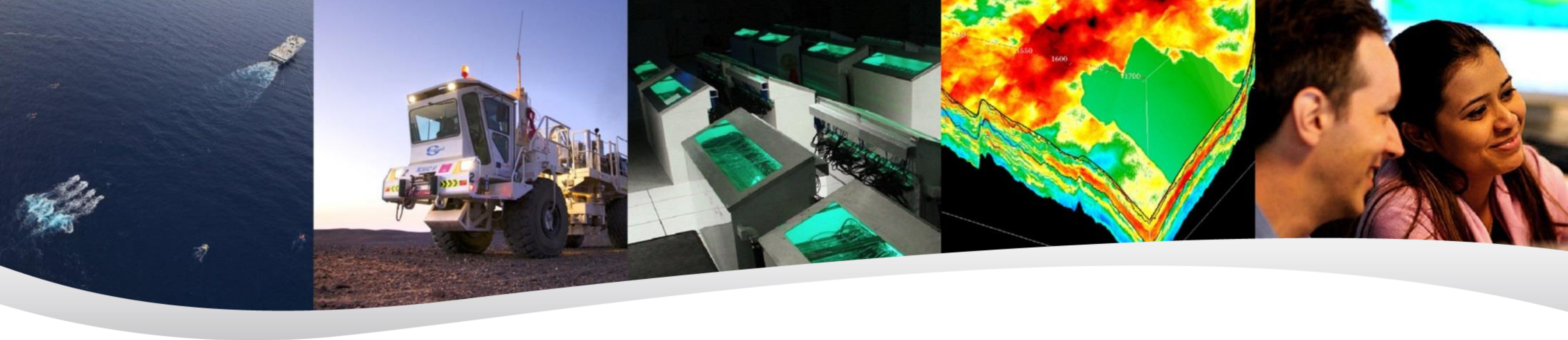

Noise in Marine Seismic Data

Presented at ROSE, NTNU, April 24-25th 2013

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Passion for Geoscience

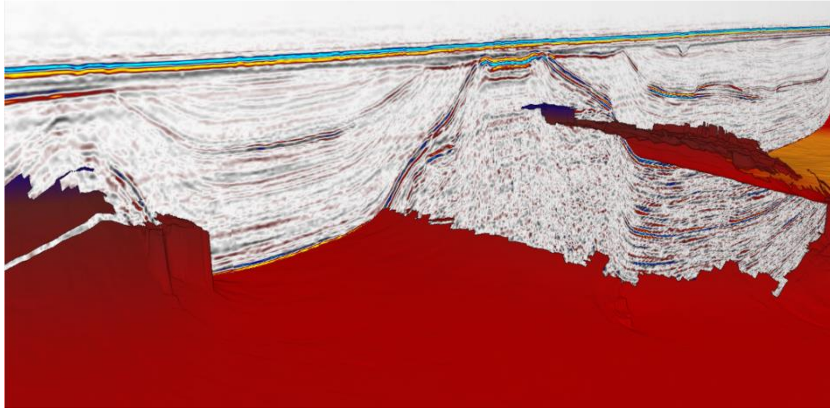
CGG

Background

There are basically three things that seismic processing tries to achieve:

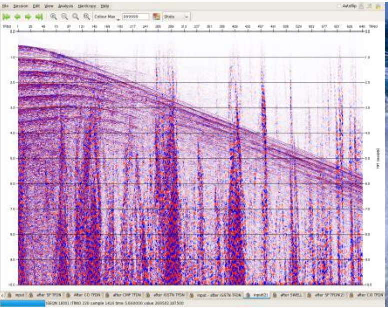
1. **The removal of unwanted noise.**
2. An increase in the resolution of the data.
3. Placing the seismic signal in the correct subsurface position (migration).

This lecture is about noise removal (to get a nice image like the one below).



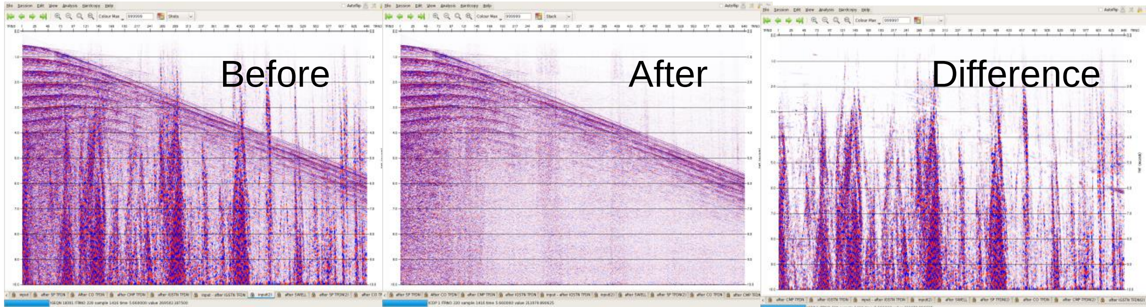
Content

What is seismic noise?



How to avoid it?

How to remove it?

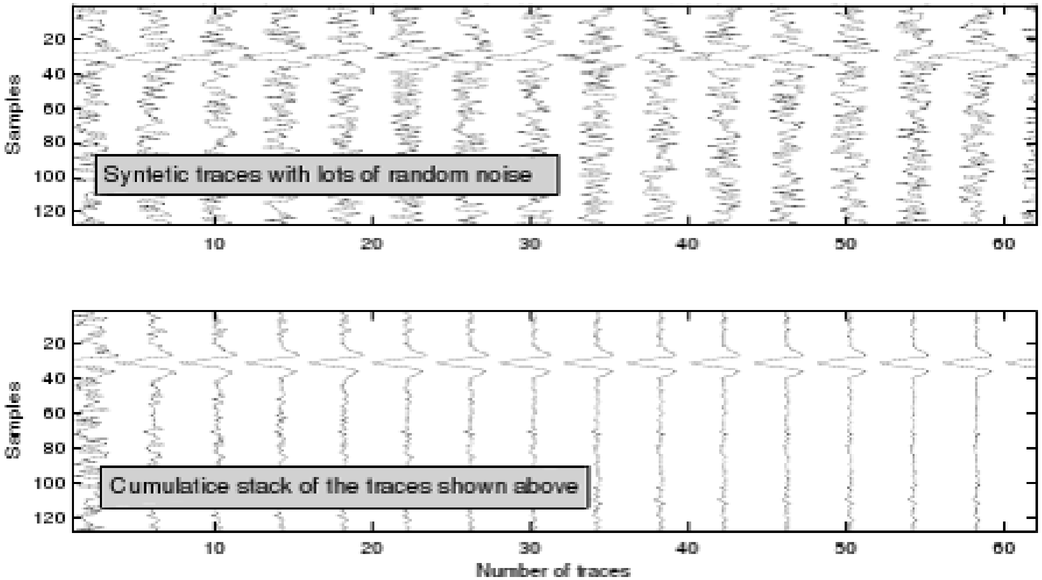


Historic development

1950	1960	1970	1980	1990	2000	2010
12 channels analog single channel recording.	24 channels analog recording on paper.	48 channels Electric stacking.	120 channels on one streamer of 2400m.	240 channels. Two streamer cables of 3200m.	480 channels. 8 streamers of up to 6 km.	600 channels. 16 streamers of up to 8 km.

Assuming that the noise is uncorrelated and the signal is correlated between traces:

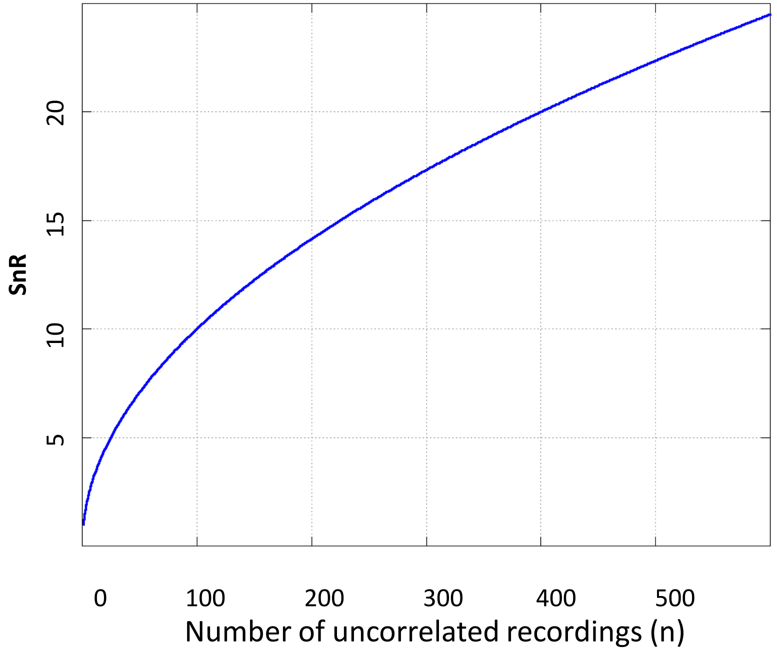
Signal-To-Noise Ratio (SNR) og a CMP stack goes as ~ √n, where n is the fold of the data.



Q: What if the noise has amplitudes that are 50 times larger than the signal?

Denoising through stacking

1950	1960	1970	1980	1990	2000	2010
12 channels analog single channel recording.	24 channels analog recording on paper.	48 channels Electric stacking.	120 channels on one streamer of 2400m.	240 channels. Two streamer cables of 3200m.	480 channels. 8 streamers of up to 6 km.	600 channels. 16 streamers of up to 8 km.



- More channels enables a better SNR
- Long streamers enable better subsurface illumination

What is seismic noise?

All parts of the recorded data that does not contain useful seismic information can be seen as noise! The most common types are:

- Multiples etc (not a topic in this lecture).
- Hydrostatic pressure fluctuations.
- Swell-noise.
- Seismic interference noise.
- Environmental...

The topic of this lecture

The different types of noise will normally make up 50-99% of all energy found in the seismic we record!

What is seismic noise?

All parts of the recorded data that does not contain useful seismic information can be seen as noise! The most common types are:

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- **Hydrostatic pressure fluctuations**.
- Swell-noise.
- Seismic interference noise.
- Environmental...

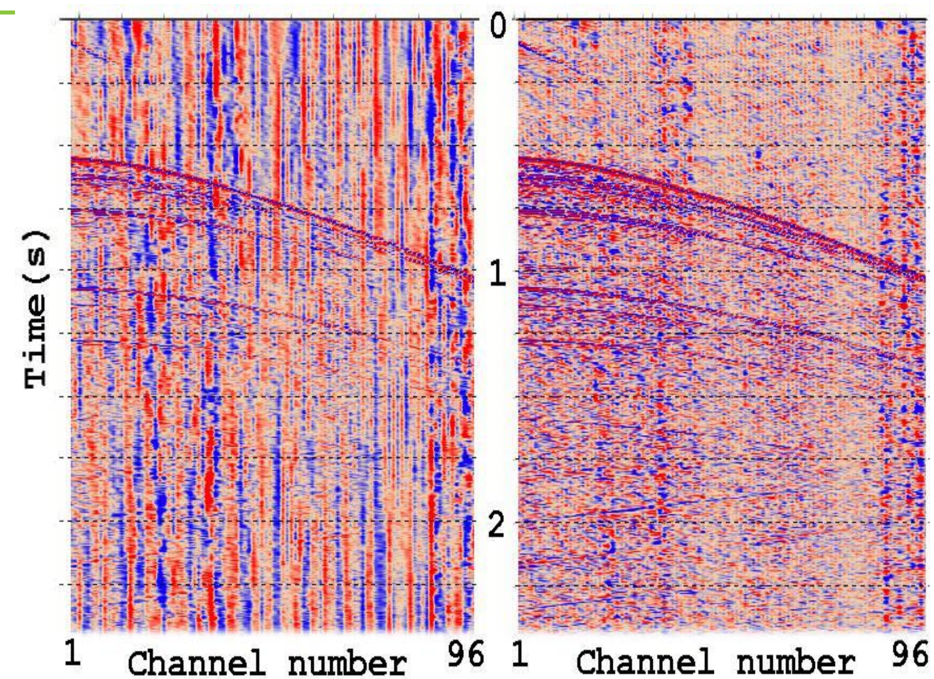
The topic of this lecture

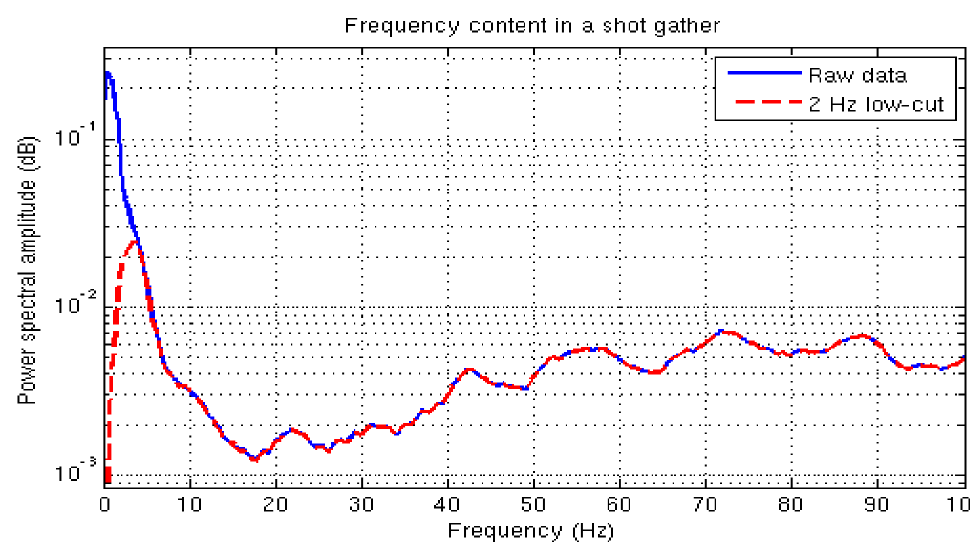
Hydrostatic pressure fluctuations

- Relates to the height of the water column above the streamer.
- Very large amplitudes.
- Very low frequencies (<1-2Hz)

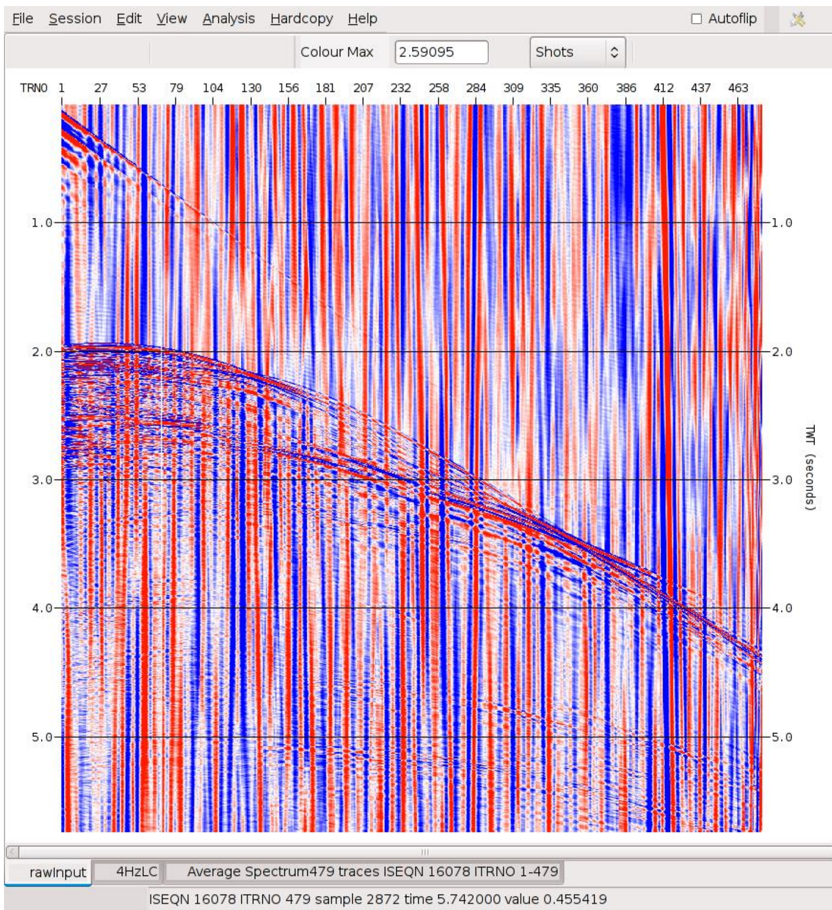
↓

Can be removed by a low-cut filter applied in the frequency domain

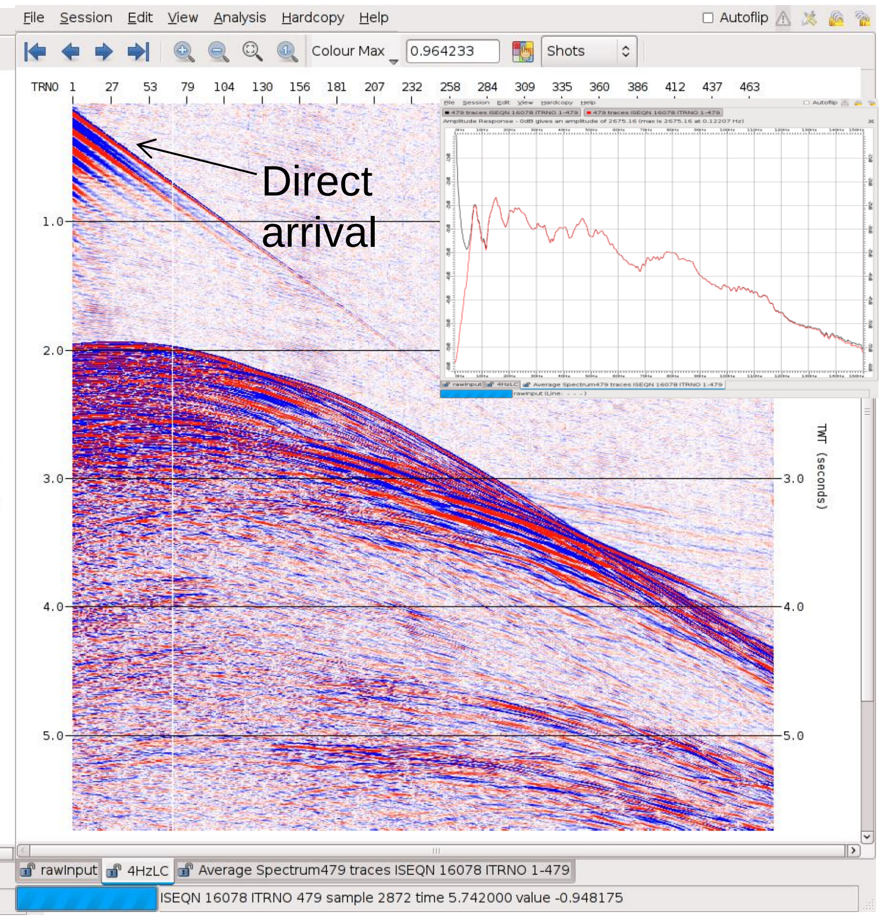




Hydrostatic pressure

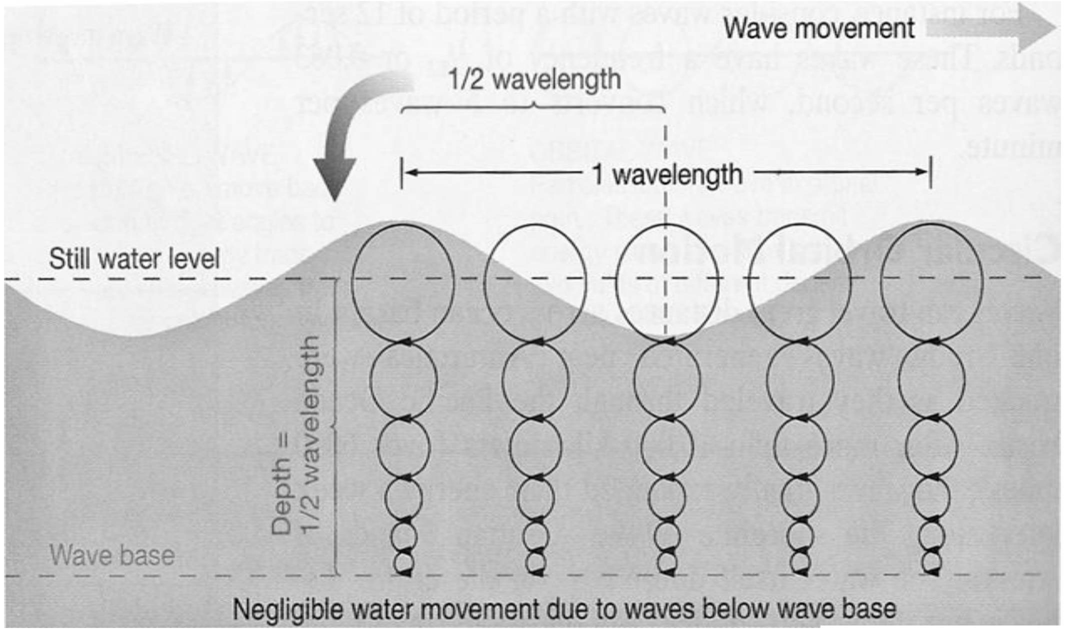


Raw data – (towing depth 15m)



4Hz 18dB low-cut filter

Hydrostatic pressure



$$W(x,z)=A\omega e^{-kz}\sin(kx-\omega t)$$

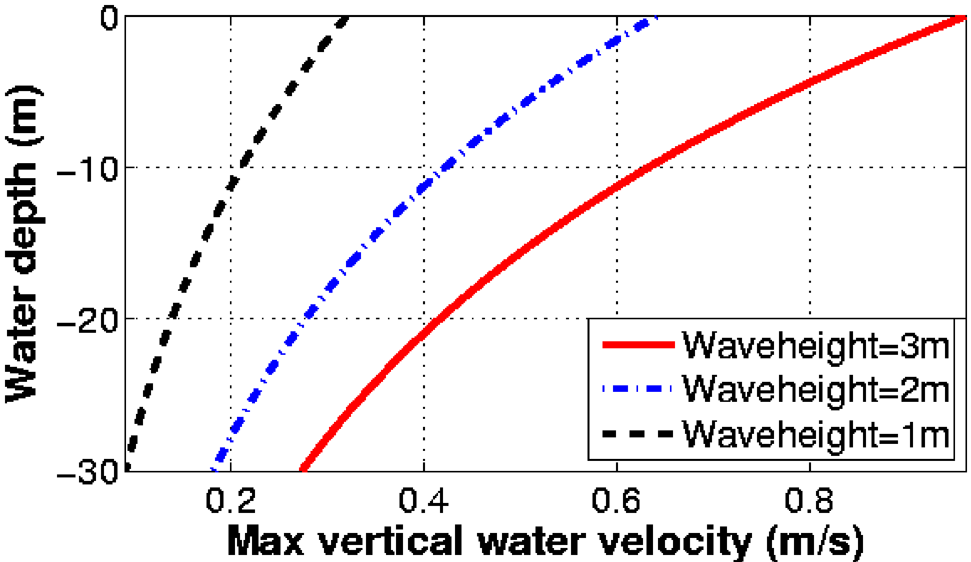
Left:
Illustration on how/why the hydrostatic pressure varies with depth

Below:
Quantifying how much cross-flow surface waves induce over a seismic Streamer at different depths.

Conclusion:
A deeper tow will experience less noise.

Q: Why can we not just tow very Deep, where there is no noise?

Q: What frequencies are relevant in seismic data?



Hydrostatic pressure fluctuation noise

Summary:

- Very large amplitudes at very low frequency.
- Can be removed by a low-cut filter.

→ Seperation of noise and signal in the frequency domain.

Q: But why do oil-companies ask for the low frequencies?

Q: How can we obtain more of low-frequency data?

Swell-noise

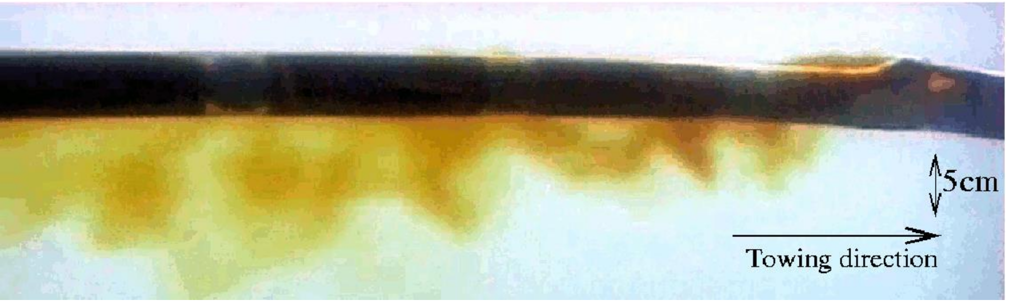
All parts of the recorded data that does not contain useful seismic information can be seen as noise! The most common types are:

- Multiples etc (not a topic in this lecture).
- Hydrostatic pressure fluctuations.
- **Swell-noise.**
- Seismic interference noise.
- Vessel noise.
- Environmental...

The topic of this lecture

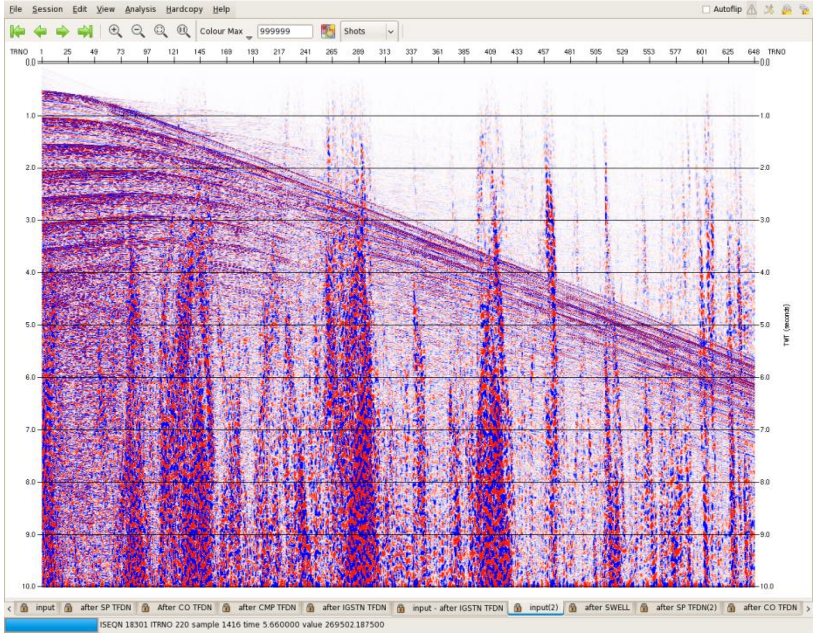
Swell-noise (flow-noise)

On modern streamer cables, flow and swell-noise is caused by flow, cross-flow and vortex shedding:



Above: seismic streamer is cross-flow

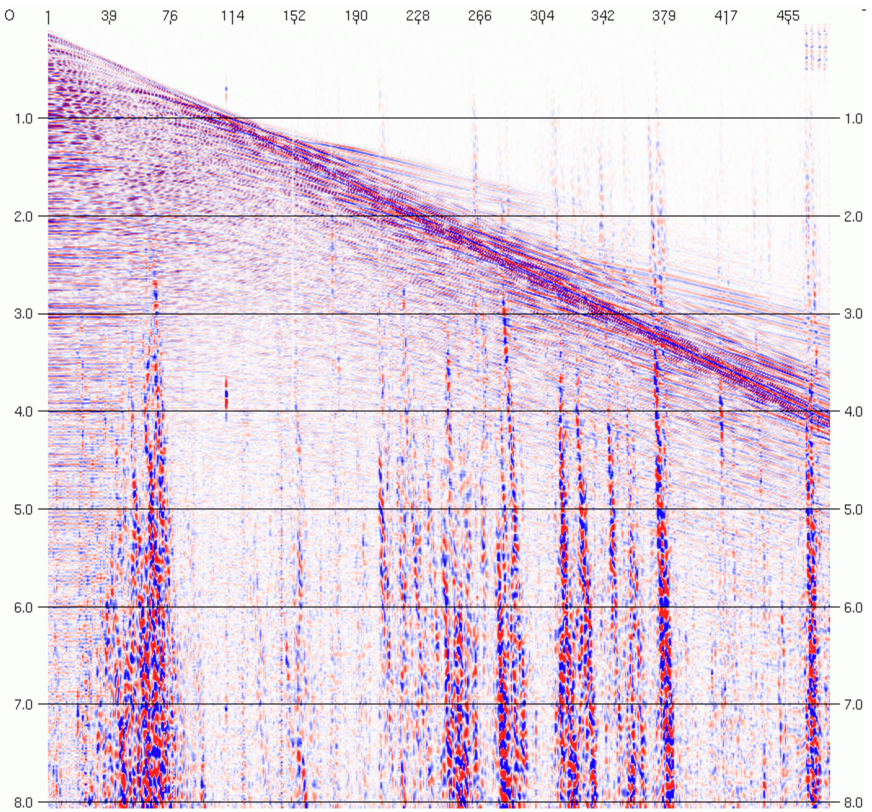
Left:
vortex shedding



Above: Swell-noise caused by cross-flow

Swell-noise characteristics

- Low frequency (normally below 10Hz, but cross-flow noise can be broad banded)
- Large amplitudes
- Intermittent
- Does not decay with time



Shot gather with swell-noise

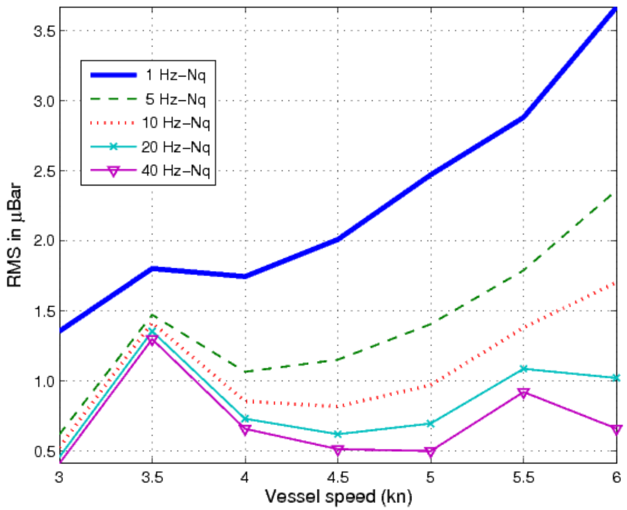
Q: Why does the swell-noise appear to increase with time on the shot gather to the right?

Q: Why is swell-noise intermittent?

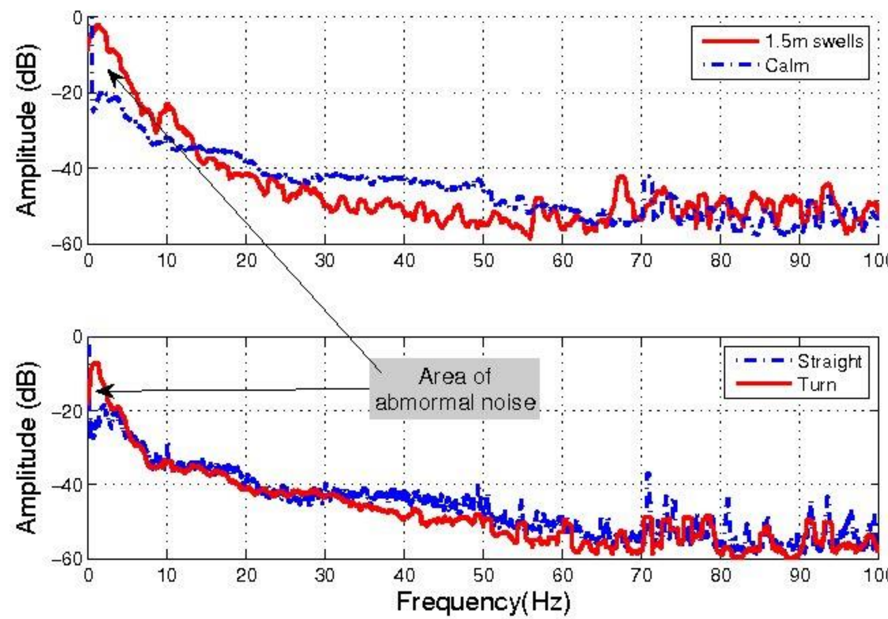
Q: What is a bulge-wave?

Measurements of swell/**flow**-noise

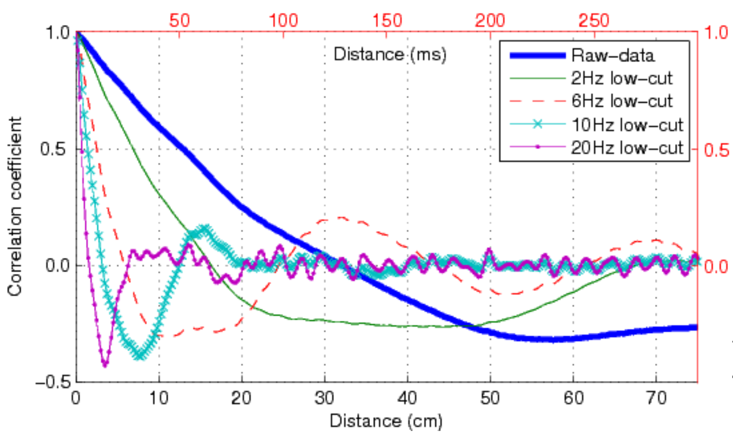
Flow-noise increase with vessel speed:



Flow-noise increase with amount of cross flow, but is always mostly low frequency:



Flow-noise is correlated for only 30cm:



*For velocities 3-6kn, this seems
To be independent of towing speed.

Mathematics of flow-noise

Following Lighthill (1952), we start with the Navier-Stokes equations

$$\rho \frac{\partial \mathbf{v}}{\partial t} + \rho(\mathbf{v}\cdot\nabla)\mathbf{v} = -\nabla p + \nabla\cdot\sigma \qquad (1)$$

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho\mathbf{v}) = 0. \qquad (2)$$

Multiply (2) by *v* and add RHS of (1) to get:

$$\frac{\partial(\rho\mathbf{v})}{\partial t} + \nabla\cdot(\rho\mathbf{v}\otimes\mathbf{v}) = -\nabla p + \nabla\cdot\sigma. \qquad (3)$$

Next we take the time-derivative of (2) and add ∇·(3)

$$\frac{\partial^2 \rho}{\partial t^2} + \frac{\partial}{\partial t}(\nabla\cdot\rho\mathbf{v}) - \nabla(\frac{\partial}{\partial t}(\rho\mathbf{v})) + \nabla\cdot\nabla(\rho\mathbf{v}\otimes\mathbf{v}) = -\nabla^2 p + \nabla\cdot\nabla\cdot\sigma. \qquad (4)$$

Then we subtract $c_0^2\nabla^2\rho$ on both sides of the equation in (4) to obtain

$$\frac{\partial^2 \rho}{\partial t^2} - c_0^2\nabla^2\rho = \nabla\cdot[\nabla\cdot(\rho\mathbf{v}\otimes\mathbf{v}) - \nabla\cdot\sigma + \nabla p - c_0^2\nabla\rho]. \qquad (5)$$

Using Einstein's notation, Lighthill's equation can be written as:

$$\frac{\partial^2 \rho}{\partial t^2} - c_0^2\nabla^2\rho = \frac{\partial^2 T_{ij}}{\partial x_i \partial x_j}, \qquad \text{where } T_{ij} = \rho v_i v_j - \sigma_{ij} + (p - c_0^2\rho)\delta_{ij}. \qquad (6)$$

This equation is exact, as it comes directly from NS with no approximations.

By assuming incompressibility: $p-p_0=c_0^2(\rho-\rho_0)$ and neglecting viscous effects, ($t_{acoustic} << t_{fluid\ flow}$) equation (6) can be simplified to:

$$\frac{\partial^2 \rho}{\partial t^2} - c_0^2\nabla^2\rho = \frac{\partial^2 T_{ij}}{\partial x_i \partial x_j}, \qquad \text{where } T_{ij} = \rho v_i v_j, \qquad (7)$$

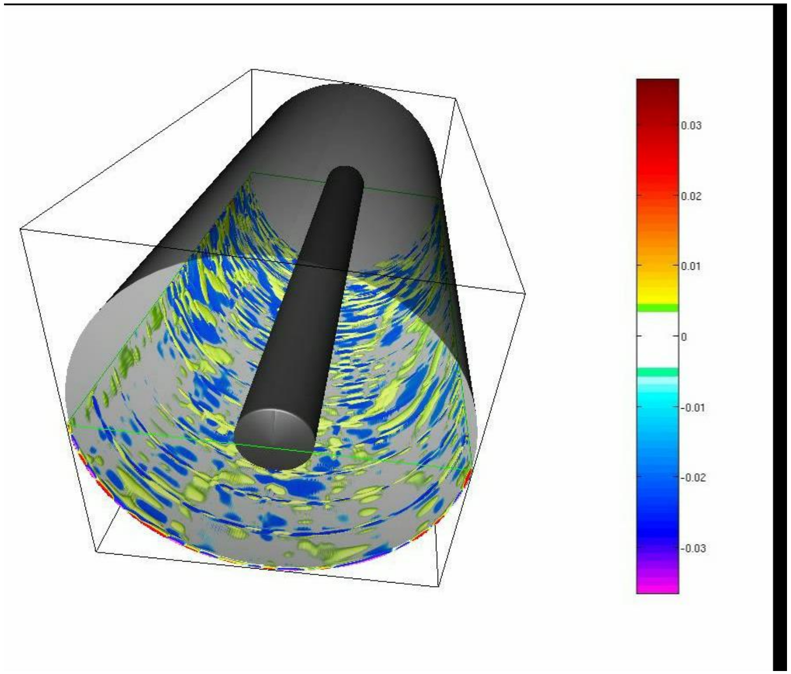
which is a wave equation with a source term that only depend on the velocities of the fluid flow. This equation (acoustic analogy) describes generation and propagation of flow noise (pressure).

ρ - density,
P - pressure,
v - the velocity vector,
v_i $i \in \{1,2,3\}$ is the velocity in the i'th direction,
C_0 - speed of sound and
σ - visosity.

In practice, a velocity-field obtained from an incompressible fluid flow simulation can be used as input to compute the essentially compressible acoustic pressure in equation (7).

How does synthetic flow-noise look?

Sound/noise field inside a cylinder (click on images to play) :



$$\frac{\partial^2 \rho}{\partial t^2} - c_0^2 \nabla^2 \rho = \rho \frac{\partial^2 (v_i \mathrm{v}_j)}{\partial x_i \partial x_j}, \quad \text{or in trems of pressure pertubation p':} \quad \frac{1}{\mathrm{c}_0^2}\frac{\partial^2 p'}{\partial t^2} - \nabla^2 p' = \rho \frac{\partial^2 (v_i \mathrm{v}_j)}{\partial x_i \partial x_j}.$$

The term $v_i v_j$ come from a fluid flow simulation.

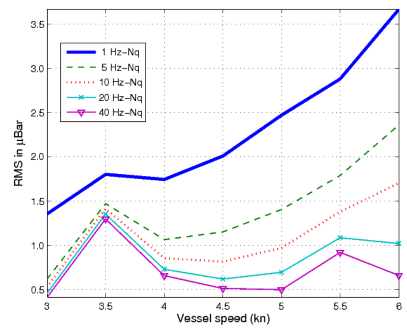
How to reduce flow-noise?

