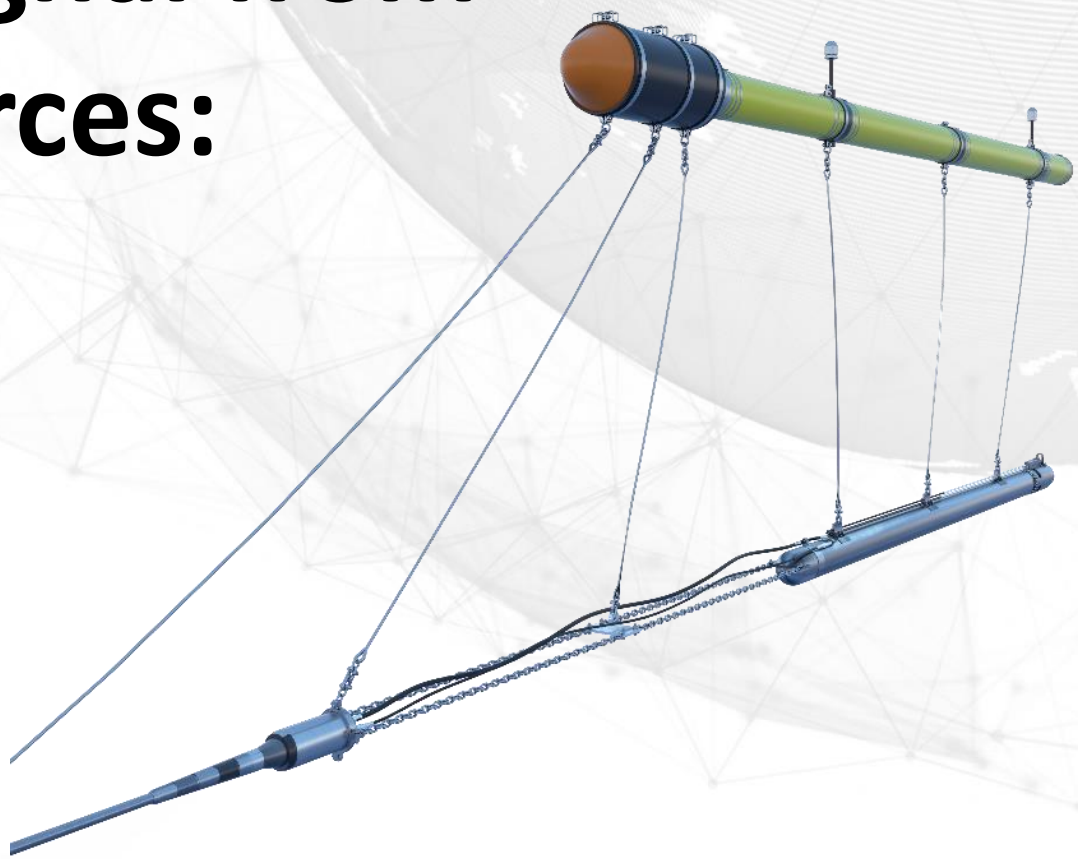
Ultra Low Frequency Signal from Pneumatic Seismic Sources: How low can we go?



Steve Chelminski and Shuki Ronen

With help from many people (to be acknowledged)

Sercel

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Session Details:
Low Frequency Seismic Data Acquisition and its impact on Imaging and Inversion—Hardware (Dedicated Session)

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Session Details:

Low Frequency Seismic Data **Acquisition** and its impact on **Imaging and Inversion**— **Hardware** (Dedicated Session)

→ Equipment manufacturing

→ Acquisition (operations)

→ Data Processing, Imaging, and Inversion

→ No interpretation in this session*

* maybe one slide

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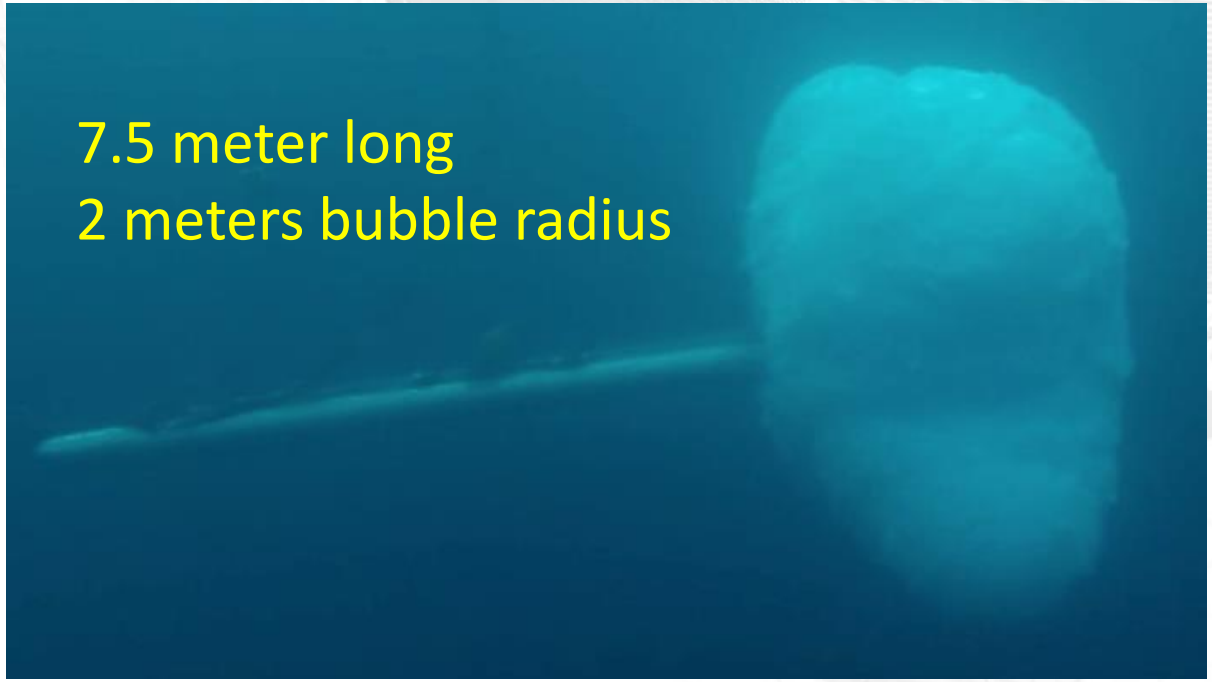
Tuned Pulse Source (TPS)

The TPS is a pneumatic source

- ✷ Impulsive
1. Low Pressure
2. Large Volumes
3. New design features
   - ❑ Cup-shaped flange
   - ❑ No acceleration distance
   - ❑ Closed mid chamber
   - ❑ Safer air supply/drain
- ➢ More low frequency signal
- ➢ Less High frequency waves



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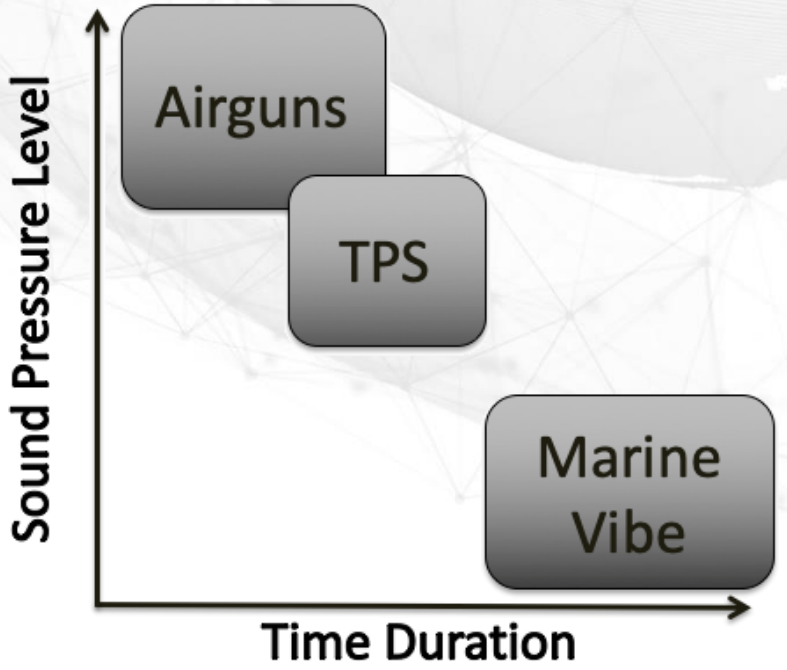

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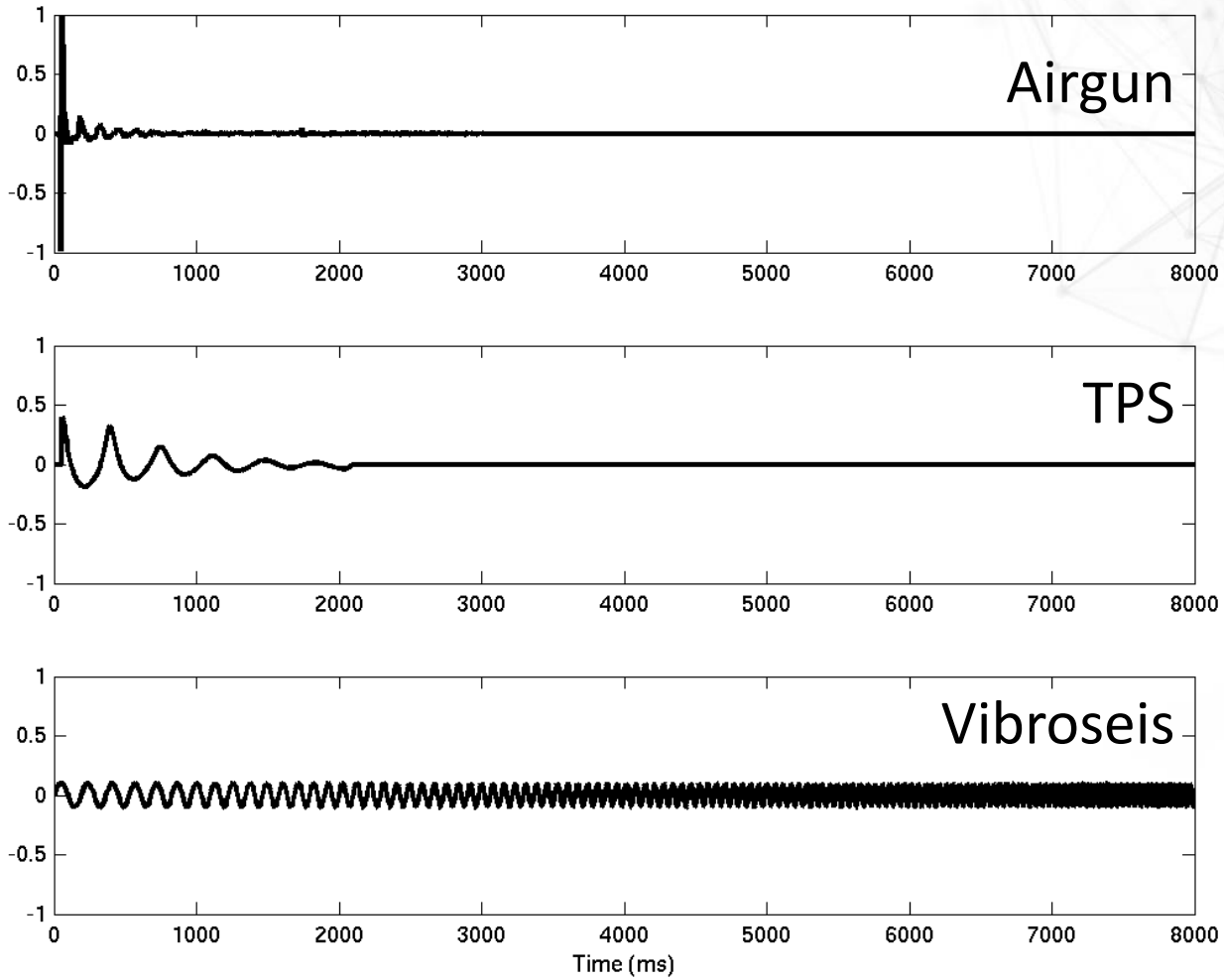
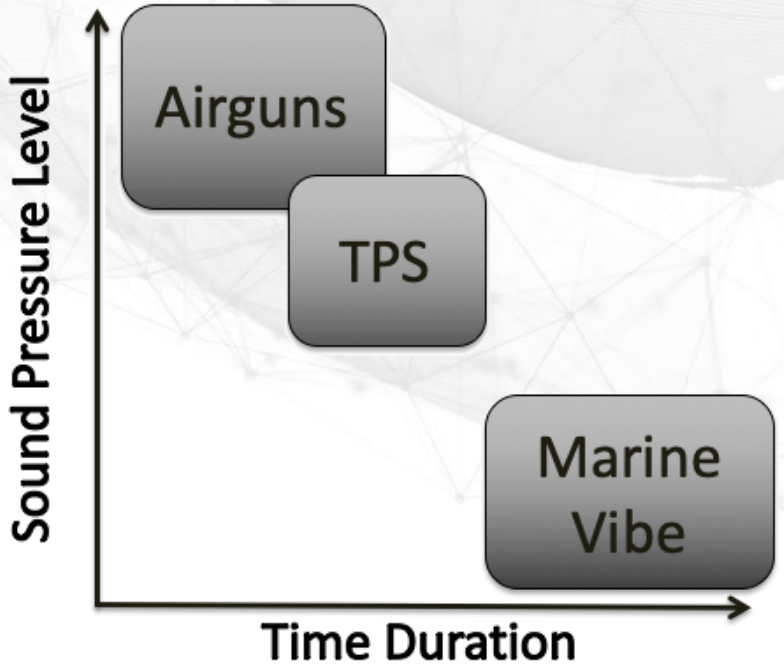
Impulsive and non impulsive sources



It’s a gray area



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Tuned Pulse Source (TPS)

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- Impulsive

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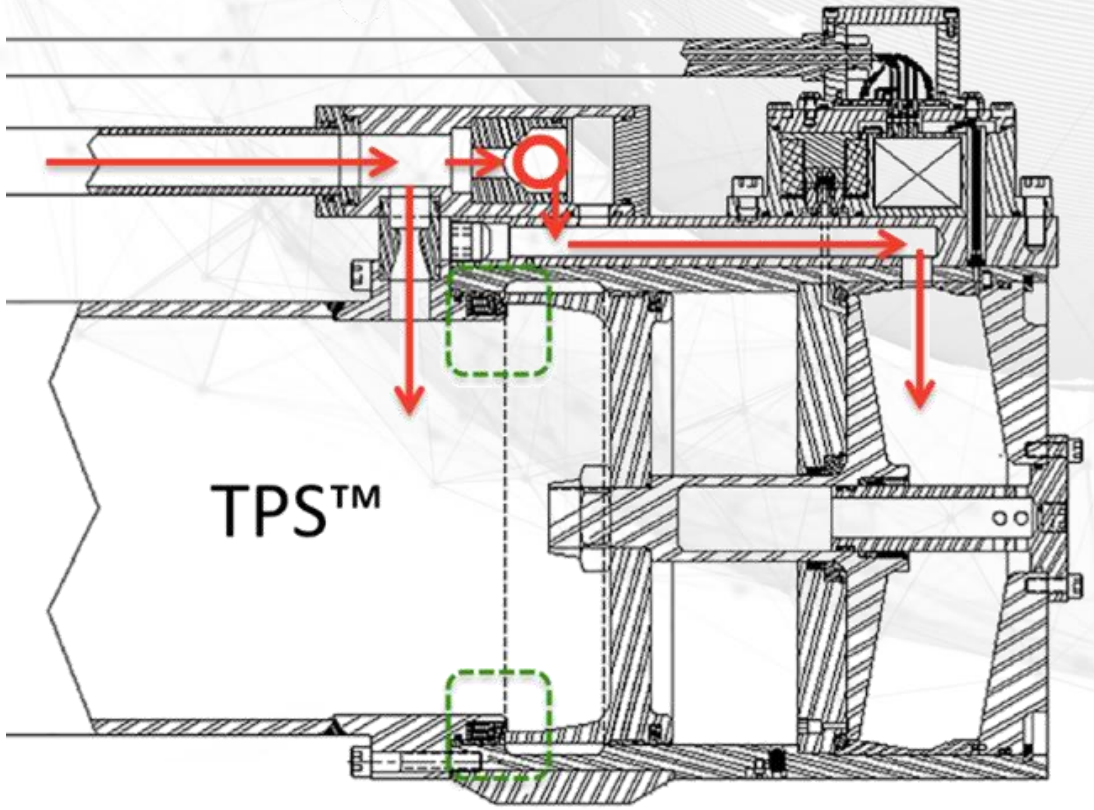
2. Large Volumes
3. **New design features**
   - ❑ **Cup-shaped flange**
   - ❑ **No acceleration distance**
   - ❑ **Closed mid chamber**
   - ❑ **Safer air supply/drain**

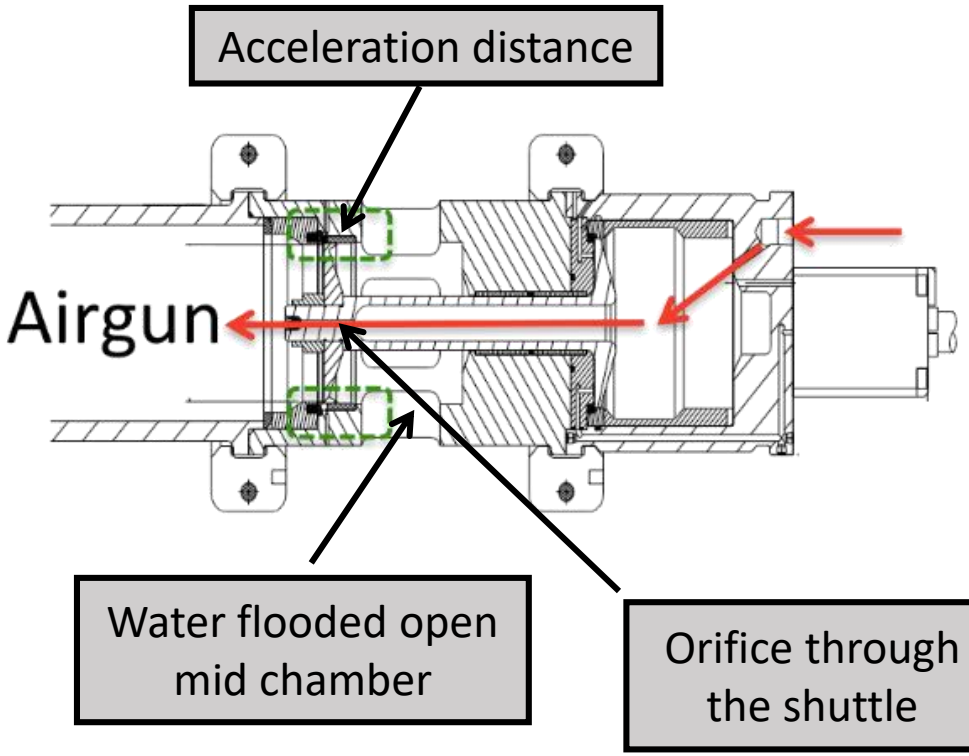
- ➢ More low frequency signal
- ➢ Less High frequency waves

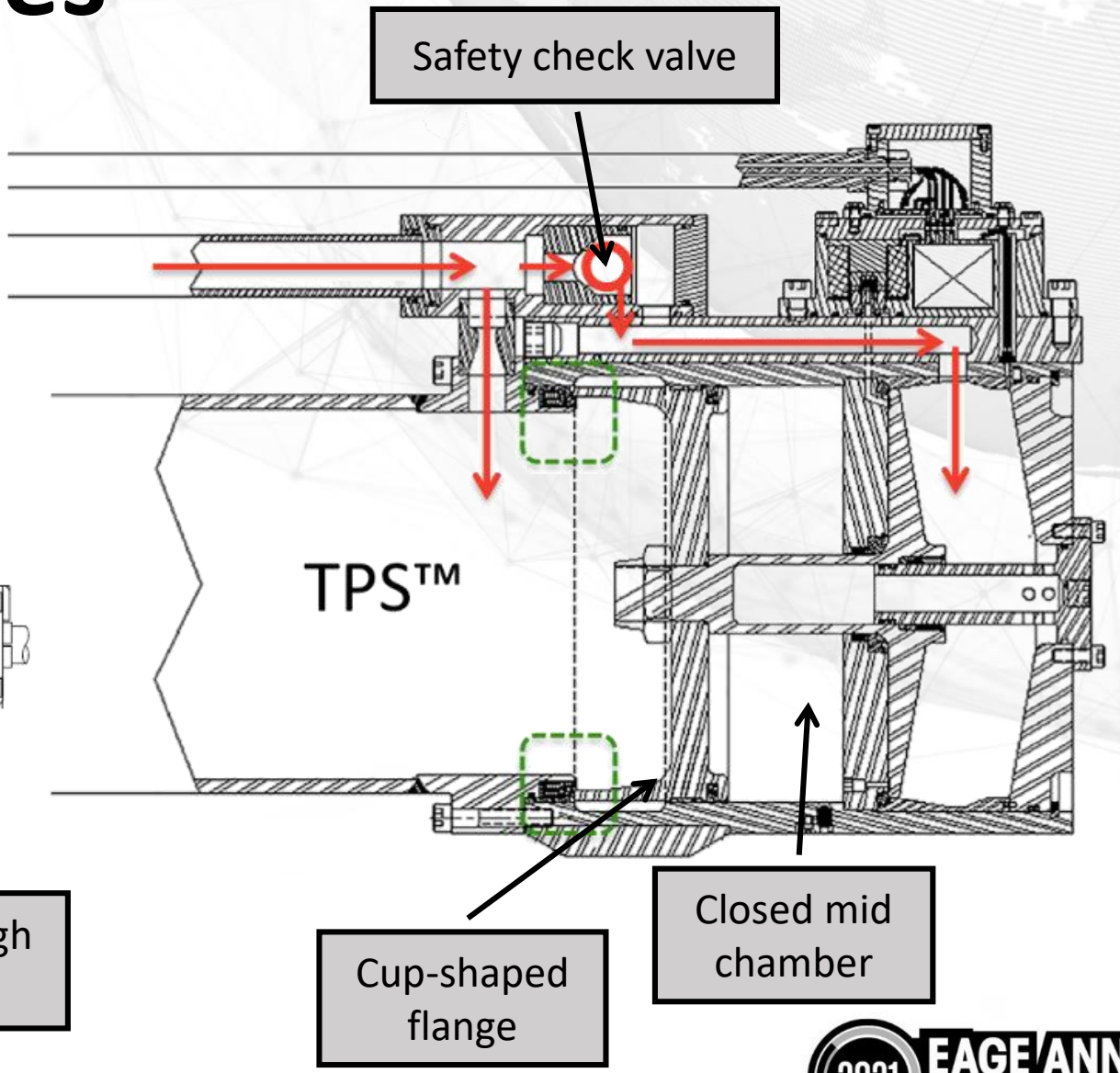


New design features

Safer air flow method

Zero acceleration distance





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Tuned Pulse Source (TPS)

The TPS is a pneumatic source

- Impulsive

1. Low Pressure
2. Large Volumes
3. New design features
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   - ❑ No acceleration distance
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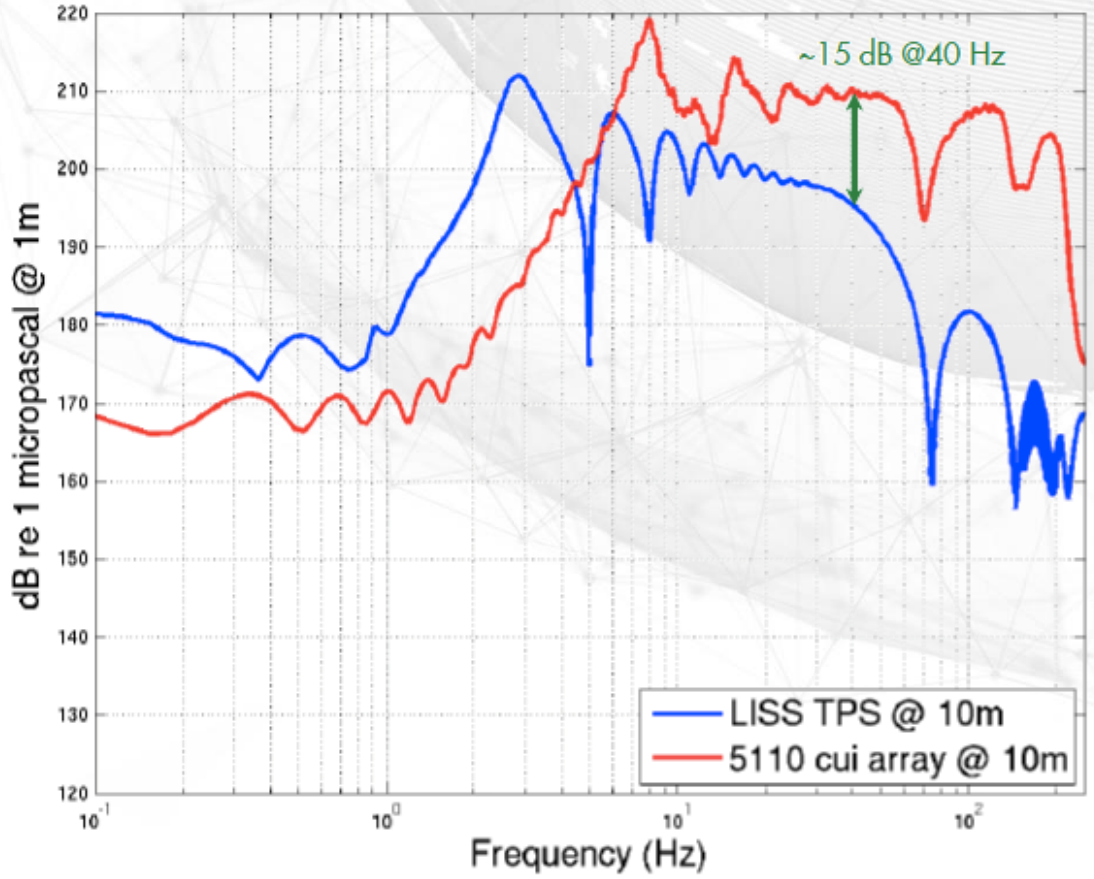

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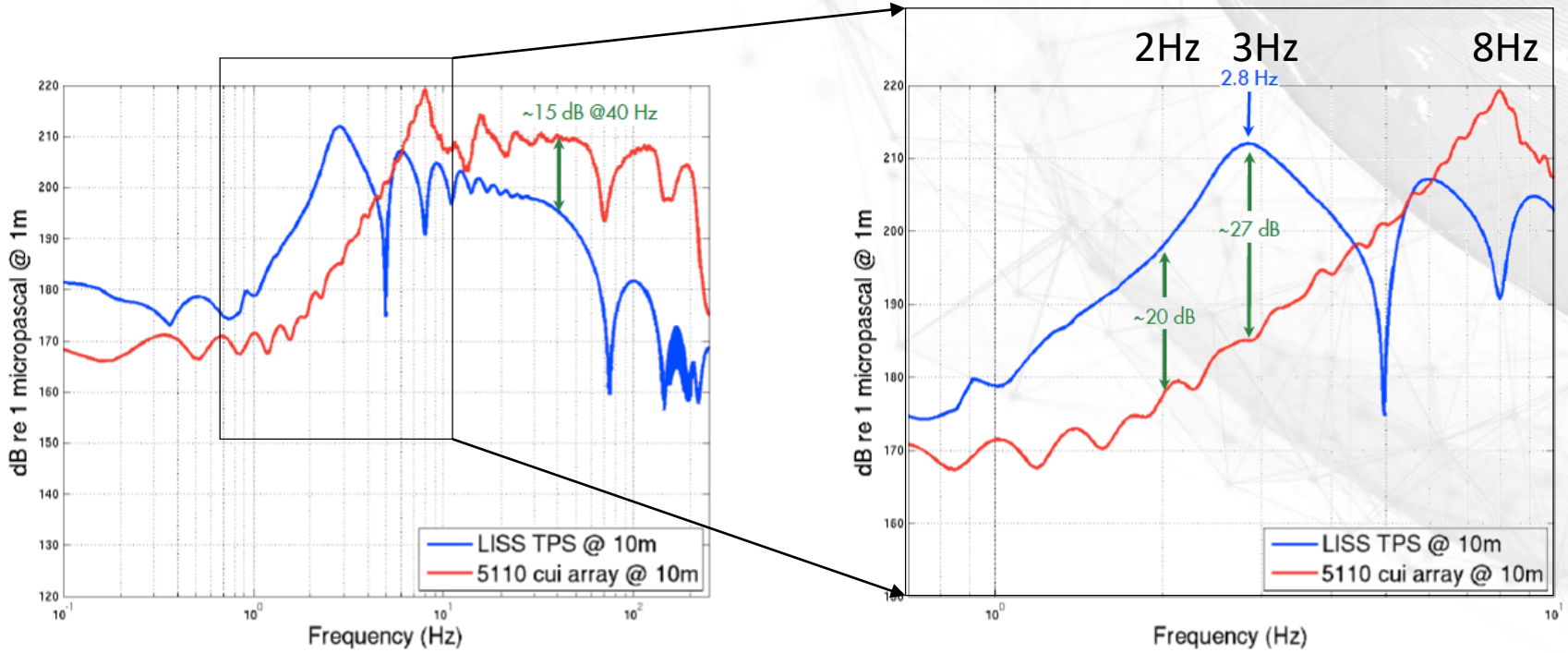
Low frequency Source



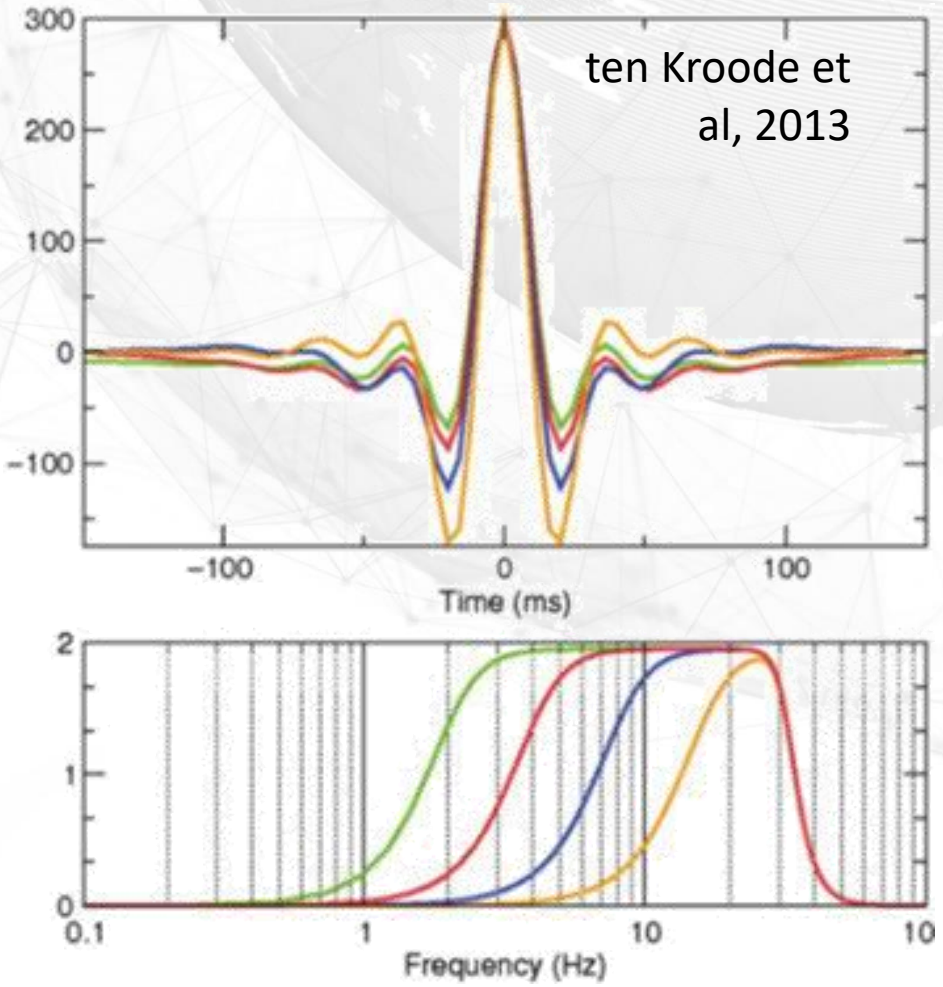
Over 20 dB stronger at 1-3 Hz (infra-sound) → Geophysical advantage

Over 15 dB weaker above 40 Hz (sound) → Environmental advantage

Geophysical motivation: low frequency signal

- Same high frequency limit
  - Same main lobe
- Lower low frequency limit
  - Shallower side lobes

—16 to 32 Hz (1 octave)
— 8 to 32 Hz (2 octaves)
— 4 to 32 Hz (3 octaves)
— 2 to 32 Hz (4 octaves)



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Deep targets, complex overburden

High frequency waves attenuate and scatter more than low frequency waves

Examples: Subsalt and sub-basalt

If everything above 32 Hz is scattered and attenuated, then

a 5 octave source 4-128 Hz will give 3 octave 4-32 data (2 octaves lost)
a 4 octave source 2-32 Hz will give 4 octave data

The difference between 2 and 4 Hz is only 2 Hz, but it is a whole octave!