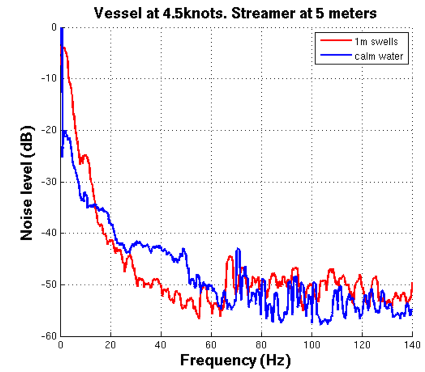
1. Avoid high waves that causes vortex-shedding on the streamer.
2. Tow slower. Intensity goes like U^8.
3. Tow straight: Make sure to avoid

   cross-flow → vortex shedding.
4. Have more hydrophones.
5. **Reduce the turbulent intensity on the streamer surface.**

   Use a **superhydrophobic surface.**

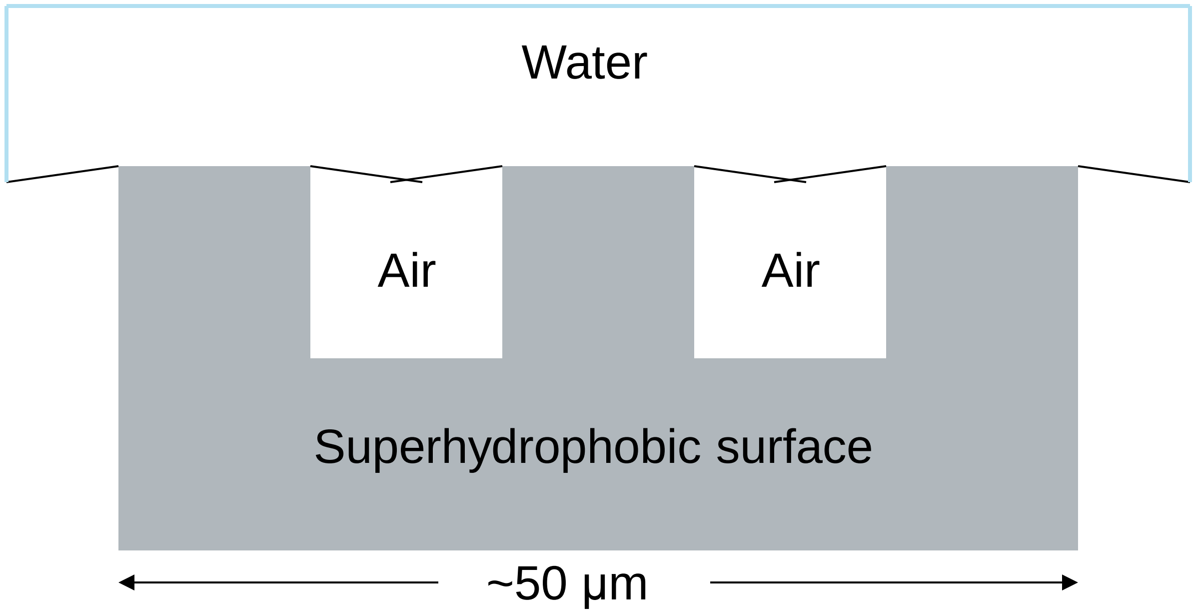
$$\frac{\partial^2 \rho}{\partial t^2} - c_0^2 \nabla^2 \rho = \rho \frac{\partial^2 (v_i v_j)}{\partial x_i \partial x_j}$$





Part of a hydrophone array during production

A superhydrophobic surface

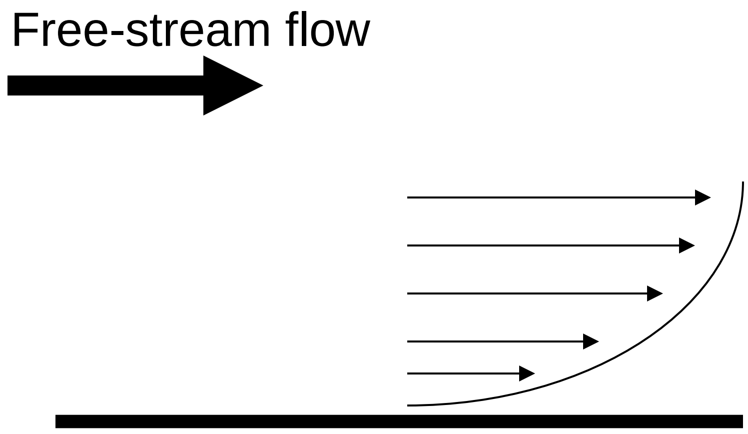


Courtesy of Michael Apel

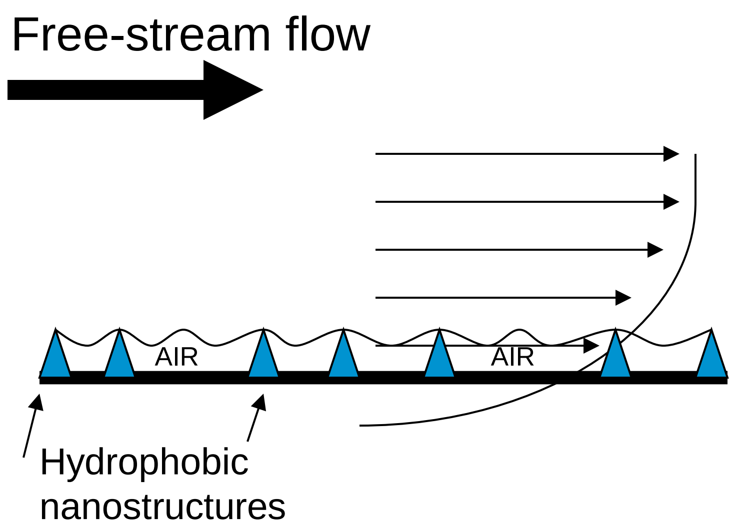
Courtesy of Staffan Enbom

Surface roughness + chemical hydrophobicity.
Traps air at the fluid surface interface →slip boundary condition.
It reduces drag.
New discovery: It also reduces flow noise!

No-slip and slip surface condition



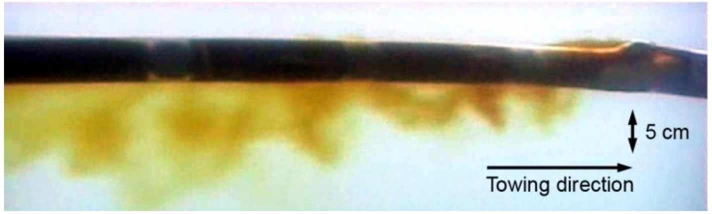
No-slip boundary (average flow).



Slip boundary.
The flow is on average not zero at the surface .

What is happening physically?

- The superhydrophobic surface makes a partial slip boundary.
- There is consequently less production of turbulence along the surface (streamer).



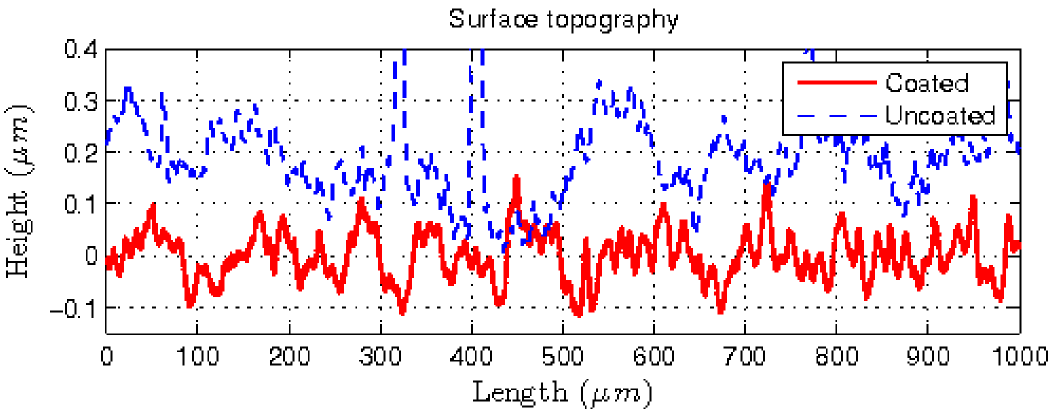
- With less turbulence, there should also be less drag, and less flow-noise.

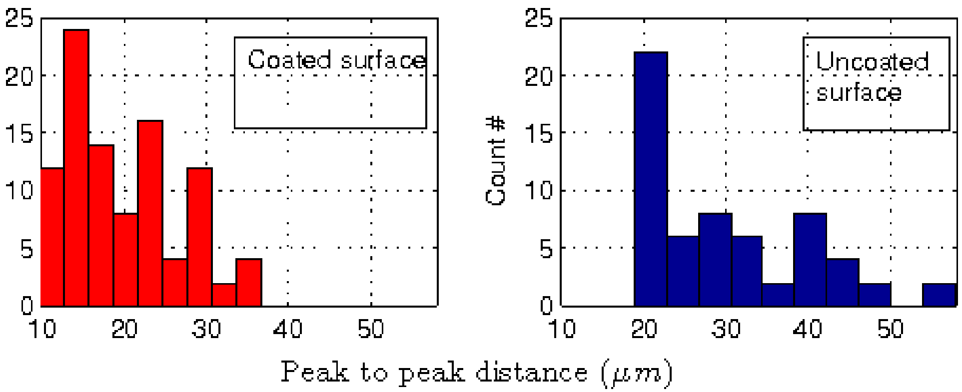
Sounds great!!!

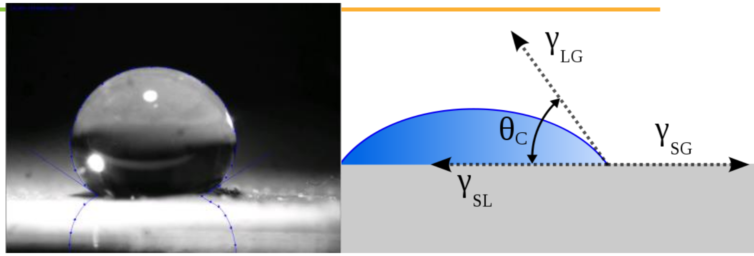
Let’s make superhydrophobic streamers!

- Semi-commercially available coat
- Sprayed onto a streamer

Surface characterization







How to measure the contact angle:

Contact angles:

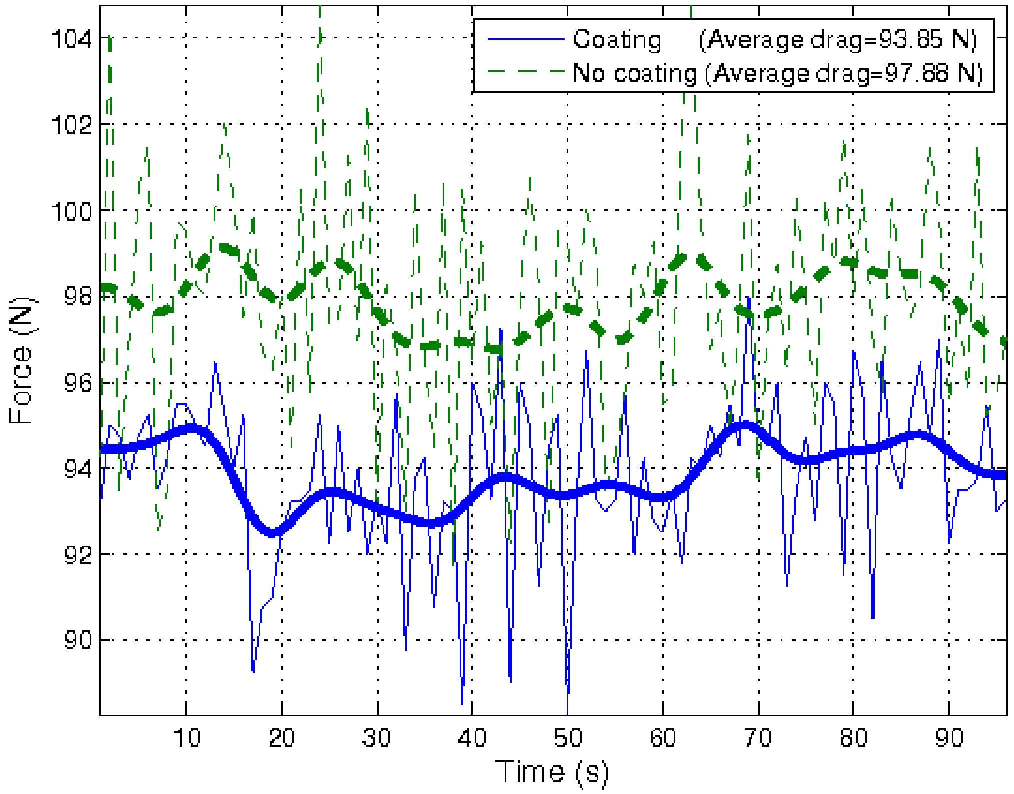
Untreated polyurethane: ~75º

Coated polyurethane: ~110º

Teflon: ~110º

True superhydrophobic surface: <150º

Test 1: Drag reduction



Two identical 25m long sections

Towed at 6knots

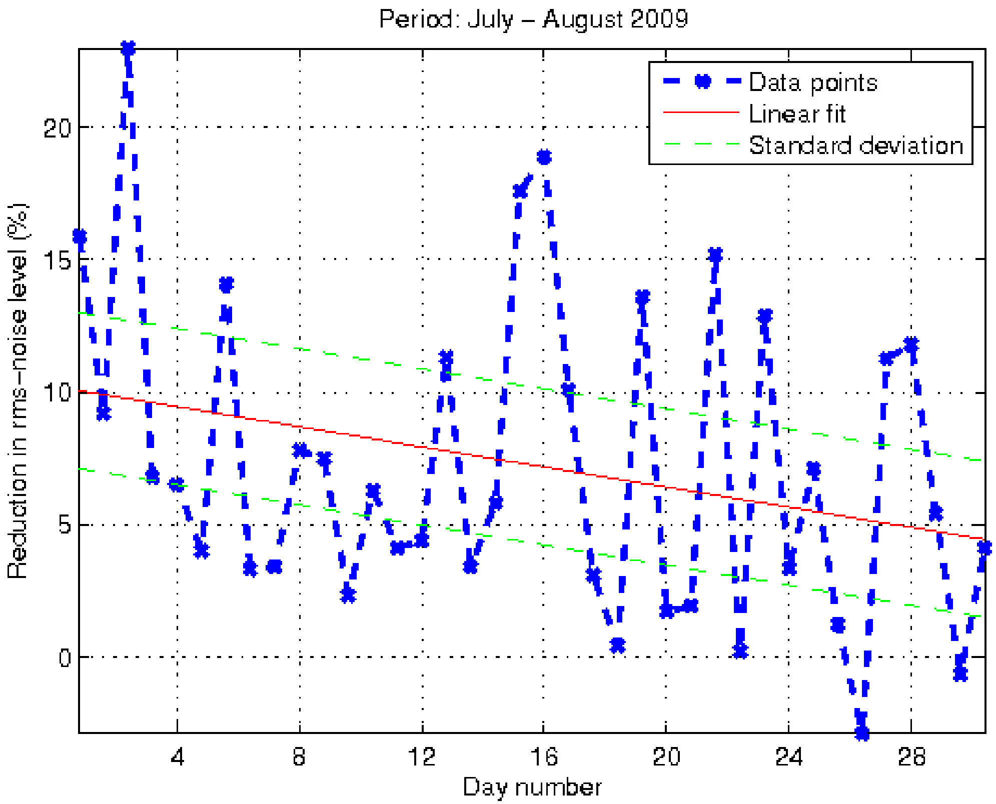
5% reduction in skin-drag (And fuel-bill)

Test 2: Measurements on a seismic vessel

- We coated three groups (37.5m) of steamer on a seismic vessel
- During a 30 day period we recorded around 2min of noise at the start and end of each line.
- Looked at how the coat affected noise level on the streamer.
- Checked to make sure that the coat did not influence hydrophone sensitivity towards the reflection signal.

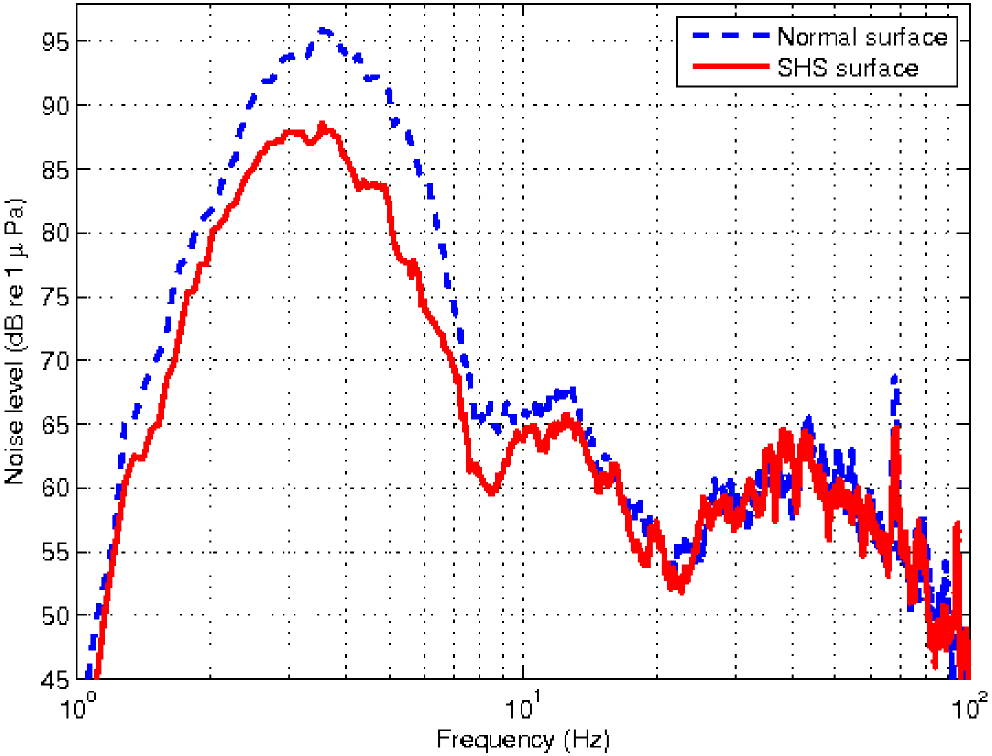
Geo Arctic

Results I – RMS level



- Initially, RMS noise level reduced by around 10% on the coated sections
- Reduced effect of the coating with time
- No effect on hydrophone sensitivity towards the seismic data

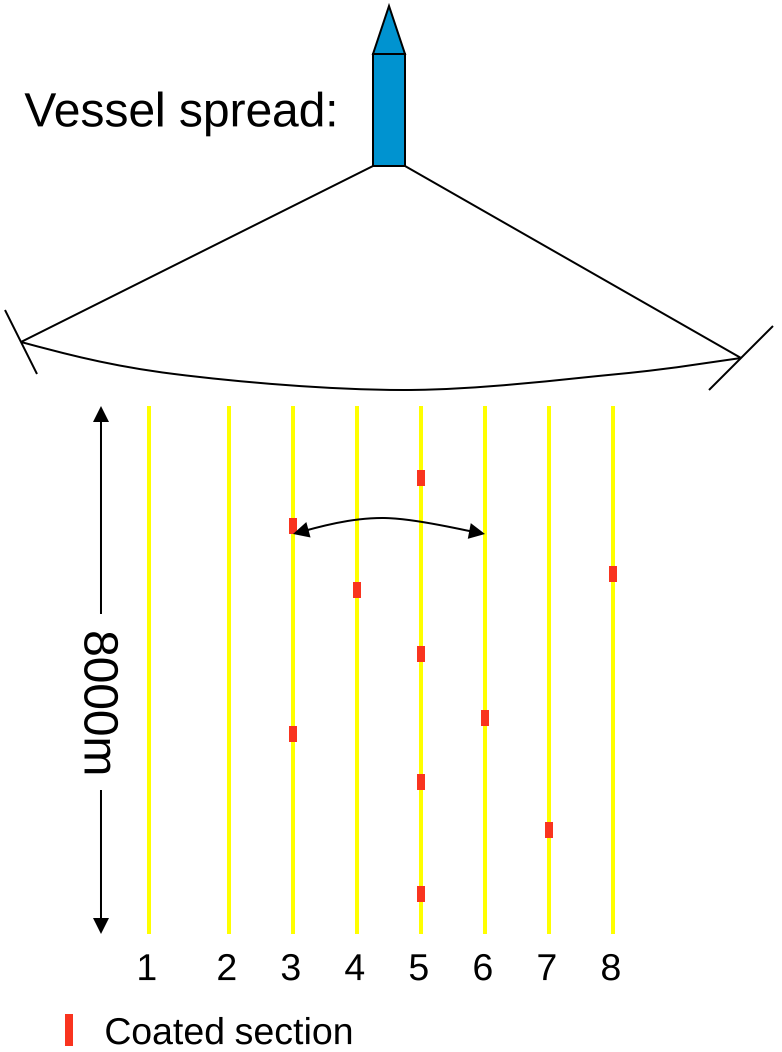
Results II – spectral analysis



- From 2-10 Hz the SHS coat reduced the noise level by up to 6dB (nearly 50%).
- This is also where we normally are troubled by swell-noise!

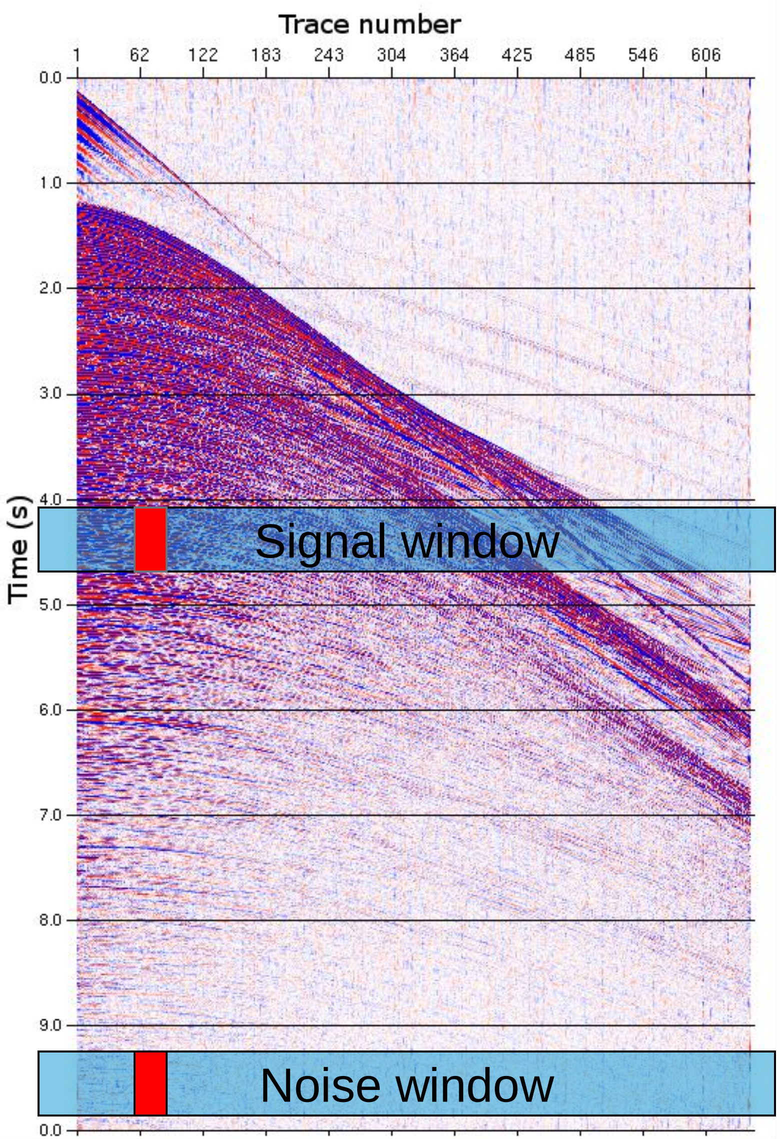
More testing:

Later, we also coated a number of 150m sections that was deployed on a vessel April and May 2011.



Geo Barents

The computations

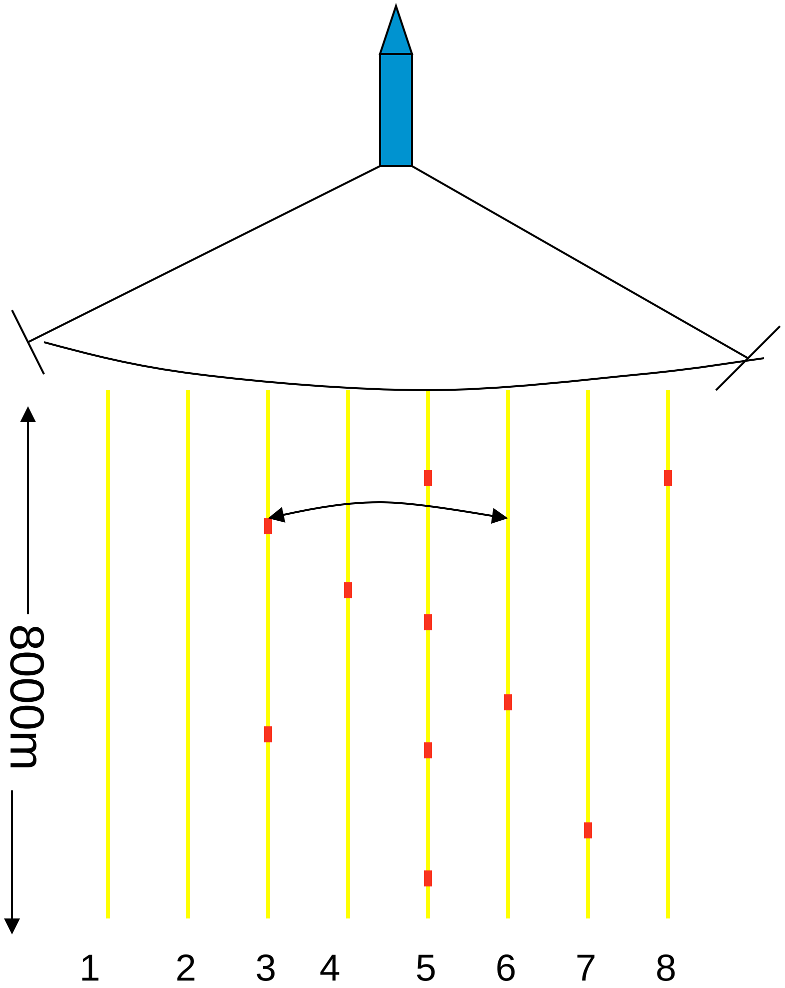


- Before the rms analysis we applied a 3Hz lowCut filter to all data.
- We used the measured difference in the signal window between neighboring streamers to adjust for variability is hydrophone sensitivity.
- We then compared the rms-level in the noise-window.

Results III:

Date	Line #	% reduction in rms noise
Mar 30	511	11.8
	512	4.4
	525	15.4
	526	20.3
	527	10.5
	528	18.9
	531	13.2
	533	17.2
	534	9,7
	535	17.2
	536	10.3
Apr 17	537	17.1

Average reduction: 13.9%



Comparing *coated* and *uncoated* sections.

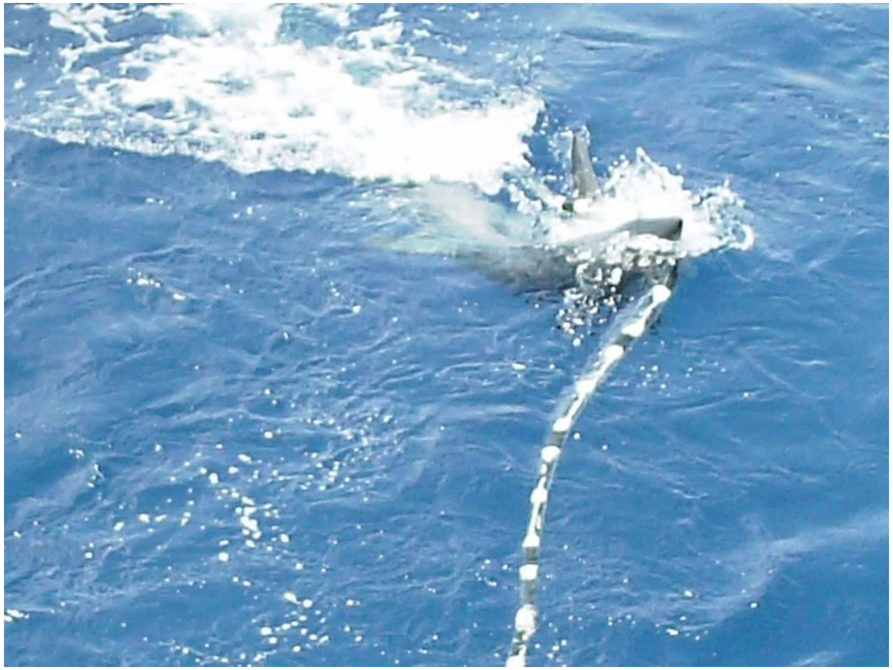
Summary on SHS

- New way to reduce noise in seismic!
- We know how & why it works.
(A GEOPHYSICS paper has been published in 2012).
- Lacking durability.
- Problems with bio-films etc.

End of swellnoise theory.

From now on we will (almost only) look at nice pictures!

Once data has been acquired, the only method of improving the quality is through signal processing.



Creating seismic noise!

Denoising algorithms

Transform the DATA into a domain where we can separate the NOISE from the SIGNAL

↓

In this new domain, remove the NOISE

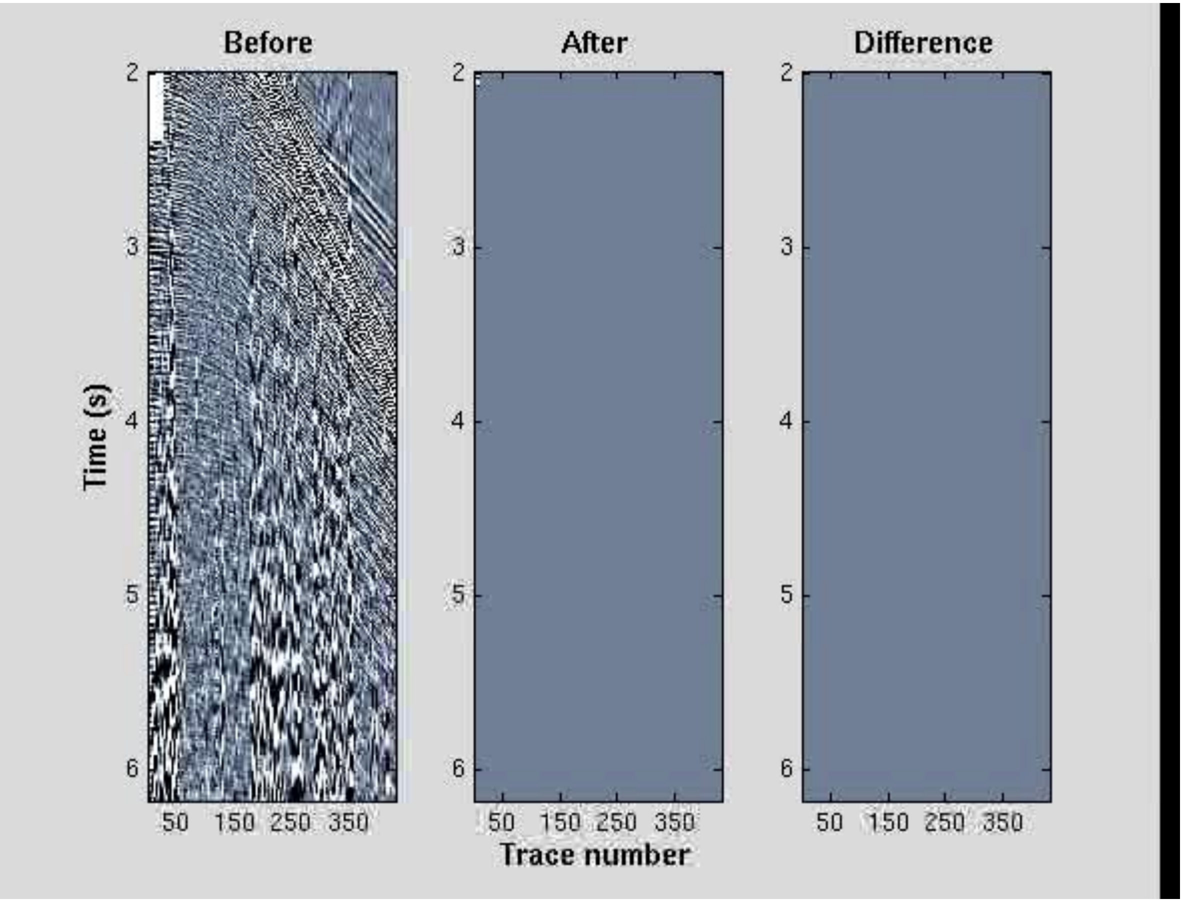
↓

Transform the denoised DATA back to the time-domain

The general idea of all denoising algorithms!

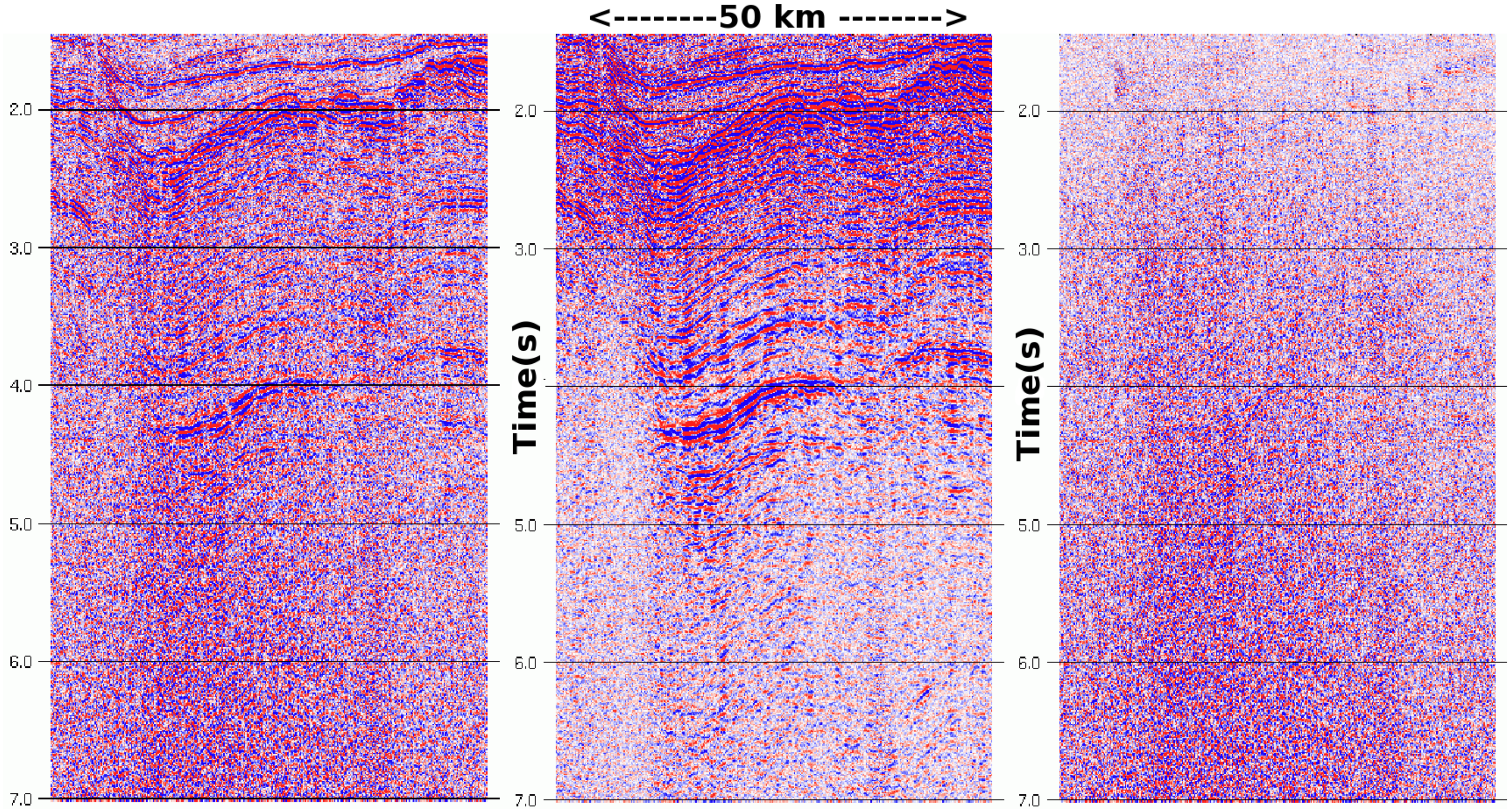
Q: Anyone that can describe A transform that might be useful?

The TFDN algorithm



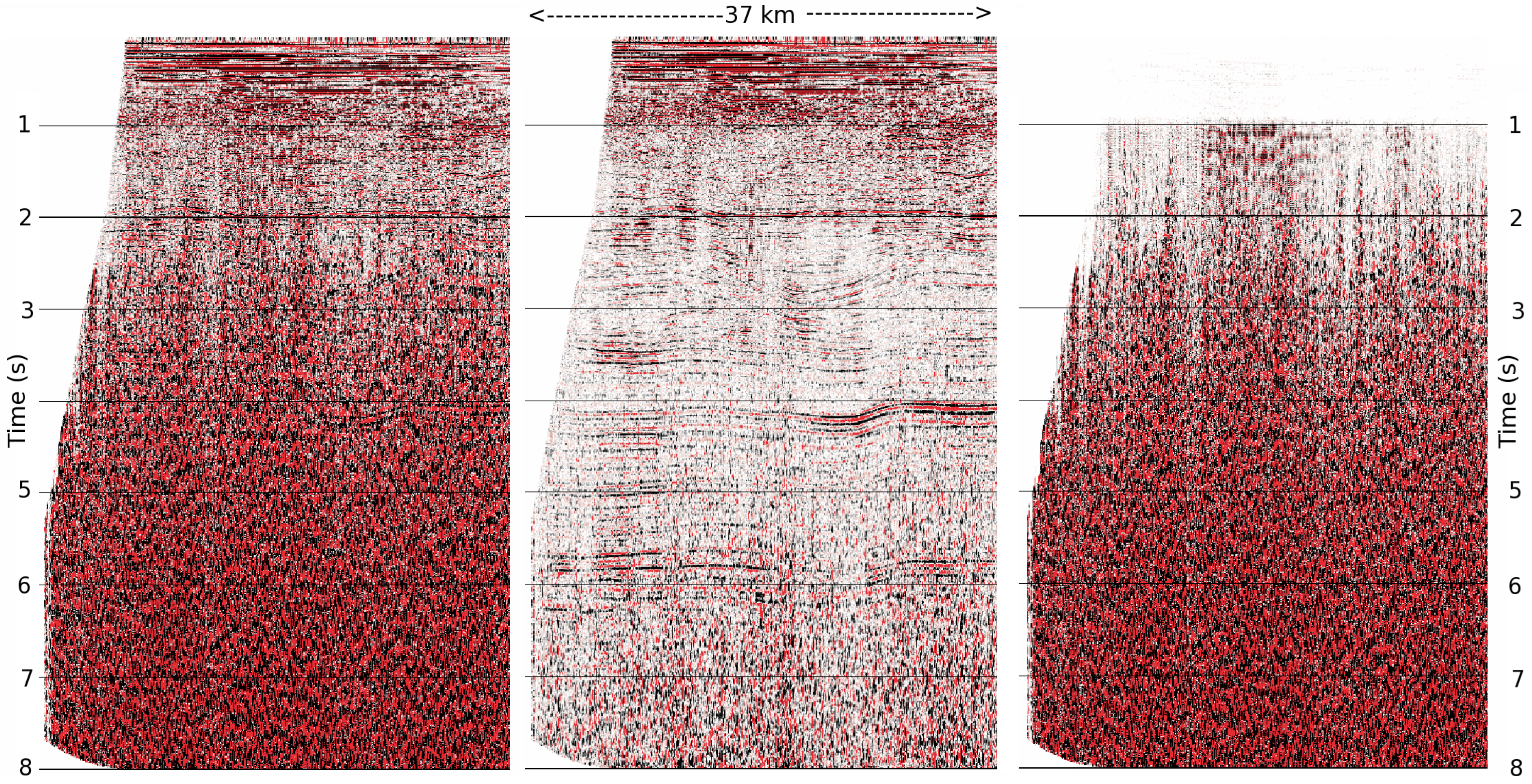
1. Transform data within sliding window to frequency-x domain
2. Apply statistical methods to identify and attenuate abnormal (noisy) data within window.
3. Transform the noise free frequency-x data back to time-x domain.
4. While not finished: Move sliding window and goto 1.

Statistical denoising – Stack from Barents Sea

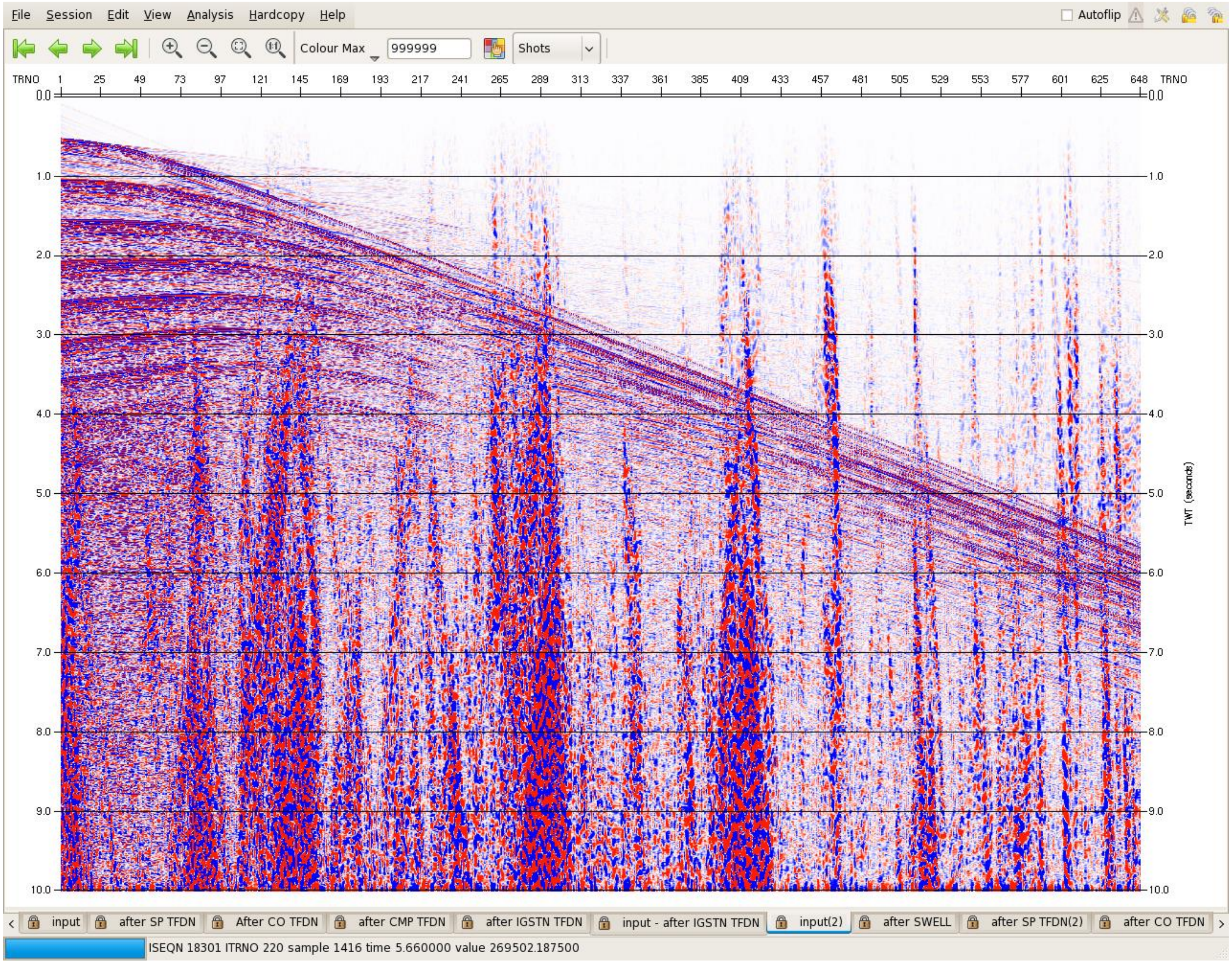


Denoising was done pre-stack!

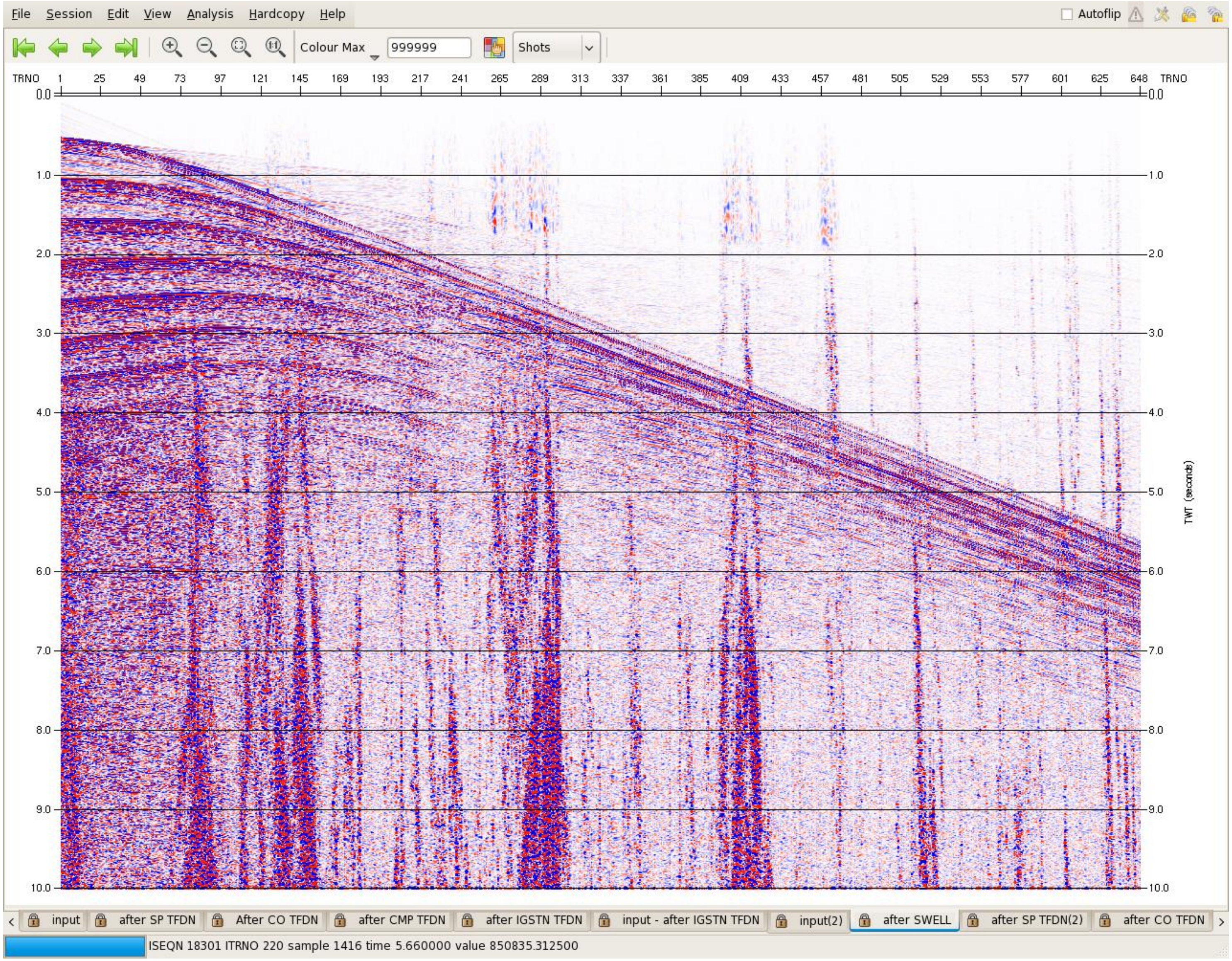
Another stack



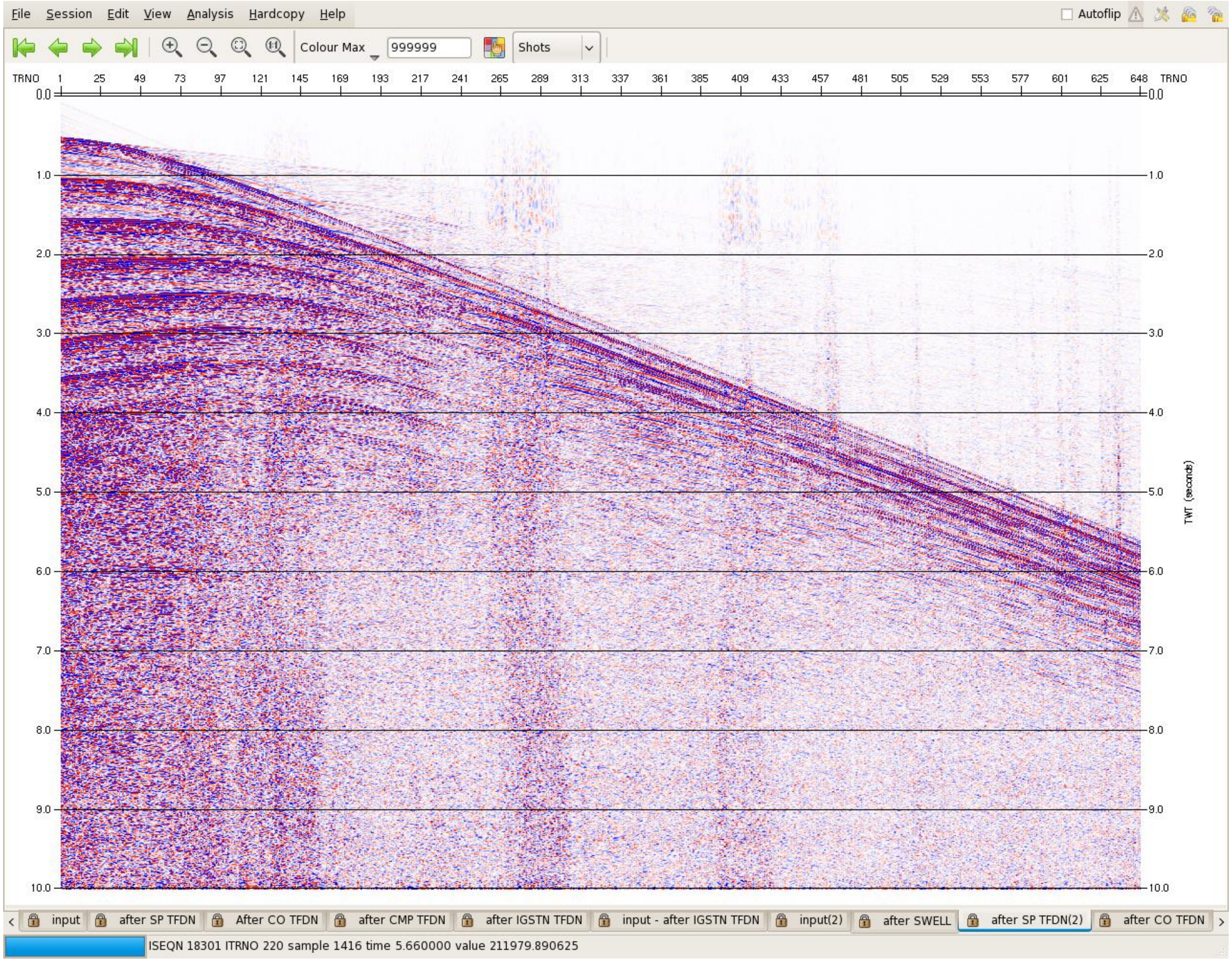
Input shot gather



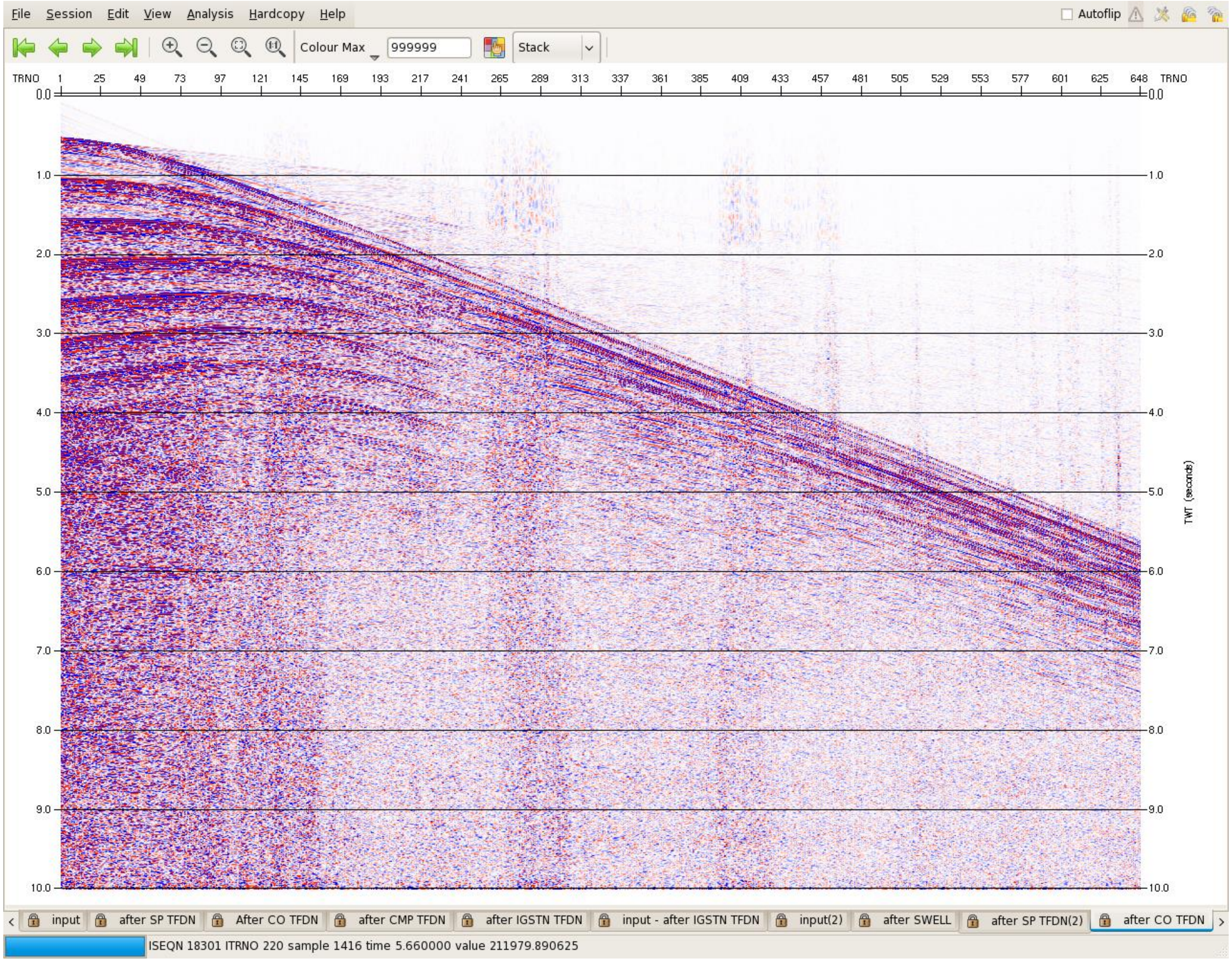
After swell-noise removal 0-8Hz



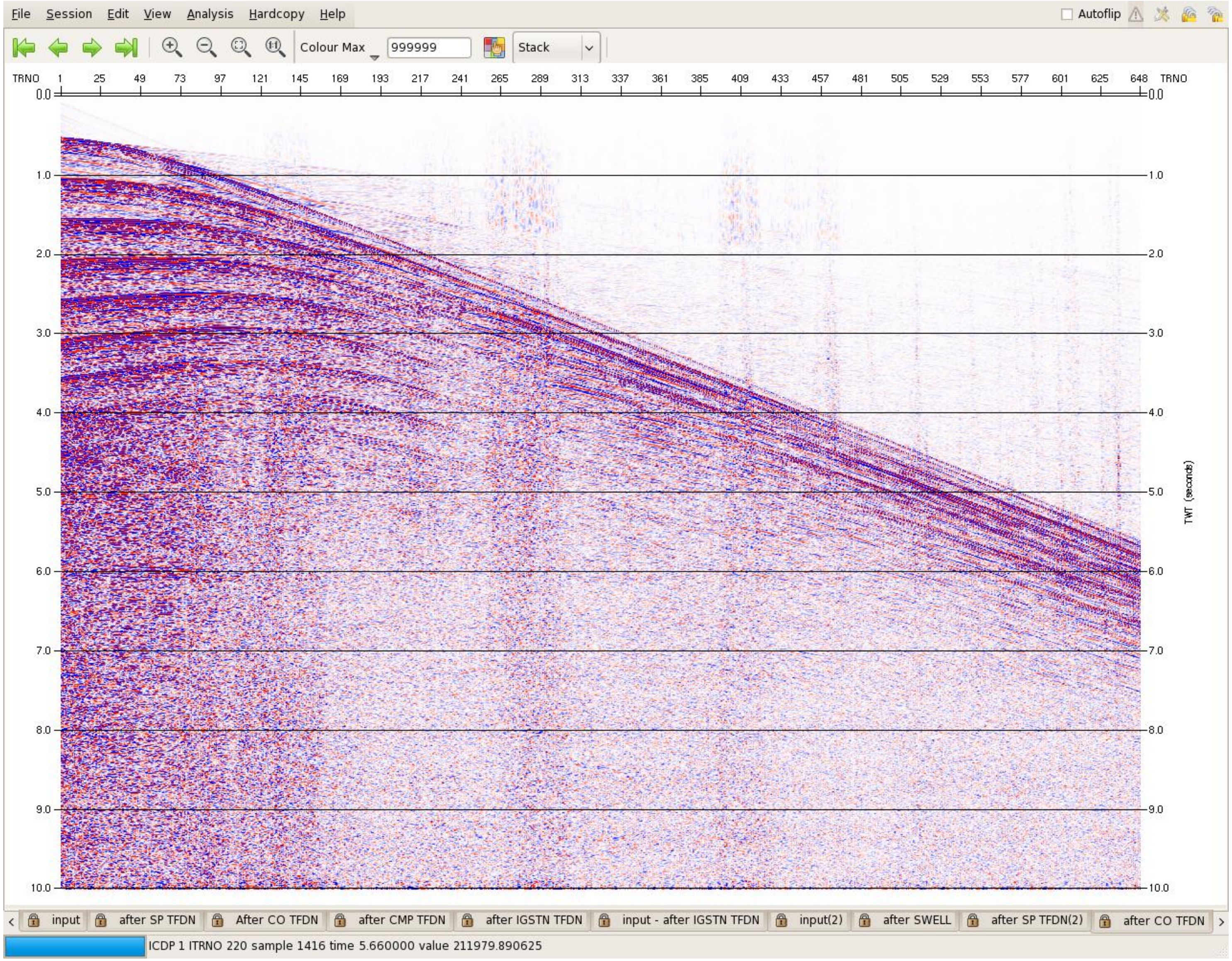
After SP denoise



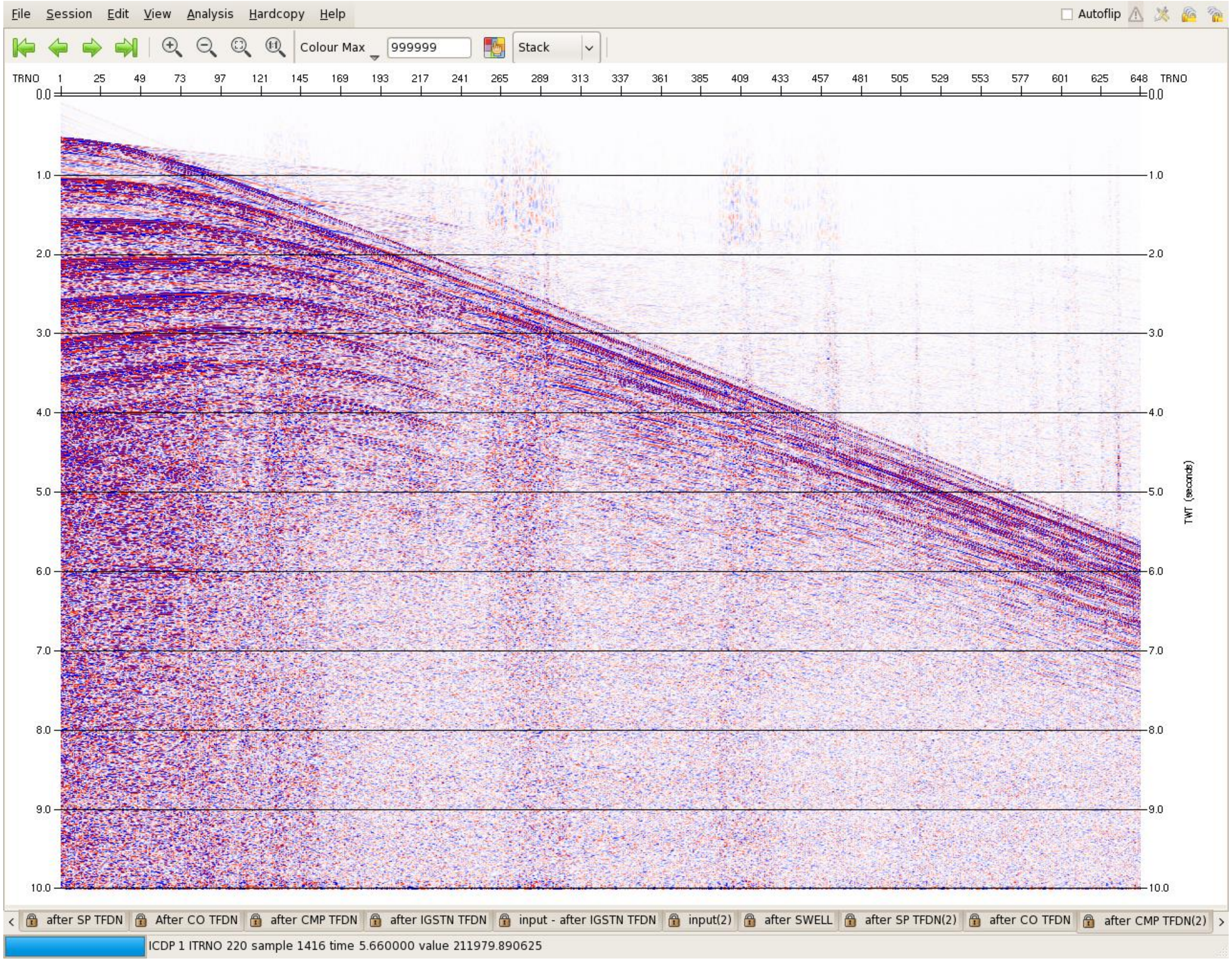
After common offsets denoise



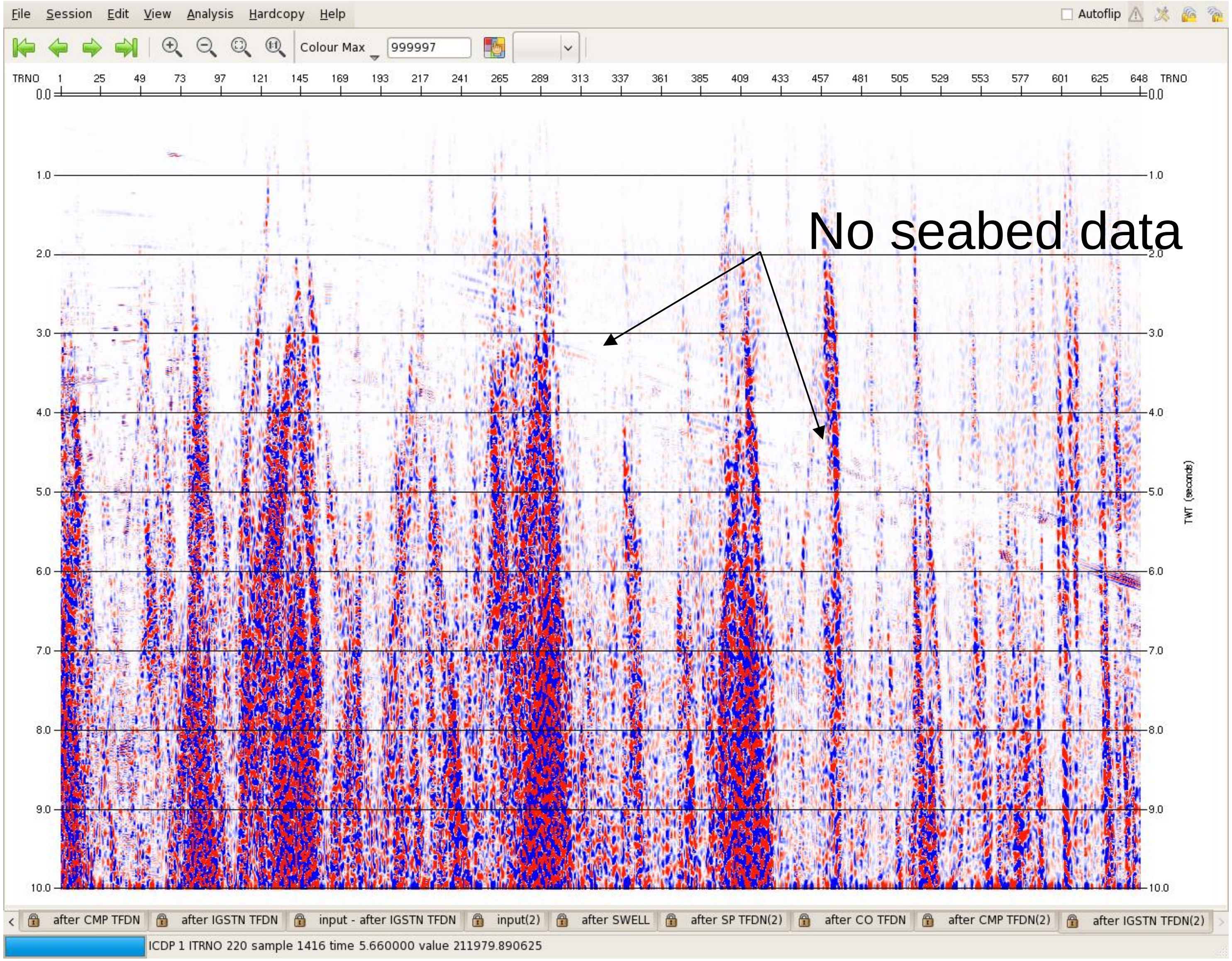
After CDP denoise



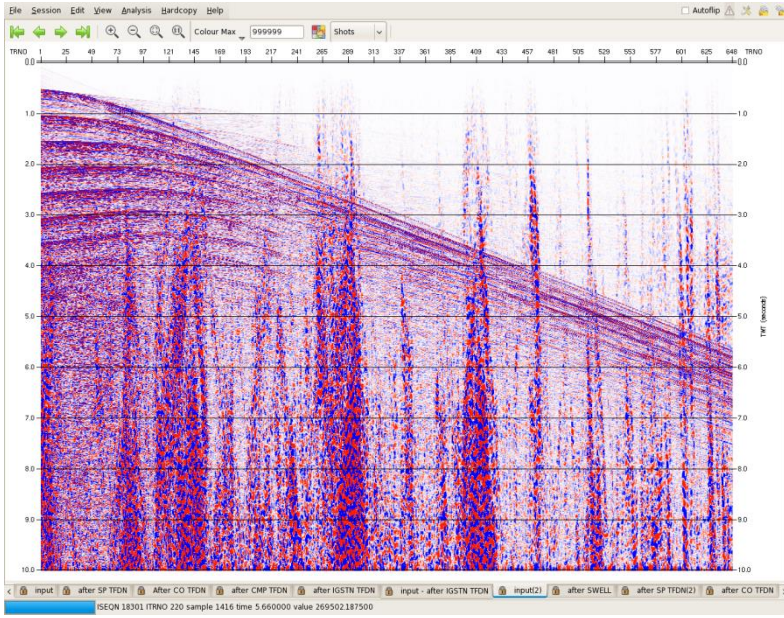
After common receiver station denoise

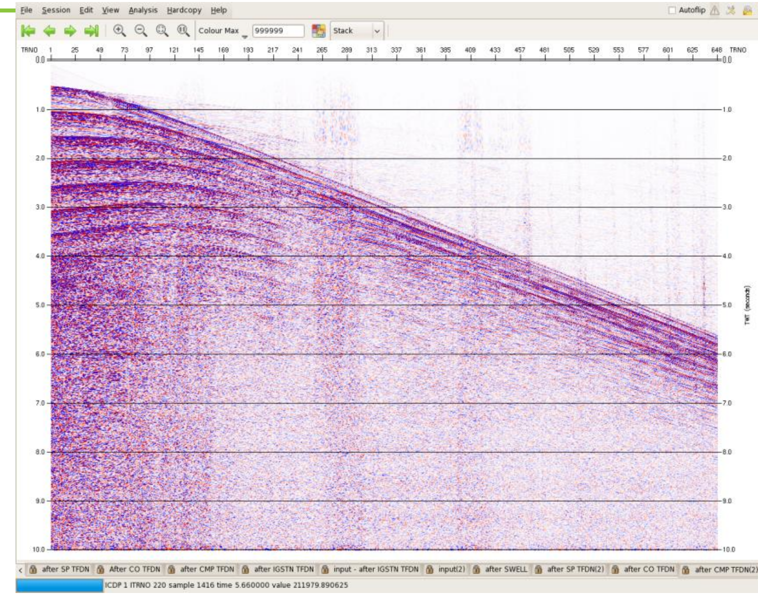


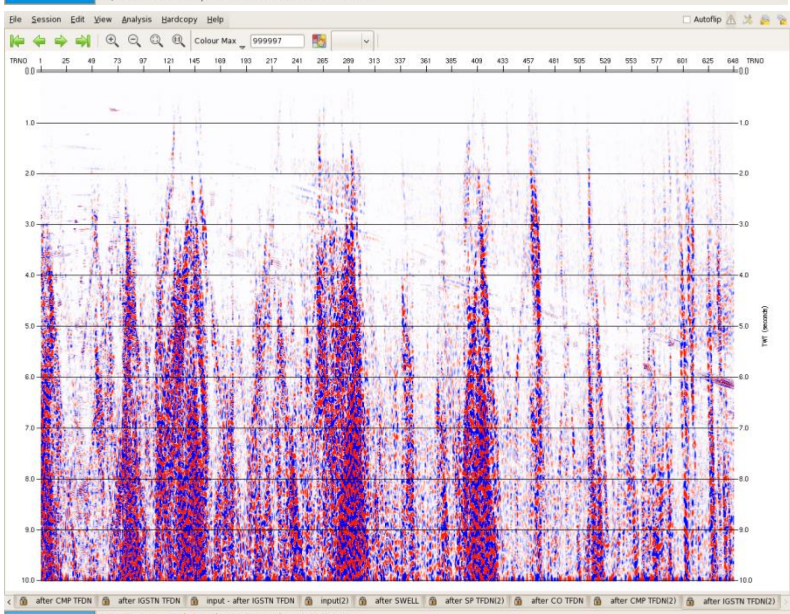
Input – output



Before – After and Difference on a shot gather



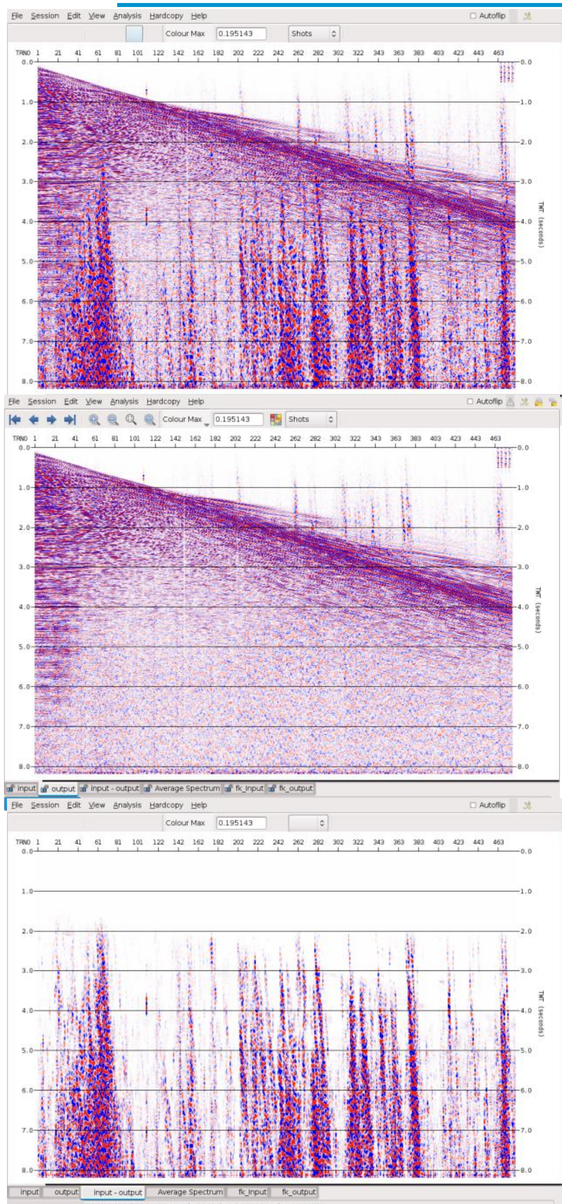




Q: What will happen with the remaining noise during processing?

Q: Does anyone observe additional noise issues in the ‘after’ plot?

Another example

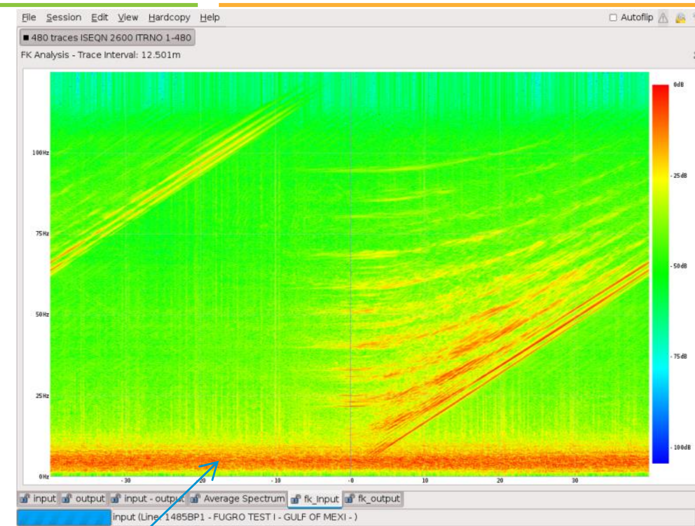


Before

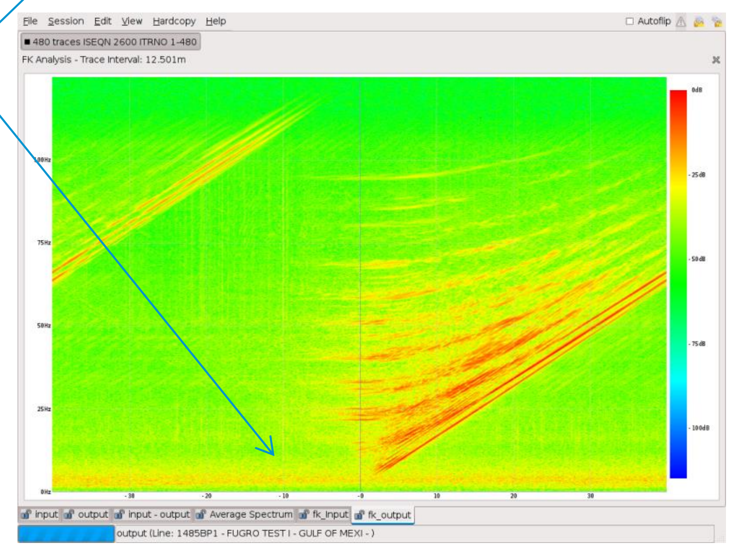
After

Difference

Q: What is the 'speed' of the swell-noise?



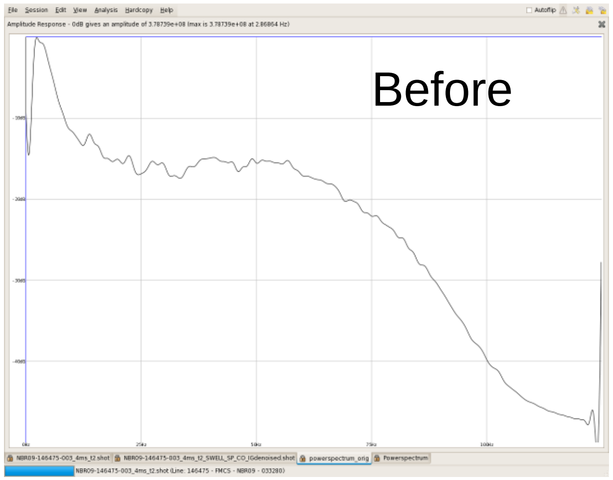
FK-spectrum before/after

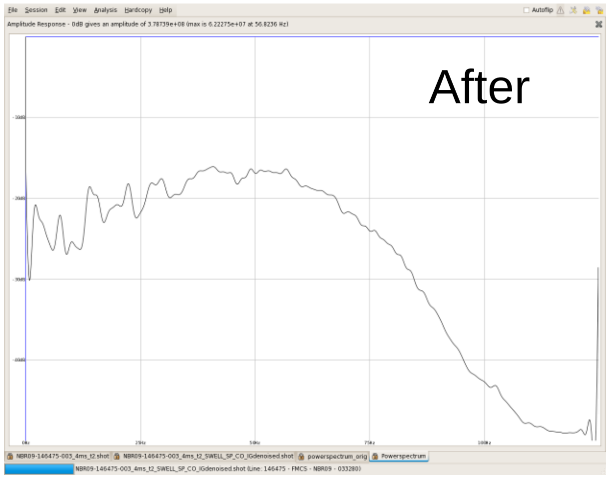


Conclusions on swellnoise

- It is vital to remove swellnoise in order to get good quality stacks.
- By combining various algorithms, we are able to clean up data that would be discarded just a few years ago.
- Sorting is used to randomize the noise, before attacking it with statistical denoising methods

(Denoising is done in shot, cmp, common offset and common receiver station domain).





Left: The frequency content of the data.

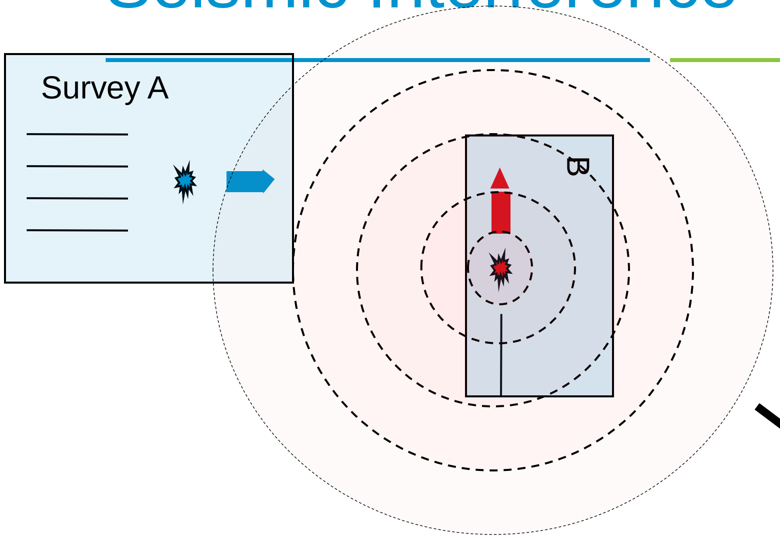
Seismic interference noise (SI)

All parts of the recorded data that does not contain useful seismic information can be seen as noise! The most common types are:

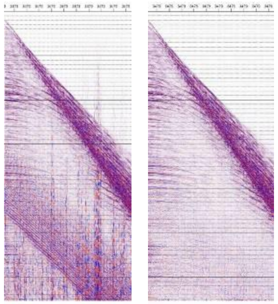
- Multiples (not a topic in this lecture).
- Hydrostatic pressure fluctuations.
- Swell-noise.
- **Seismic interference noise.**
- Environmental...

The topic of this lecture

Seismic Interference

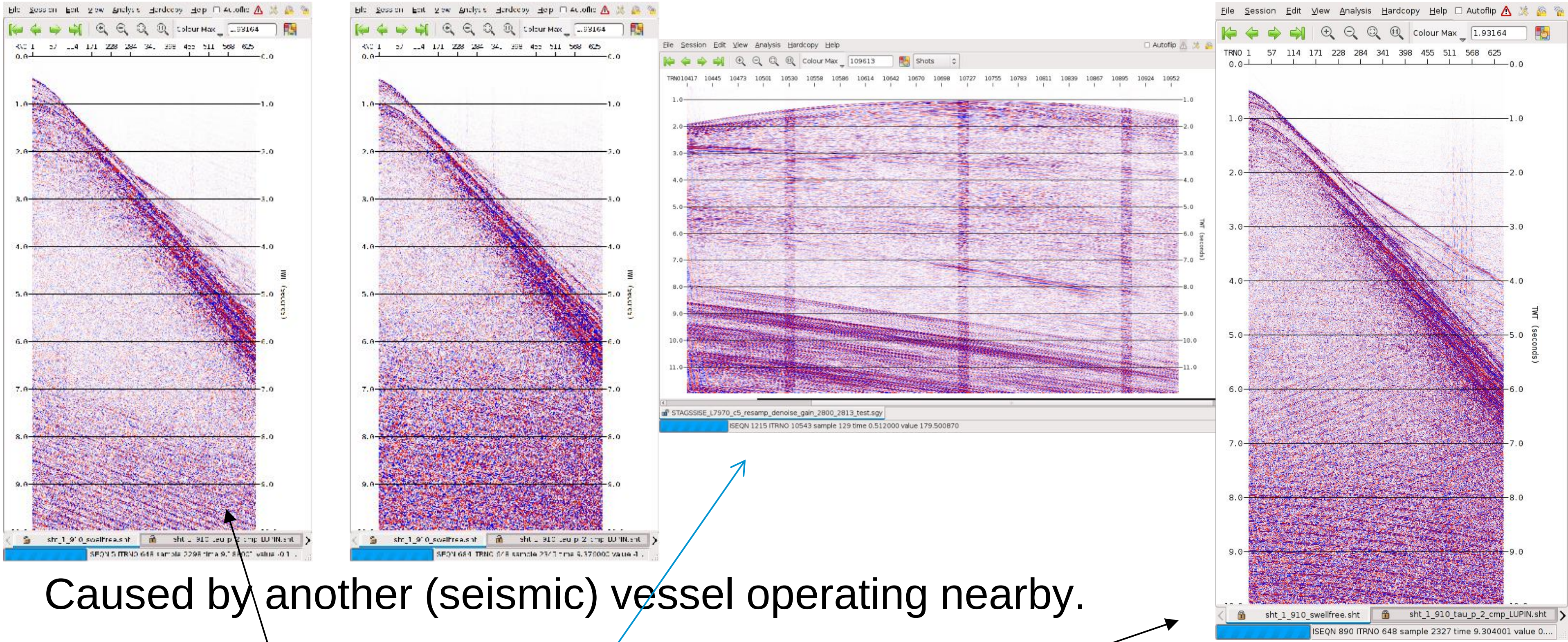


How to remove



Future approaches

Seismic interference



Caused by another (seismic) vessel operating nearby.