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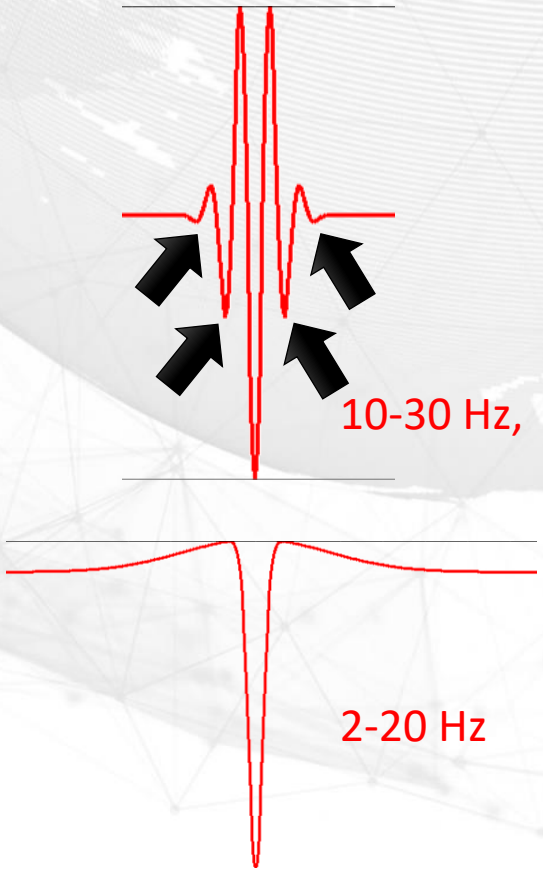
Velocity model building

- Full Waveform Inversion (FWI)
- Full waveform: use reflections, refractions, primaries, multiples, body waves, and surface waves
- Find the earth model that best fits the data
  - Minimize the misfit
  - Local minima also known as cycle skips
- Alternative point of view (equivalent)
  - Maximize the stack power
  - Local maxima also cycle skips



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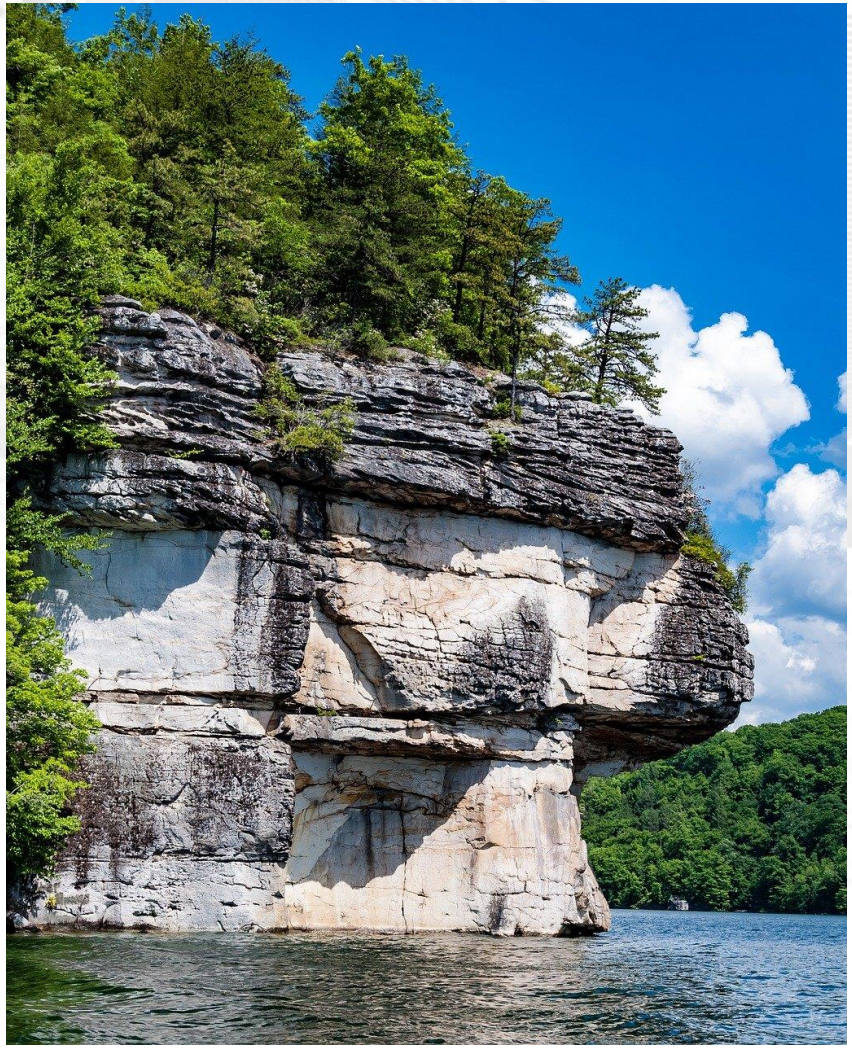
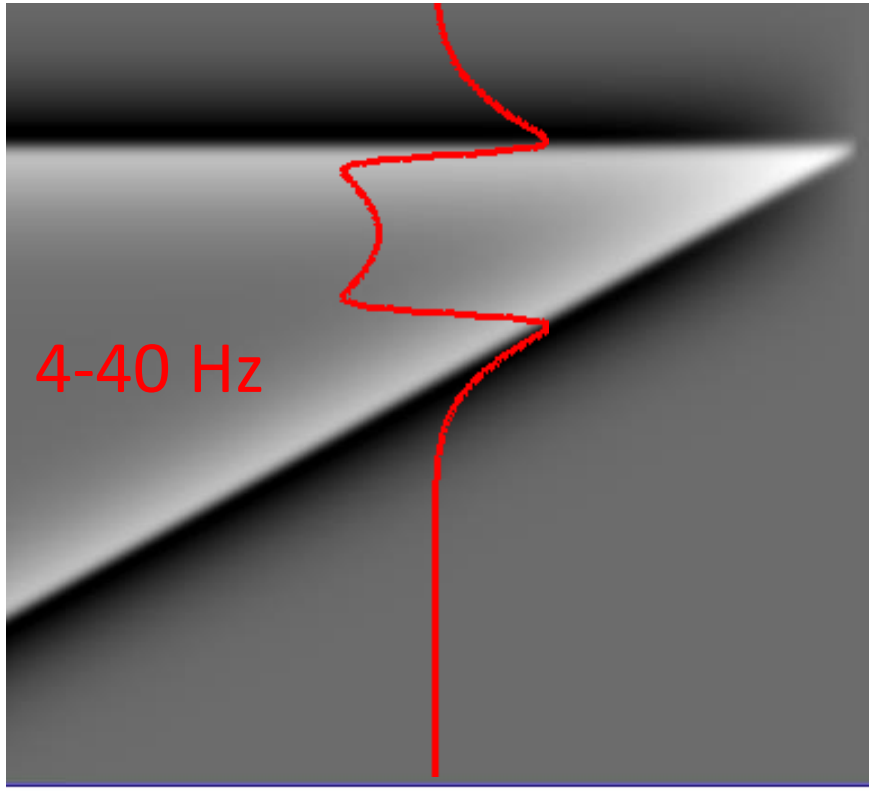
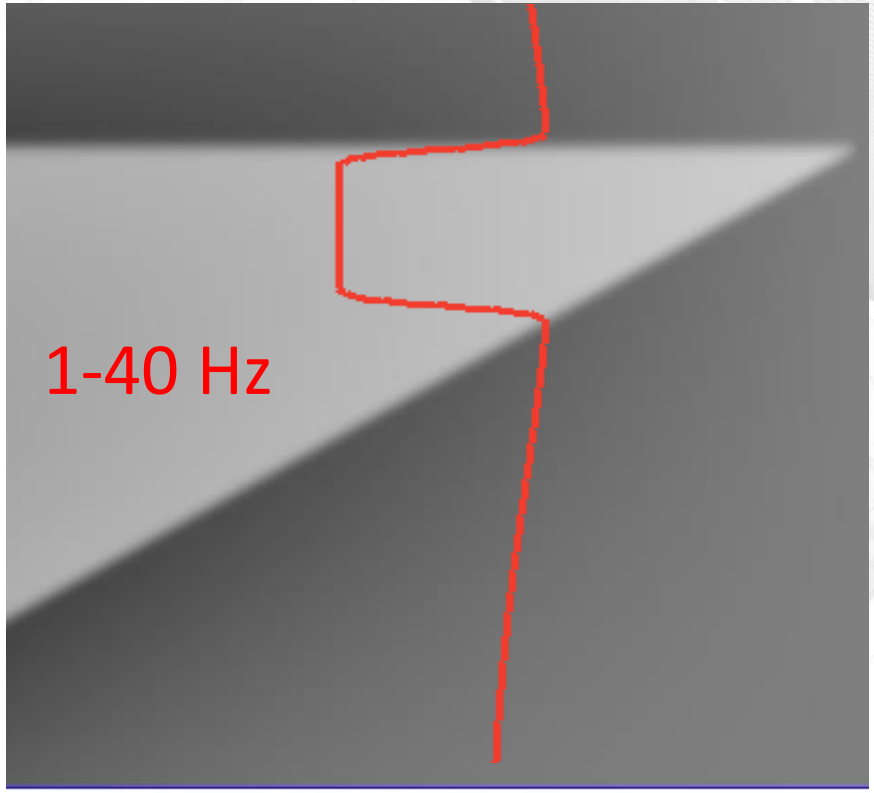
Blocky earth

- We know from well logs and outcrops that the earth is usually blocky
- Reflections are coming from impedance contrasts
- Blocky impedance → spiky reflectivity
- Processing: reflectivity → impedance
- A spike requires broad band signal
- If the low frequencies are missing then a spike is not a spike and a block is not a block



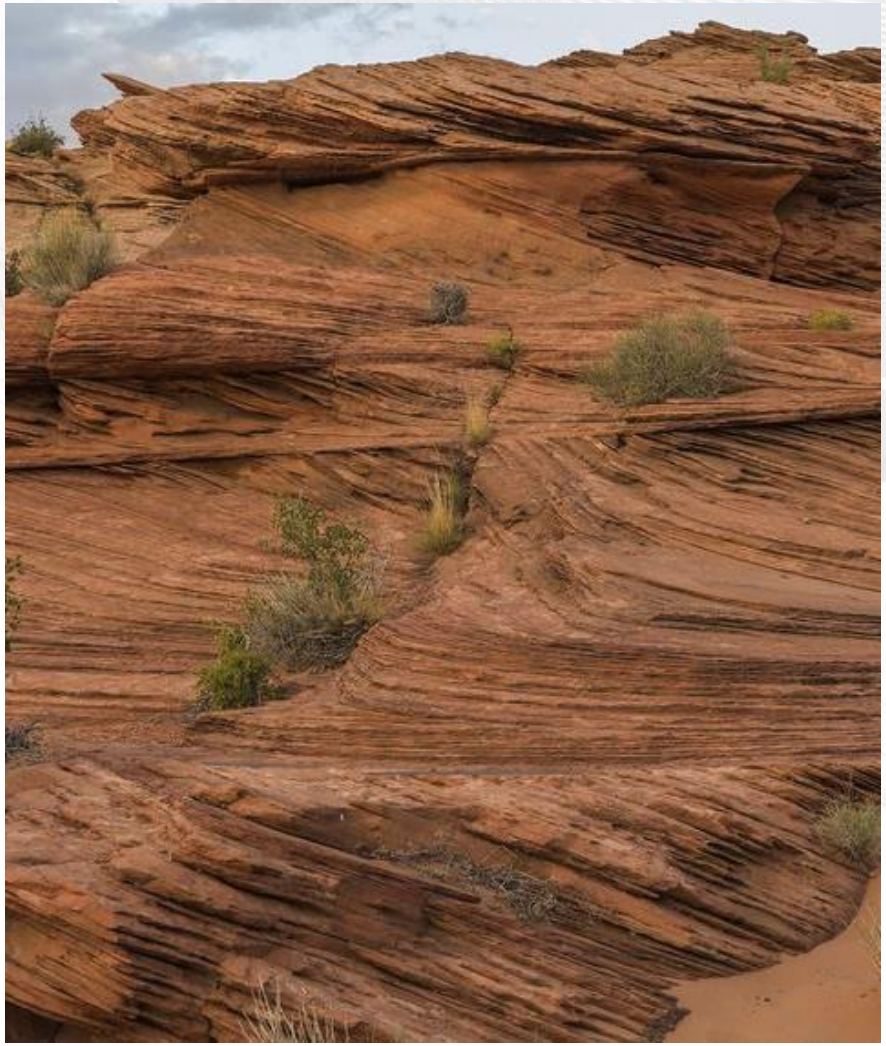
Blocky acoustic impedance



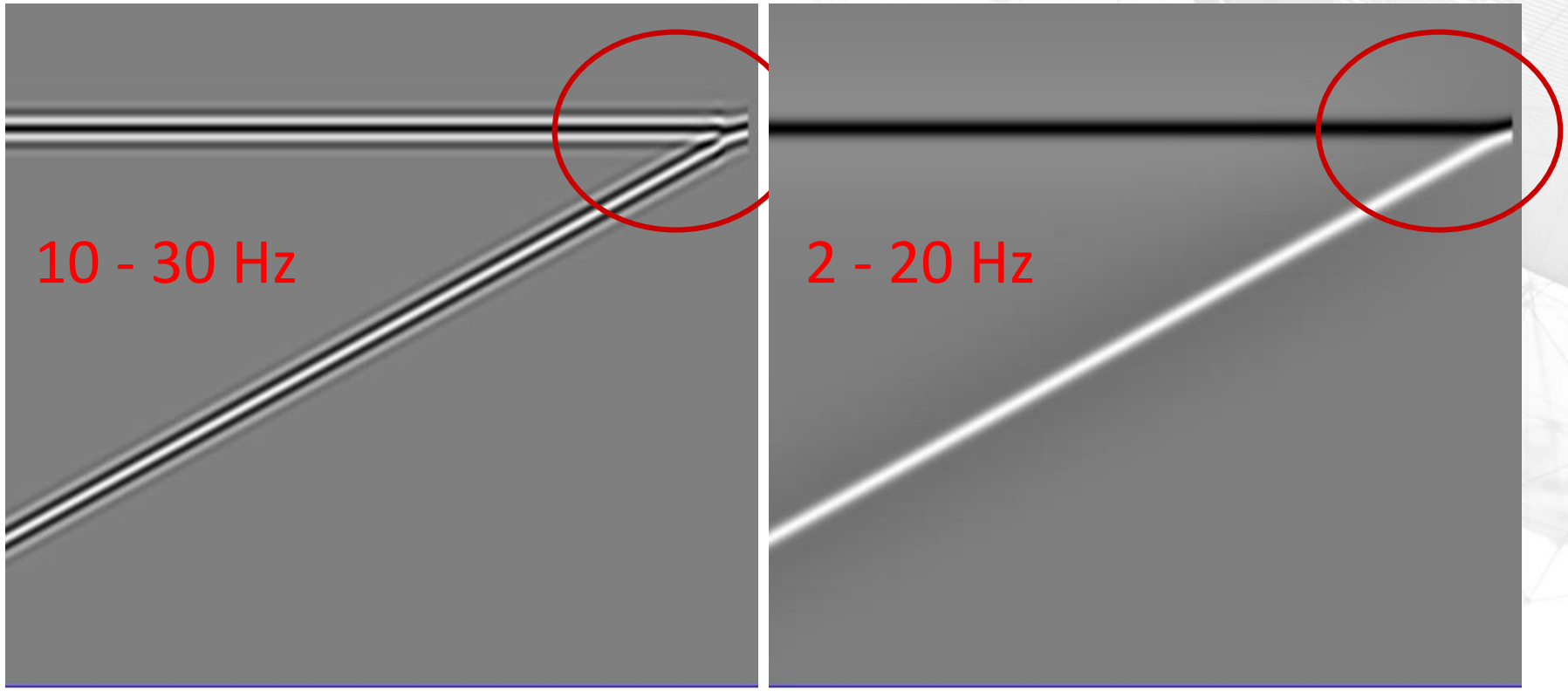


Resolution

- Why do we need low frequency signal to improve resolution?
- The high frequency limit control the width of the main lobe of the wavelet
- The low frequency content controls the depth of the side loves
- The sidelobes interfere and may prevent high resolution from high frequency wavelets



Side lobe interference



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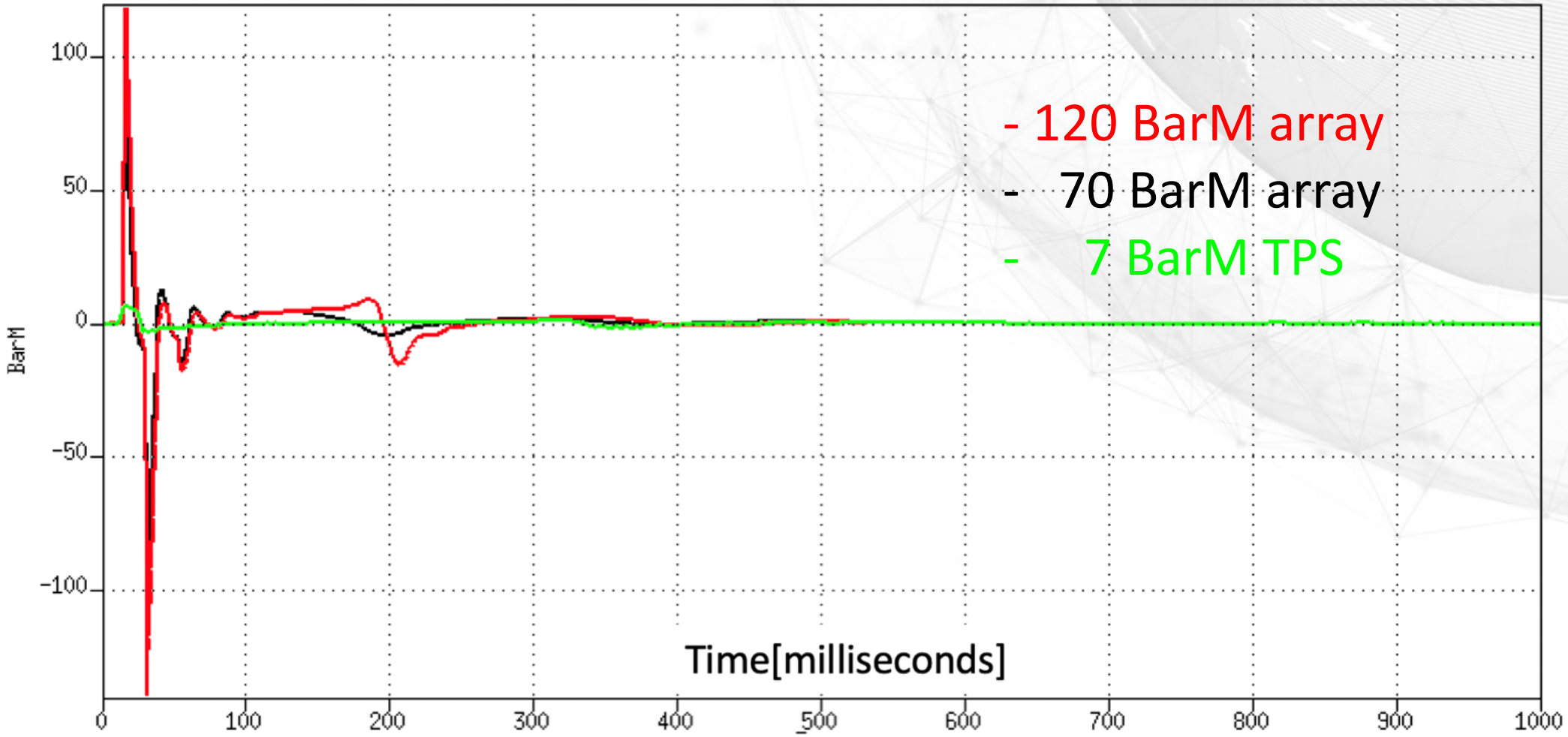
Environment: Sound Pressure Level (SPL)