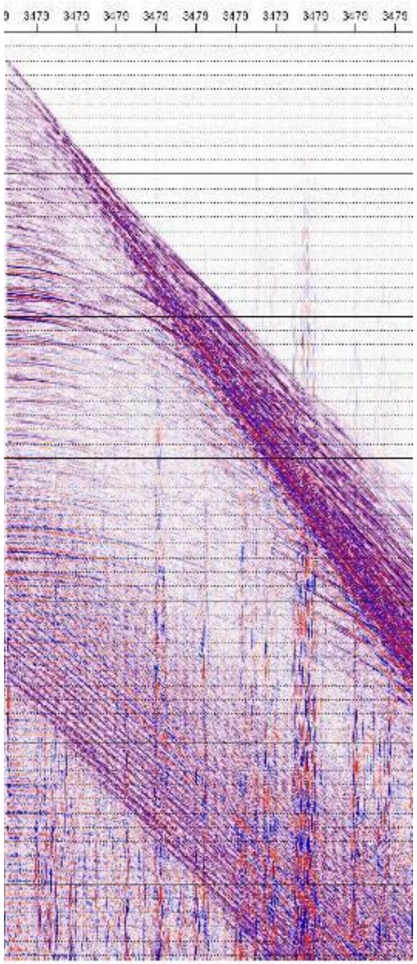
Q: Where is the interfering vessel?

Q: What is the frequency of SI?

Background

Seismic interference:

- Similar frequency content to real data (broadband)
- Intensity depends on:
  - Distance
  - Water depth
  - Sea-bottom reflectivity
  - *(The pycnocline)*



Shot gather with SI

SI-Solutions

Traditional:

- Timesharing
  - Problem:

    Cost: US$ ~300K pr vessel pr day
  - Advantage:

    Perfect results

'New' solution:

- Ignore SI. Attenuate it in processing
  - Problem:

    Remove all types of SI
  - Advantage:

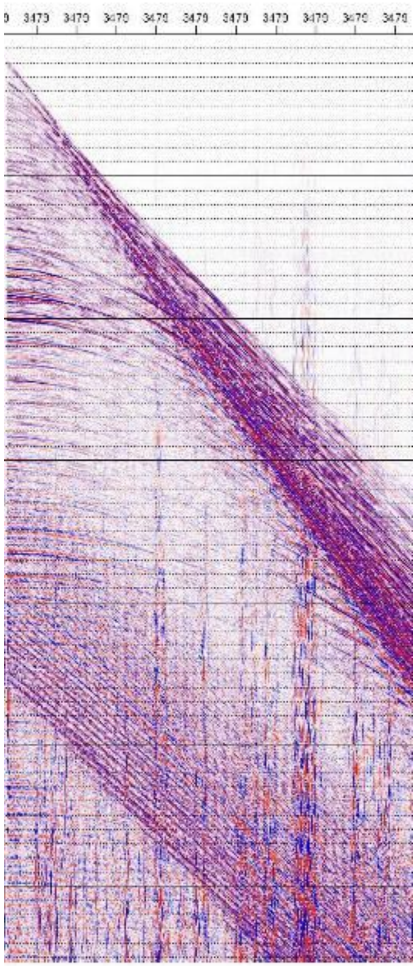
    Low cost (when it works!)

The signal processing challenge

- The seismic amplitudes (A) decay

- SI does not!

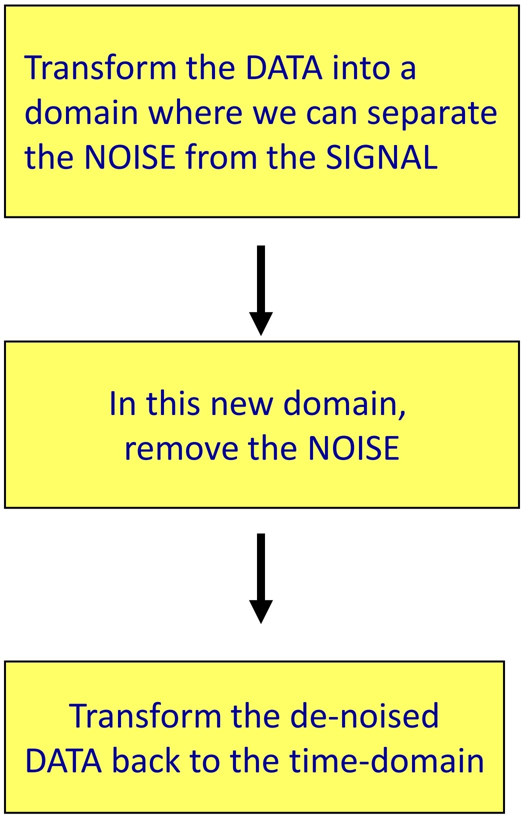
|A| ≈1000
|SI| ≈ 100



|A| ≈ 1
|SI| ≈ 100

A 8s shot gather.

General approach to remove SI



1. All denoising follow this algorithm.

2. The challenge is to find the optimal domain.

The story

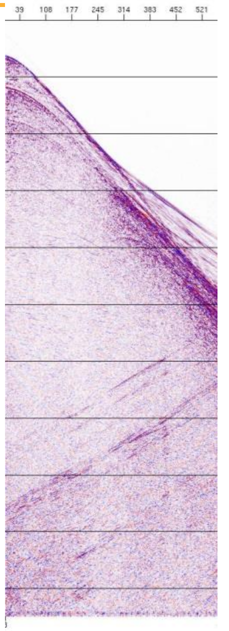
- We present a number of examples on how we through careful processing have removed SI.
- The first are fairly simple cases, while the last ones required a more complicated work flow.
- The question to answer is: Should we ignore SI during acquisition, and just handle it in processing?

Case 1: Onboard SI-removal flow

- Strong seismic interference was seen on some shot gathers
- Flow 1 + Flow 2 as described below was applied:

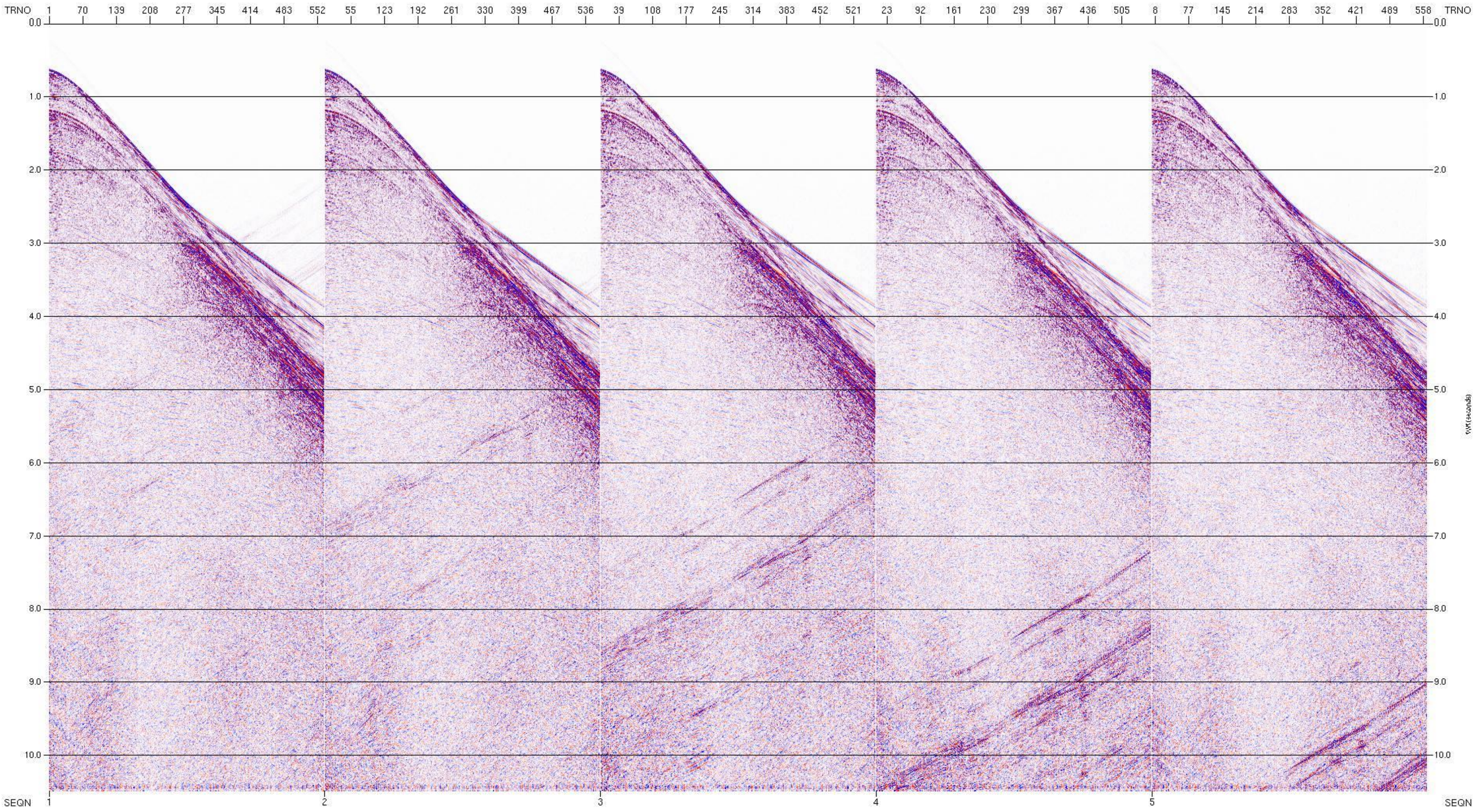
- **Flow 1. Create a model of the SI :**
- Apply FK filter designed around the SI + statistical denoise outputting the model of the SI
- Subtract the model from the data

- **Flow 2: statistical denoise in common offset domain**
- Sort data to CO-domain
- Apply statistical denoise:

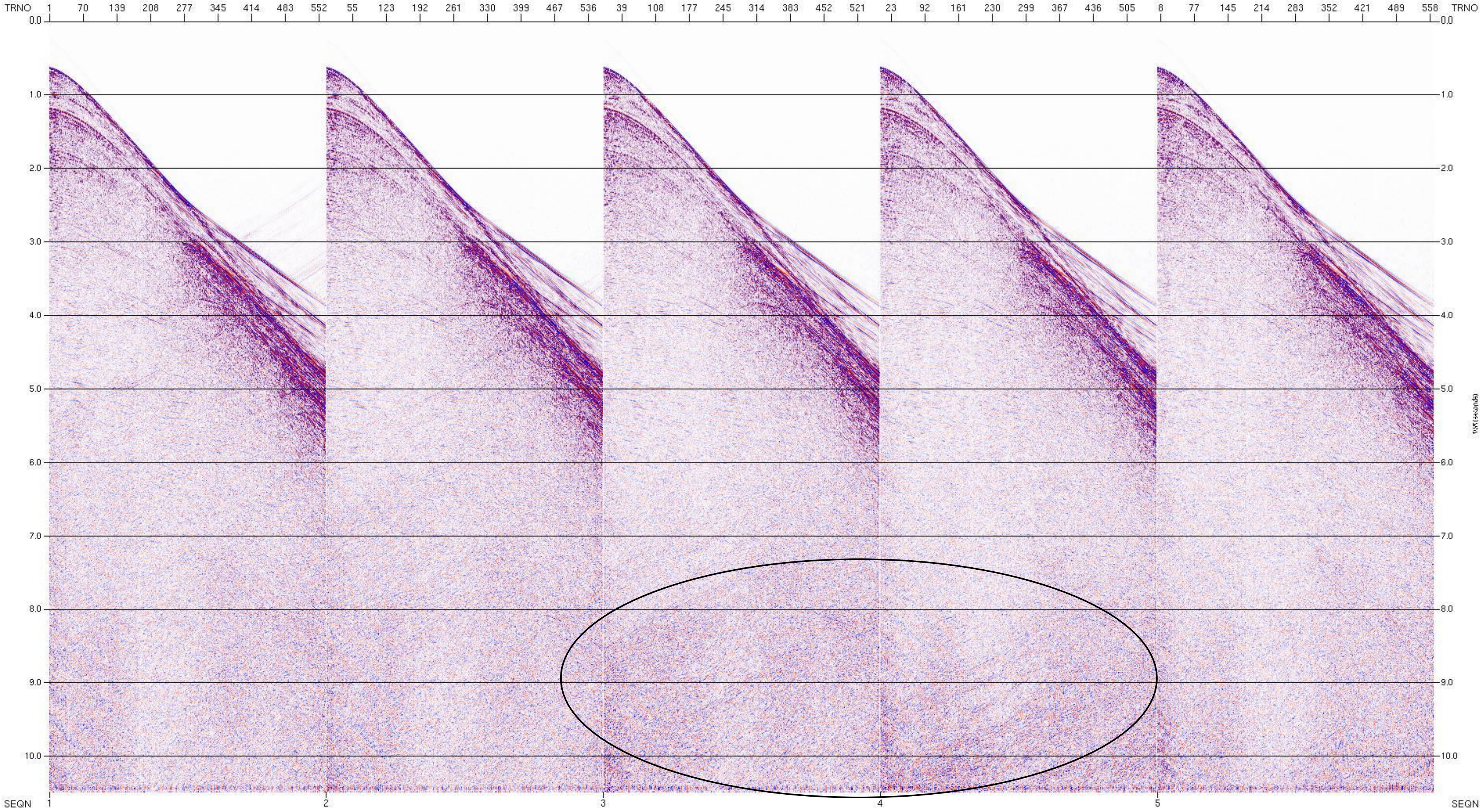


Example shot gather

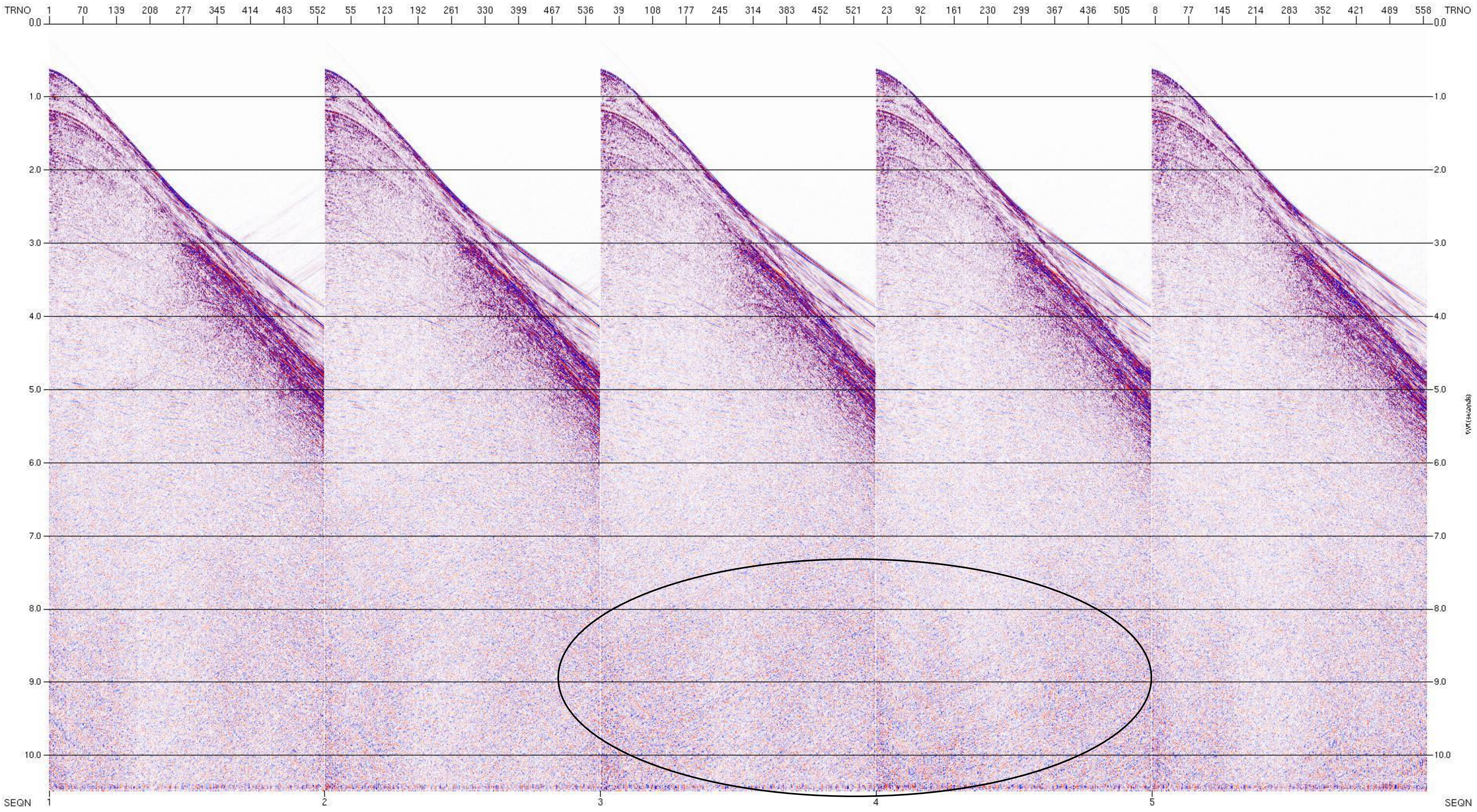
Shot Input


TRNO
1 70 139 208 277 345 414 483 552 55 123 192 261 330 399 467 536 39 108 177 245 314 383 452 521 23 92 161 230 299 367 436 505 8 77 145 214 283 352 421 489 558
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
SEQN
1 2 3 4 5

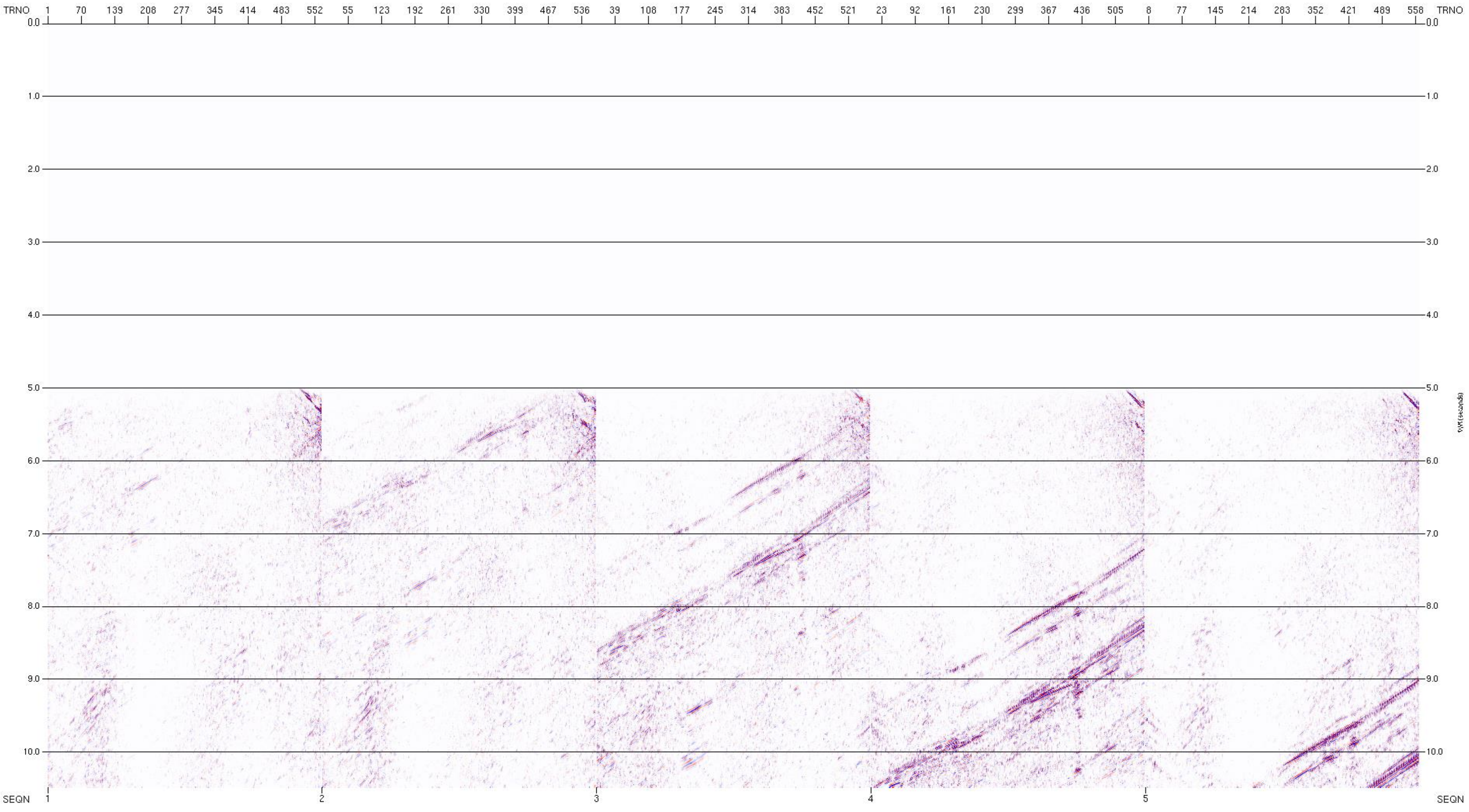
Shot after SI_flow1



Shot after SI_flow2



Difference



TRNO 1 70 139 208 277 345 414 483 552 55 123 192 261 330 399 467 536 39 108 177 245 314 383 452 521 23 92 161 230 299 367 436 505 8 77 145 214 283 352 421 489 558 TRNO
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
SEQN 1 2 3 4 5 SEQN

Case 1: Summary

- Flow 1 using a FK filter + statistical denoising for the creation of the seismic interference model, is efficient.

- Flow 2 (the extra pass of statistical denoising) further improved the results.

Comments:

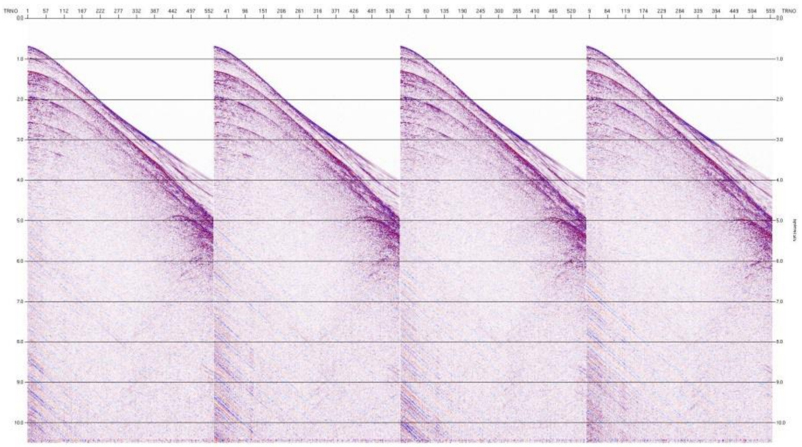
This was easy because the SI and the data had opposite move-out.

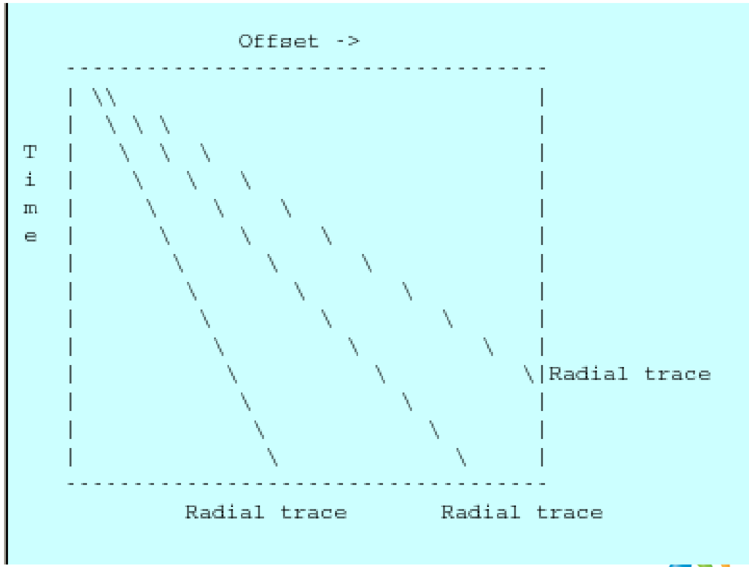
Results were not perfect, but demultiple + migration will attenuate the remaining SI.

Case 2: Radial Trace transform

- Linear noise on the streamers
  - (SI or tugging???)

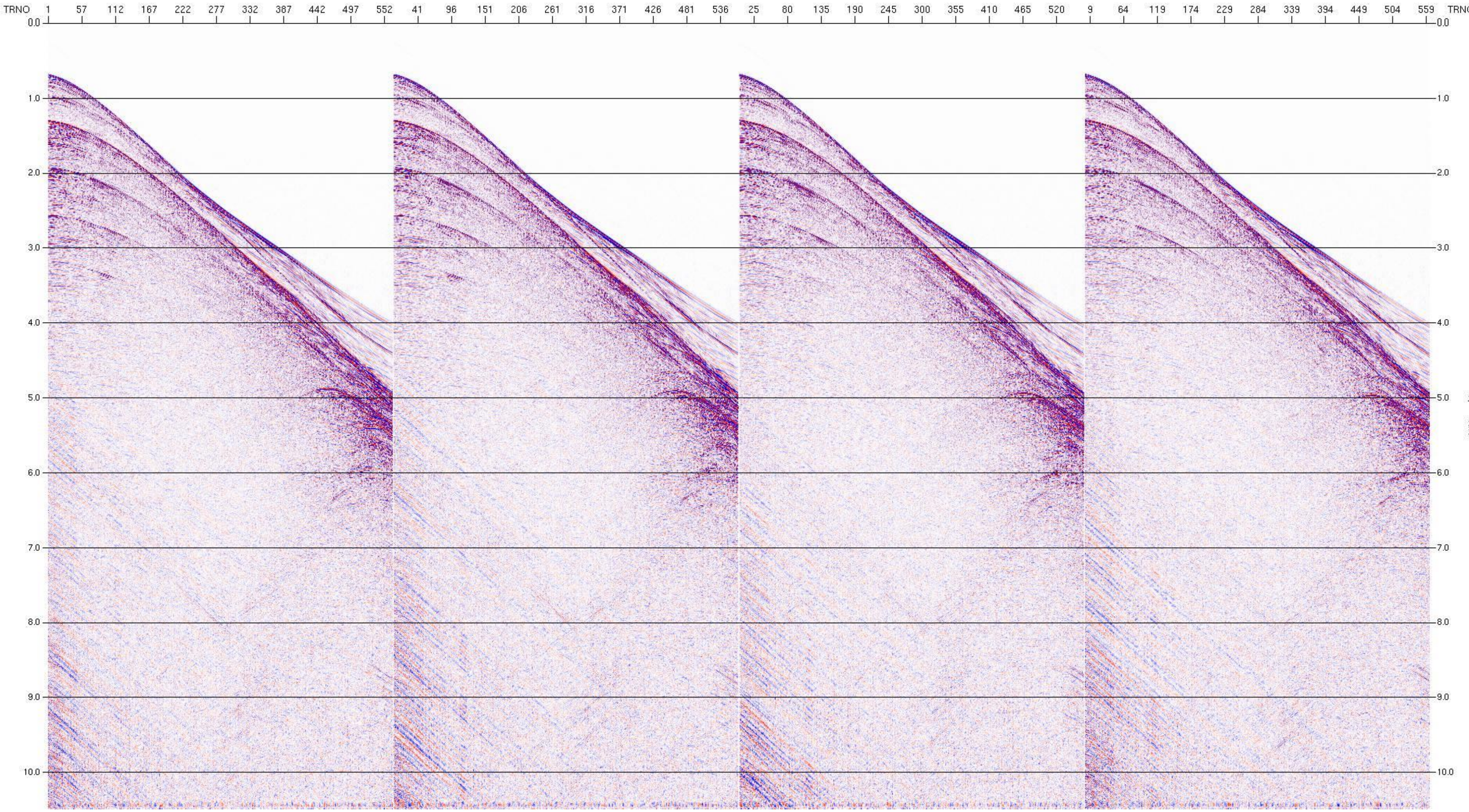
- Move-out similar to the seismic data, so FK/Tau-p mutes are difficult.





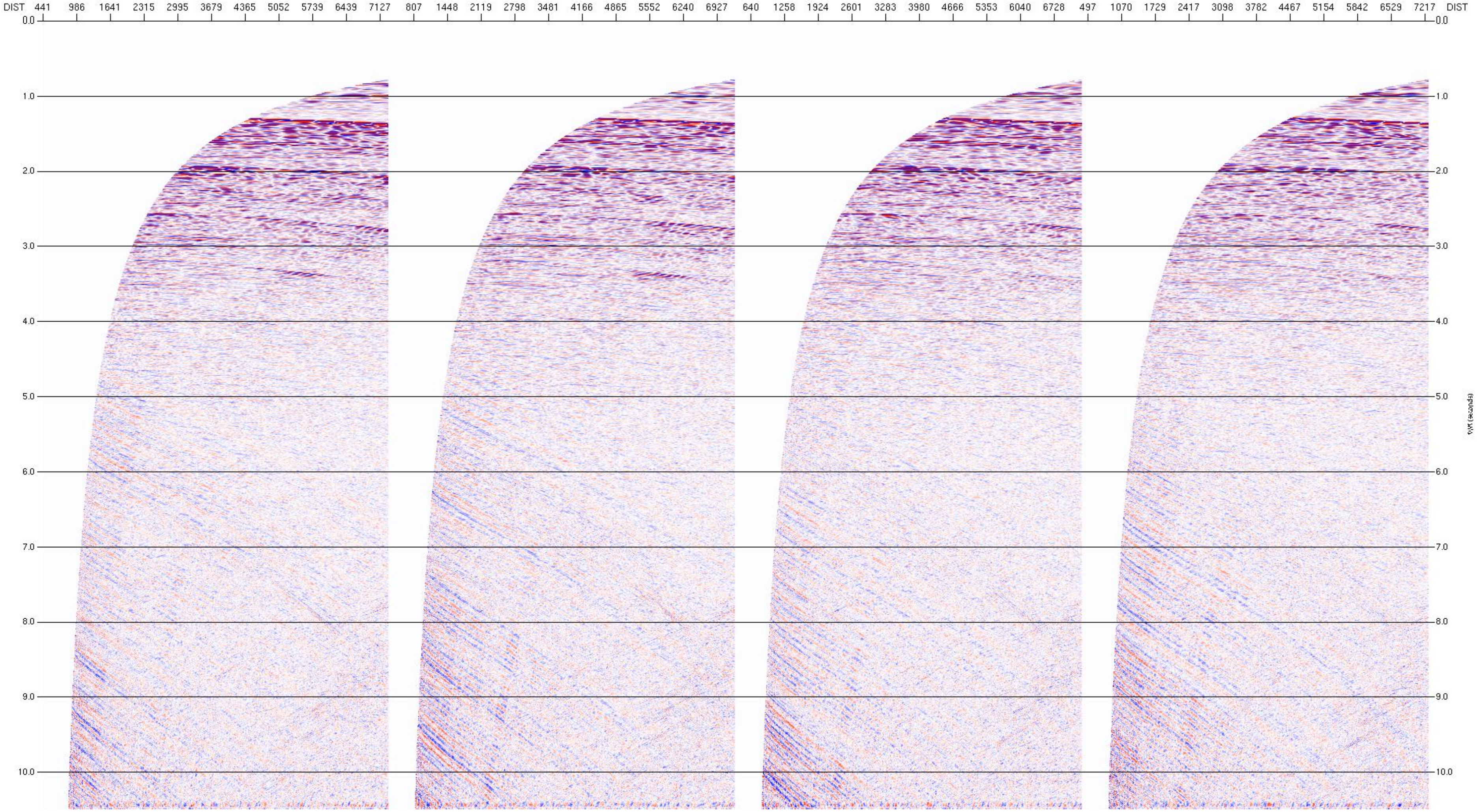
Radial traces paths; They fan out radially from a user specified origin with varying directions.

Shot input

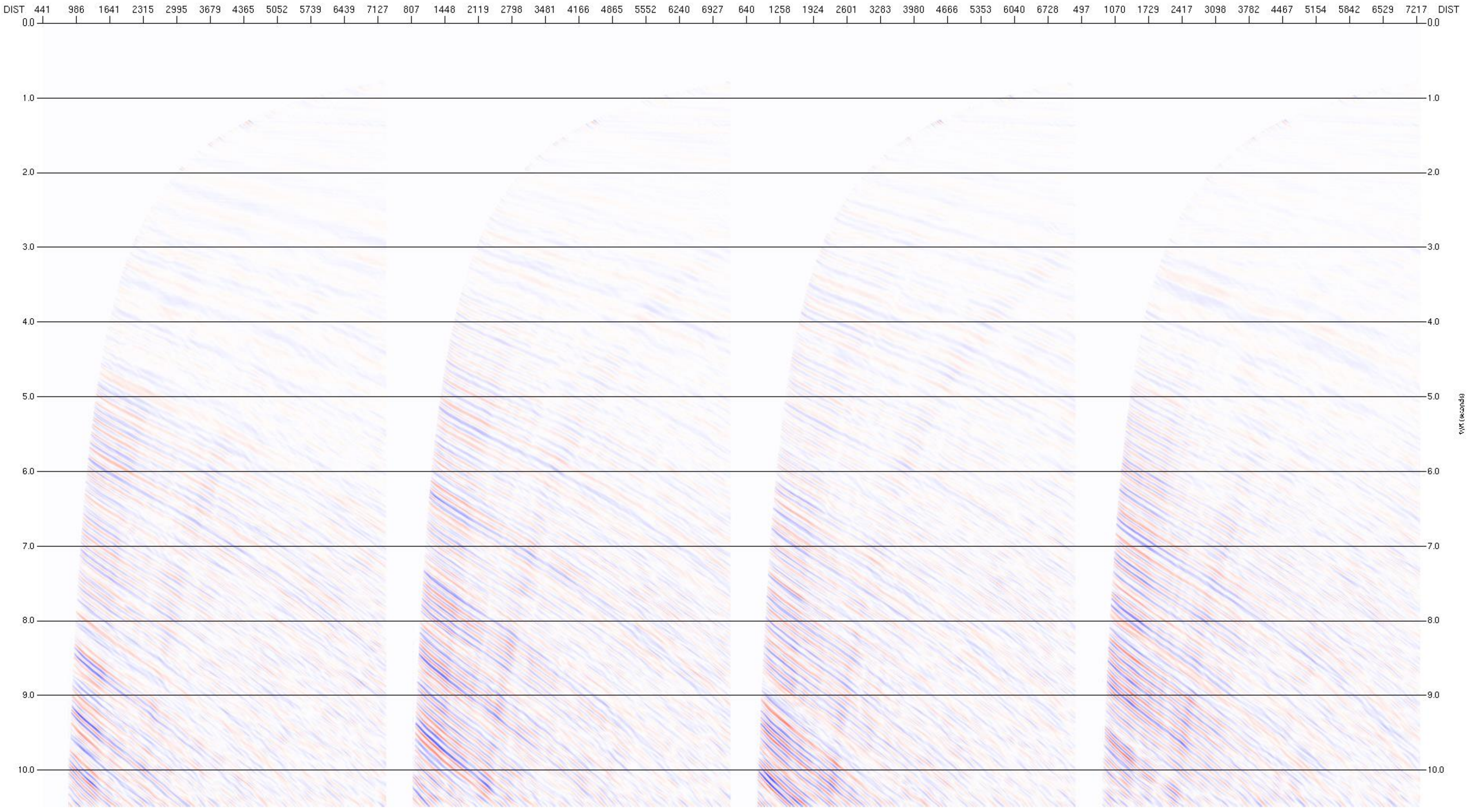


Tugging??? Click to play!

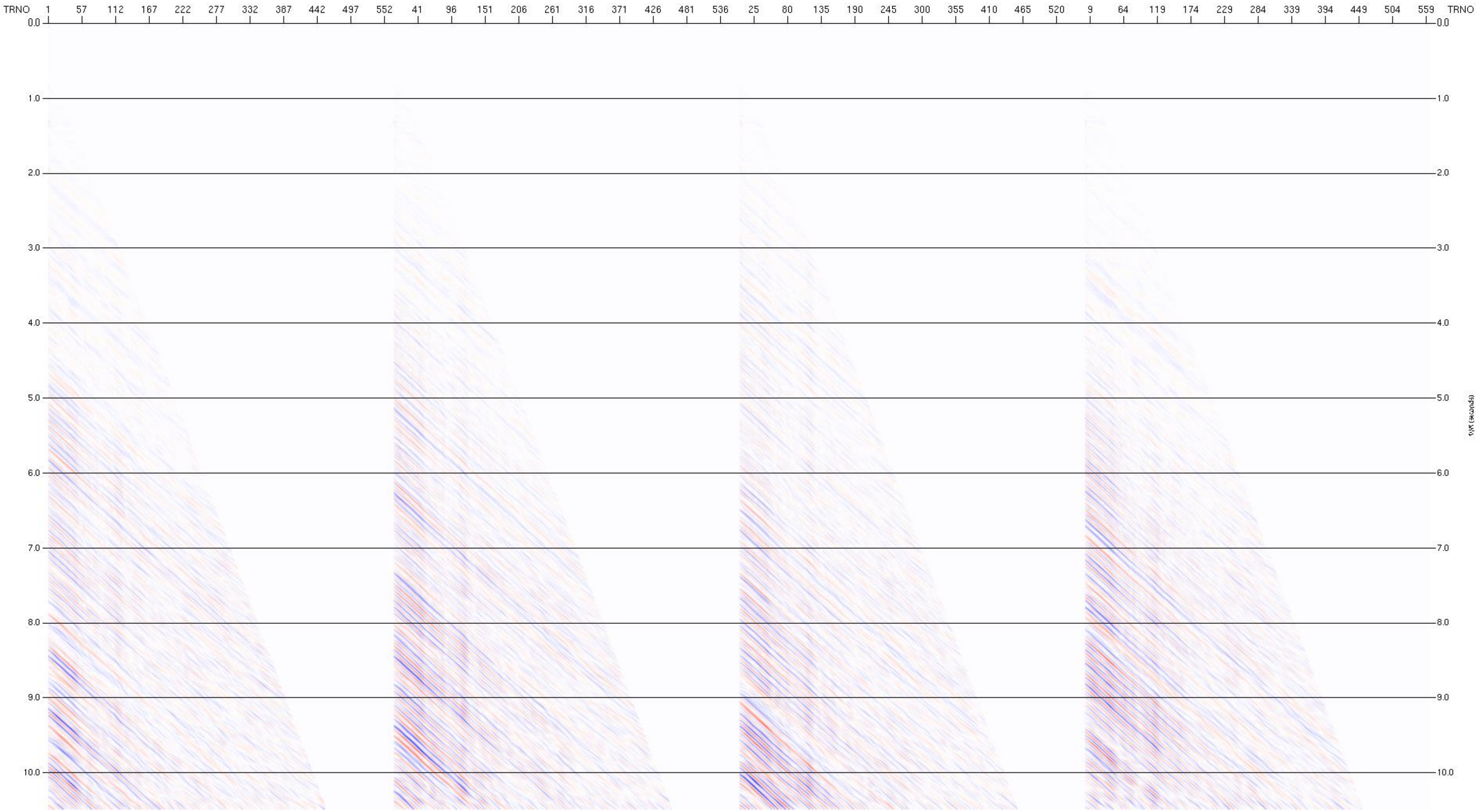
Radial domain : Input



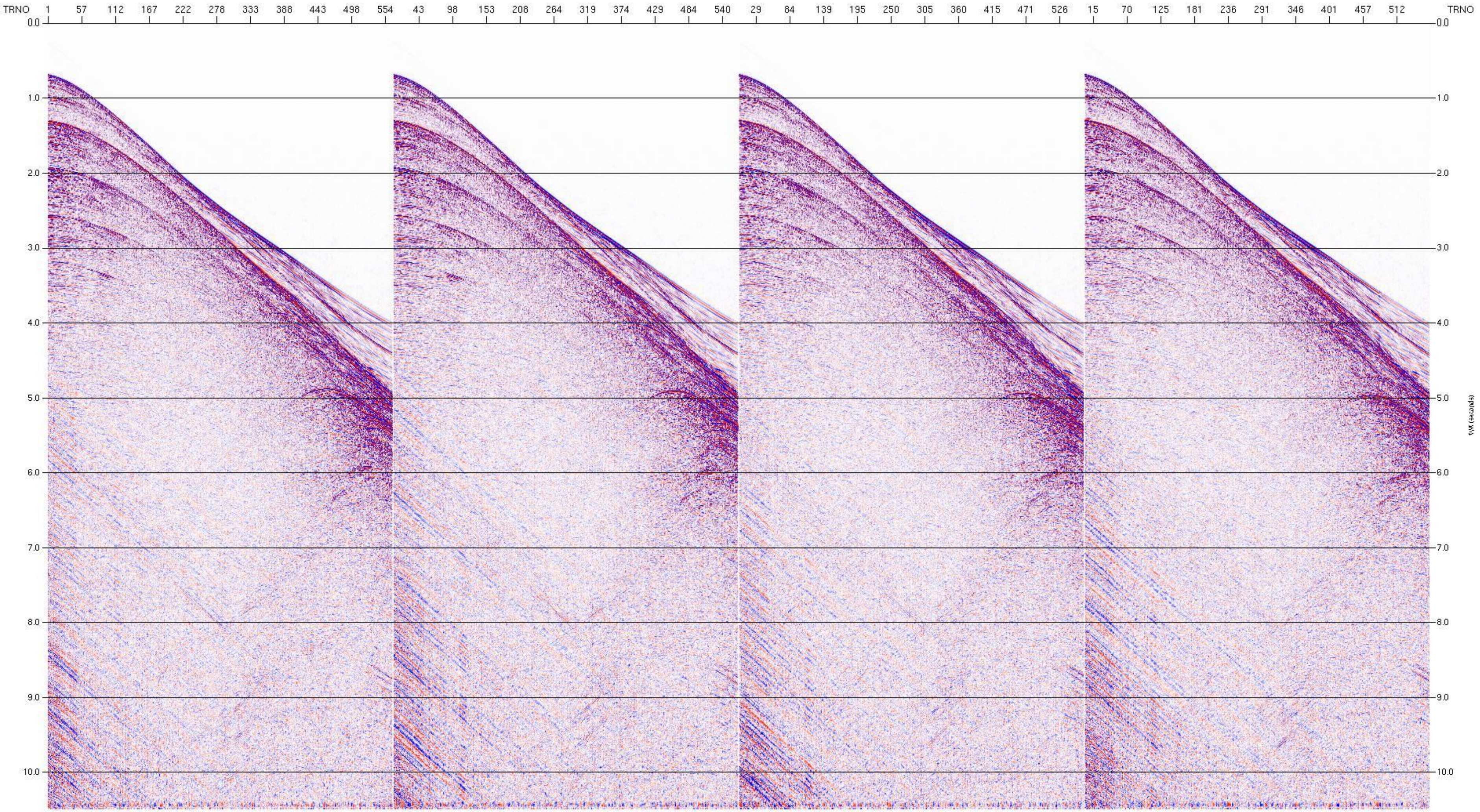
Radial domain : After FK



Shot : Model

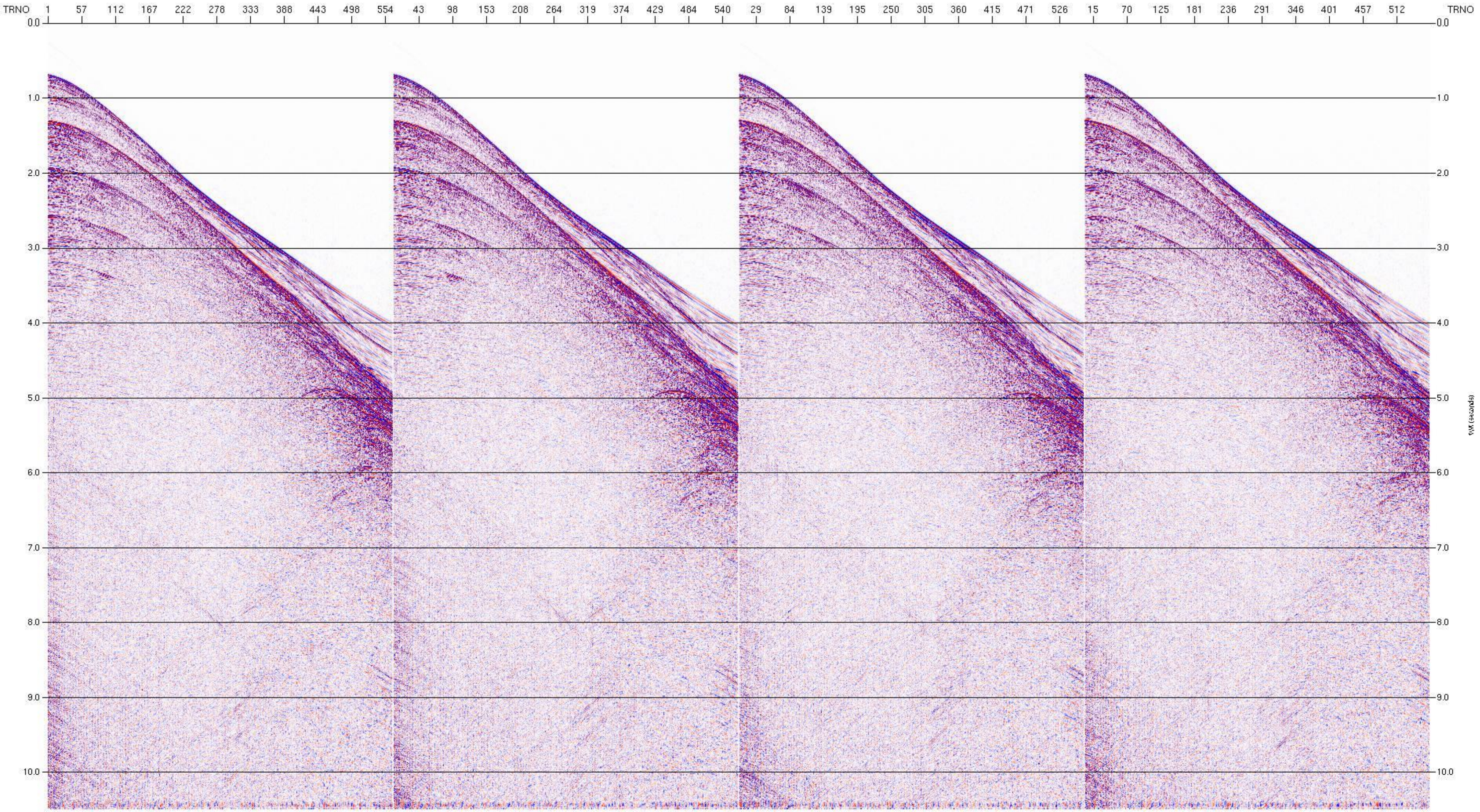


Shot : Input

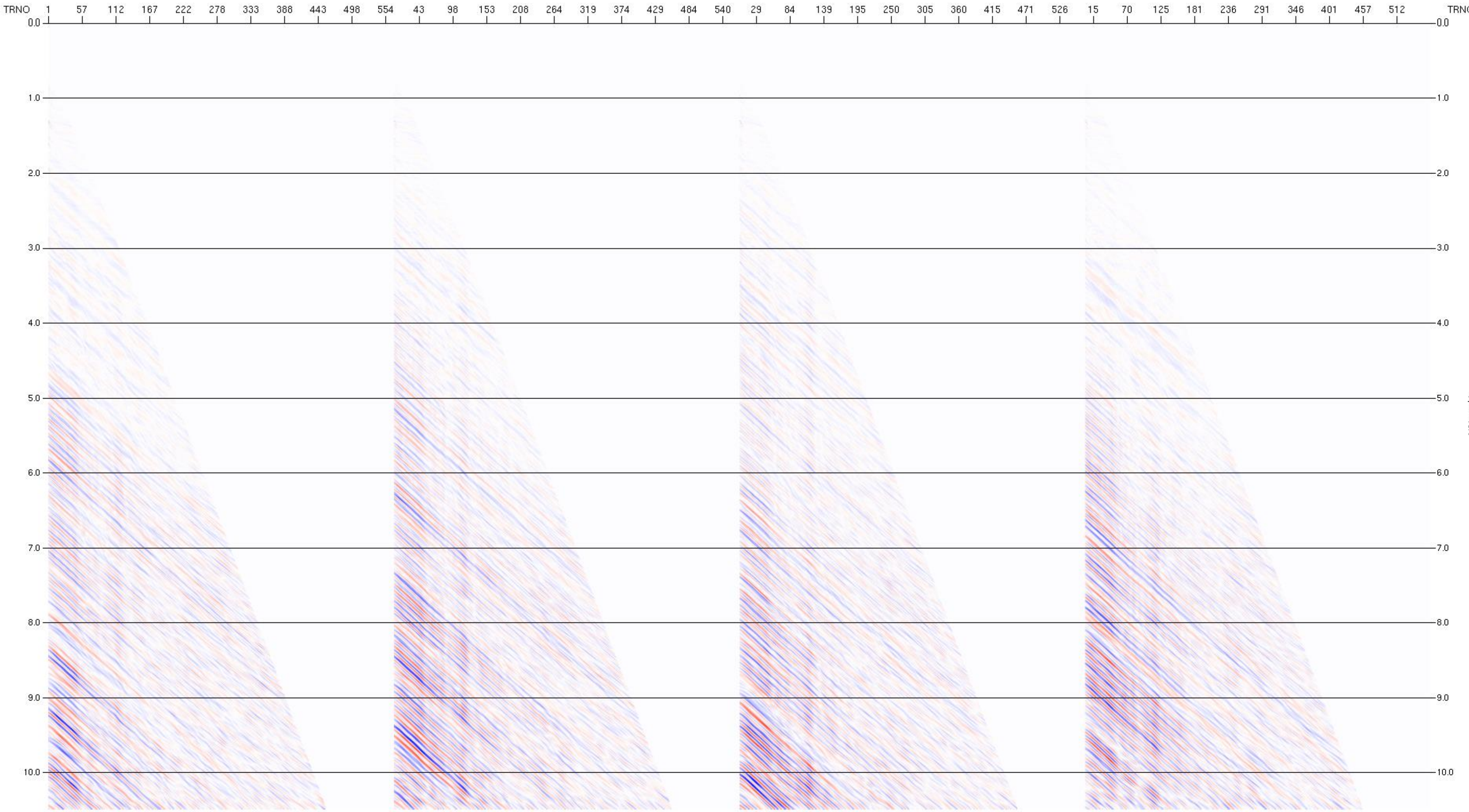


TRNO
1 57 112 167 222 278 333 388 443 498 554 43 98 153 208 264 319 374 429 484 540 29 84 139 195 250 305 360 415 471 526 15 70 125 181 236 291 346 401 457 512
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0

Shot : After linear noise attenuation

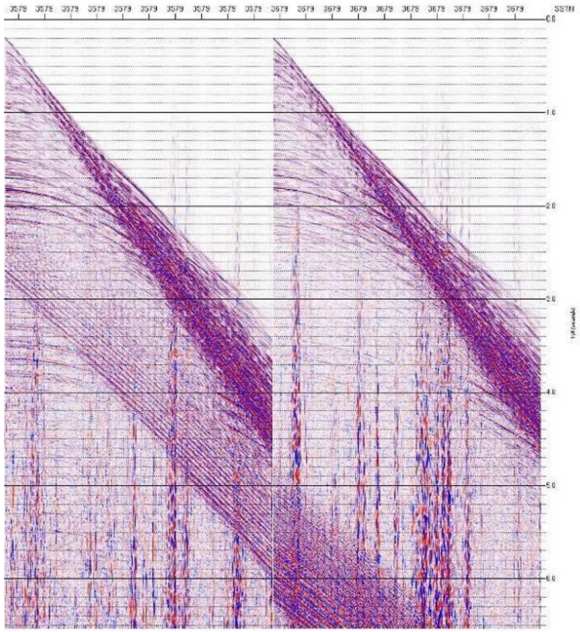


Difference : Input – after linear noise attenuation



Case 3: In-house workflow

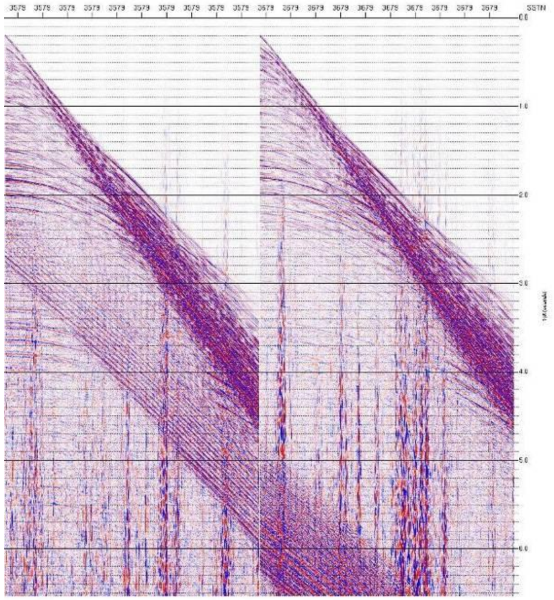
- Strong SI + some swell-noise.
- SI comes from the front.
- SI is visible on all shots.



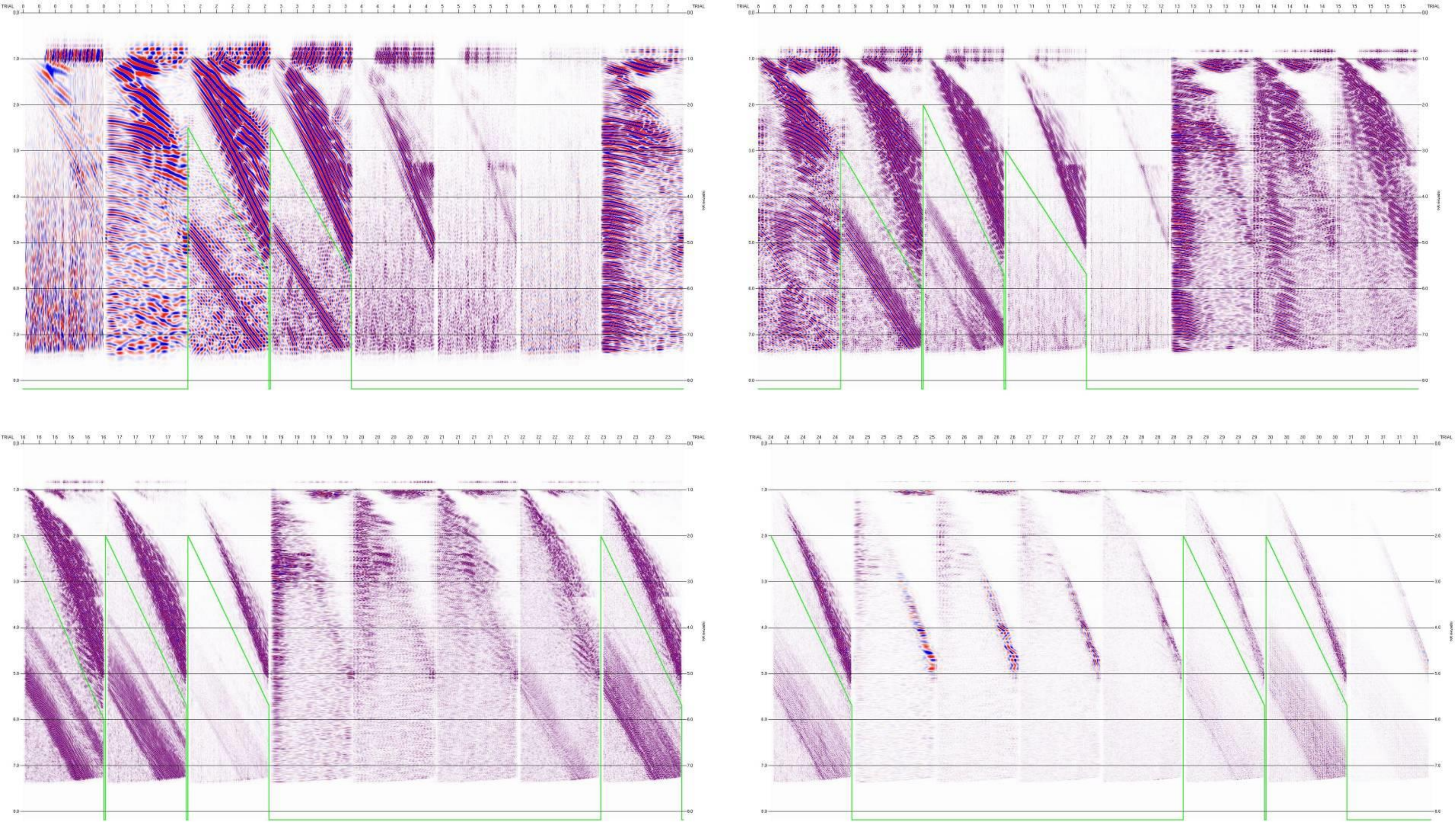
Example shot gathers

Parameters : Seismic Interference removal

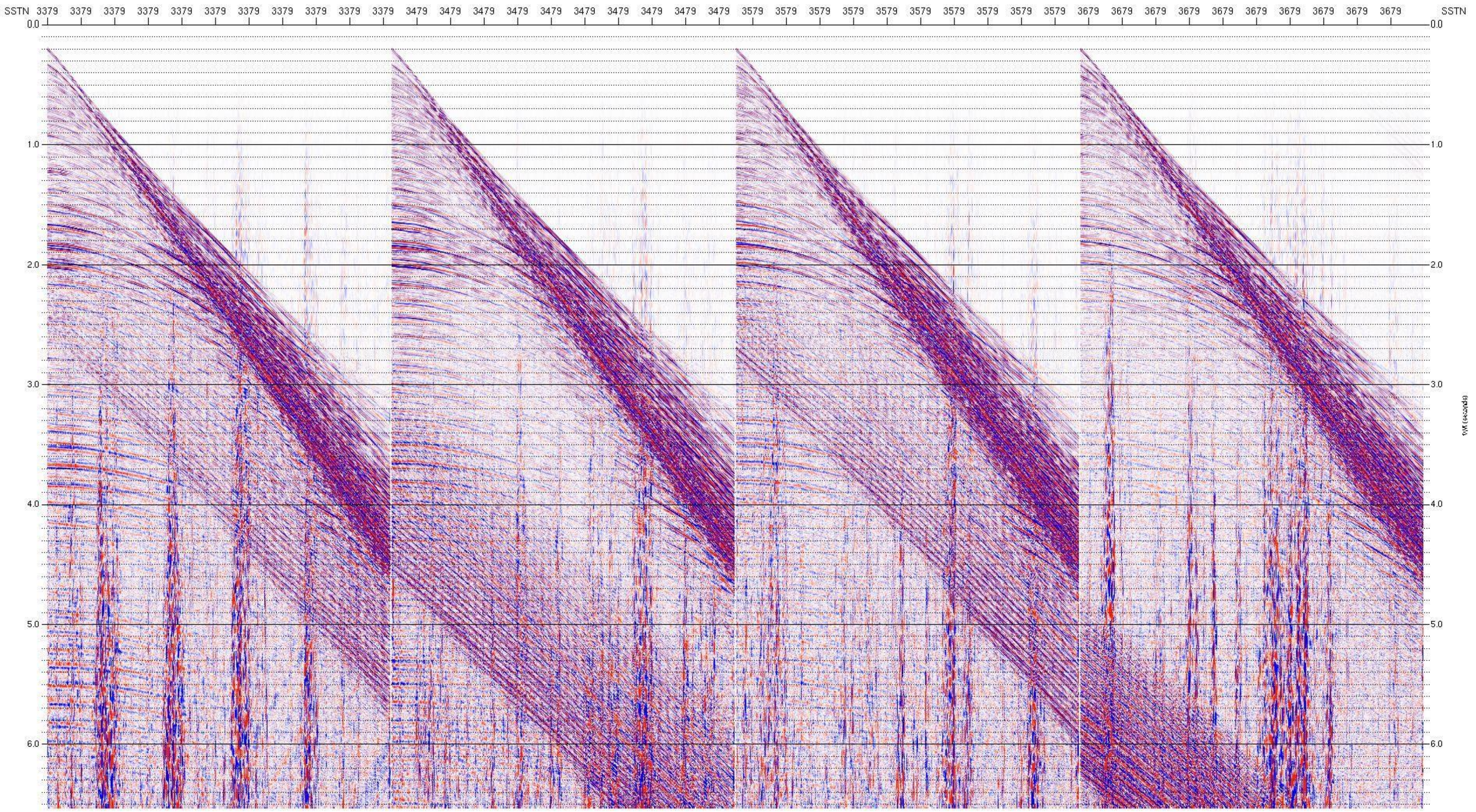
- 1. Mild swell-noise attenuation in CO-domain using statistical denoising.
- 2. Make a model of the SI from the data using a Stationary Wavelet transform:
  - Transform to wavelet domain
  - Mute the SI (examples will follow)
  - Transform data back to time-domain
  - Apply noise attenuation to improve the model of SI
  - Output SI model
- 3. Subtract the output model 2. from the Input data 1.
- 4. Output shot with SI removed.
- 5. Additional swell-noise/SI attenuation.



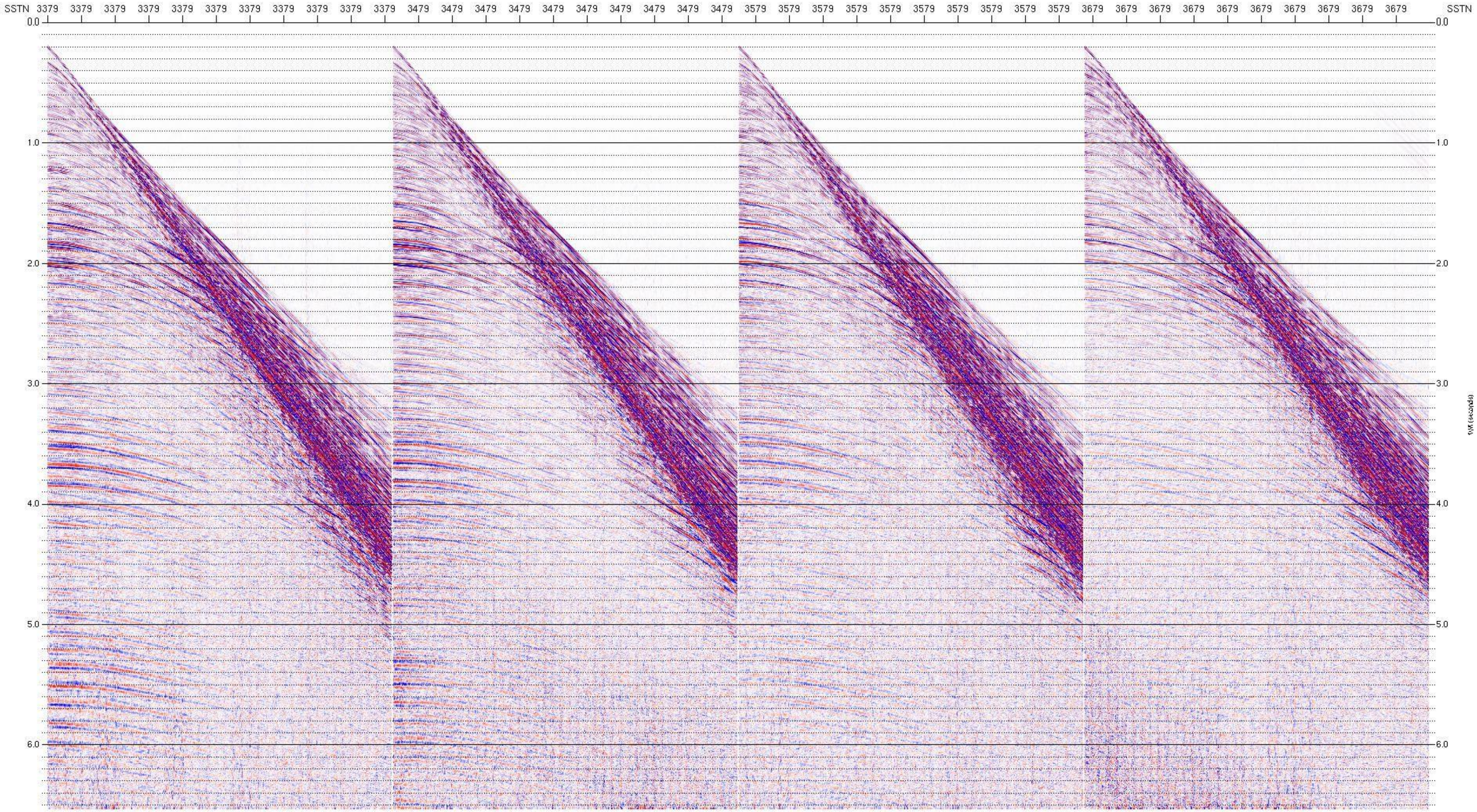
Wavelet Transform : Panels 1 - 31



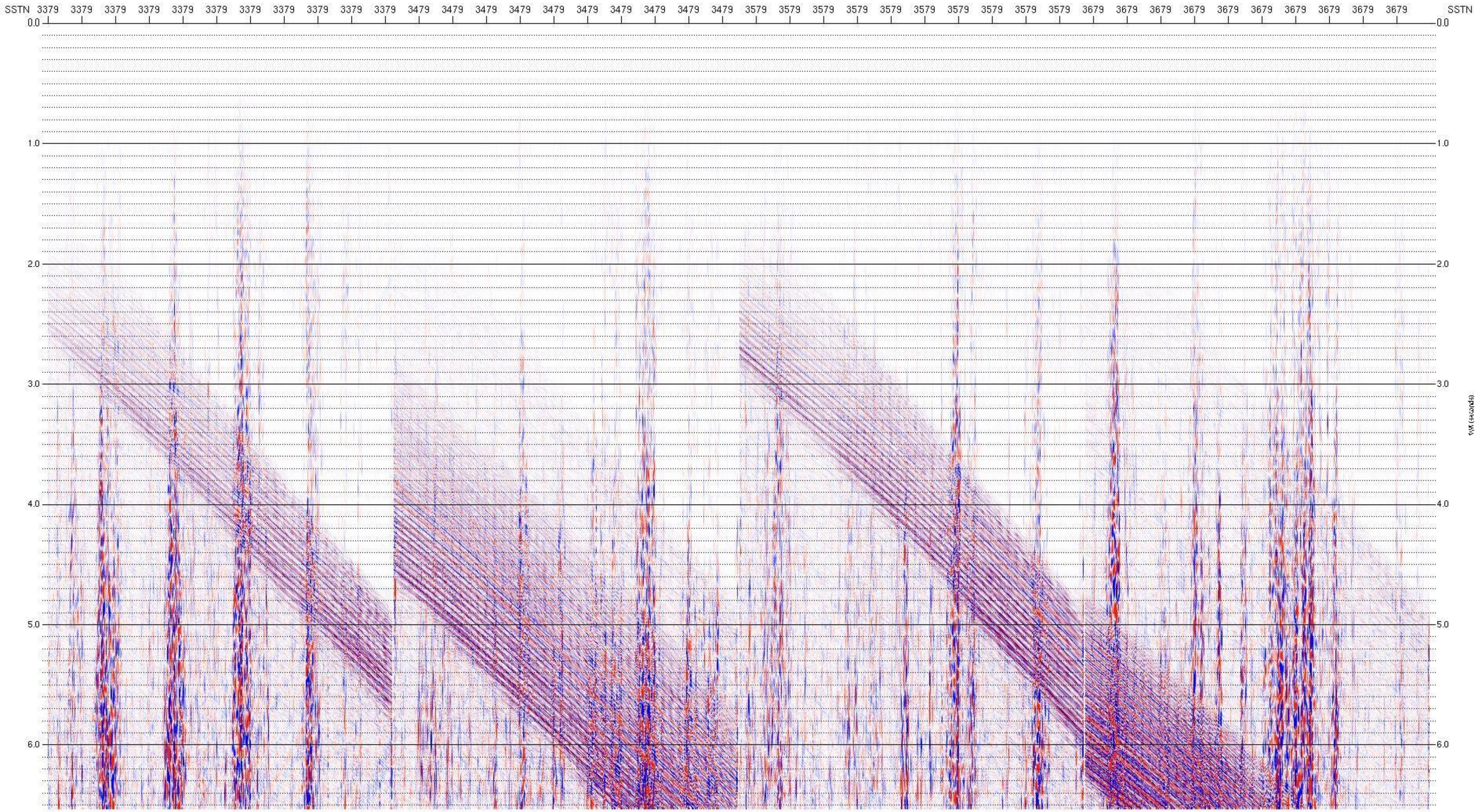
1. Shots : Input



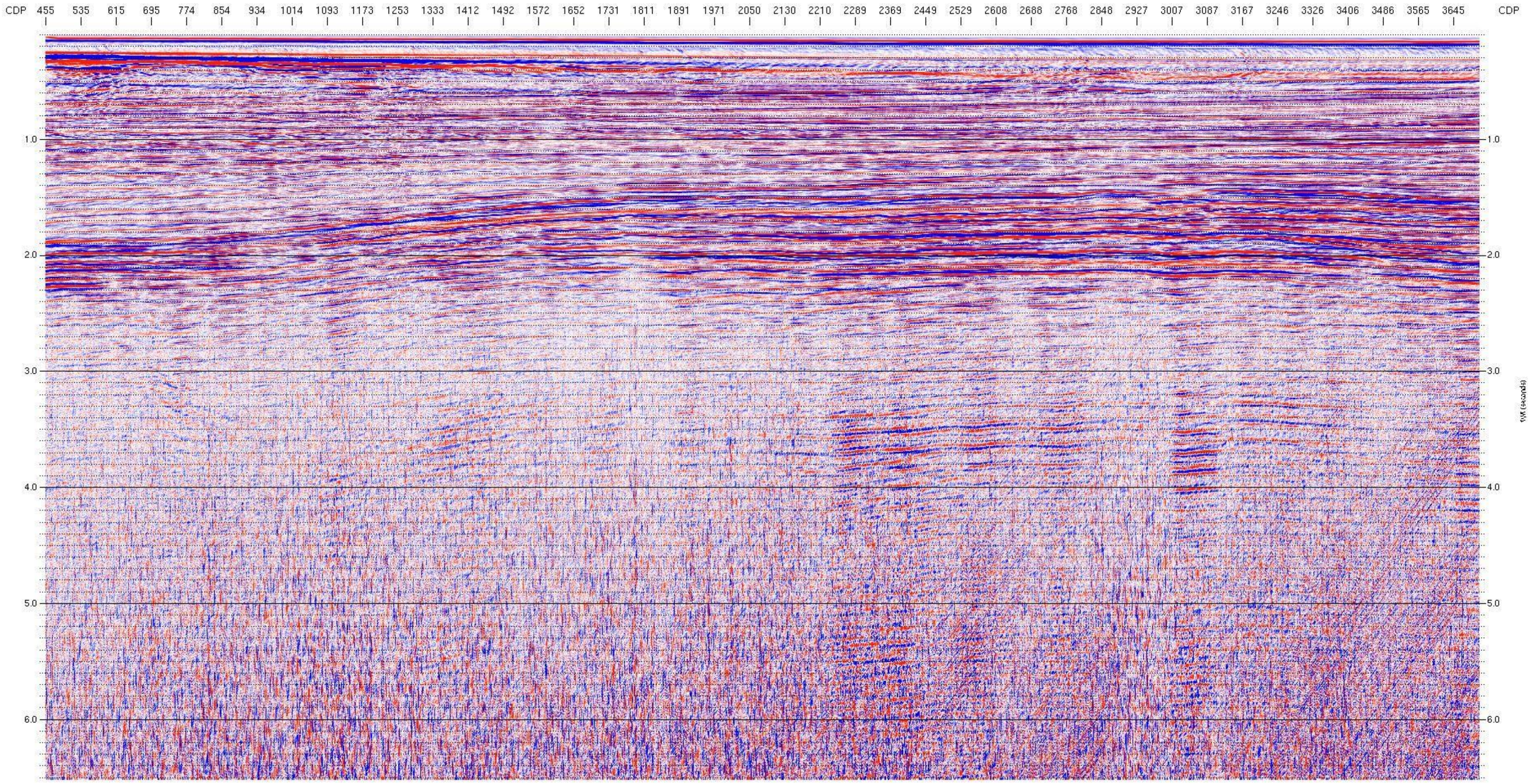
After final noise attenuation



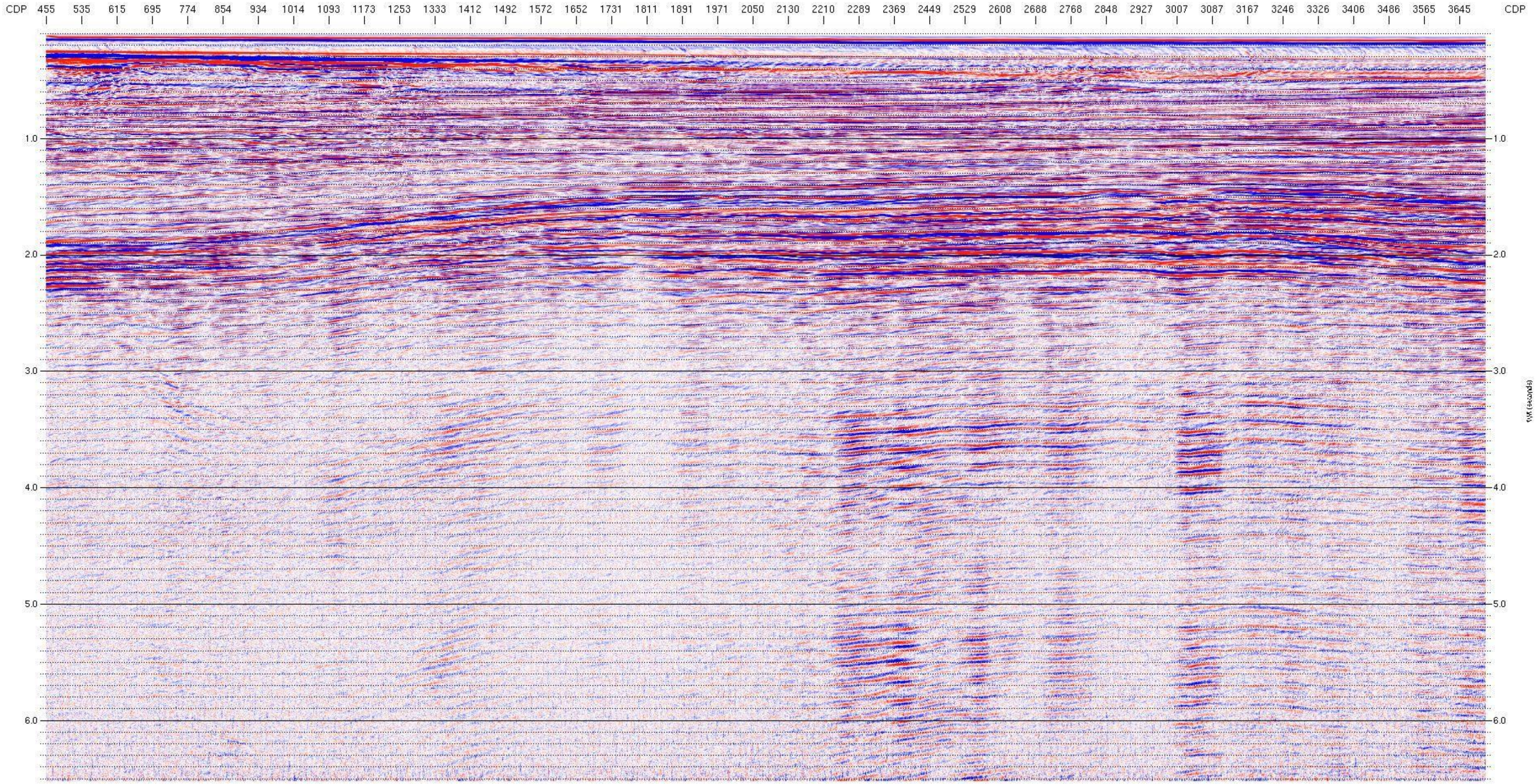
Difference



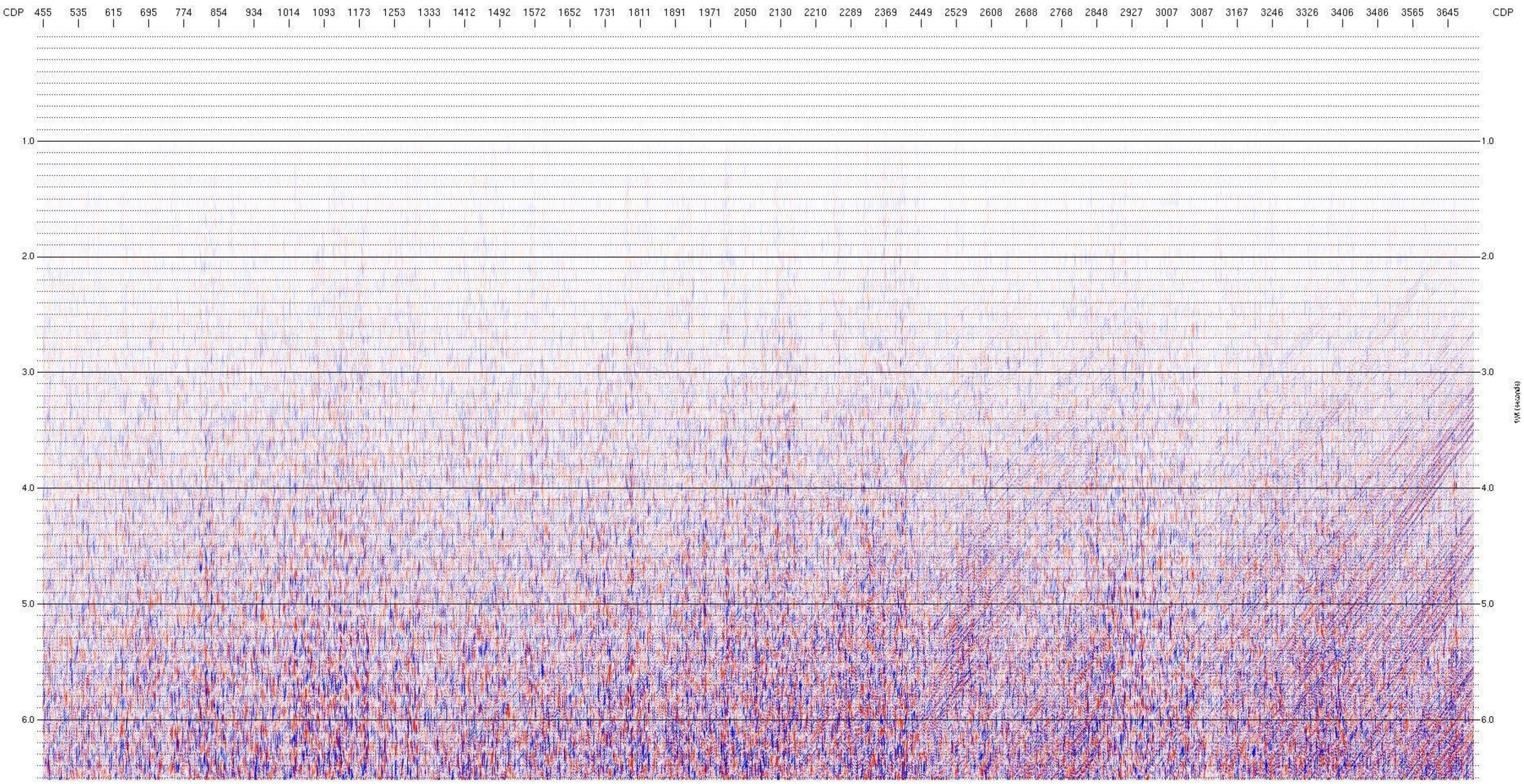
Stack : Input


CDP
455
535
615
695
774
854
934
1014
1093
1173
1253
1333
1412
1492
1572
1652
1731
1811
1891
1971
2050
2130
2210
2289
2369
2449
2529
2608
2688
2768
2848
2927
3007
3087
3167
3246
3326
3406
3486
3565
3645
CDP
1.0
2.0
3.0
4.0
5.0
6.0