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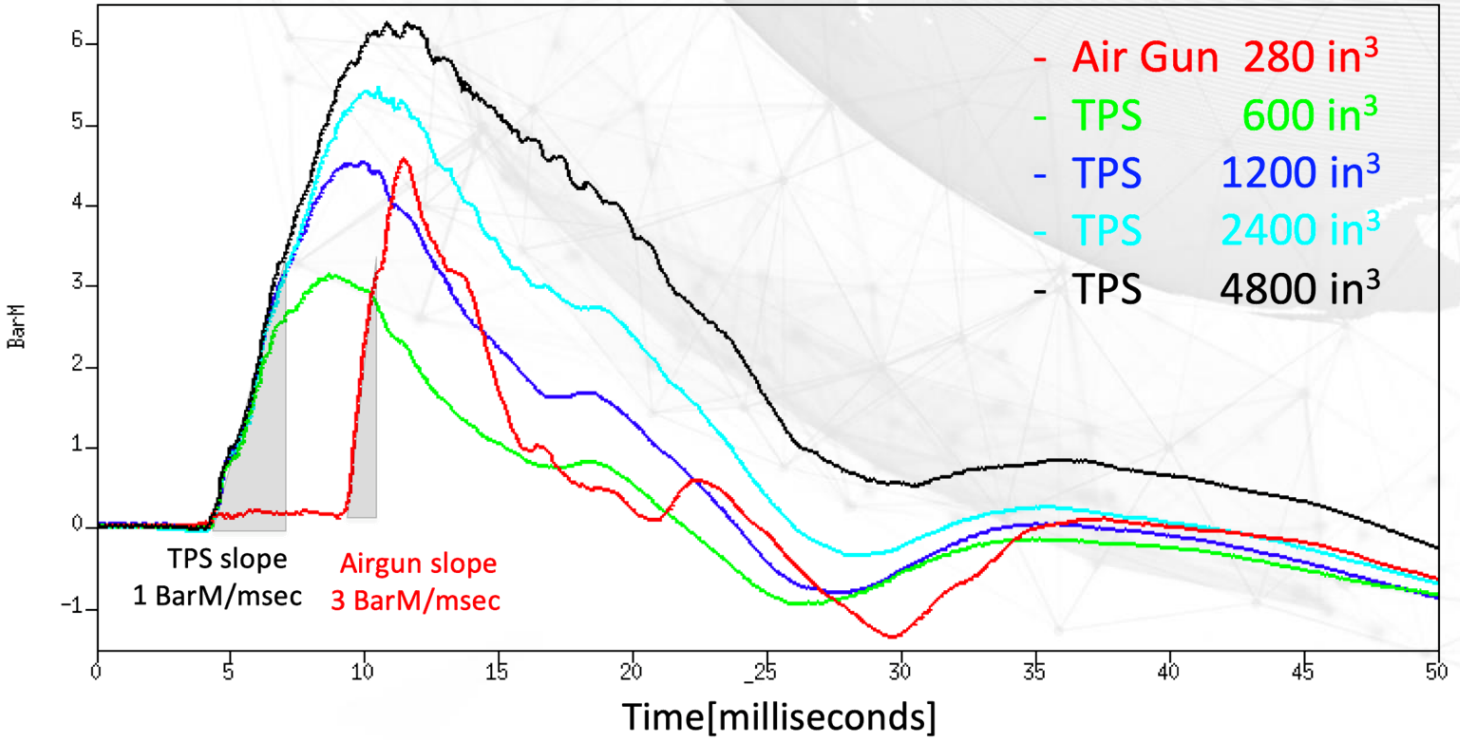
Environment: The SPL Slope

Pressure = Impedance times particle velocity

- 1 Bar → 7 cm / sec
- 1 Bar/msec → 7 g
- Each Airgun produces 3 BarM/msec
- 33 Airguns produce 100 BarM/msec
- 100 meters under → 7g
- TPS slope is 1 BarM/msec
- 100 meters under → 0.07 g



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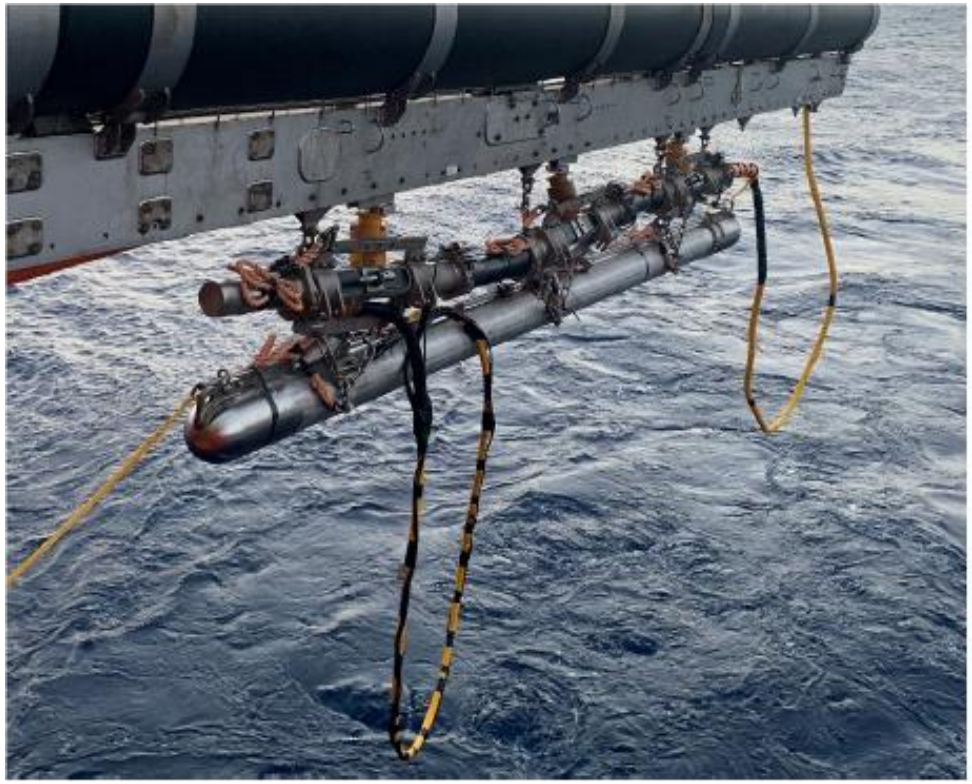
One Acquisition slide: Plug-and-play

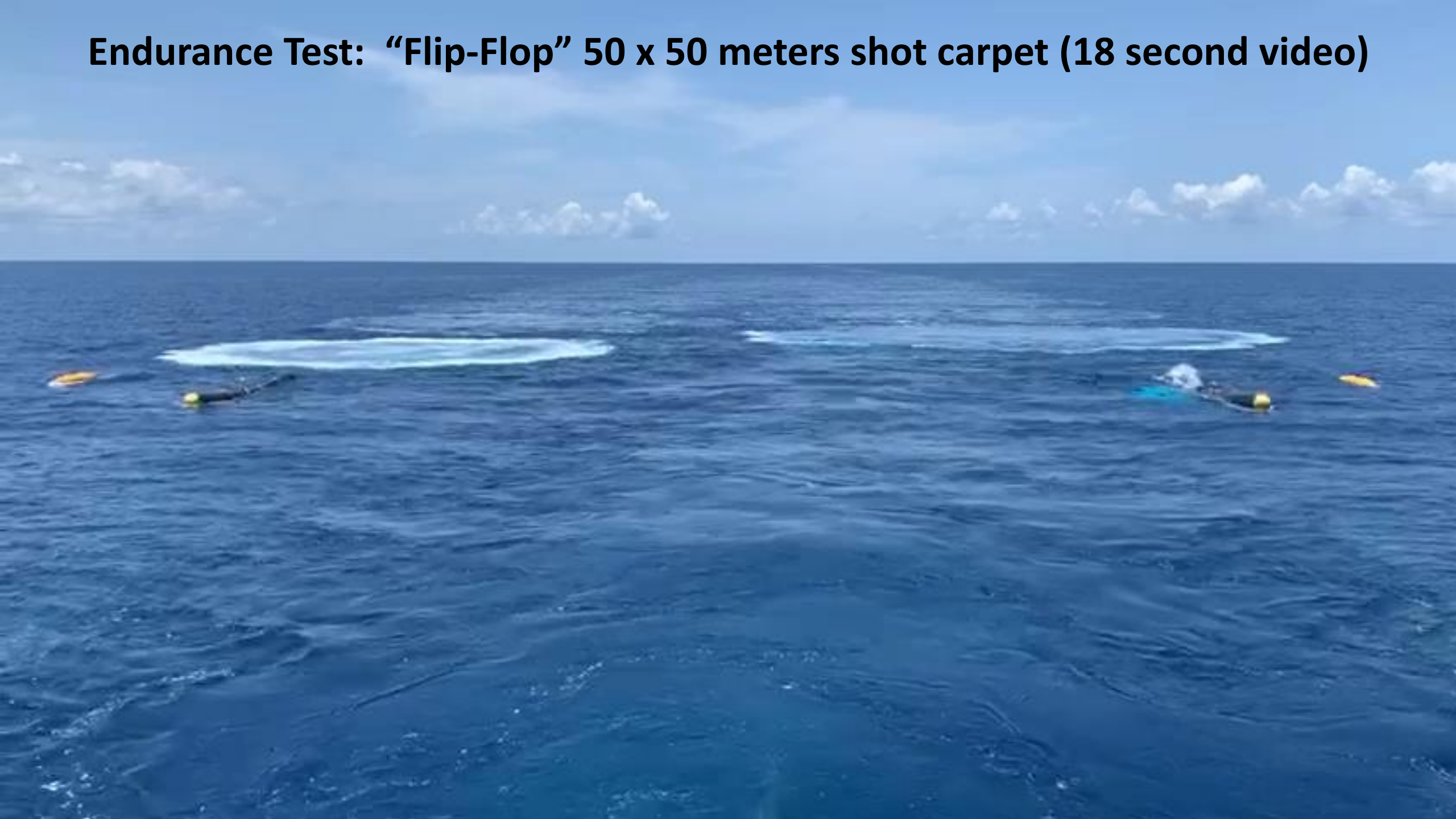
2020 “Sea Trial”
booms and rigid floats



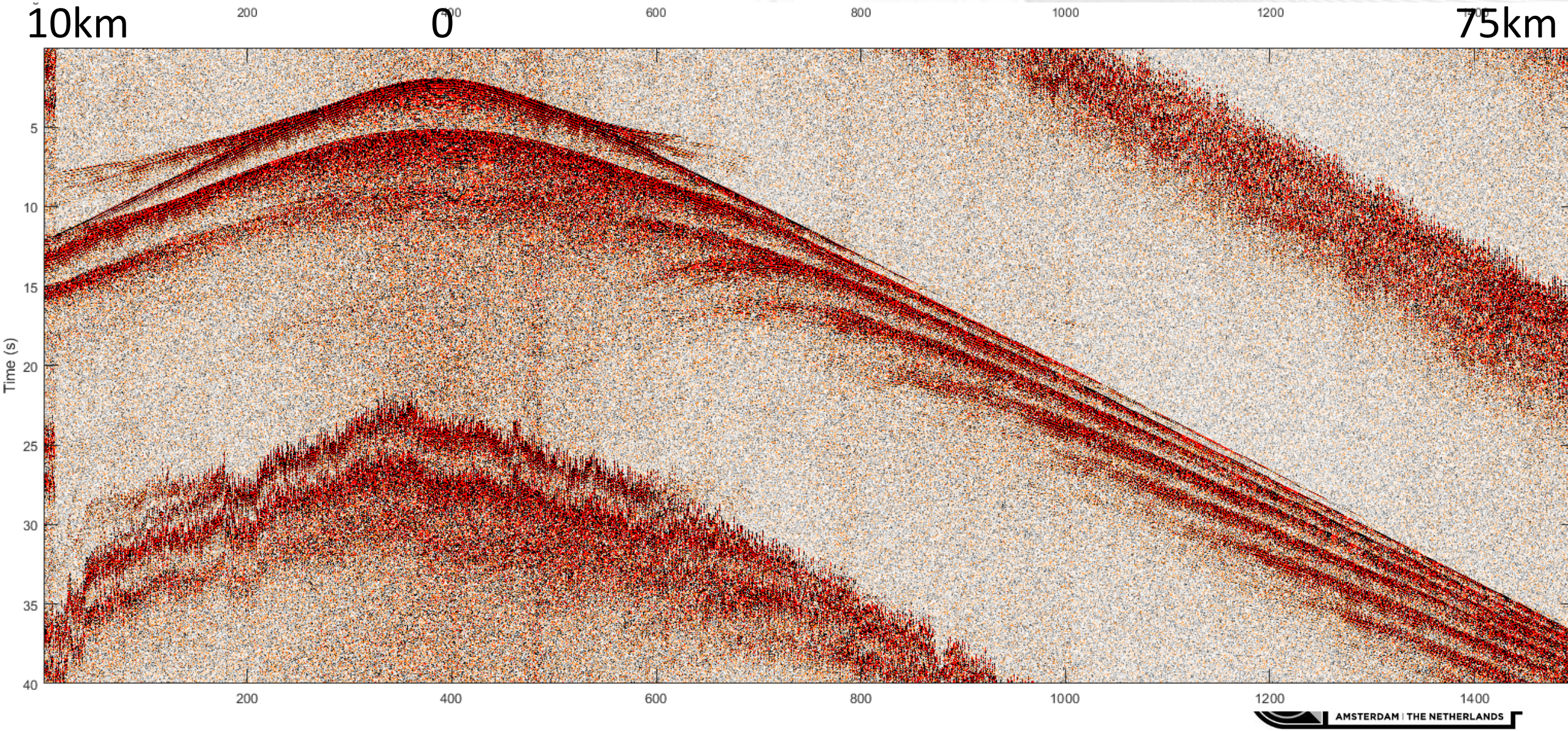
2021 “Endurance Test”
Slipway with flexible floats



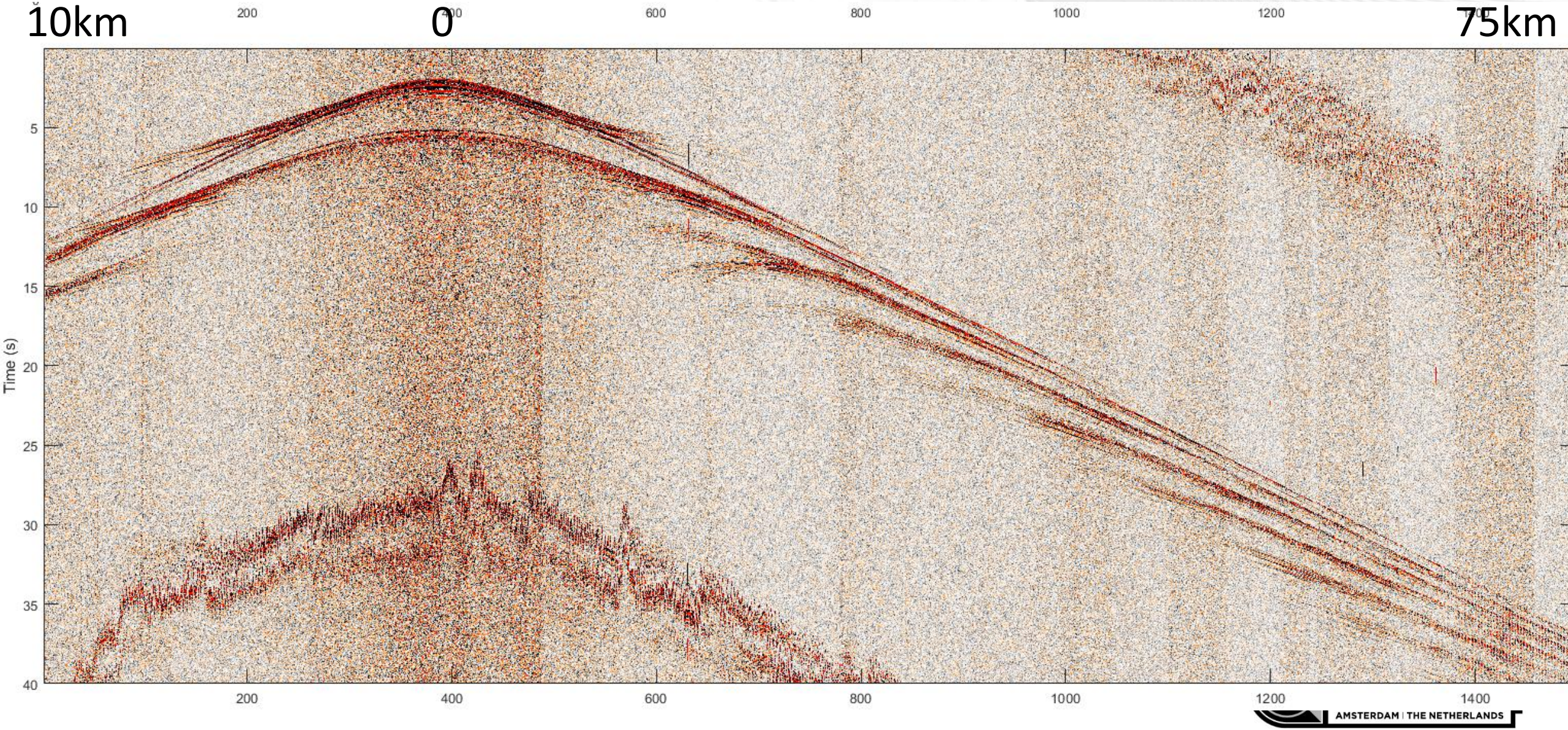
Endurance Test: “Flip-Flop” 50 x 50 meters shot carpet (18 second video)



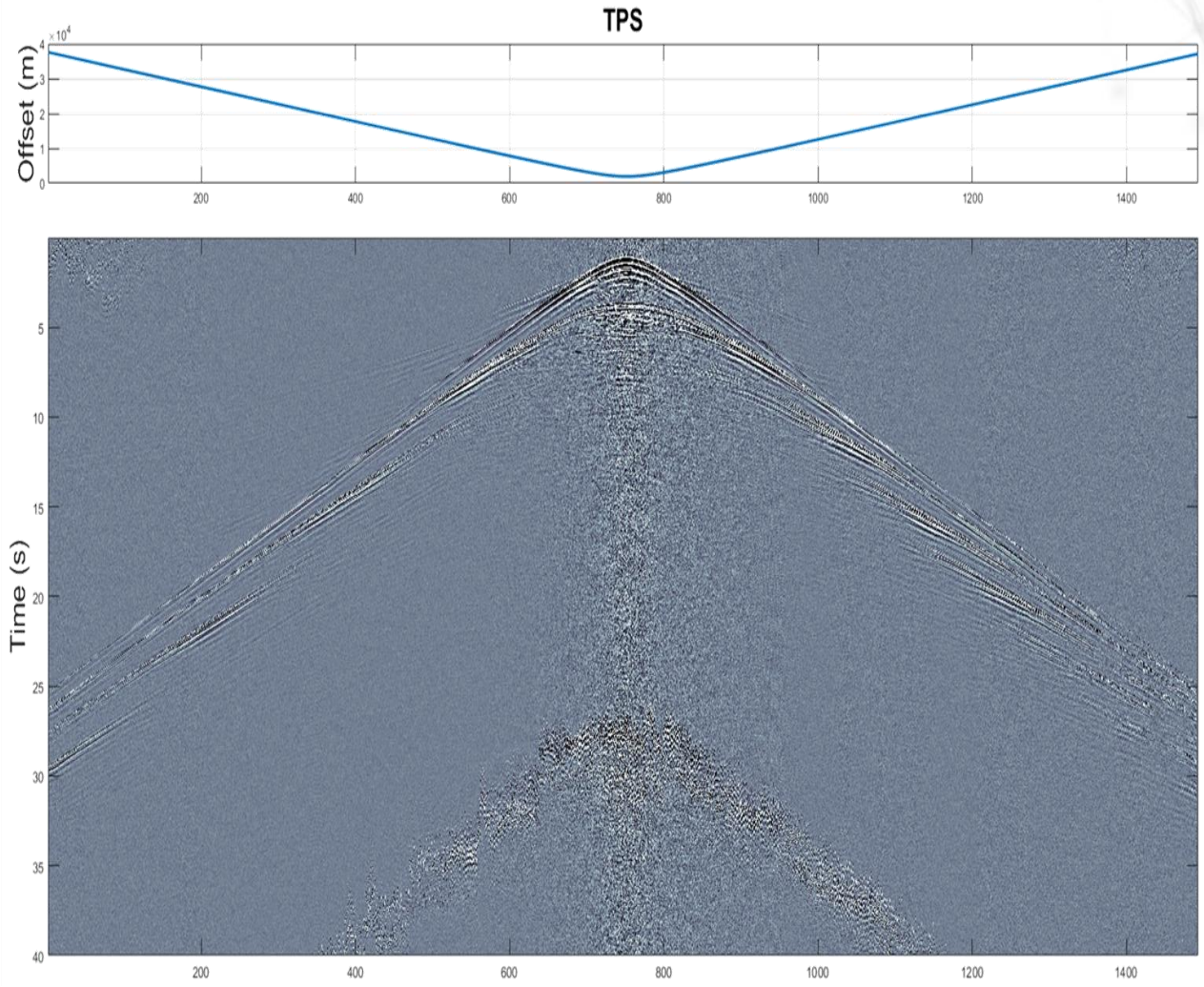
Common Receiver Gather—Airgun array

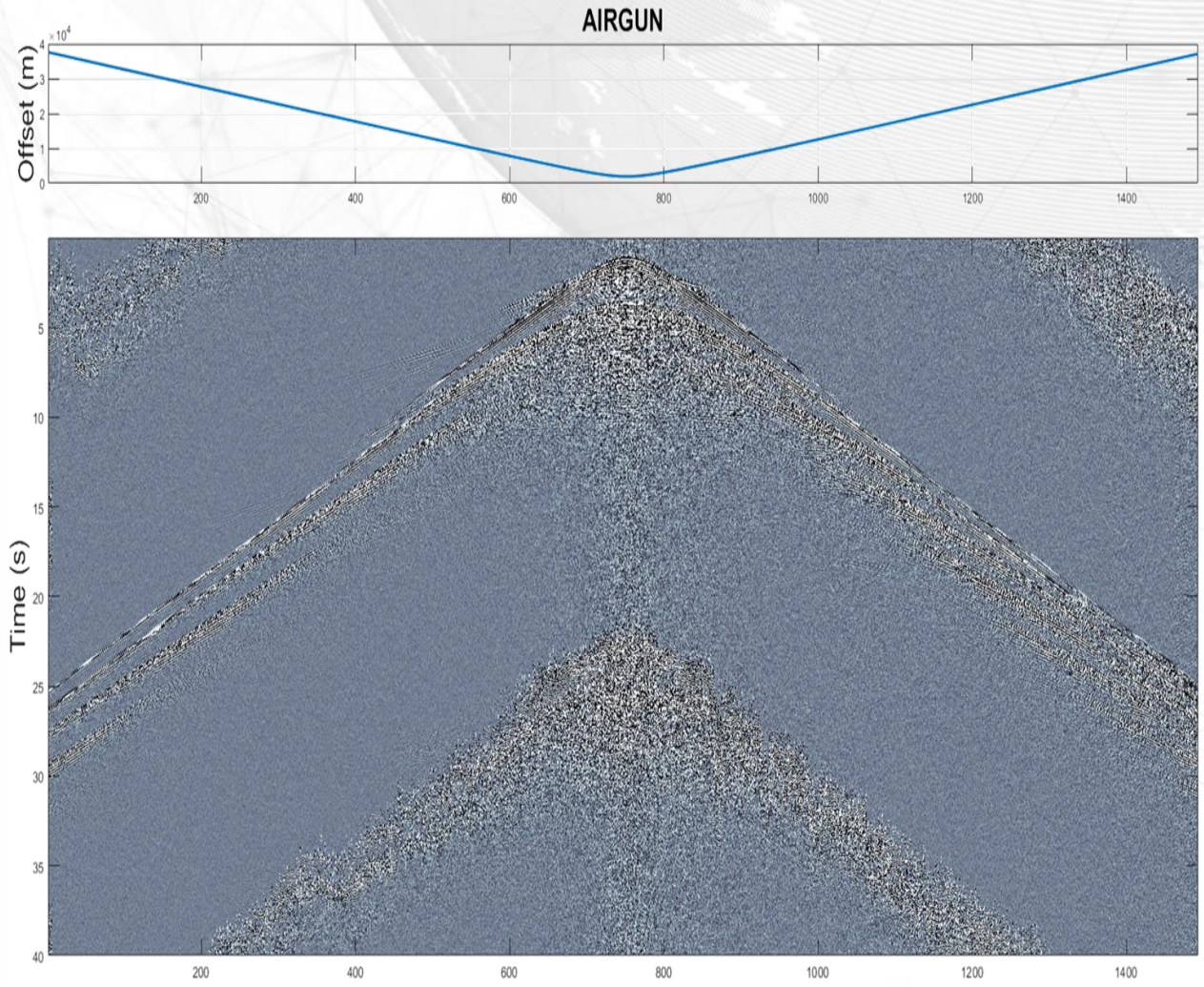


Common Receiver Gather—TPS



Side by side





Next few slides

Limited Time and space

0 to 40 km offset (one side)

20 seconds time window

Limited Frequency Displays (in time space domain)

High cuts: 10Hz, 5, 4, 3,2 ,1 Hz

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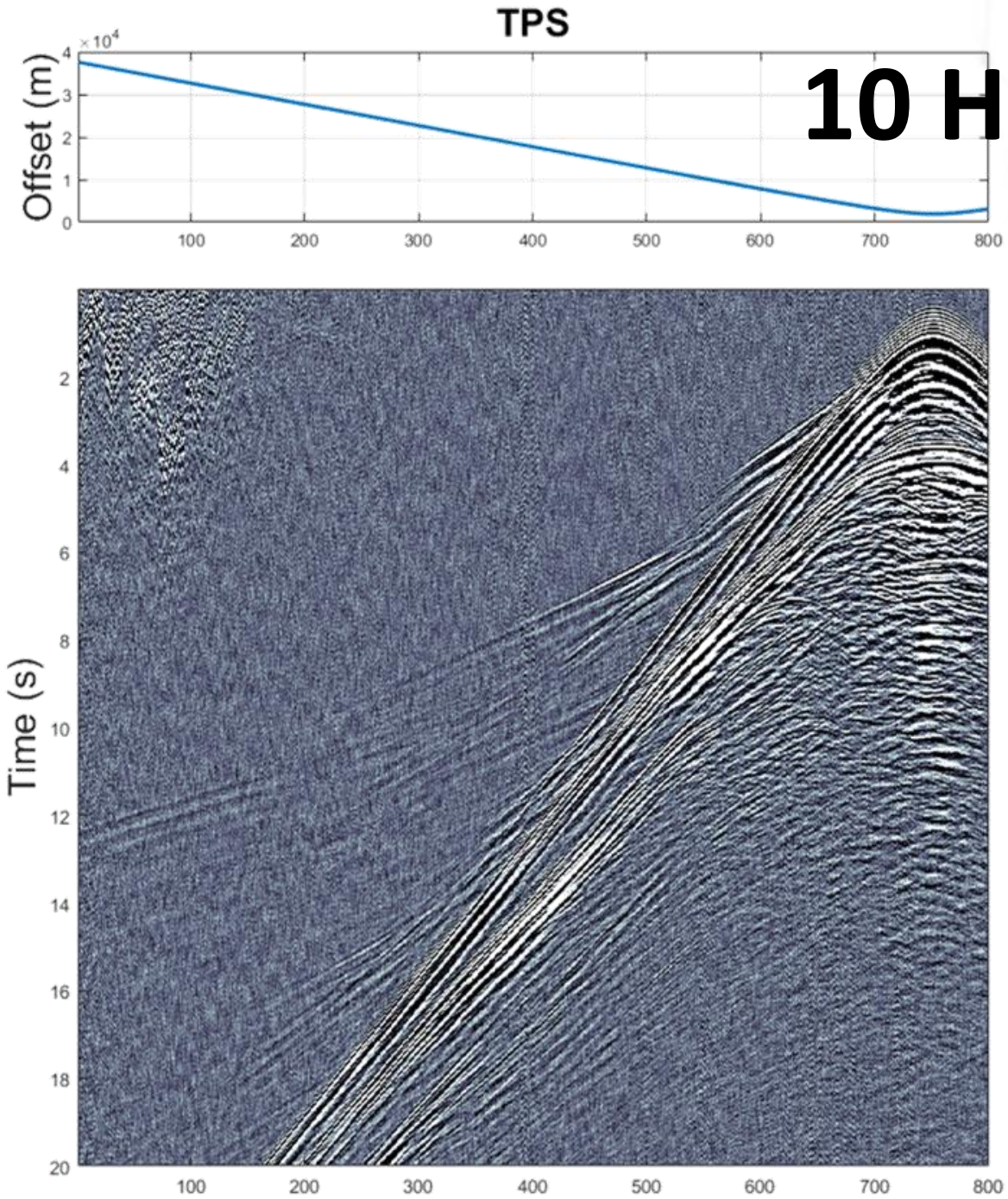
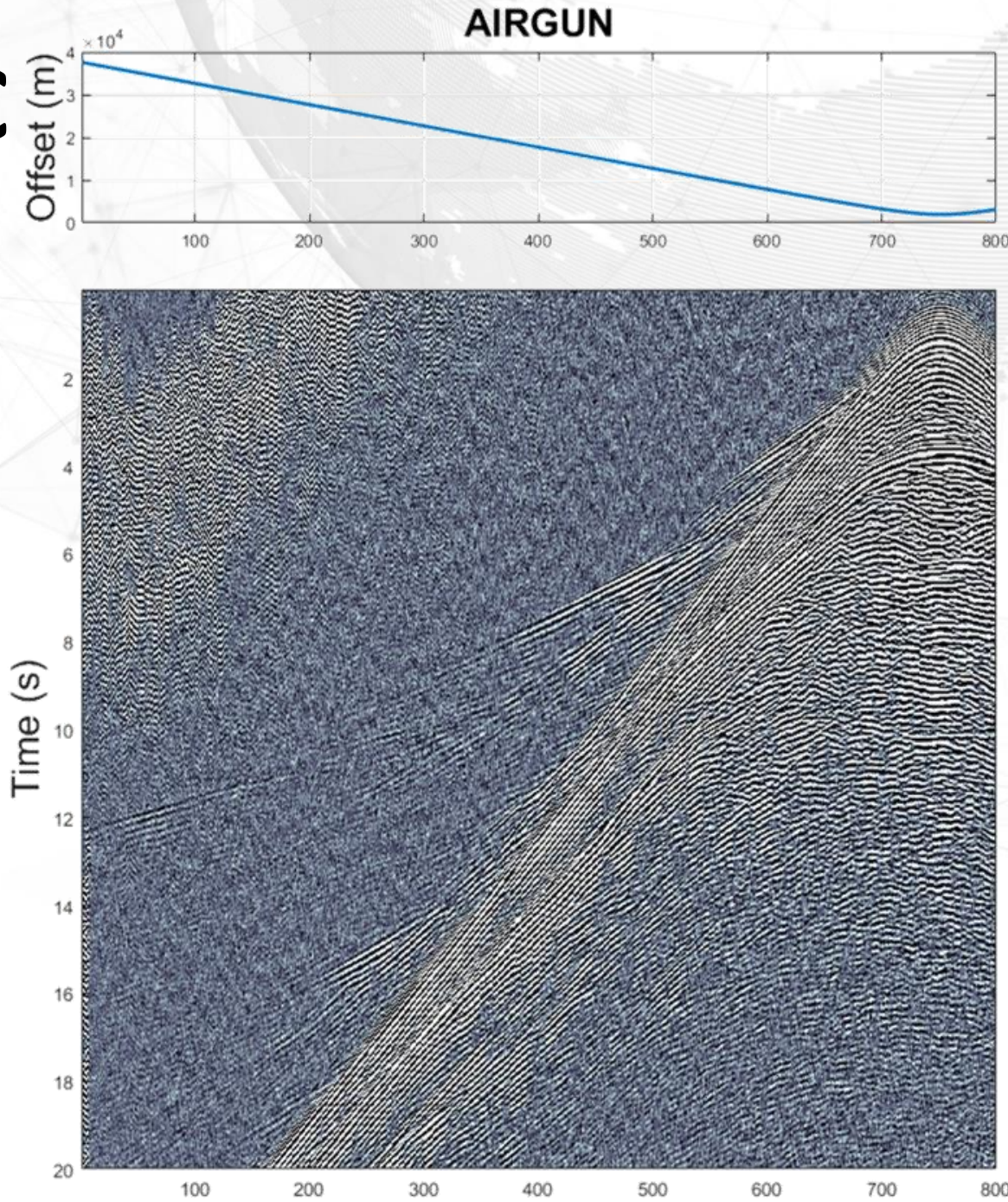
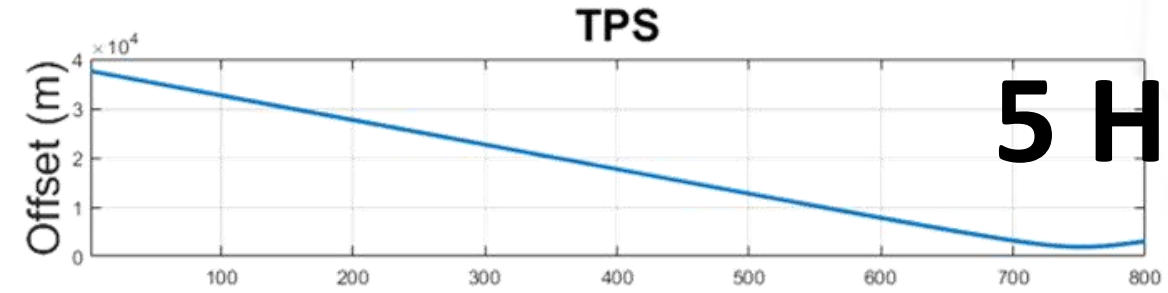
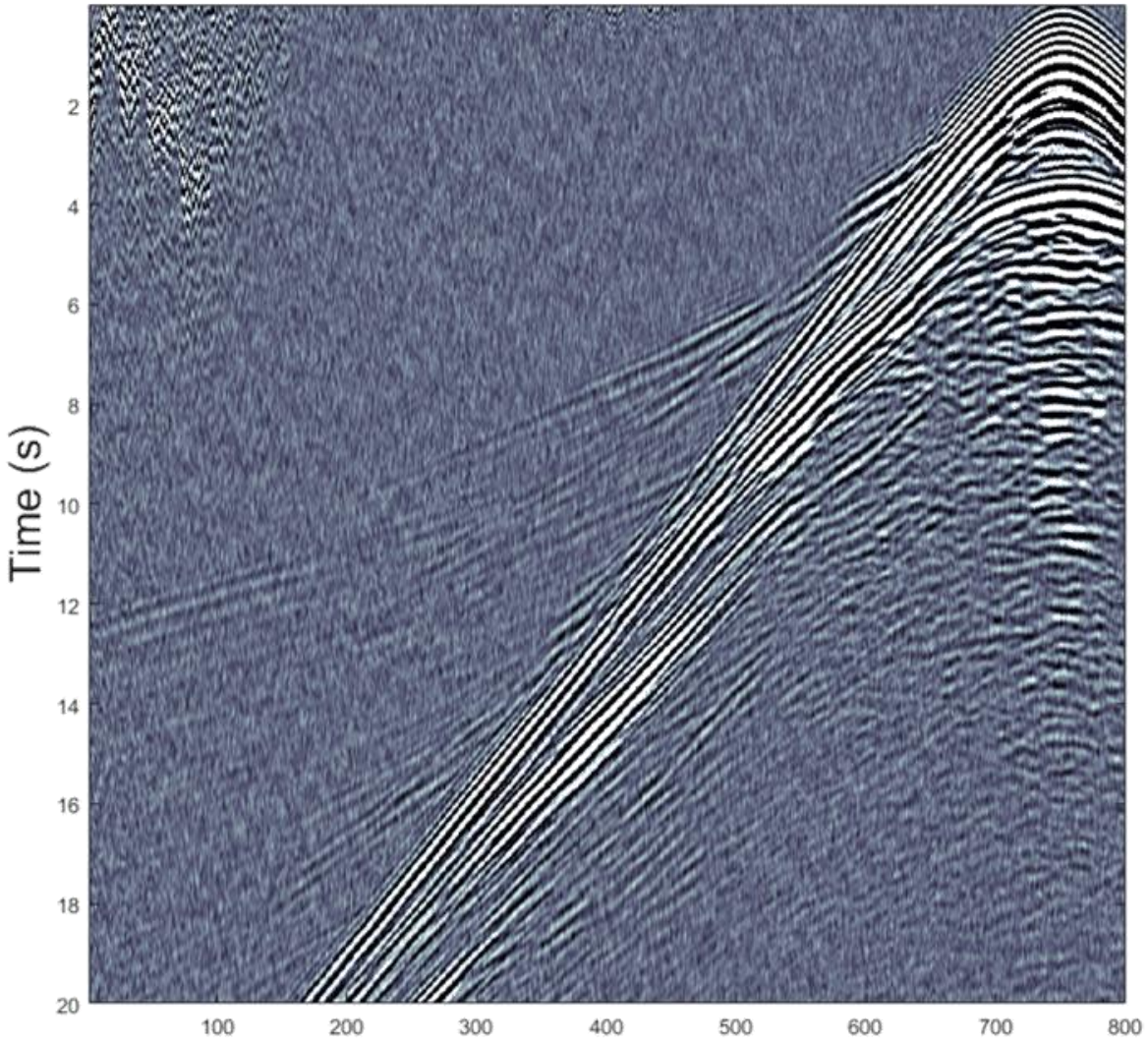
10 Hz HC