Stack : After final noise attenuation



Difference

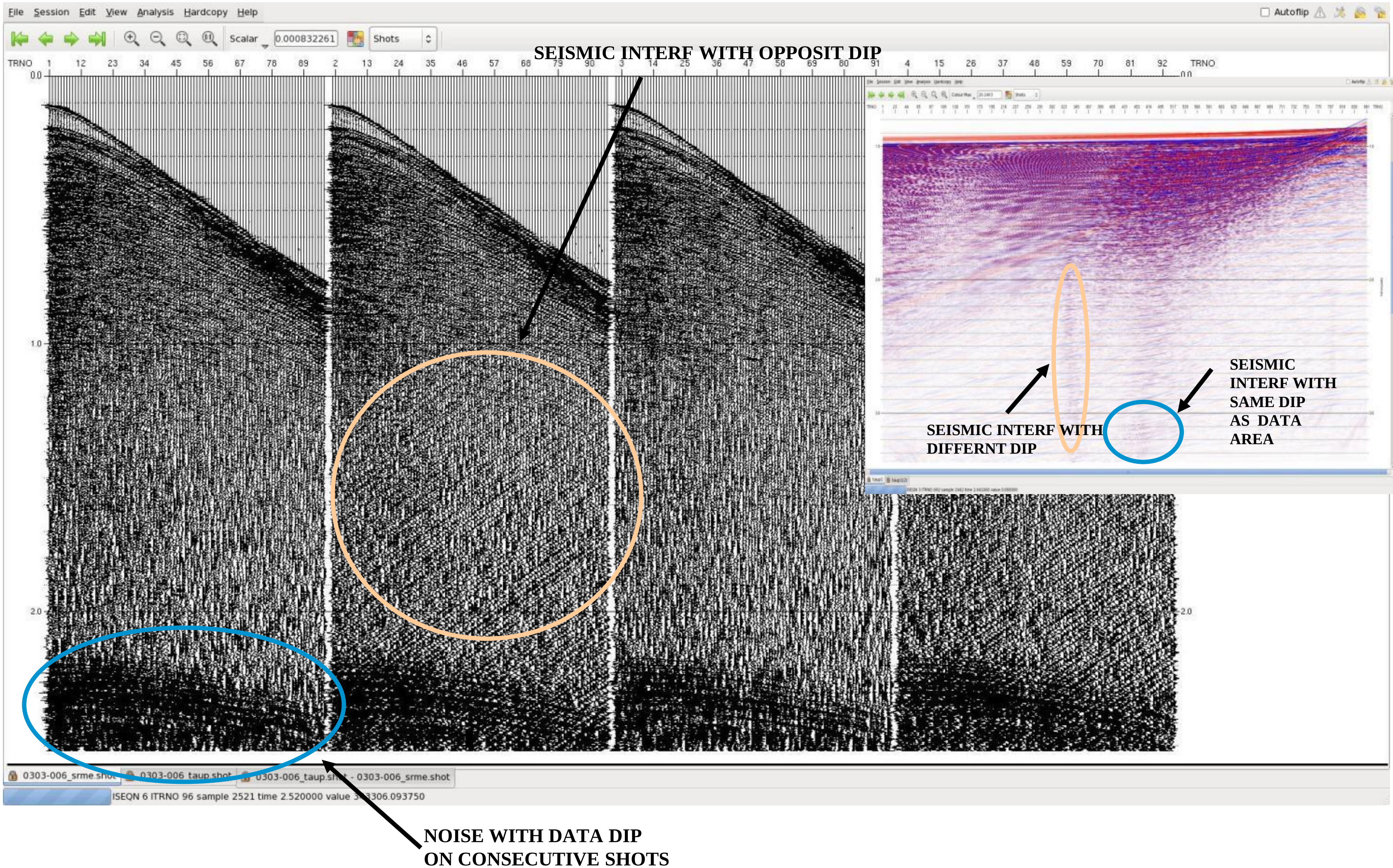

CDP
455 535 615 695 774 854 934 1014 1093 1173 1253 1333 1412 1492 1572 1652 1731 1811 1891 1971 2050 2130 2210 2289 2369 2449 2529 2608 2688 2768 2848 2927 3007 3087 3167 3246 3326 3406 3486 3565 3645
CDP
1.0
2.0
3.0
4.0
5.0
6.0

Case 4: Site-survey data

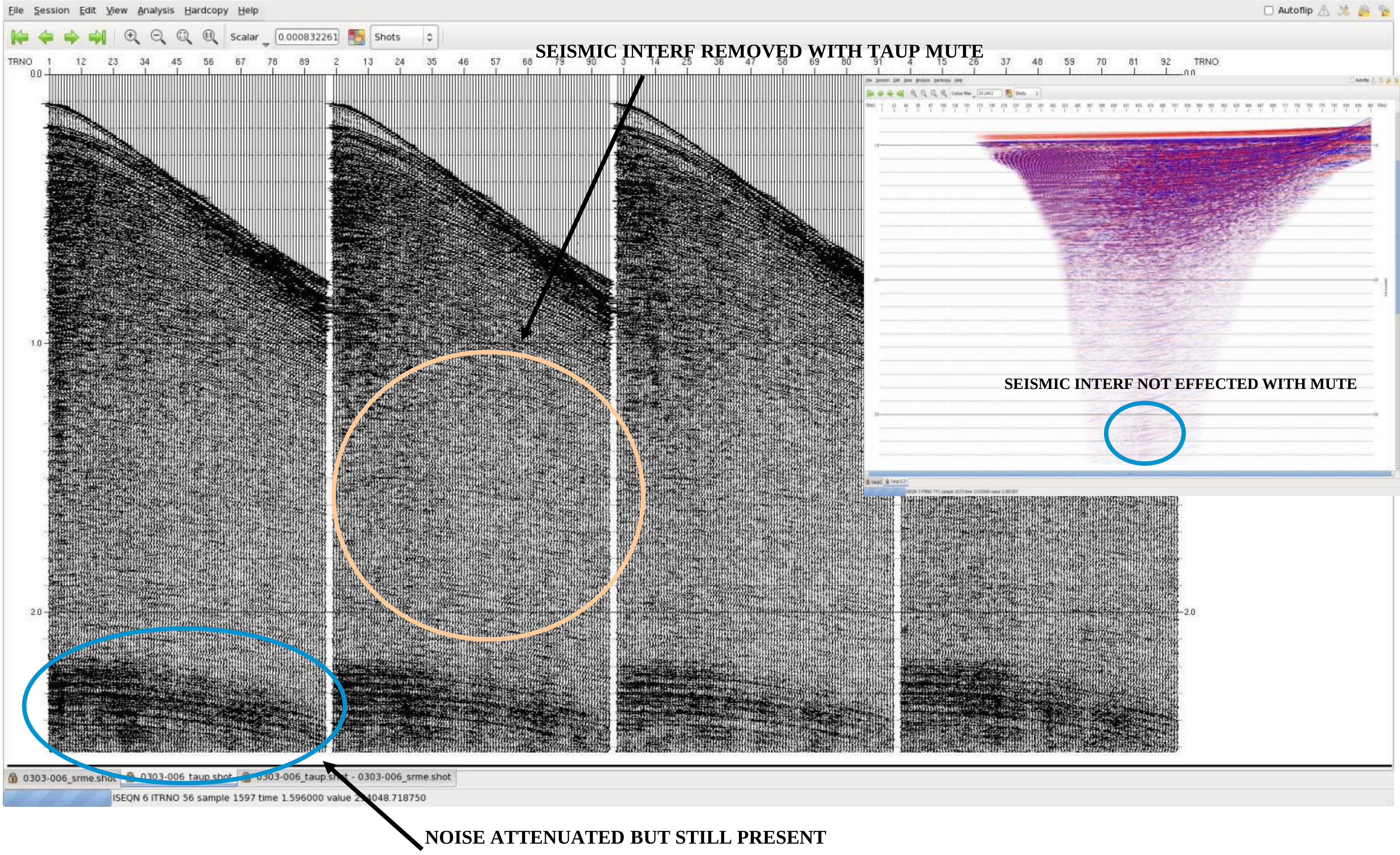
- Examples from site-survey processing in the North Sea and the Barents Sea.

- The flows are based on combining Tau-p muting and statistical denoising.

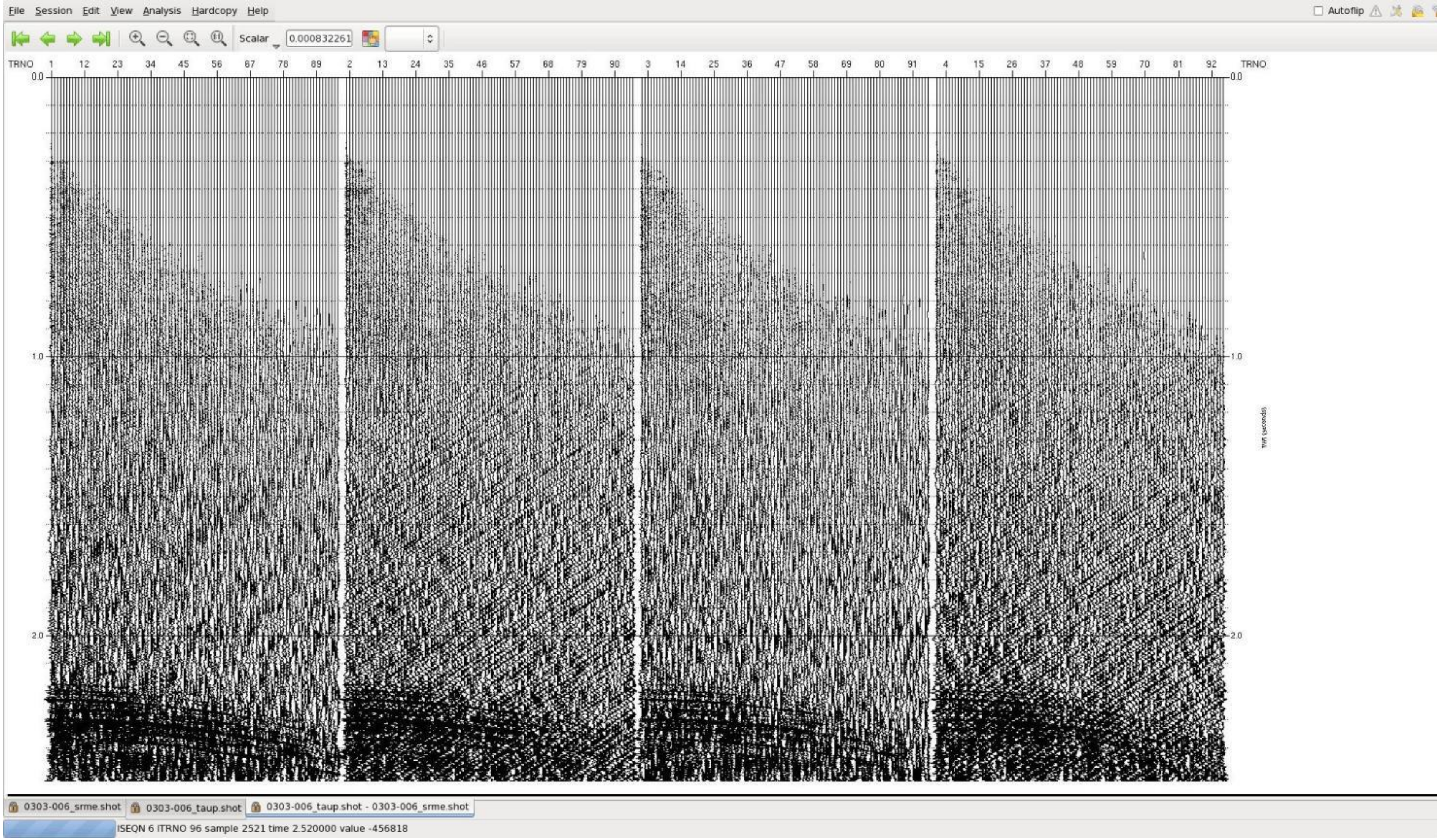
Shot gathers



TAUP SHOT

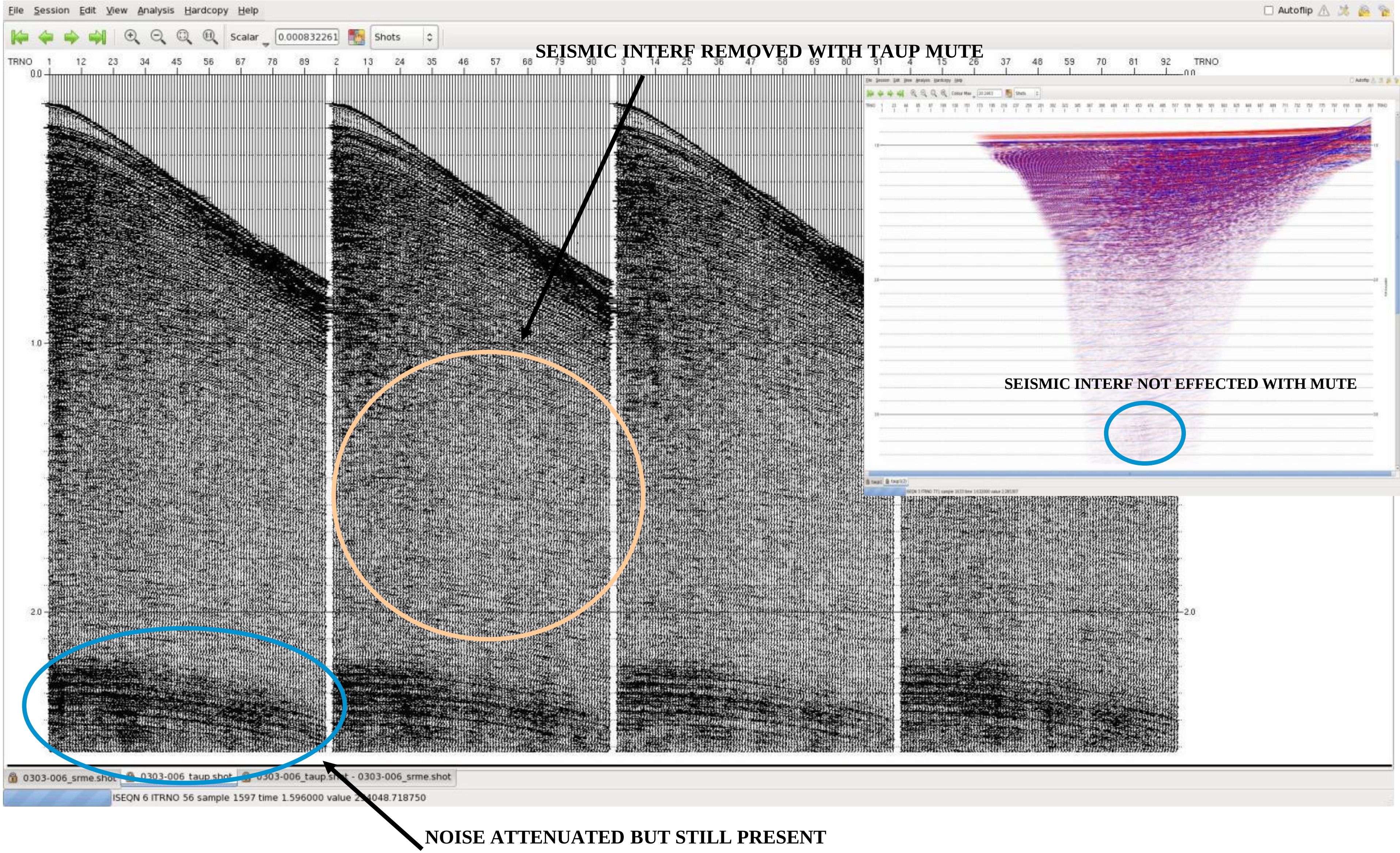

SEISMIC INTERF REMOVED WITH TAUP MUTE
SEISMIC INTERF NOT EFFECTED WITH MUTE
NOISE ATTENUATED BUT STILL PRESENT
File Session Edit View Analysis Hardcopy Help
Scalar
0.000832261
Shots
Autoflip
TRNO
0303-006_srme.shot
0303-006_taup.shot
0303-006_taup.shot - 0303-006_srme.shot
ISEQN 6 ITRNO 56 sample 1597 time 1.596000 value 2.4048.718750

DIFFERENCE

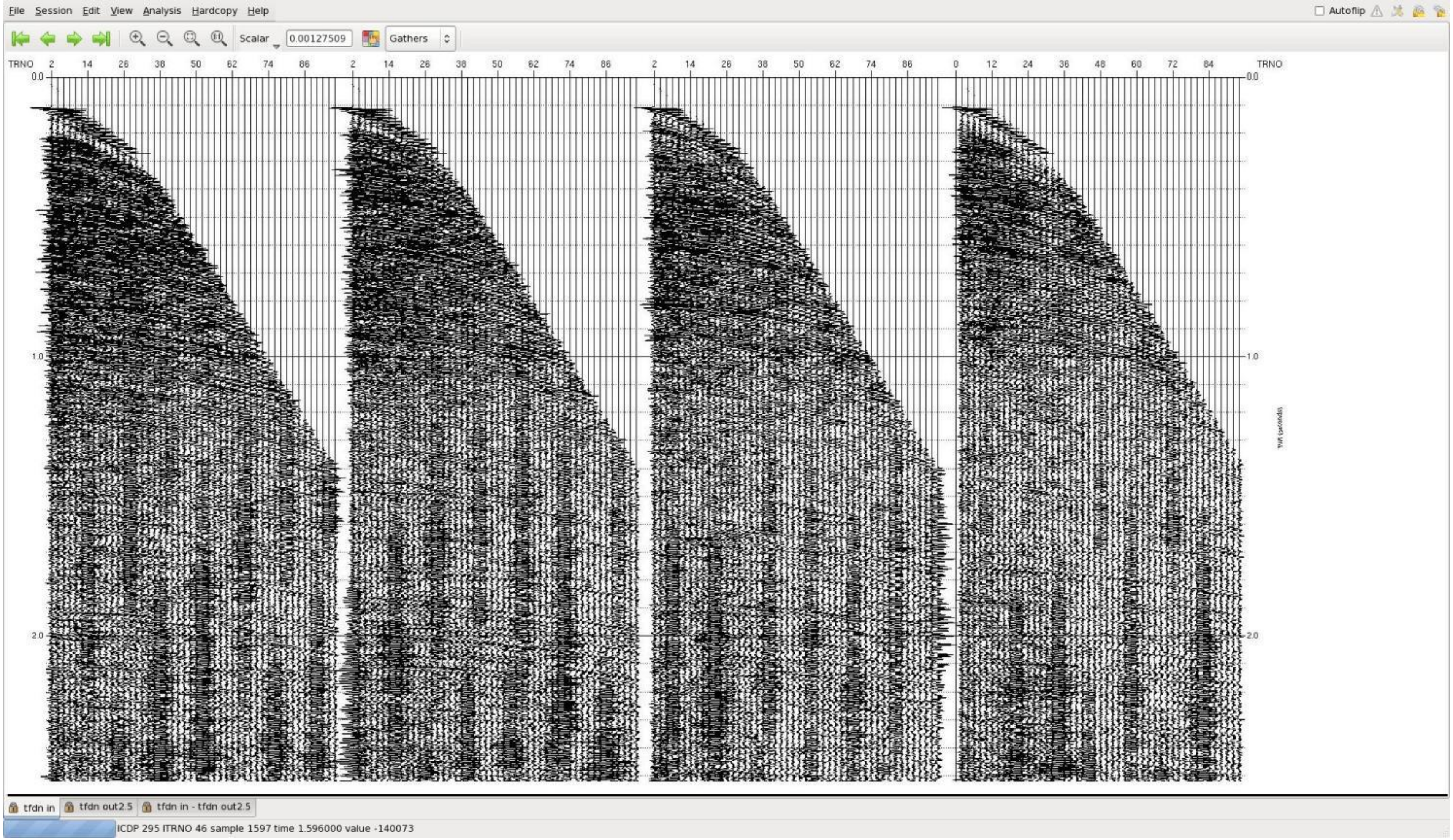


File Session Edit View Analysis Hardcopy Help
Autoflip
Scalar
0.000832261
TRNO 1 12 23 34 45 56 67 78 89 2 13 24 35 46 57 68 79 90 3 14 25 36 47 58 69 80 91 4 15 26 37 48 59 70 81 92 TRNO
0.0
1.0
2.0
0303-006_srme.shot
0303-006_taup.shot
0303-006_taup.shot - 0303-006_srme.shot
ISEQN 6 ITRNO 96 sample 2521 time 2.520000 value -456818

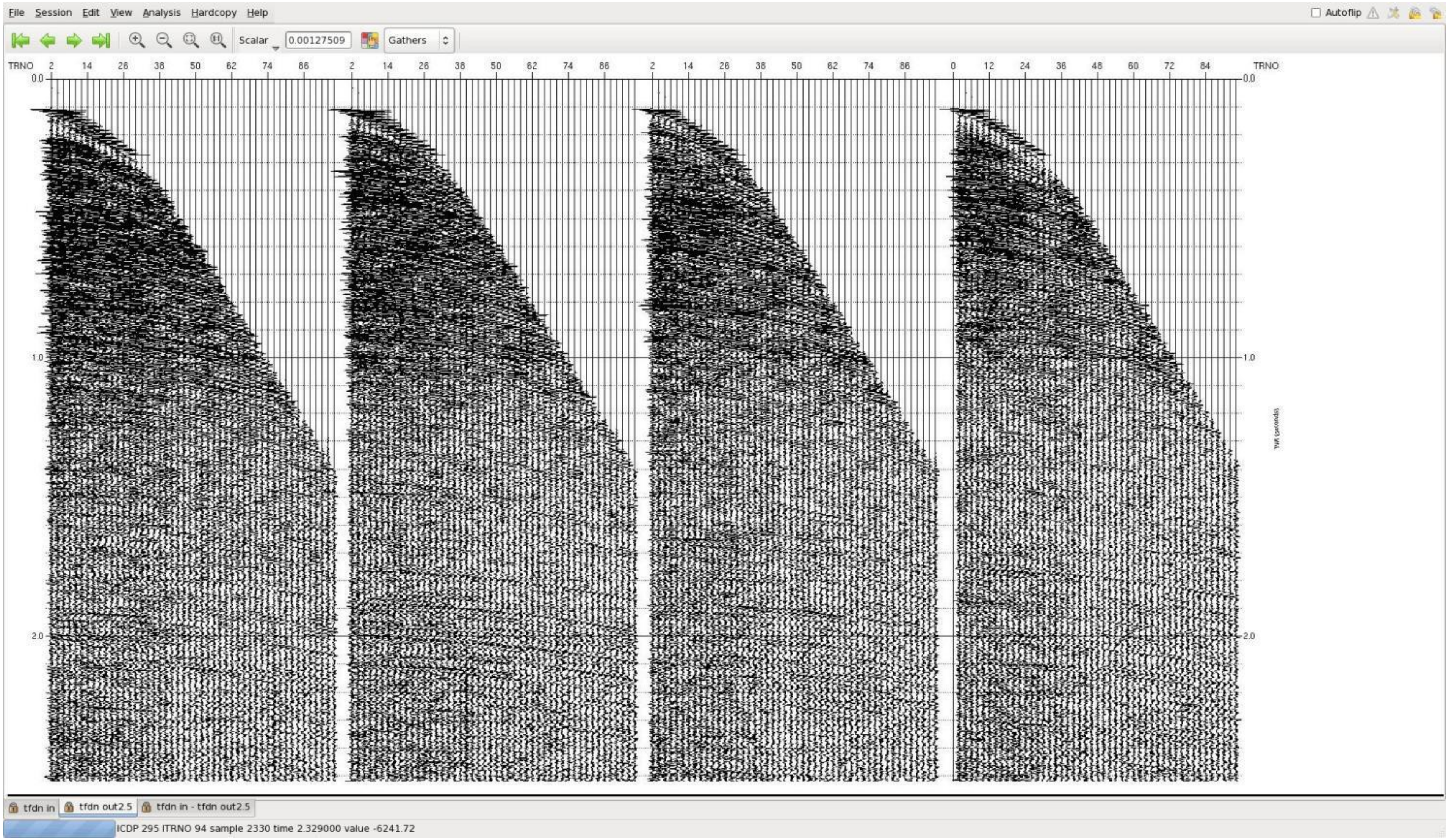
TAUP SHOT


SEISMIC INTERF REMOVED WITH TAUP MUTE
SEISMIC INTERF NOT EFFECTED WITH MUTE
File Session Edit View Analysis Hardcopy Help
Autoflip
Scalar
0.000832261
Shots
TRNO
0303-006_srme.shot
0303-006_taup.shot
0303-006_taup.shot - 0303-006_srme.shot
ISEQN 6 ITRNO 56 sample 1597 time 1.596000 value 2?4048.718750
NOISE ATTENUATED BUT STILL PRESENT

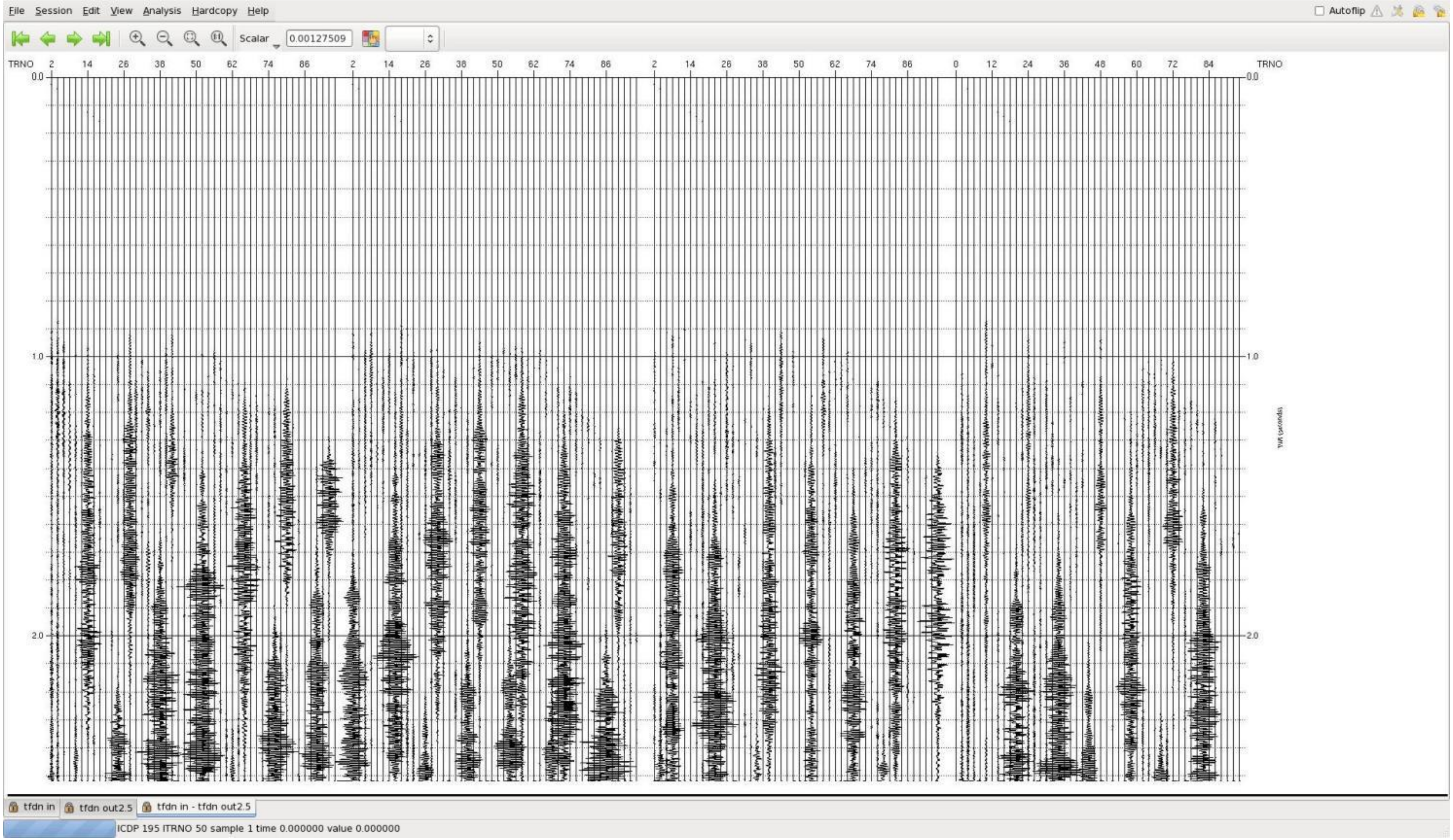
CDP's after Tau-p mute



CDP's after TFDN



Difference


File Session Edit View Analysis Hardcopy Help
Autoflip
Scalar 0.00127509
TRNO 2 14 26 38 50 62 74 86 2 14 26 38 50 62 74 86 2 14 26 38 50 62 74 86 0 12 24 36 48 60 72 84 TRNO
0.0
1.0
2.0
tfdn in
tfdn out2.5
tfdn in - tfdn out2.5
ICDP 195 ITRNO 50 sample 1 time 0.000000 value 0.000000

A new algorithm

Transform the DATA into a domain where we can separate the NOISE from the SIGNAL

↓

In this new domain, remove the NOISE

↓

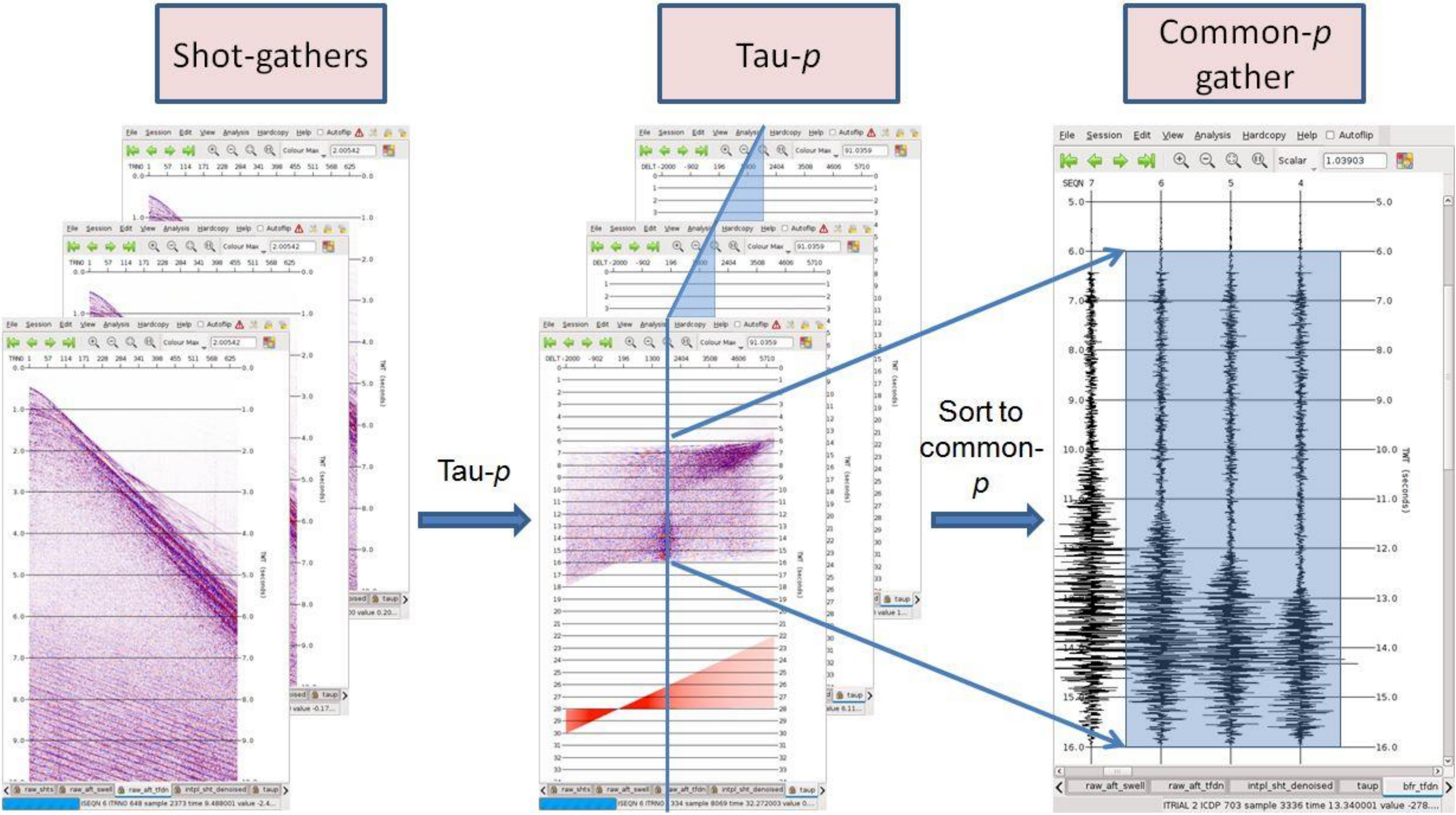
Transform the de-noised DATA back to the time-domain

1. Tau-p transform
2. Statistical denoising

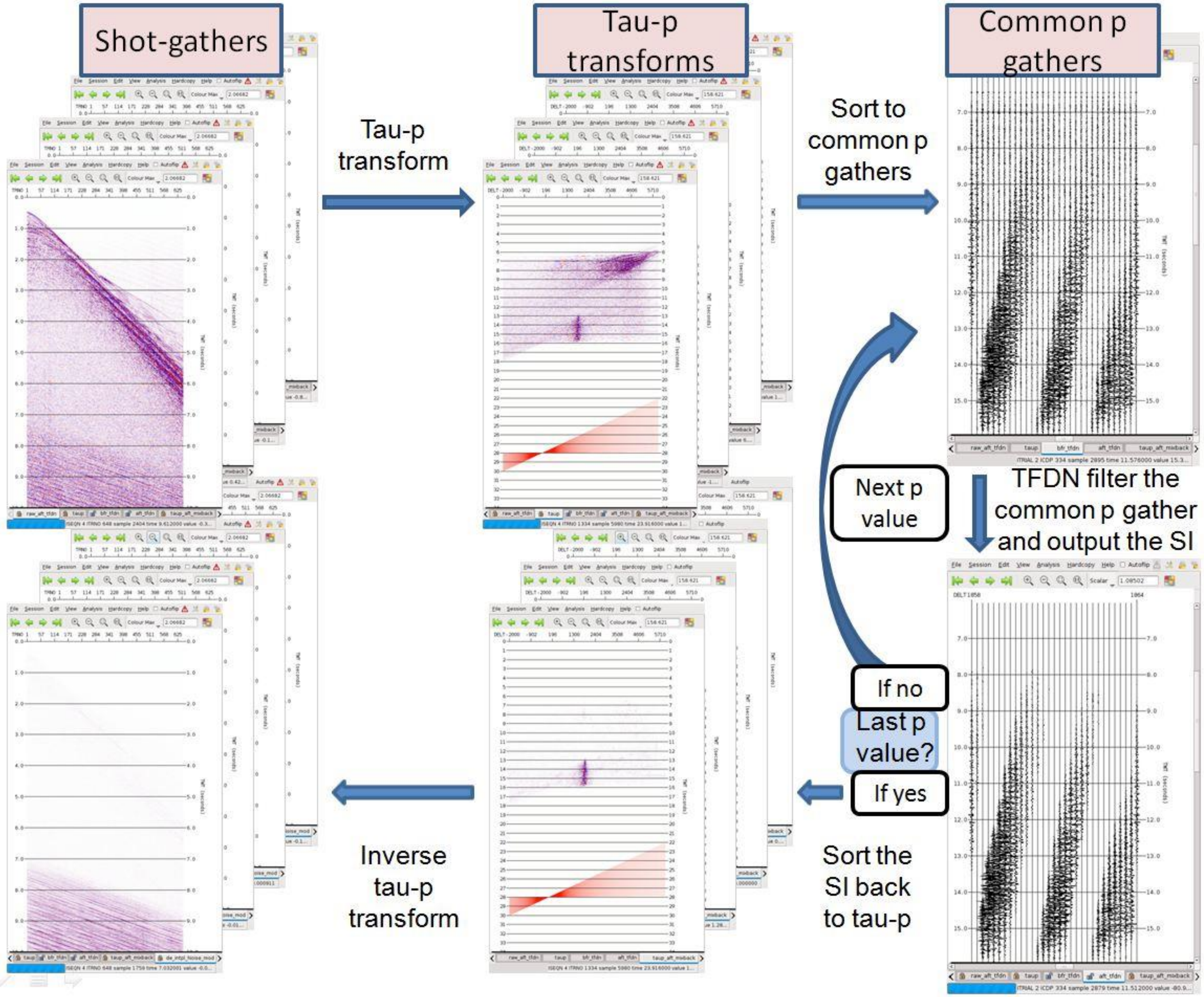
Combinations of the algorithms above + sorting to make the SI random. (Elboth et.al. EAGE 2009)

Getting the best of both worlds!

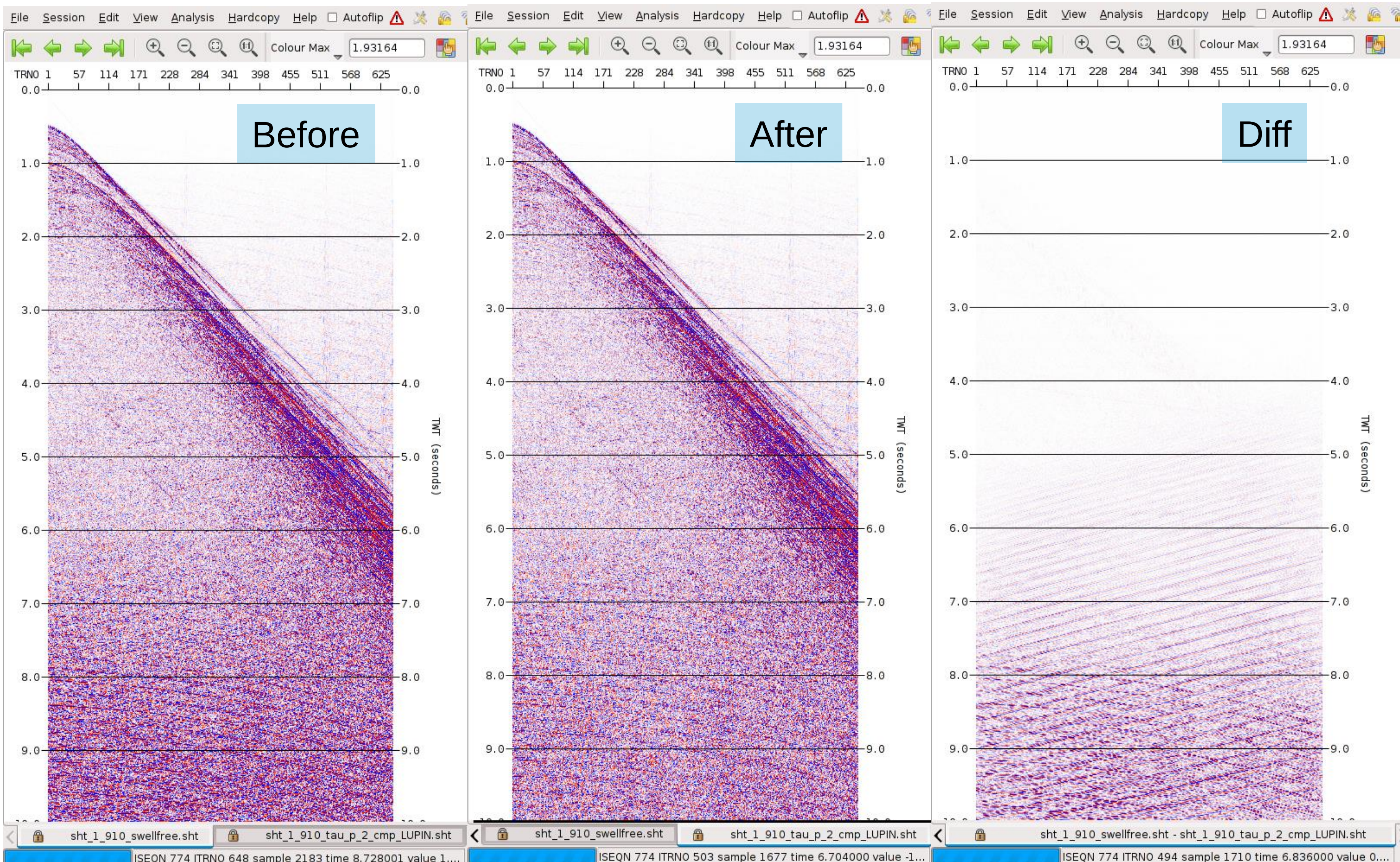
An ‘advanced’ SI removal algorithm I:



An ‘advanced’ SI removal algorithm II:



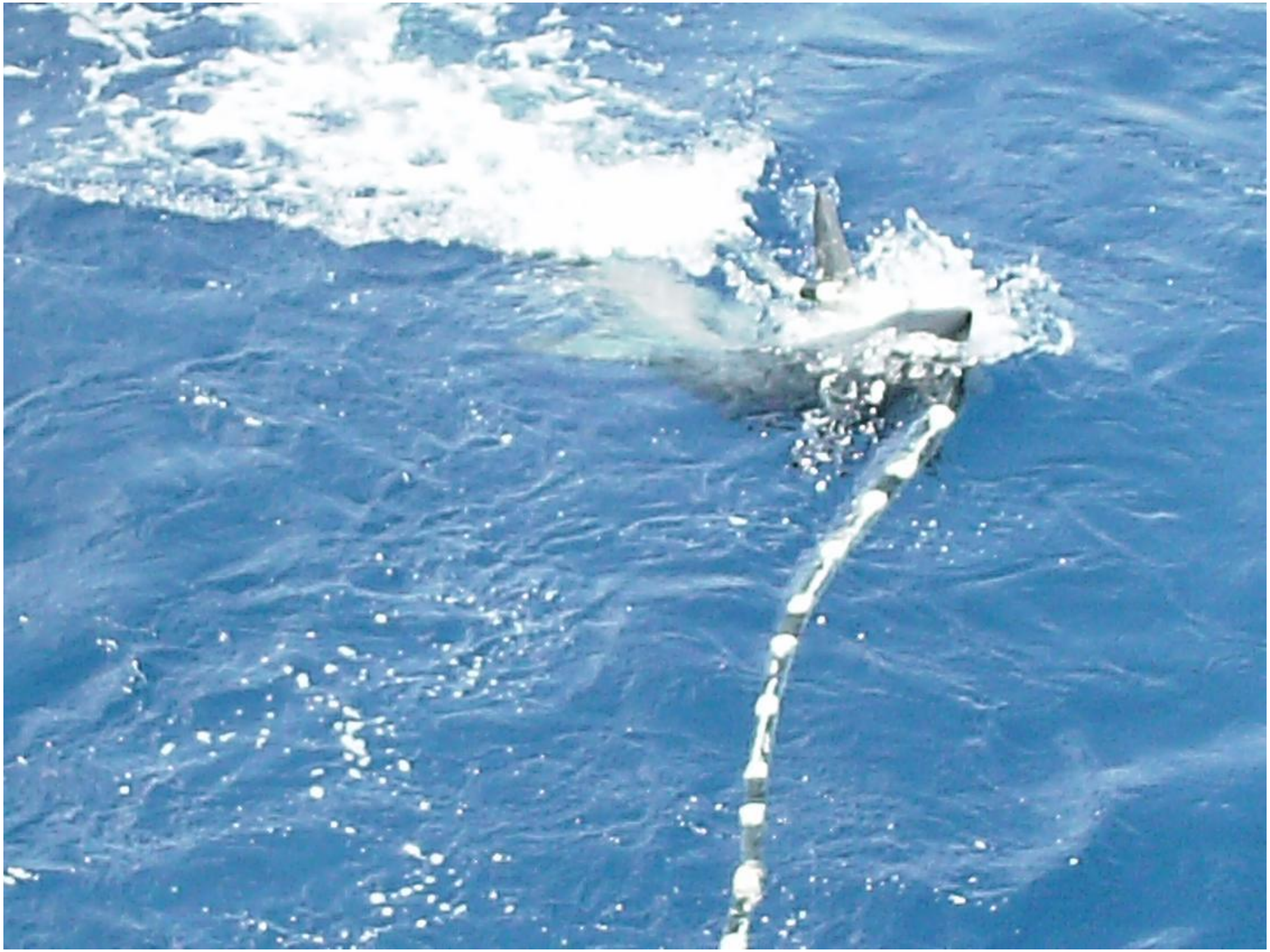
tau-p common p results



Summary

- Can we drop timesharing when we have SI?
- Answer: Yes!
- But, removing SI can sometimes be challenging, and some degradation in data quality can occur.
- We should still plan/coordinate surveys to minimize SI.