5 Hz HC


TPS
Offset (m)
×10^4
0
1
2
3
4
100
200
300
400
500
600
700
800


Time (s)
2
4
6
8
10
12
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16
18
20
100
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500
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700
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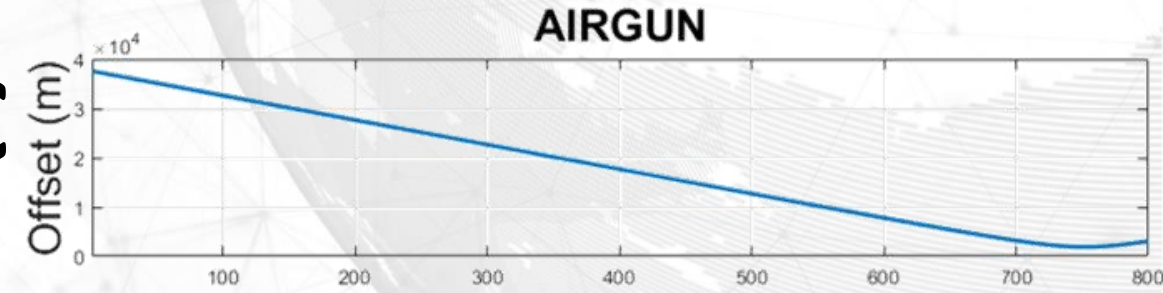
AIRGUN
Offset (m)
×10^4
0
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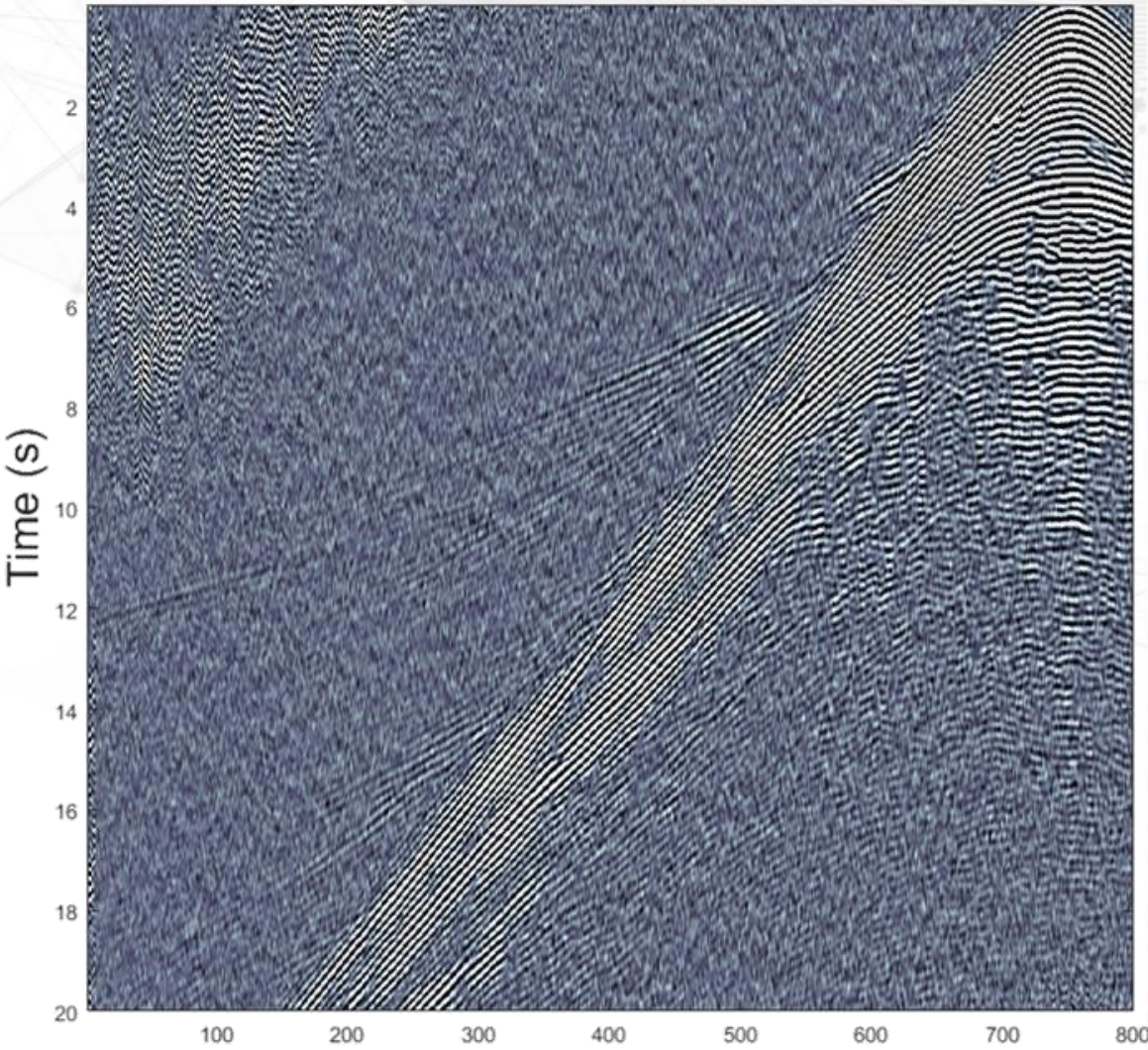
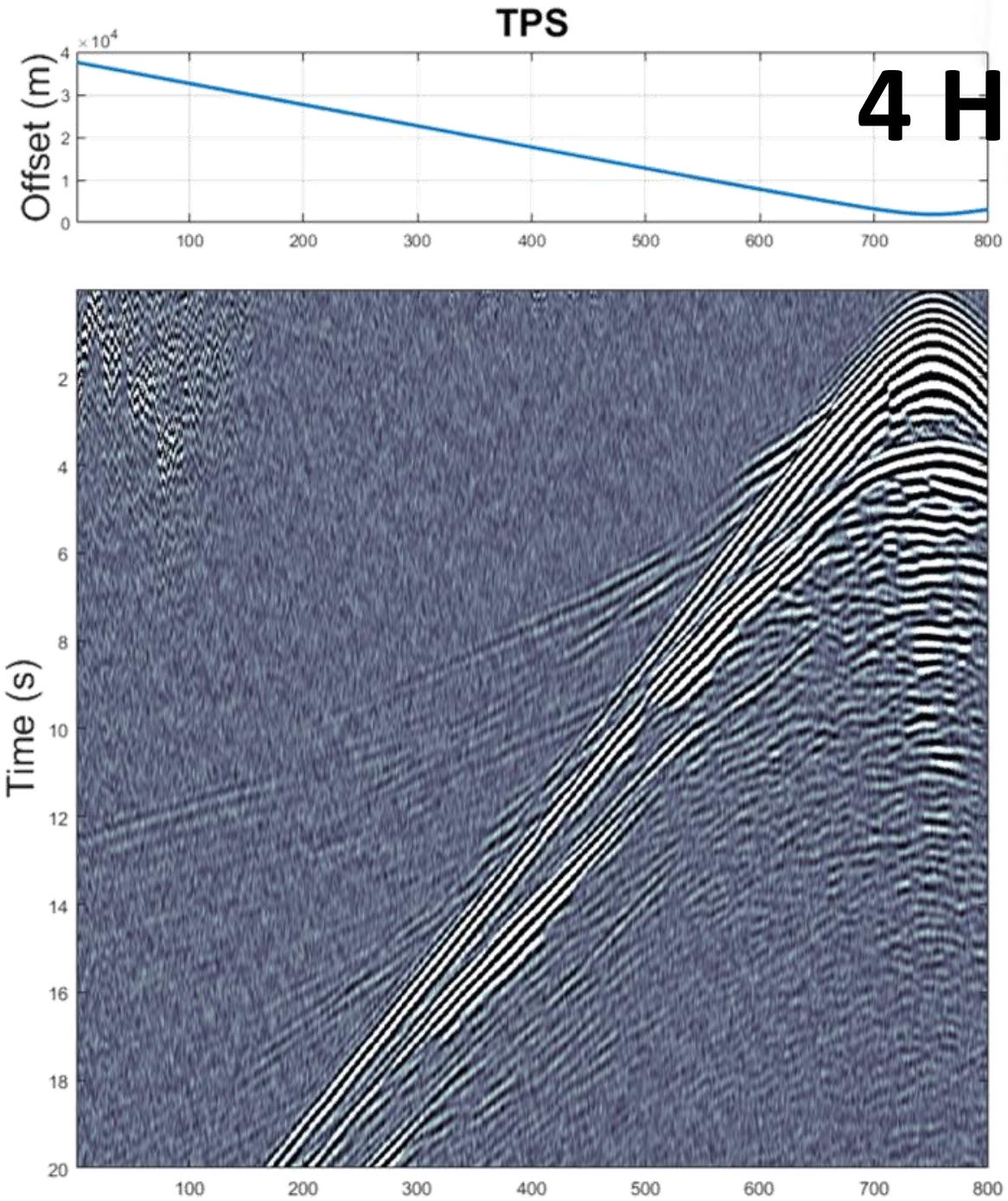
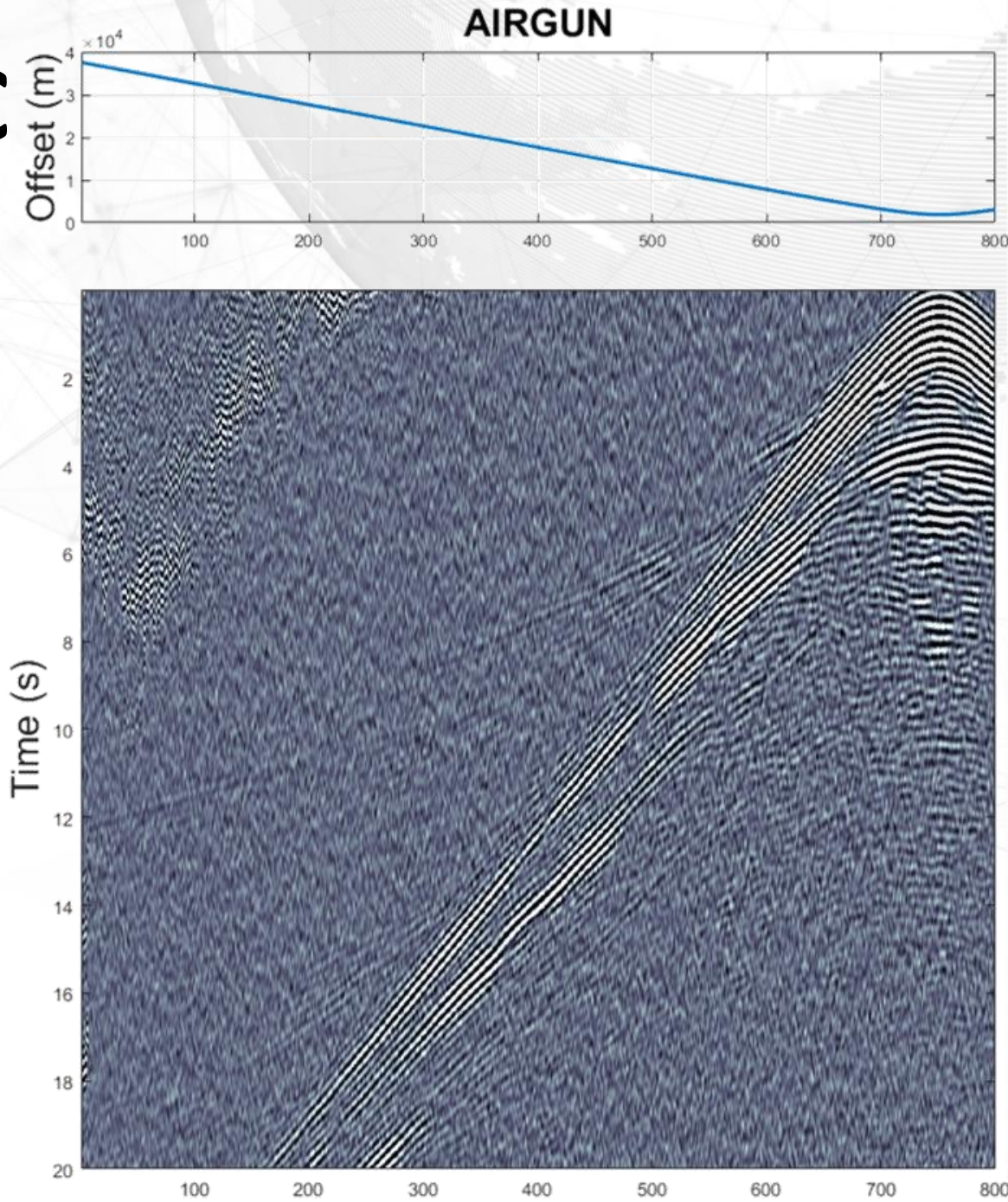
500
600
700
800