This type of ‘Interference Noise’ might be difficult to handle.



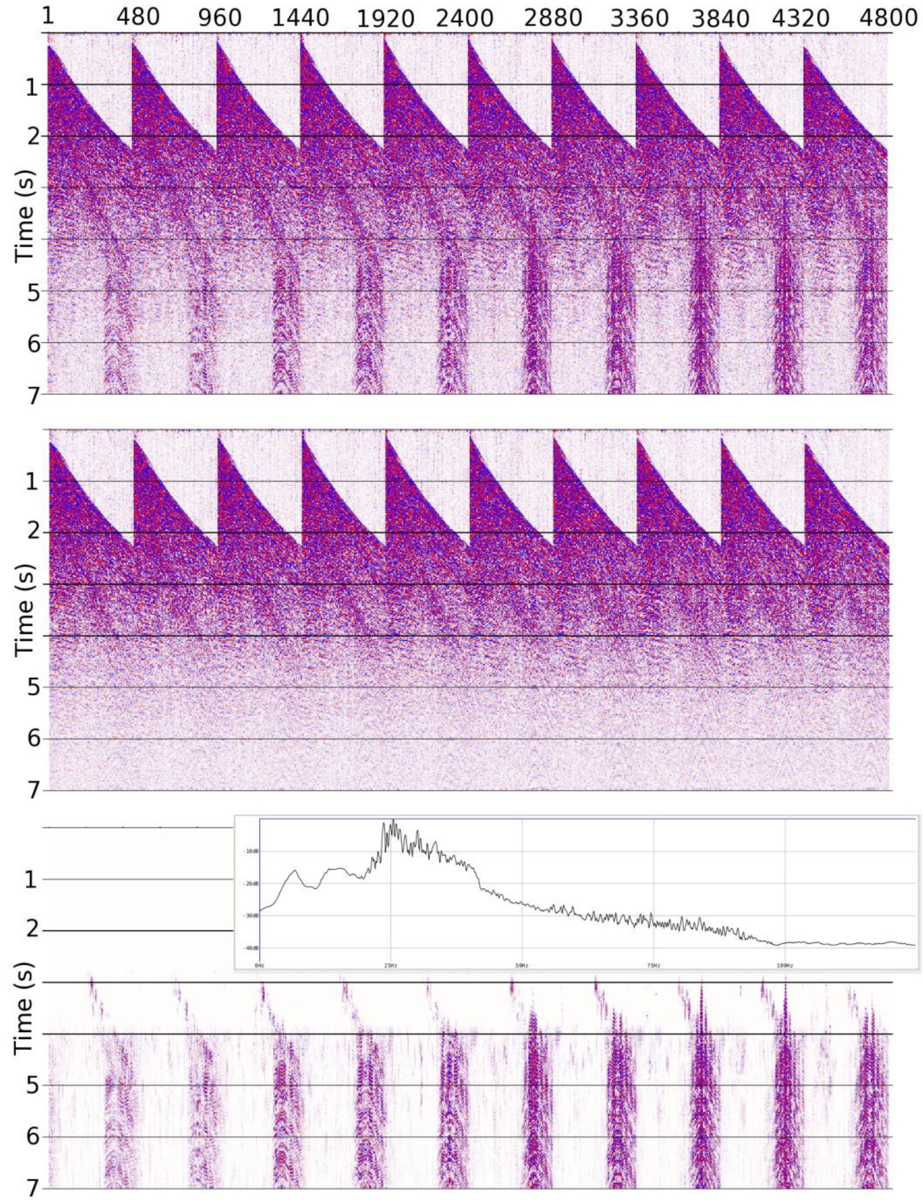
Some other types of noise

All parts of the recorded data that does not contain useful seismic information can be seen as noise! The most common types are:

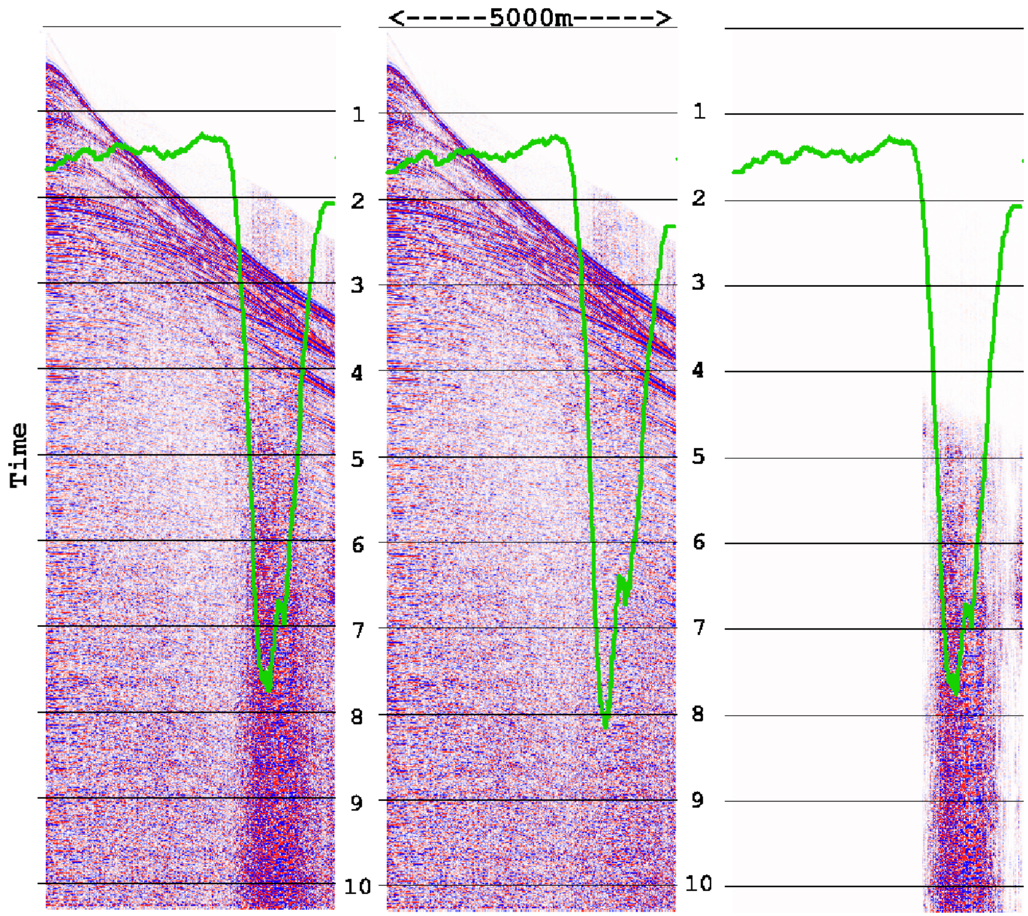
- Multiples (not a topic in this lecture).
- Hydrostatic pressure fluctuations.
- Swell-noise.
- Seismic interference noise.
- **Environmental...**

The topic of this lecture

Singing whale

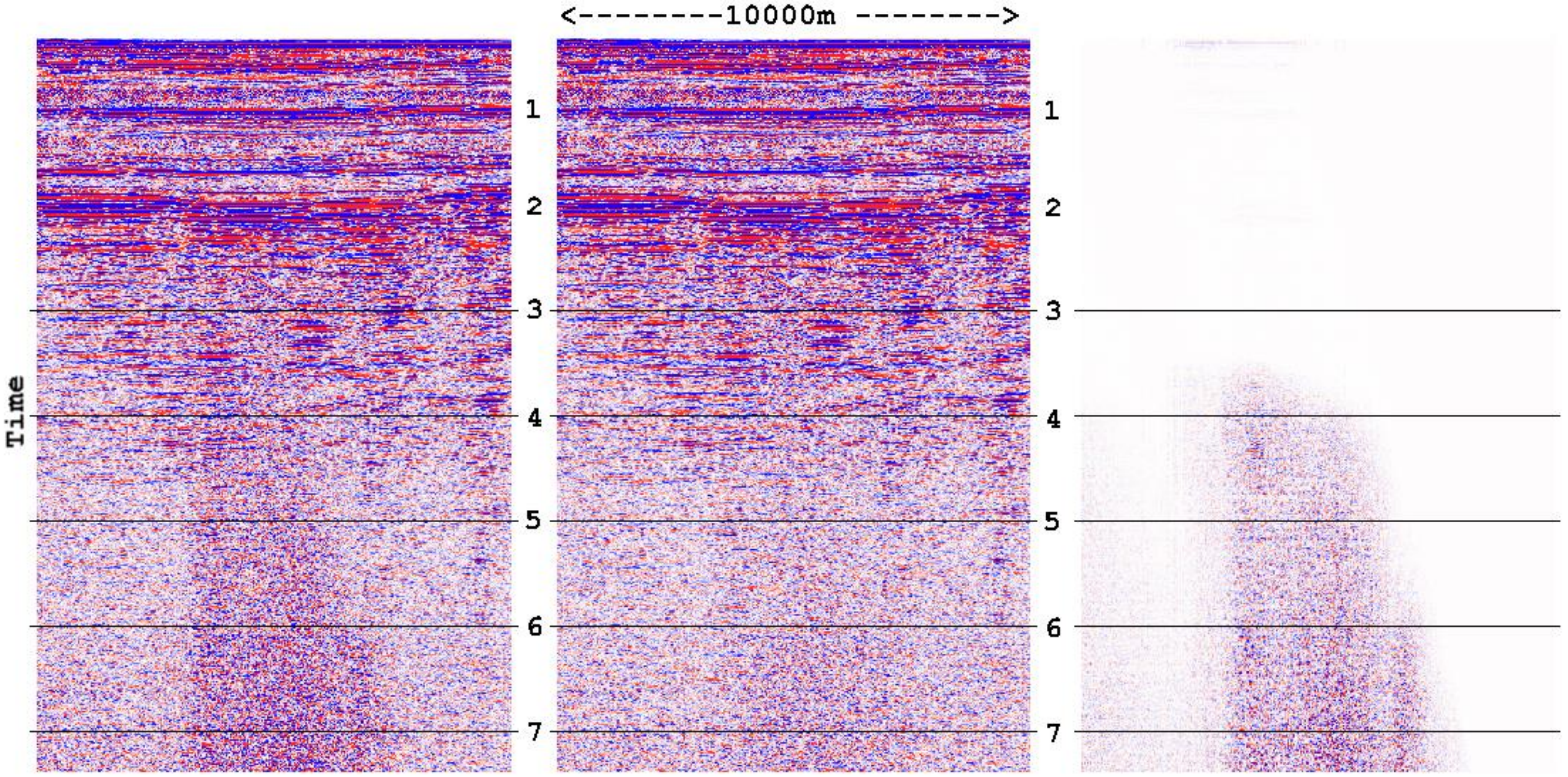


Rig noise on CDP gather

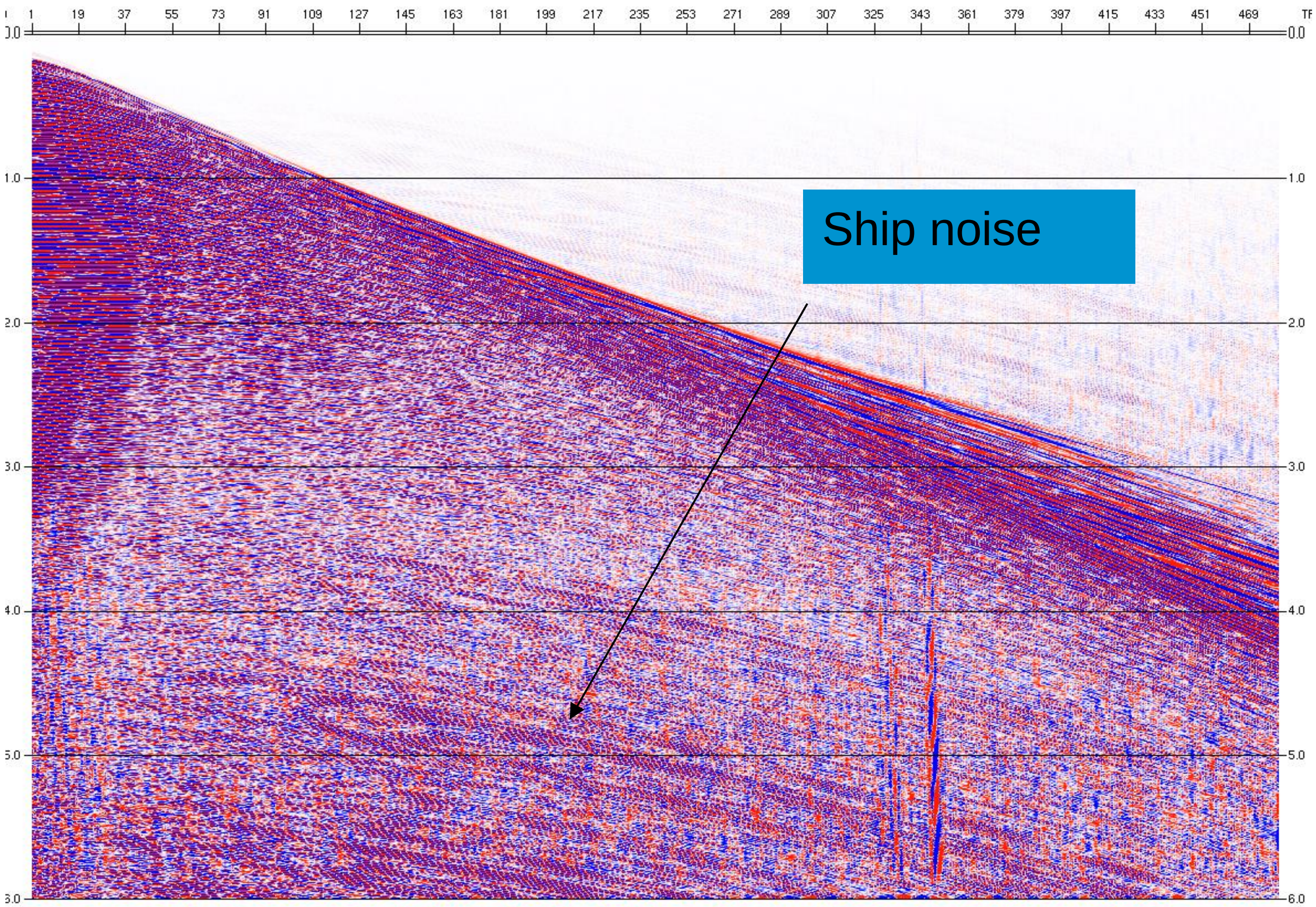


Q: Why does not stacking take care of the noise here?

Stack with rig-noise



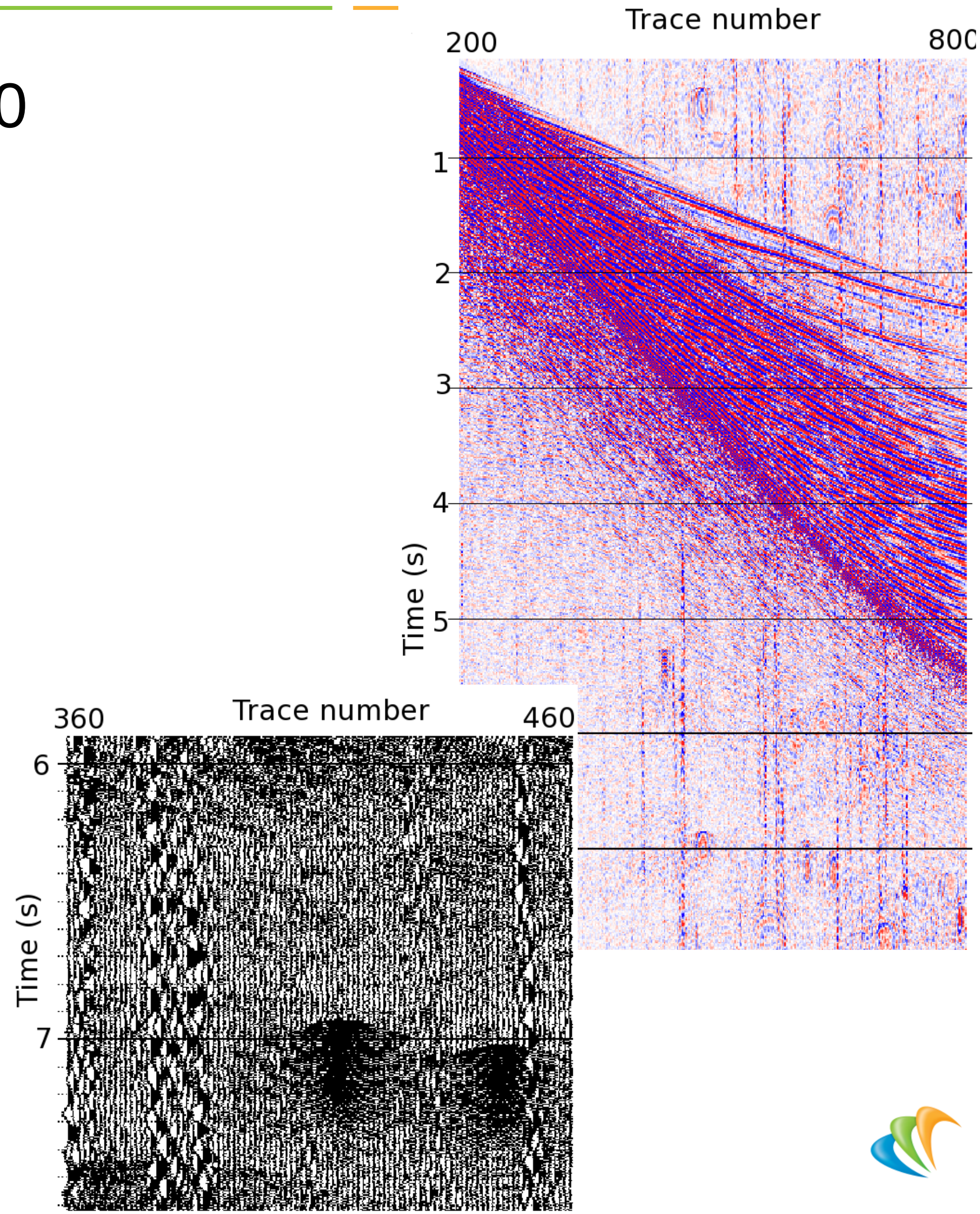
Ship noise



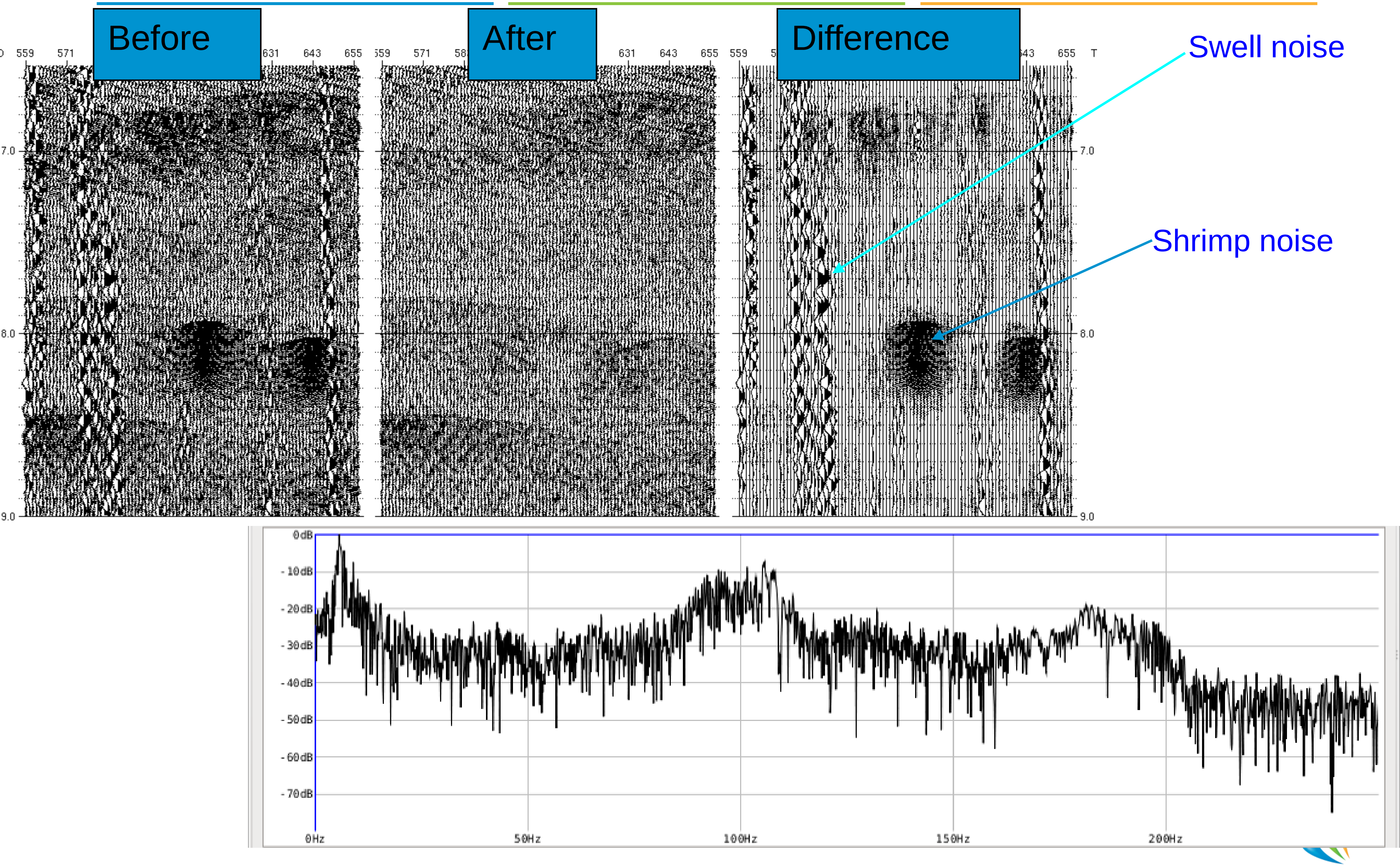
Q: Where is the vessel causing the noise?

Snapping schrimps

- Recorded in GoM in 2010
- Broad-banded ‘random’ noise bursts
- Shallow and warm water phenomena



Denoising + Spectra of difference plot



How is the noise made

- Snapping shrimp have asymmetrical claws, the larger of which is typically capable of producing a loud snapping sound.

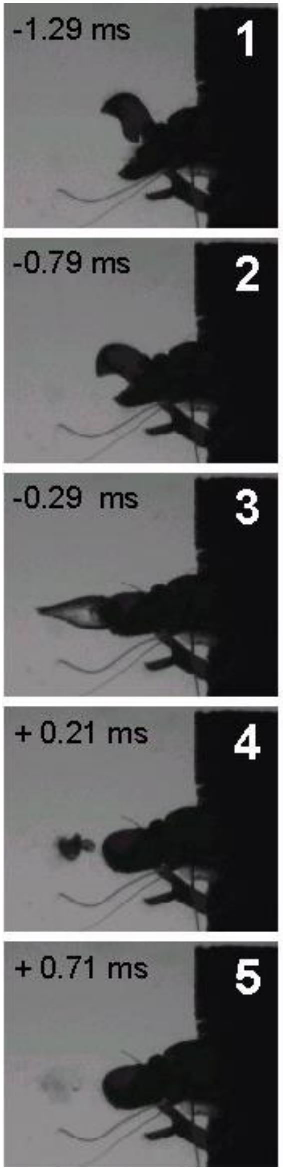
- The shrimps grows to 3–5 cm. The claw has a pistol-like feature made of two parts. A joint allows the "hammer" part to move backward into a right-angled position. When released, it snaps into the other part of the claw, emitting a cavitation bubbles capable of stunning fish.

Pistol shrimp (Alpheus distinguendus) is part of a family consisting of about 600 species within 38 or more genera.

Click here for a [movie](http://www.youtube.com/watch?v=ONQlTMUYCW4) about snapping shrimps

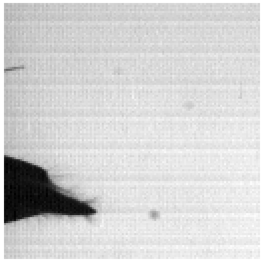
or follow this link: http://www.youtube.com/watch?v=ONQlTMUYCW4

Cavitation noise



- The sound originates from the collapse of a cavitation bubble

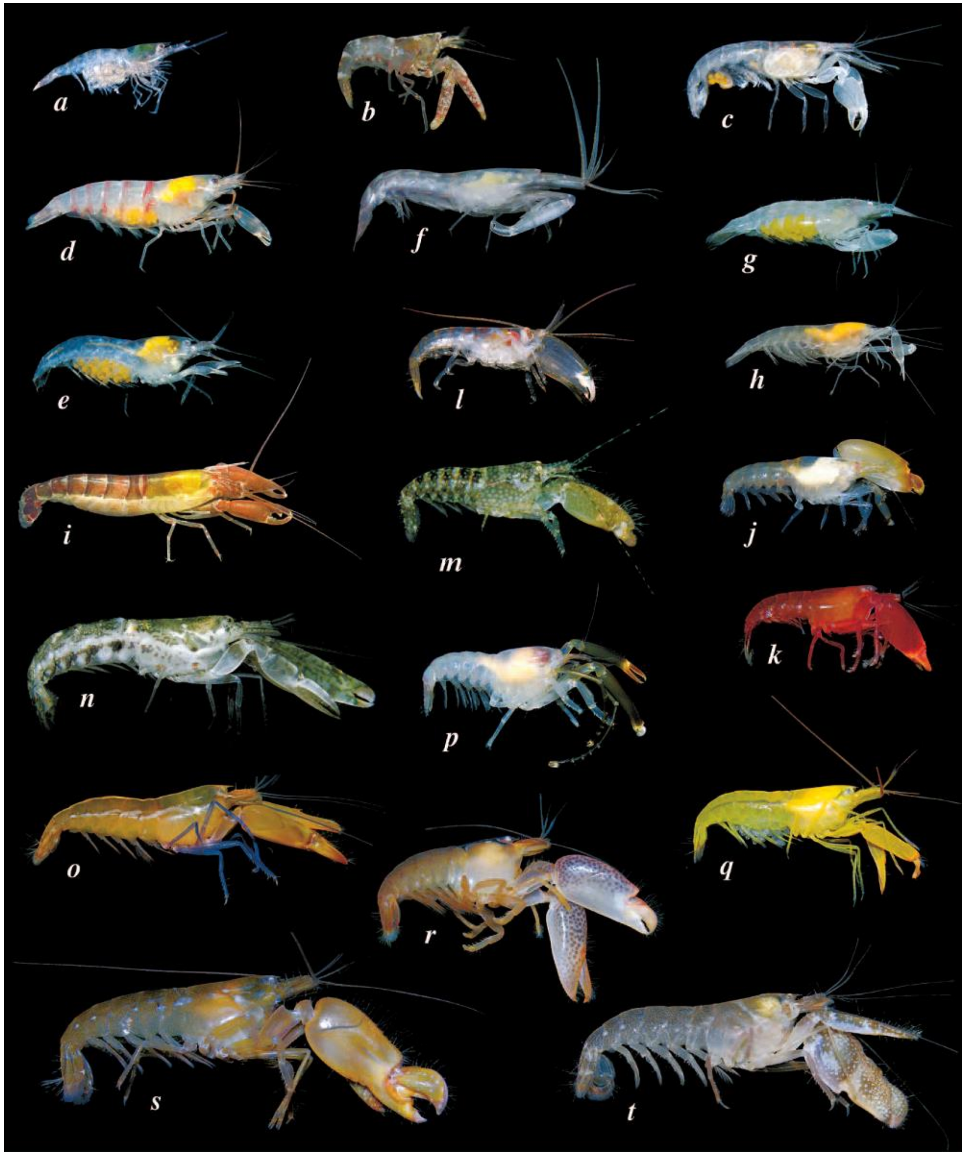
- With a colony of a few thousand such shrimps we get a lot of noise…



Images taken from http://stilton.tnw.utwente.nl/shrimp/

Some species of snapping shrimps

Examples of Alpheid
shrimp diversity,
taken from (Anker et al., 2006)



Summary on the snapping shrimps

- Encountered in warm and shallow waters

- Seen as bursts of high frequency noise that affect neighboring traces

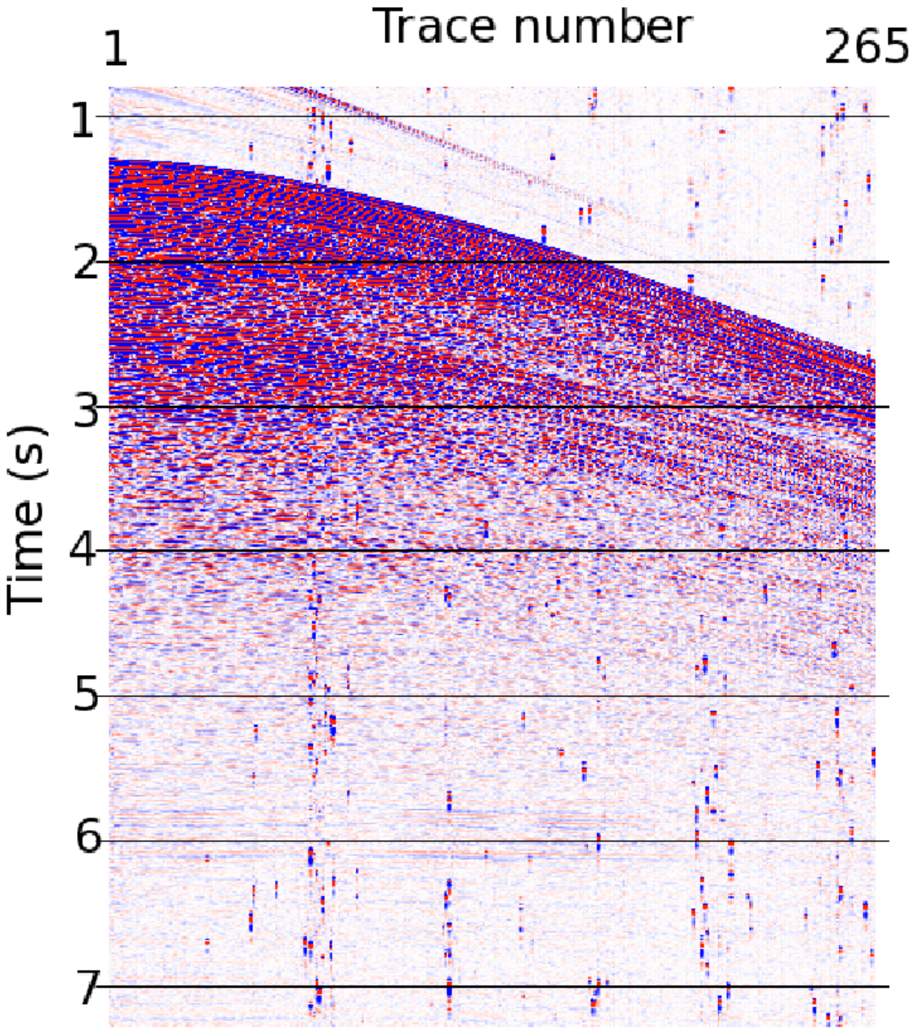
- Can normally be removed in processing

Feeding fish noise?

- Spikes were observed in data acquired outside East Africa in early 2012

- Only a few scattered lines in the survey, were affected

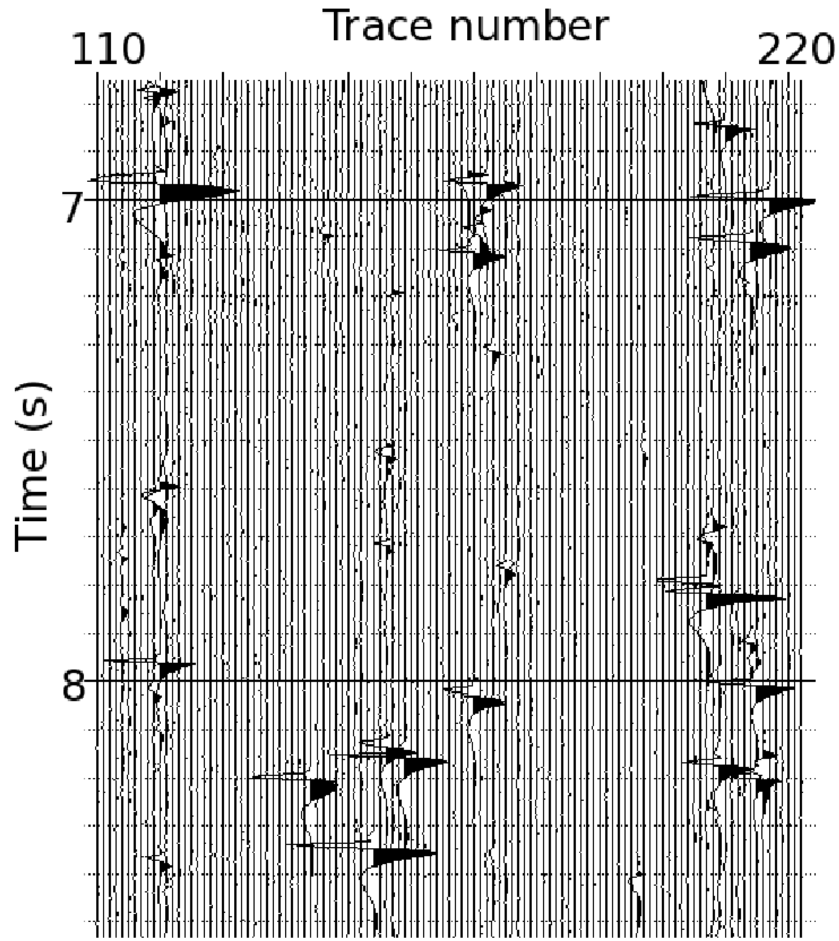
- The noise was encountered in known fishing grounds



Zoom of the data

- Amplitude similar to reflection data near the sea-bed
- The spikes disappeared without intervention
- They disappeared when approached by the work boat, often reappearing on adjacent streamers

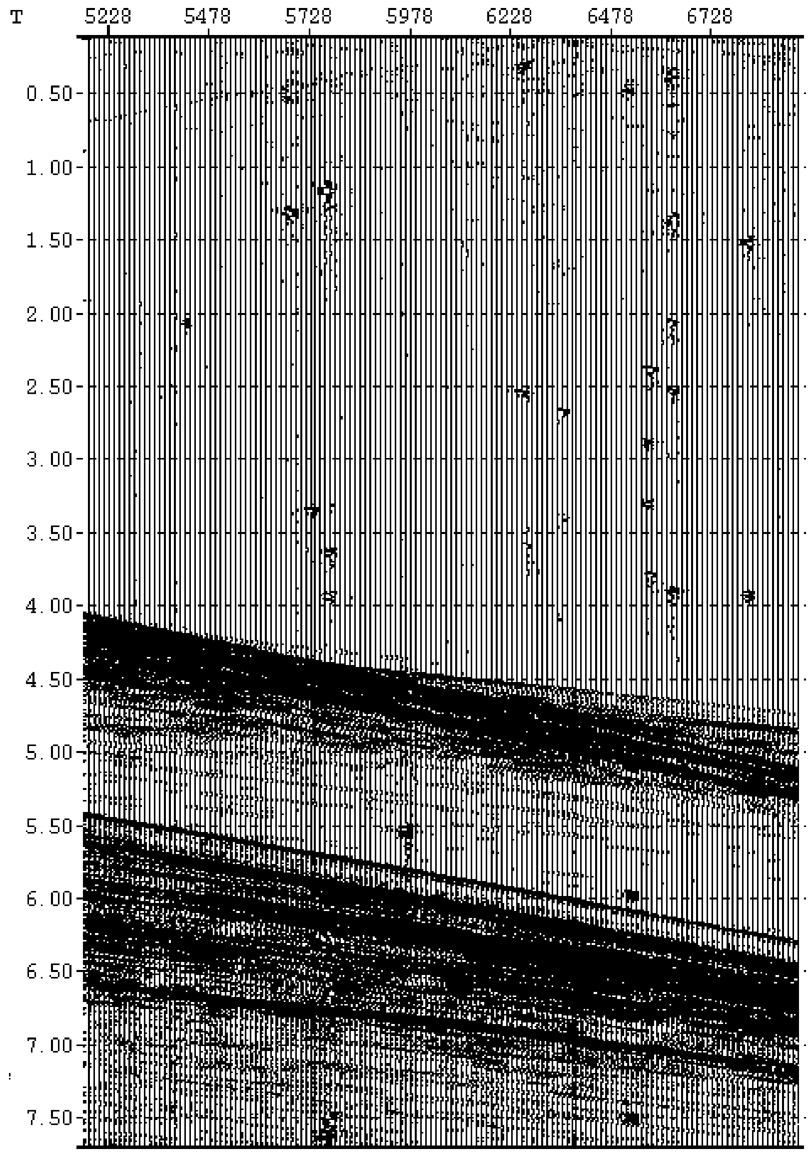
Initial vessel reaction was that the noise was caused by water ingress (electrical problems). However, this turned out to be wrong…



Click here for a movie showing all shots in a line

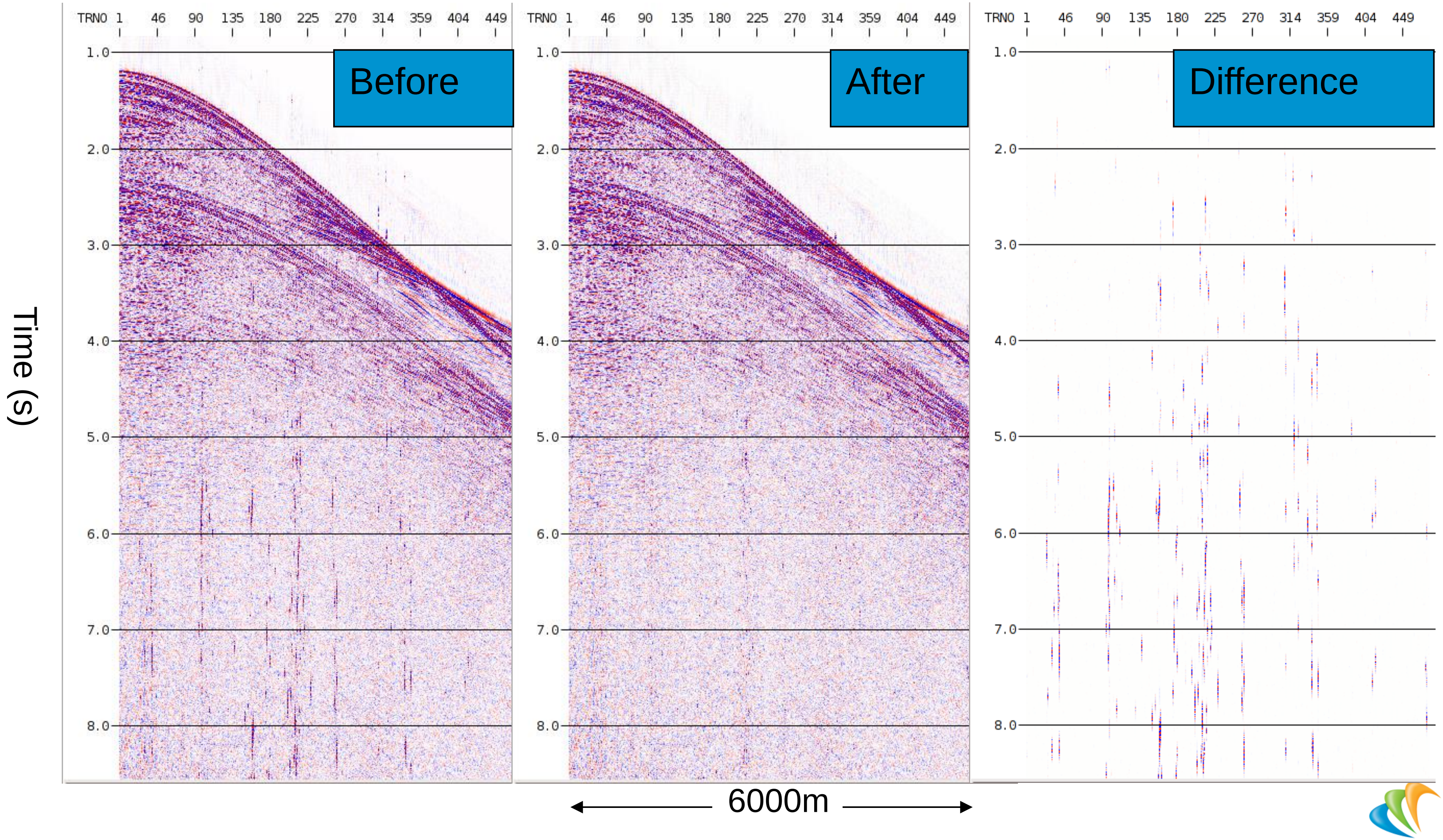
Data from a 2-D survey off East Timor in 2005