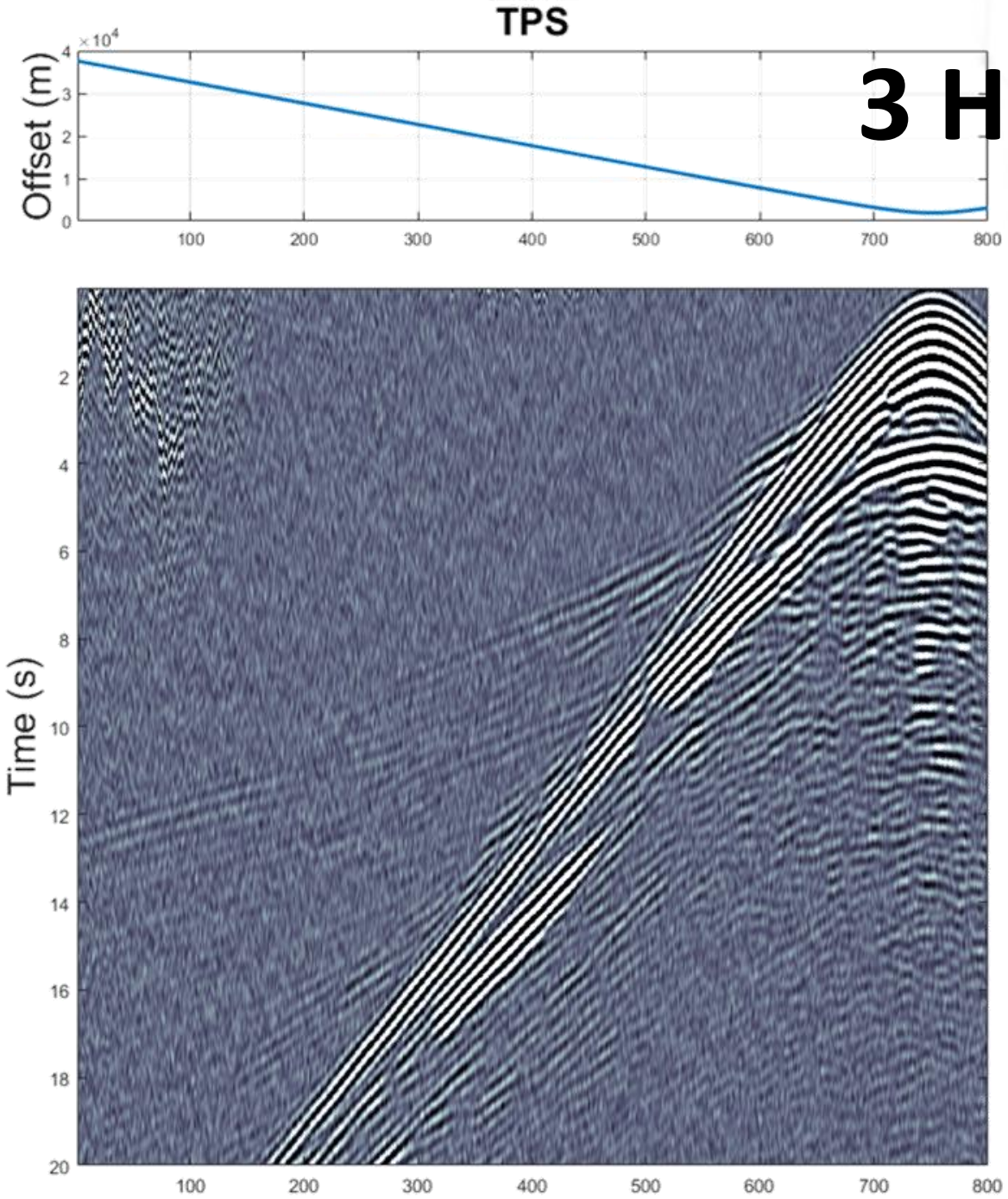

Time (s)
2
4
6
8
10
12
14
16
18
20
100
200
300
400
500
600
700
800

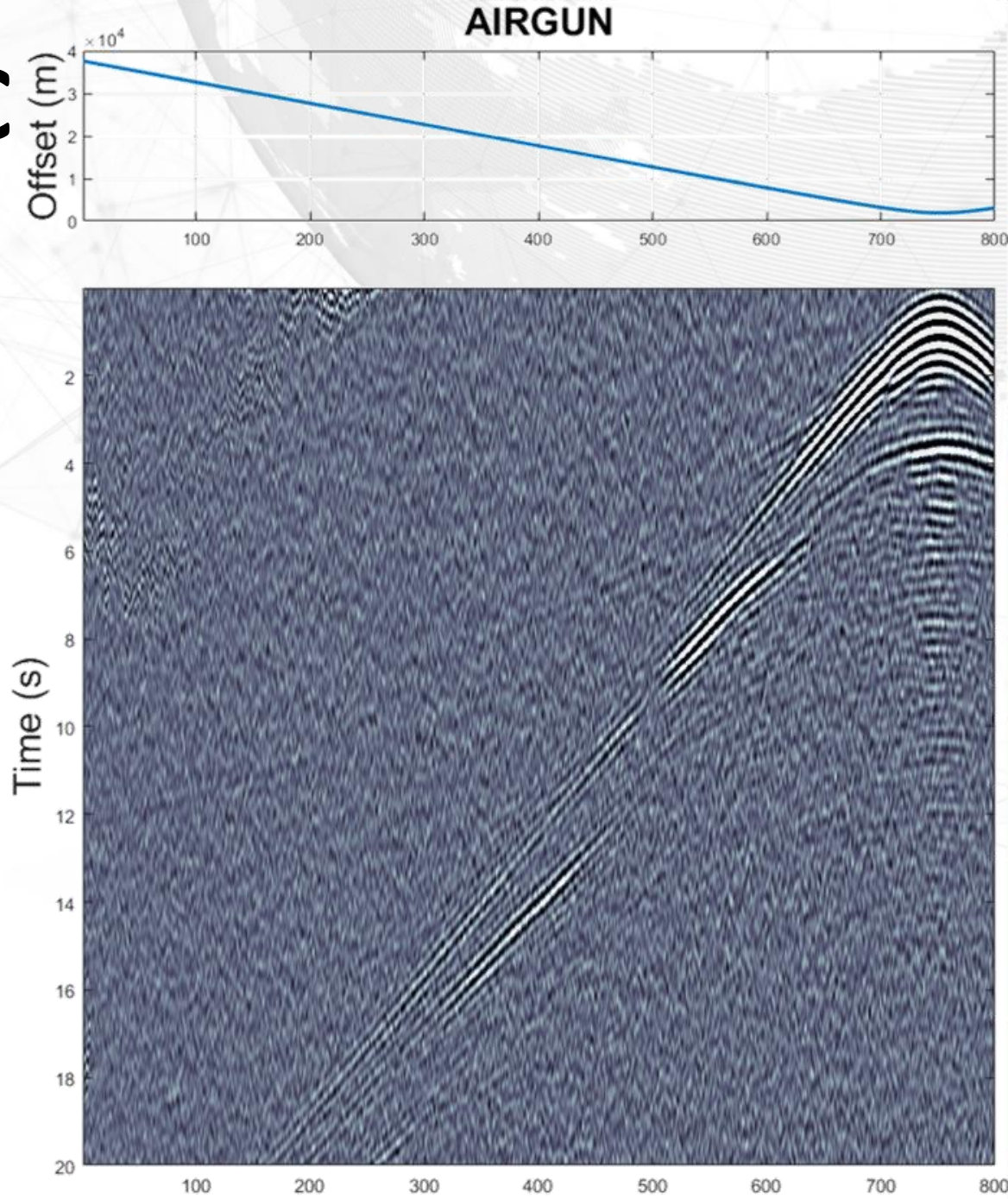
4 Hz HC



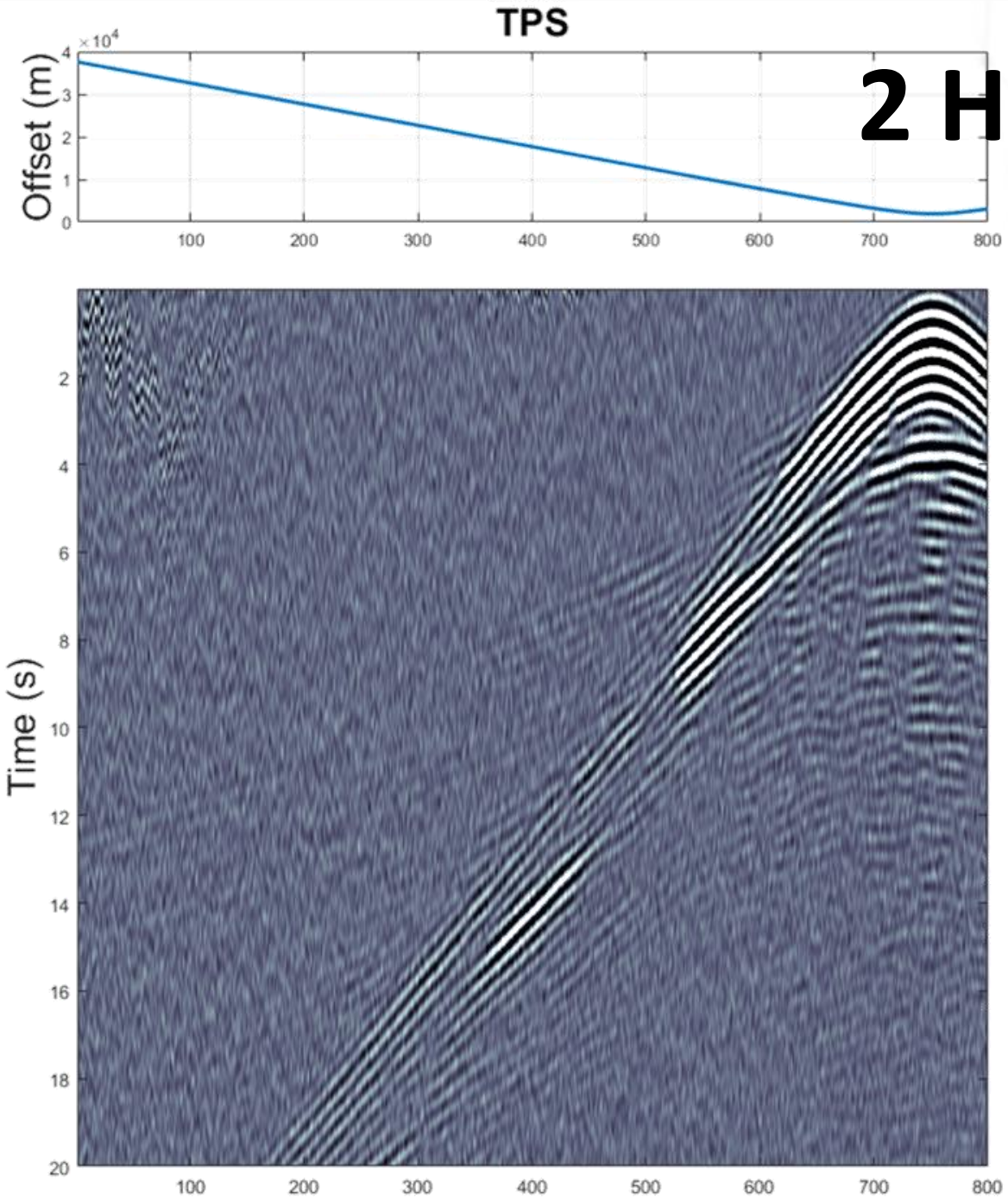


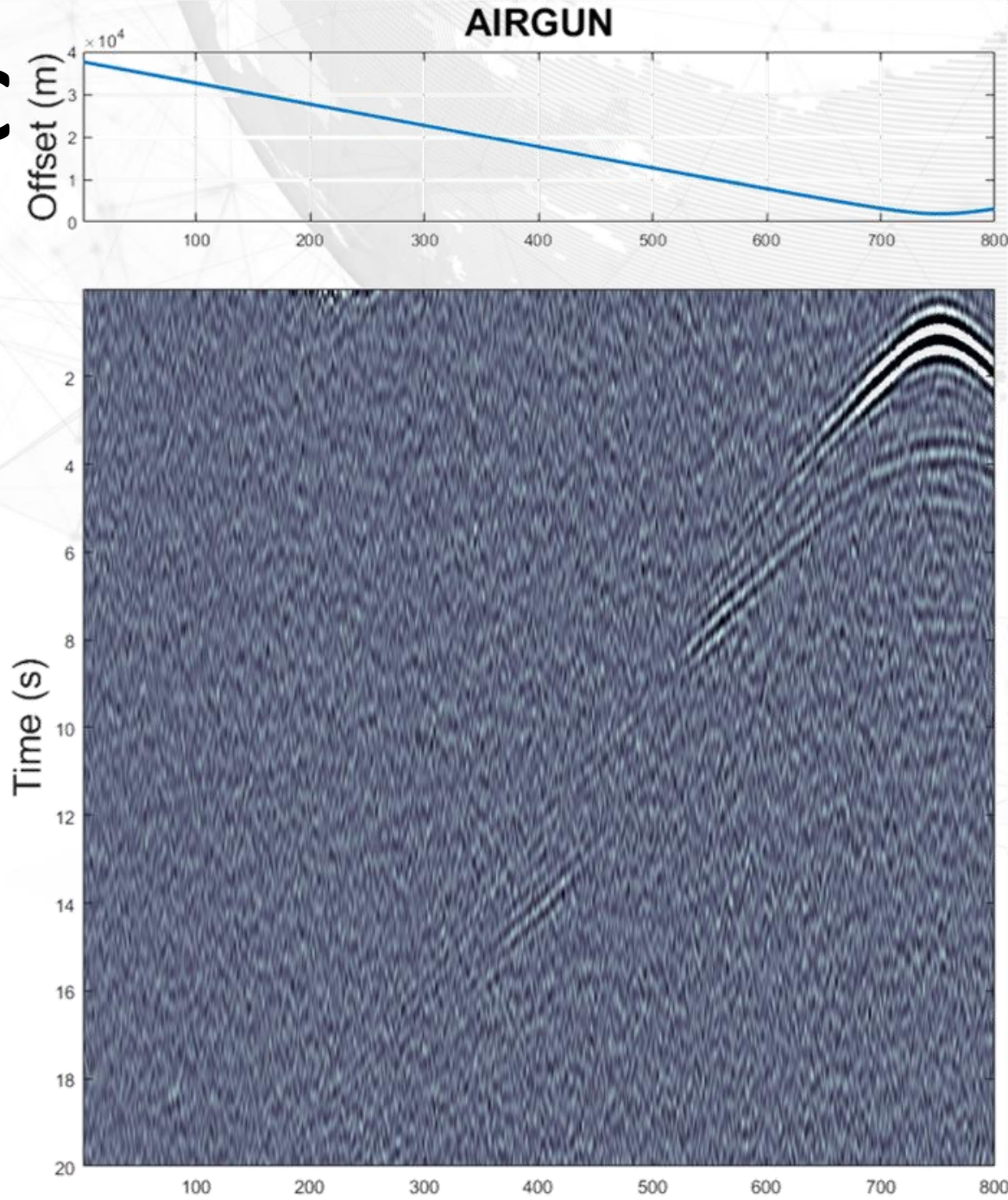
3 Hz HC



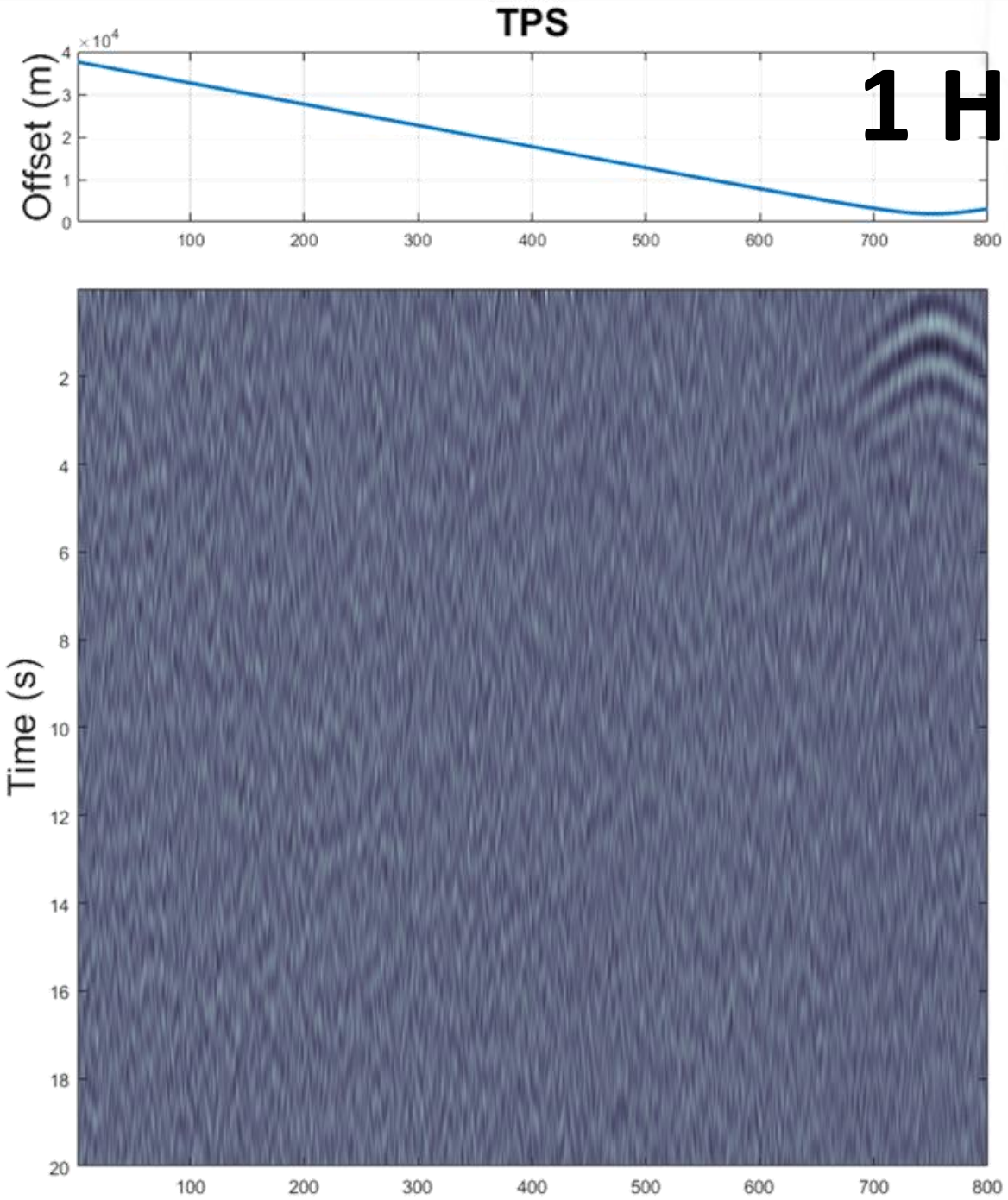


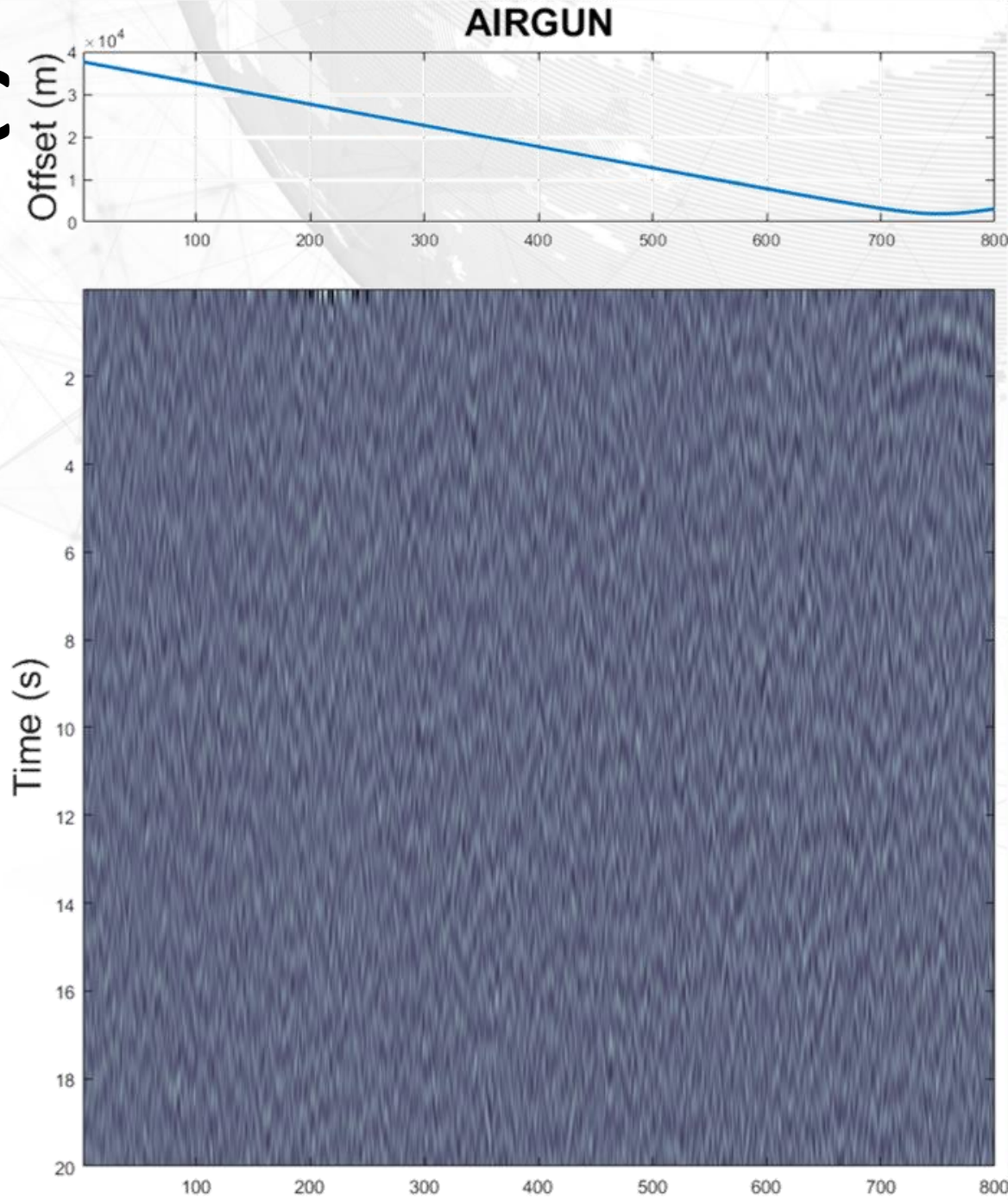
2 Hz HC





1 Hz HC





Next two slides

CRG after HMO aka LMO

CRG = Common receiver Gather

HMO = Hyperbolic Move Out (flattens the direct arrivals)

LMO = Linear Move Out (same thing)

Limited Frequency Displays (in time space domain)

Next slide: Full band (unlimited frequency)