- Similar appearance as the East Africa data
- Spikes randomly appearing on some lines
- The spikes were encountered in a rich fishing area



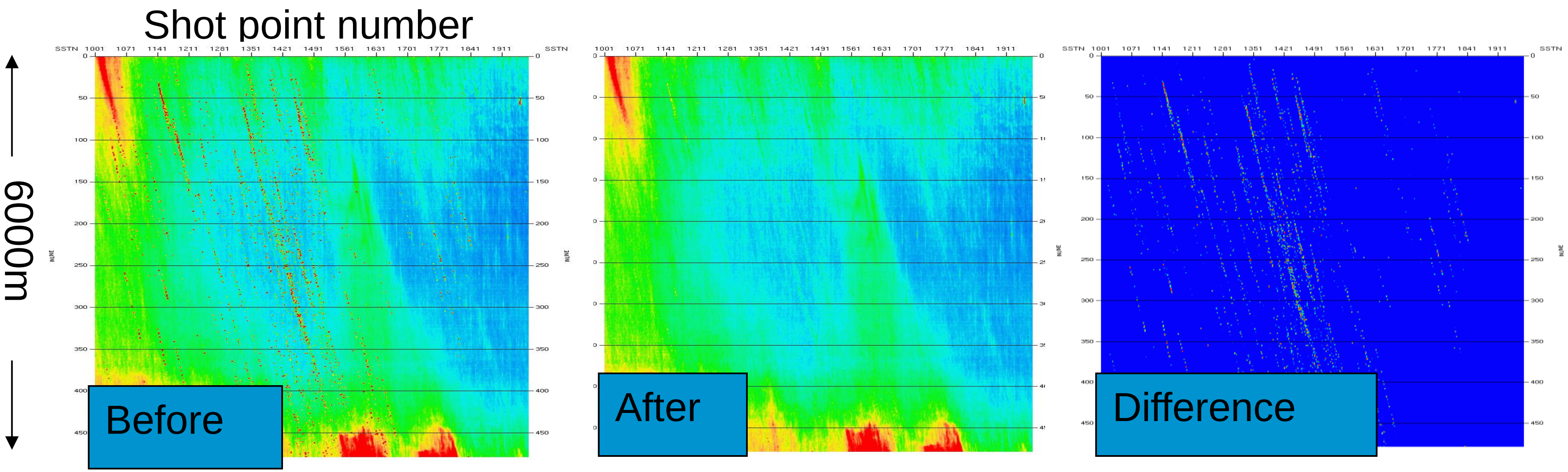
Removing the spikes through processing

A shot from the survey:

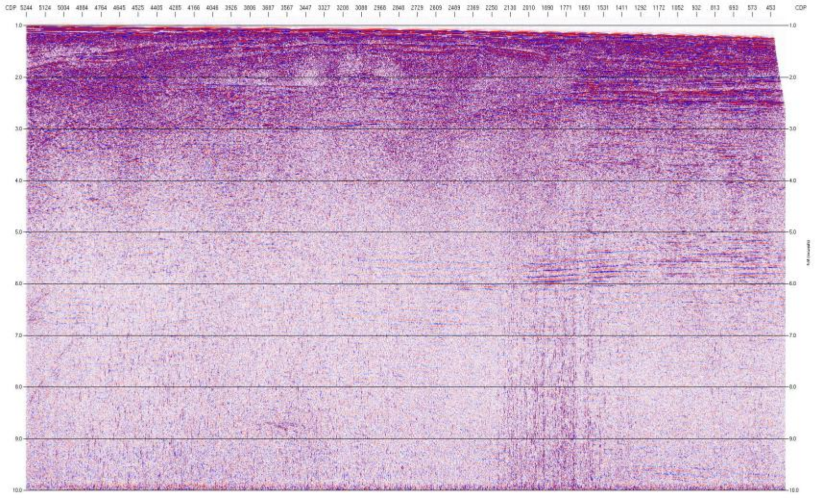


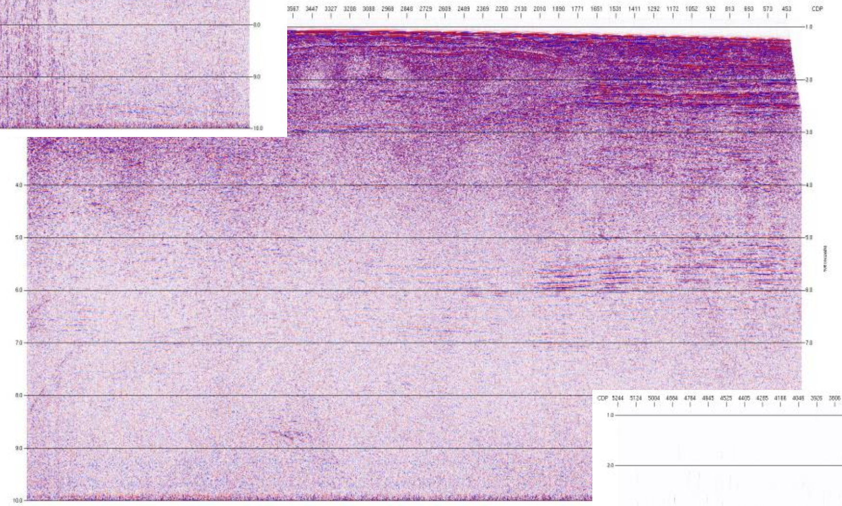
Removing the spikes through processing

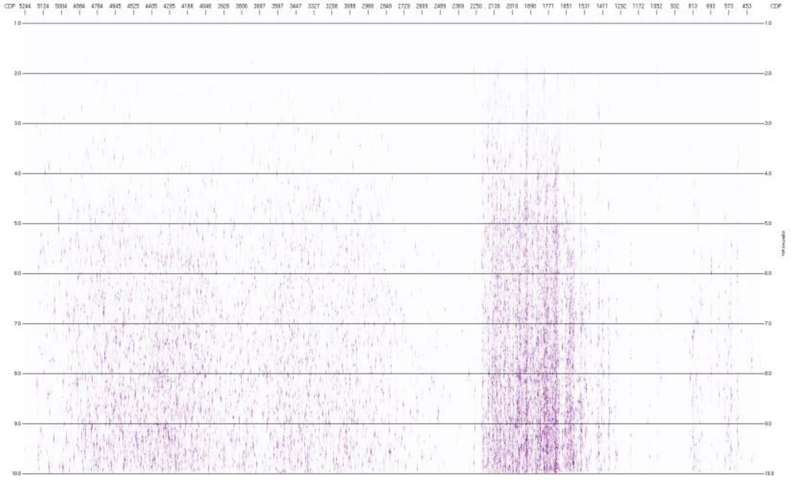
RMS noise plots from the survey:



Stack: Before,after and diff from denoise flow

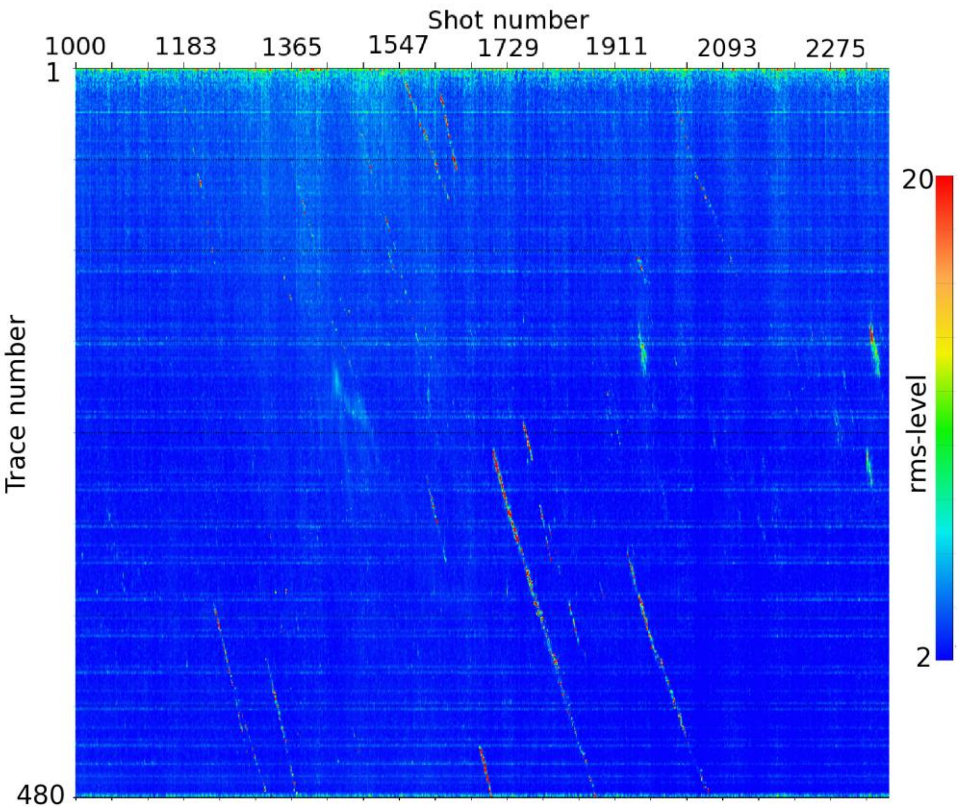






RMS-plots from a spiky sequence

- Noise source(s) appear stationary in the water
  - →it can not be caused by electrical problems. It must be external
- Only individual traces are affected
  - →the noise source must be very close to the streamer itself



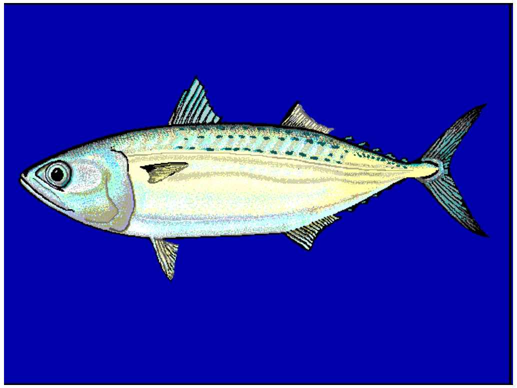
What is causing the noise?

We present three hypothesis to explain the spikes:

1. Fish school cluster around the gear, and attract predators like Tuna, Barracuda, Mackerel that deal blows to the streamers while hunting for pray. (Jumping 'bait fish' were actually observed during this survey).

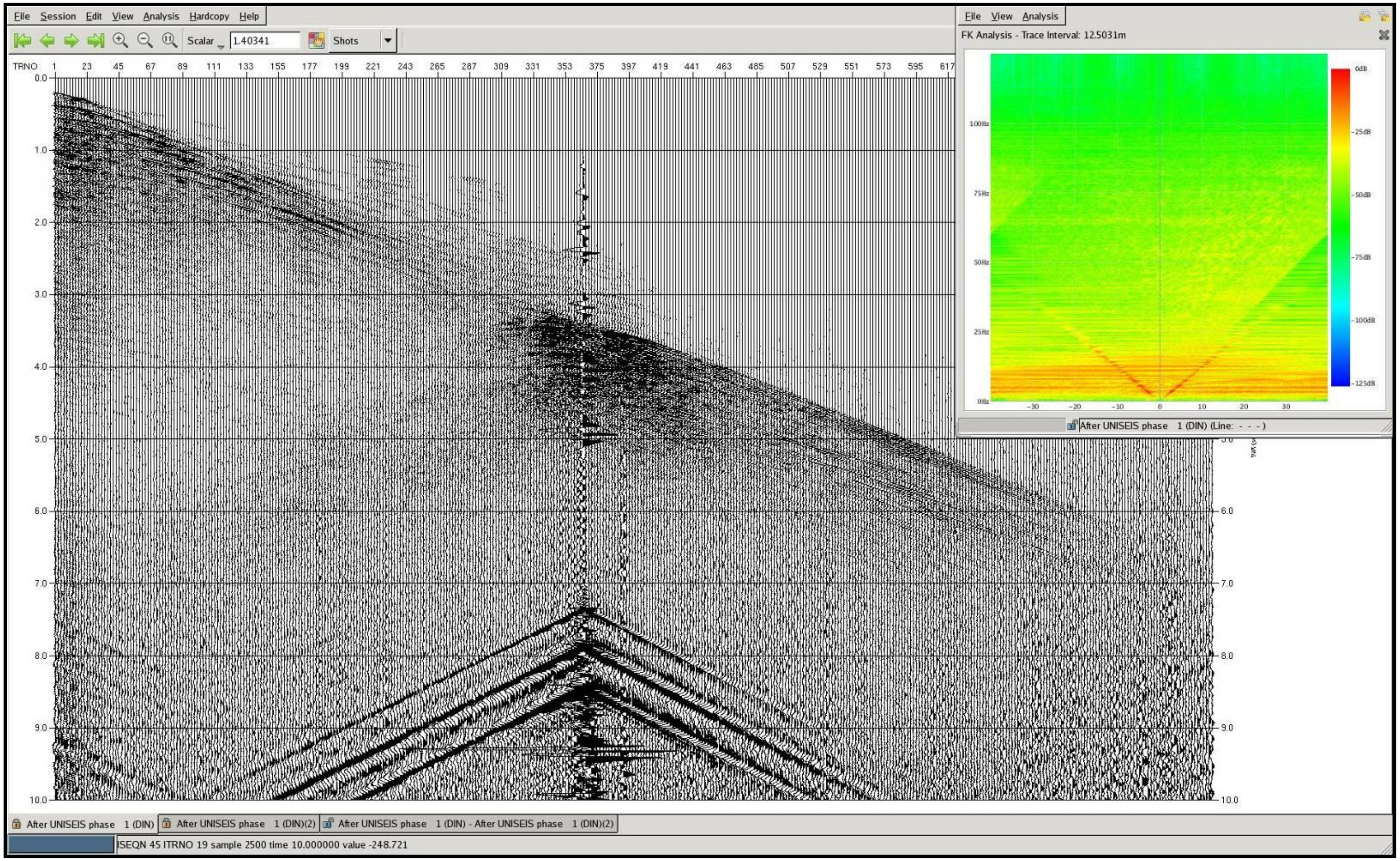
2. Barnacles growing on the streamers attract feeding fish. When the fish take a bite on the barnacle we get noise in our data. (There was significant barnacle growth on the streamers during this survey).

3. The streamers were hitting something under the water. (No fishing gear or debris were observed on the surface during this survey, so this does not sound like a good explanation).

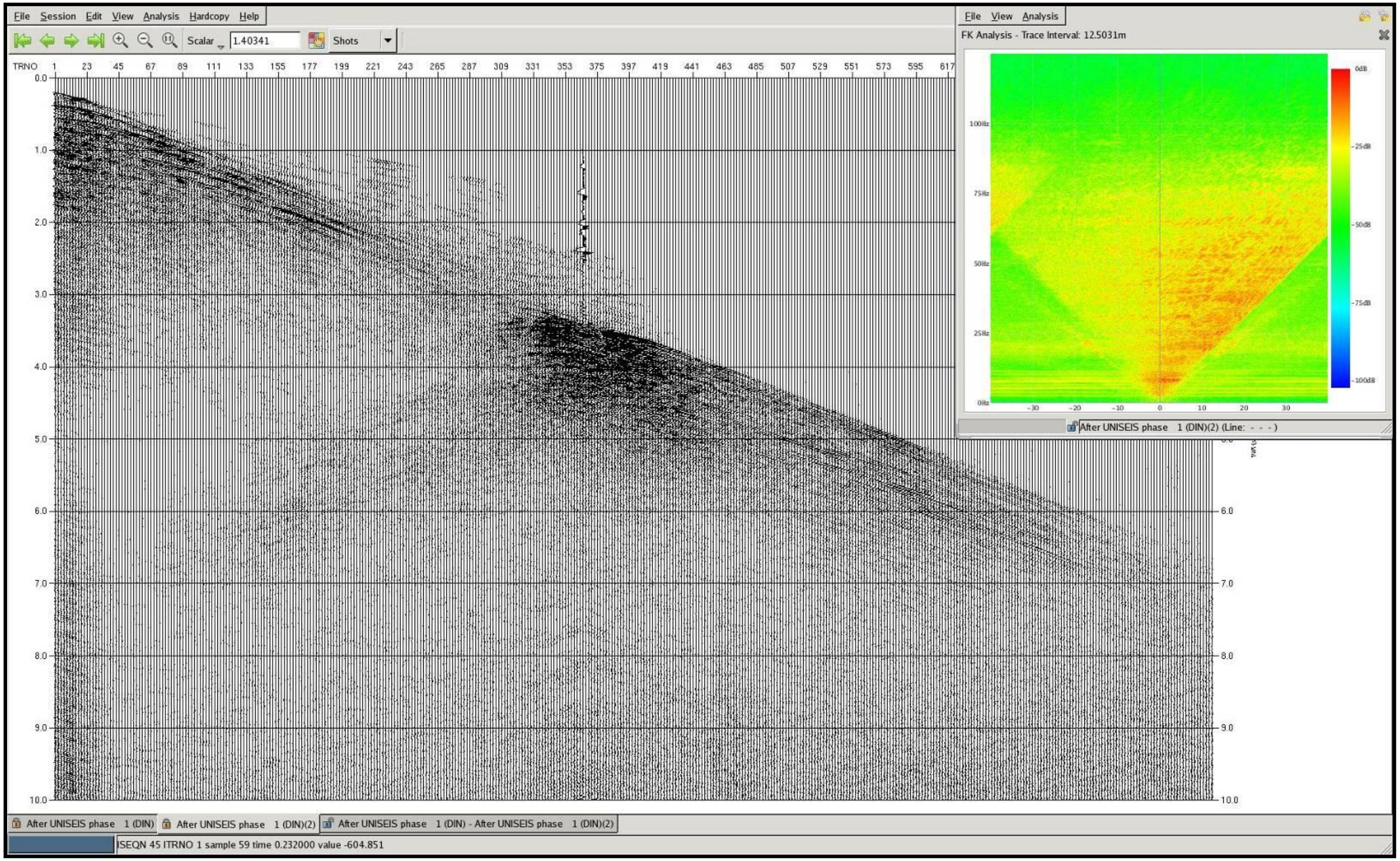


Top: Mackerel fish
Bottom: Barnacles on the streamer

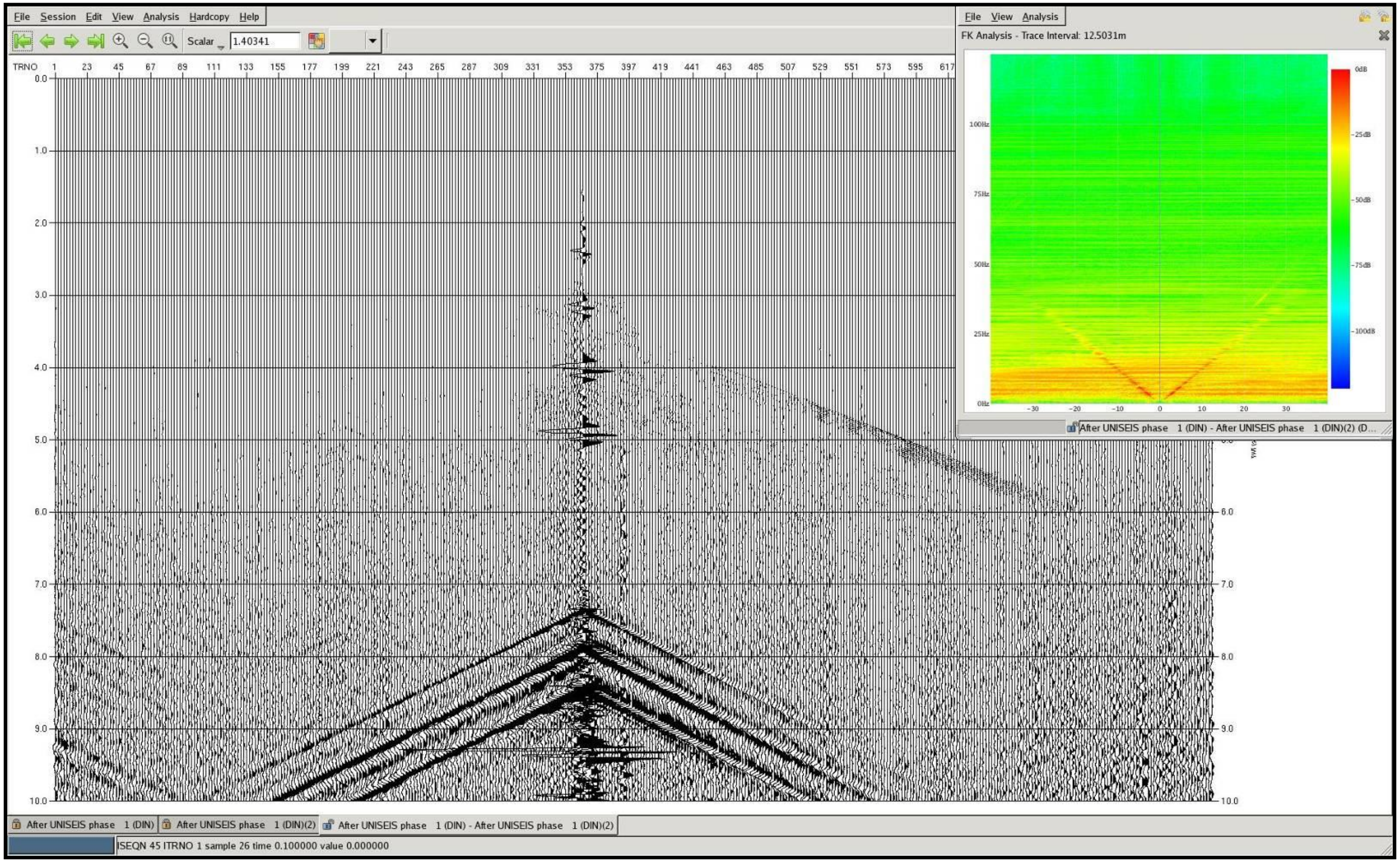
What is causing this noise?



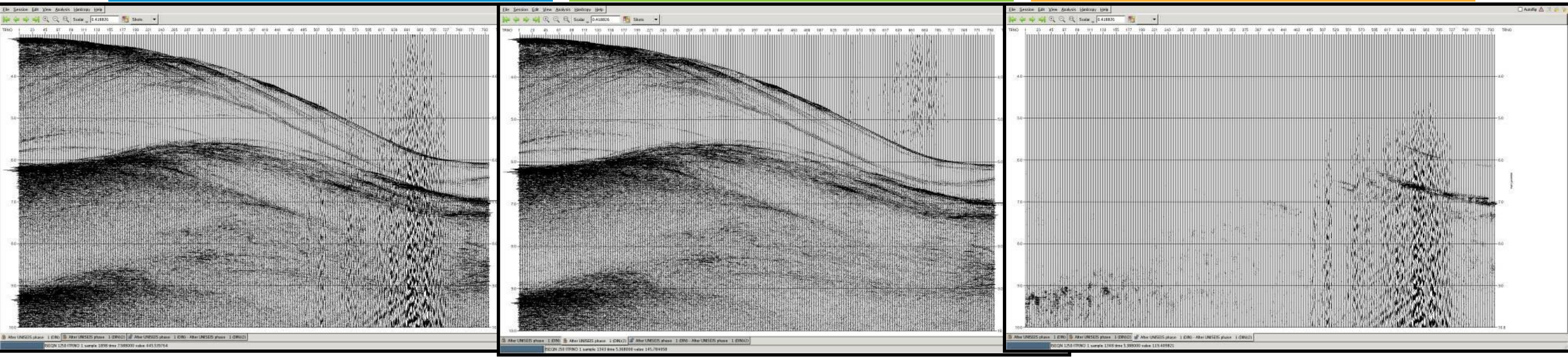
After statistical denoising



Difference

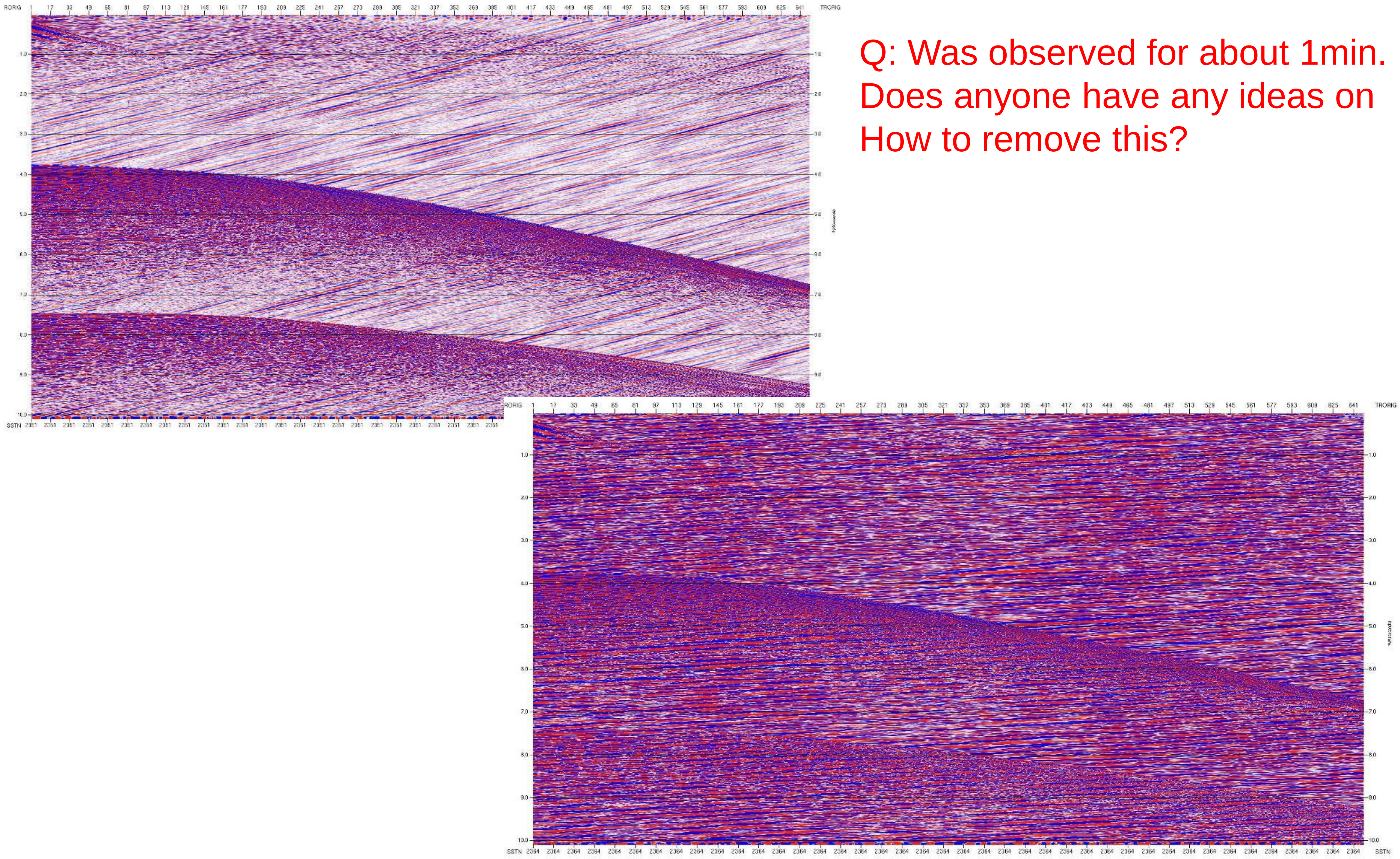

File Session Edit View Analysis Hardcopy Help
Scalar 1.40341
TRNO
File View Analysis
FK Analysis - Trace Interval: 12.5031m
After UNISEIS phase 1 (DIN) - After UNISEIS phase 1 (DIN)(2) (D...
After UNISEIS phase 1 (DIN)
After UNISEIS phase 1 (DIN)(2)
After UNISEIS phase 1 (DIN) - After UNISEIS phase 1 (DIN)(2)
ISEQN 45 ITRNO 1 sample 26 time 0.100000 value 0.000000

Cross flow noise



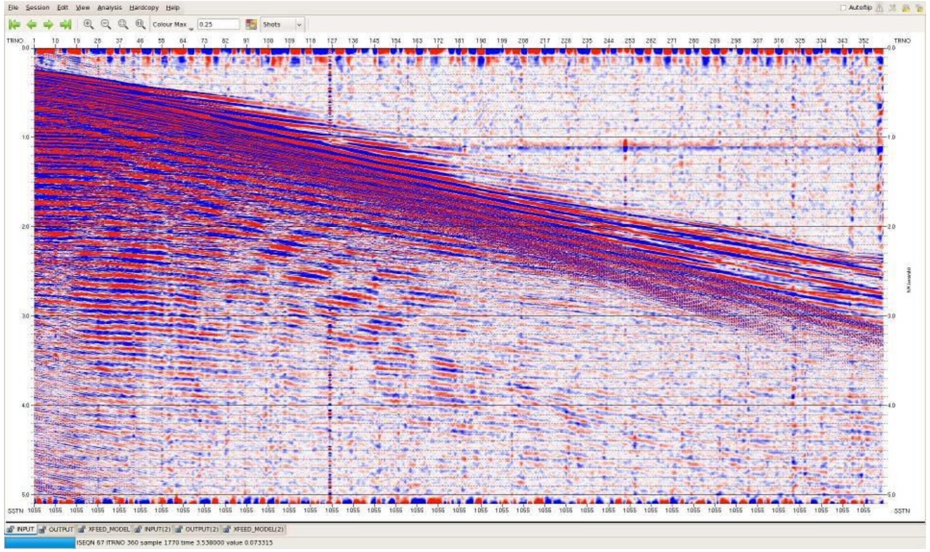
Q: Why the strange move-out on the shot gather?

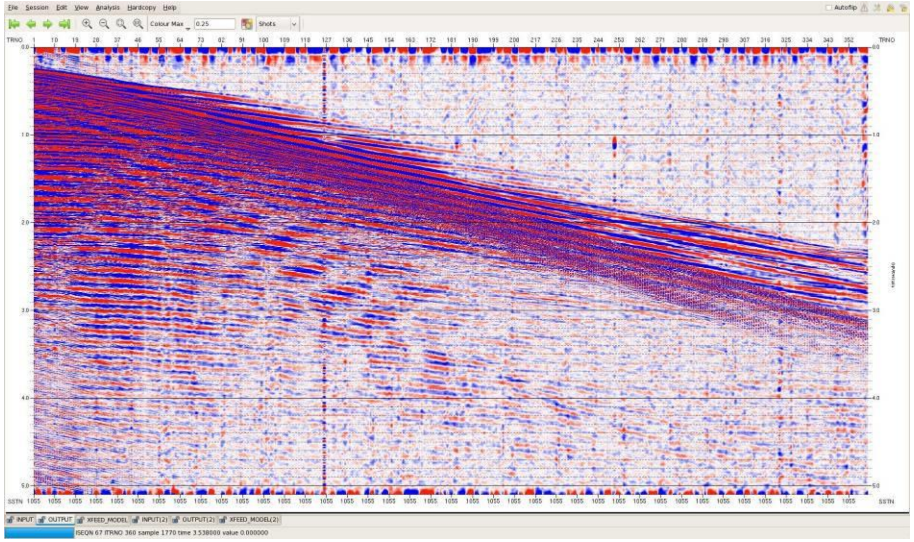
Earthquake noise

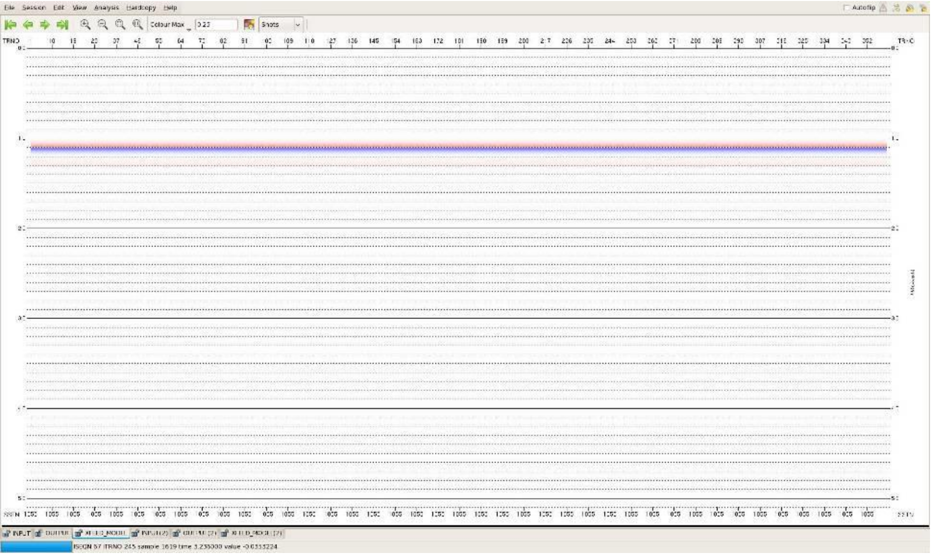


Q: Was observed for about 1min. Does anyone have any ideas on How to remove this?

Electrical cross-feed noise





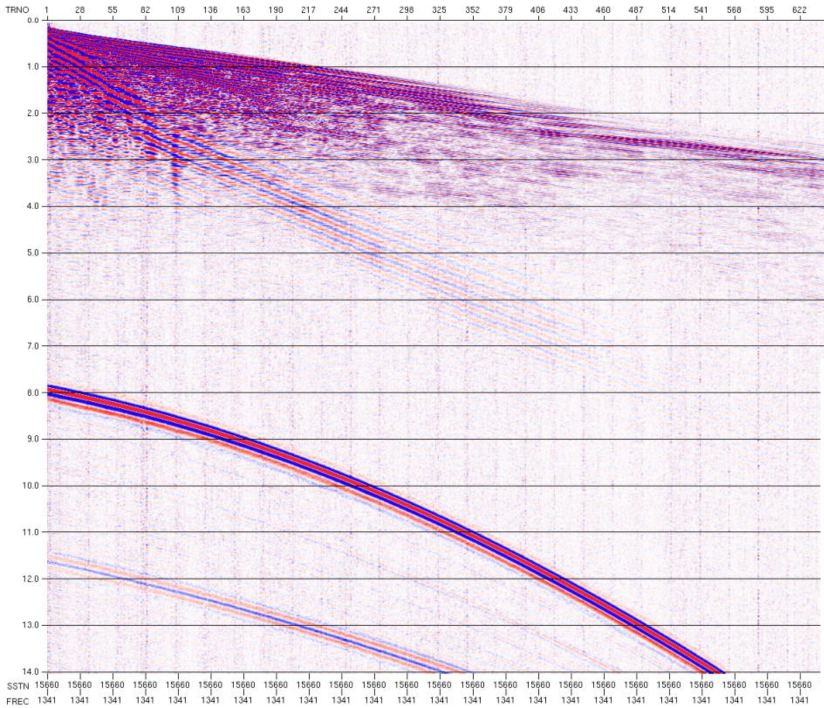


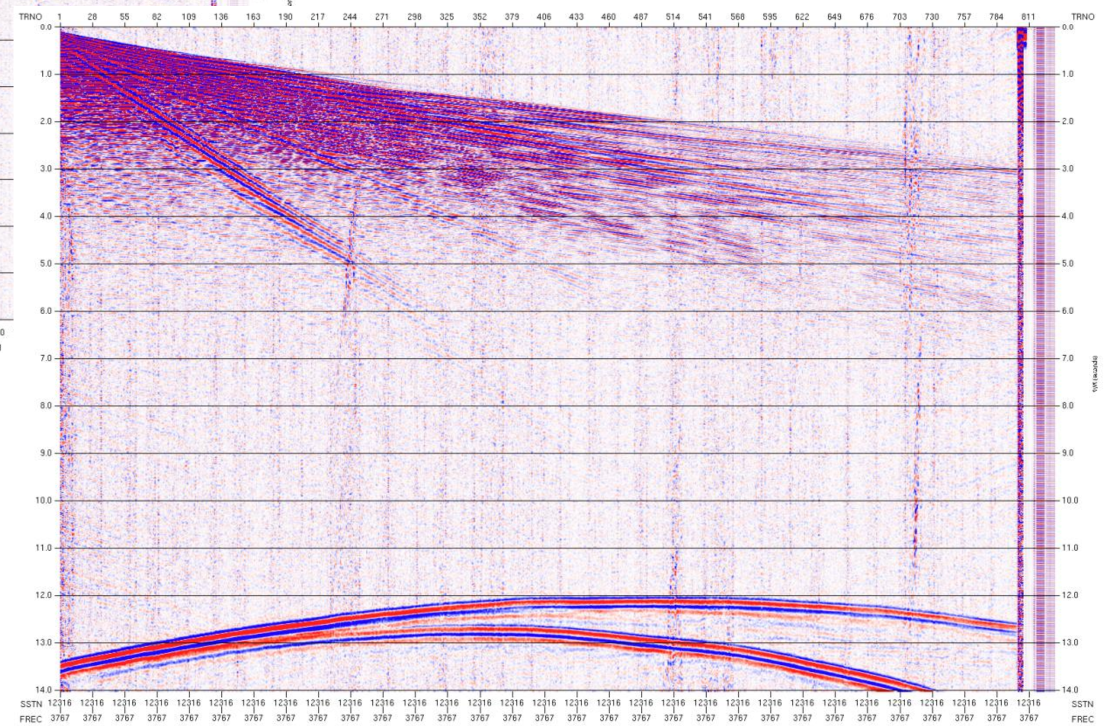
Algorithm:

1. Stack up shot gather.
   (Noise is coherent, while signal is not)
2. Pick out time of max peak in stack.
3. Subtract scaled stack from each trace in a small time-window around the peak.
2. That's it!

Q: How would this X-feed look on a stack?

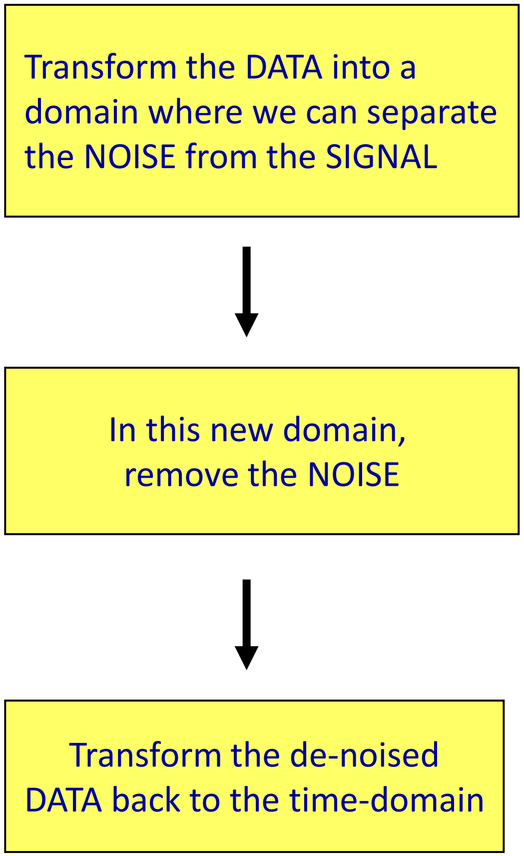
Sonic boom – military jet over North Sea





Q: How would you go about denoising
This kind of noise?

Conclusions (Last slide ☺)



1. All denoising follow the algorithm on the left hand side.
2. The challenge is often to find a domain where we can separate the noise from the signal.
   - For low freq hydrostatic pressure fluctuations, separation was easy
   - For SI separation was difficult.

Thank you

And thanks to all colleagues who contributed images to this lecture

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