Next^2 slide: 0-2 Hz (2 Hz high-cut)

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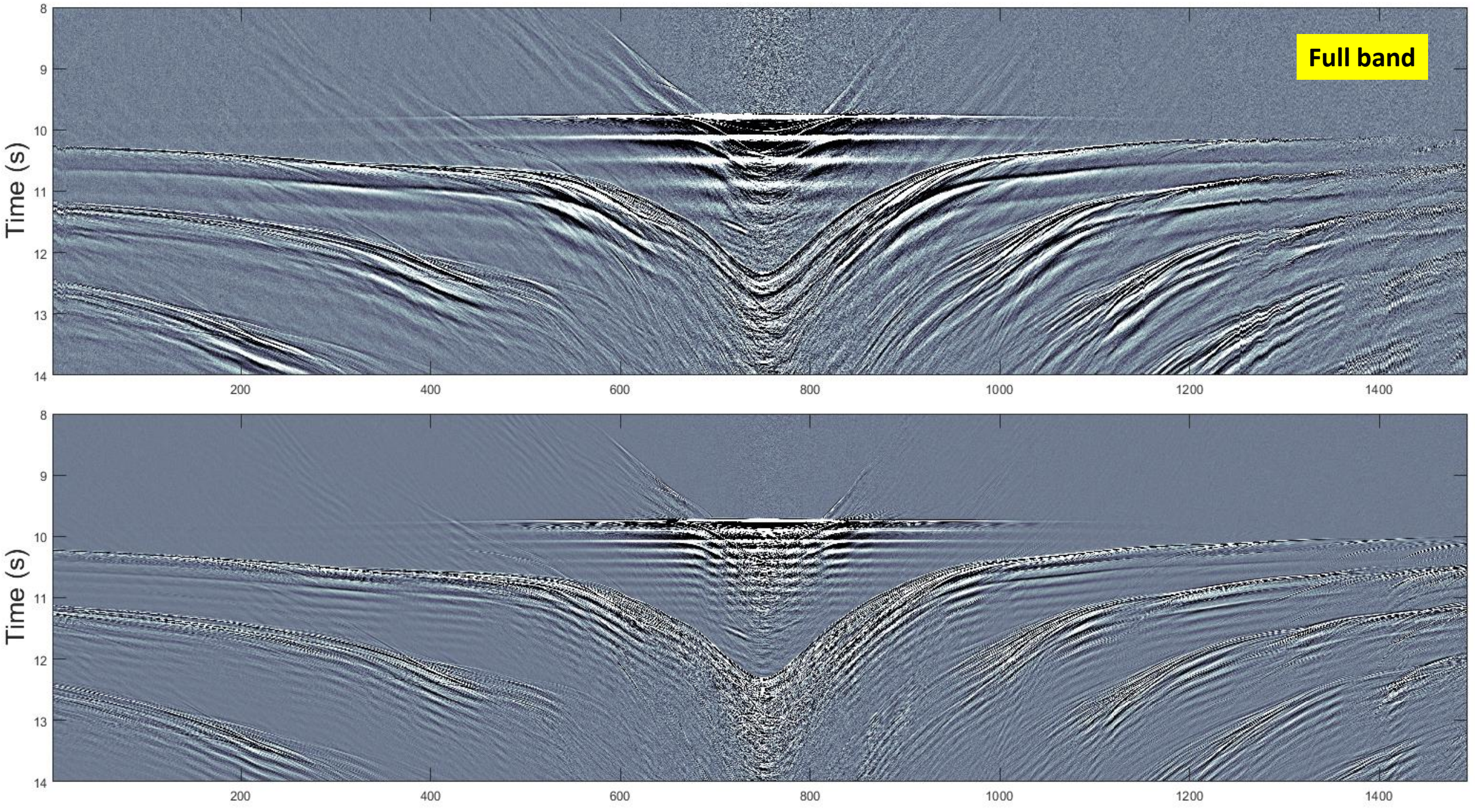
Full band
Time (s)
8
9
10
11
12
13
14
200
400
600
800
1000
1200
1400
Time (s)
8
9
10
11
12
13
14
200
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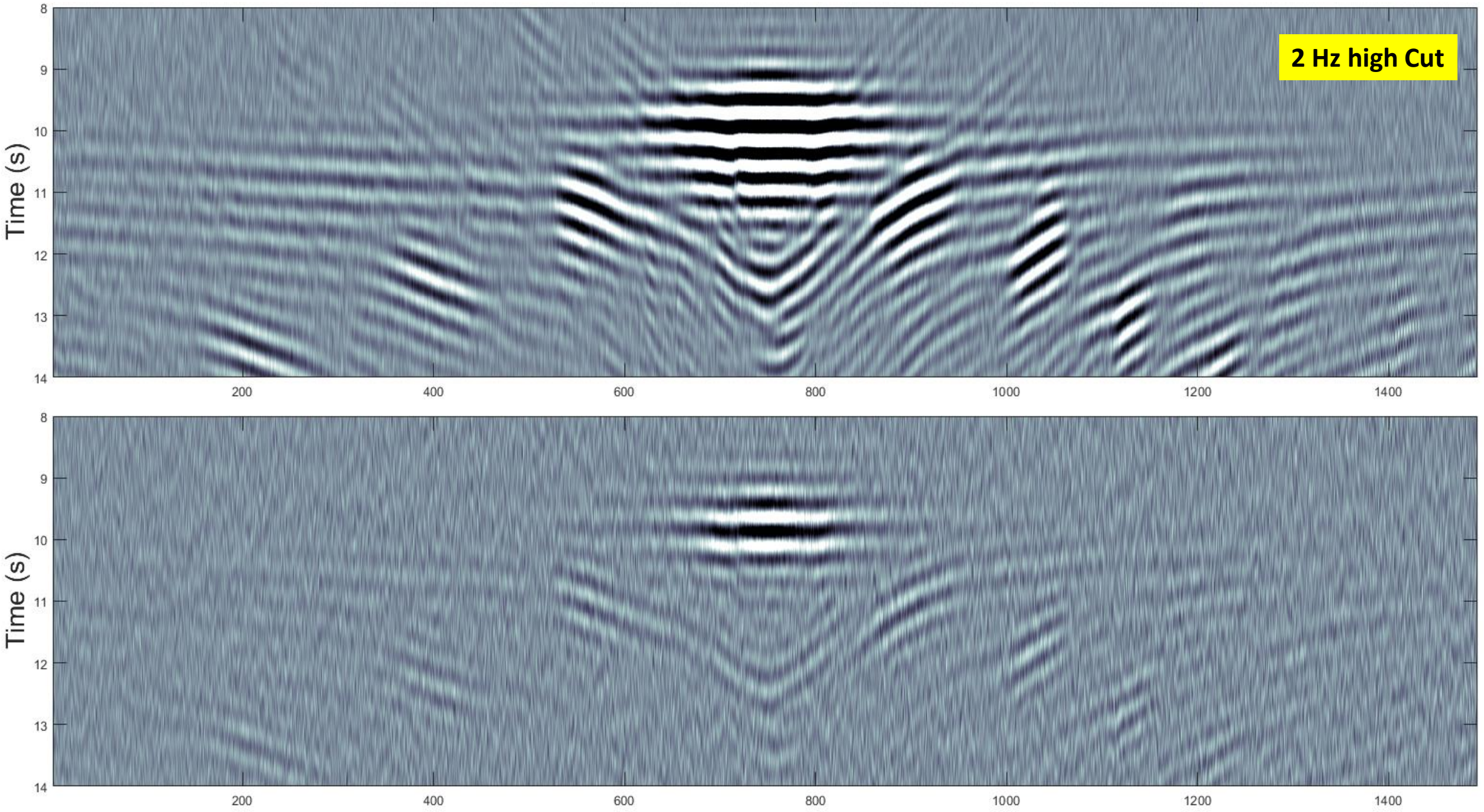
600
800
1000
1200
1400


2 Hz high Cut
Time (s)
8
9
10
11
12
13
14
200
400
600
800
1000
1200
1400
Time (s)
8
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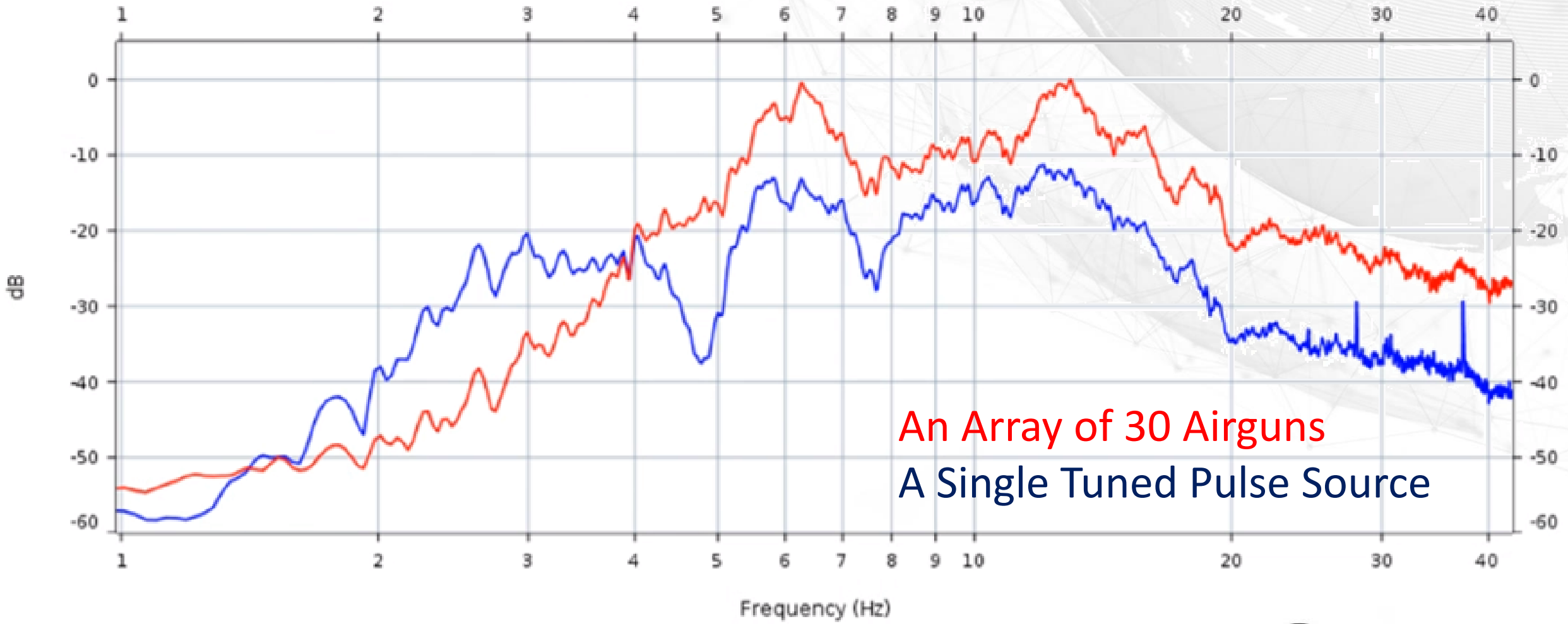
1000
1200
1400

Spectral overlay (OBN data)



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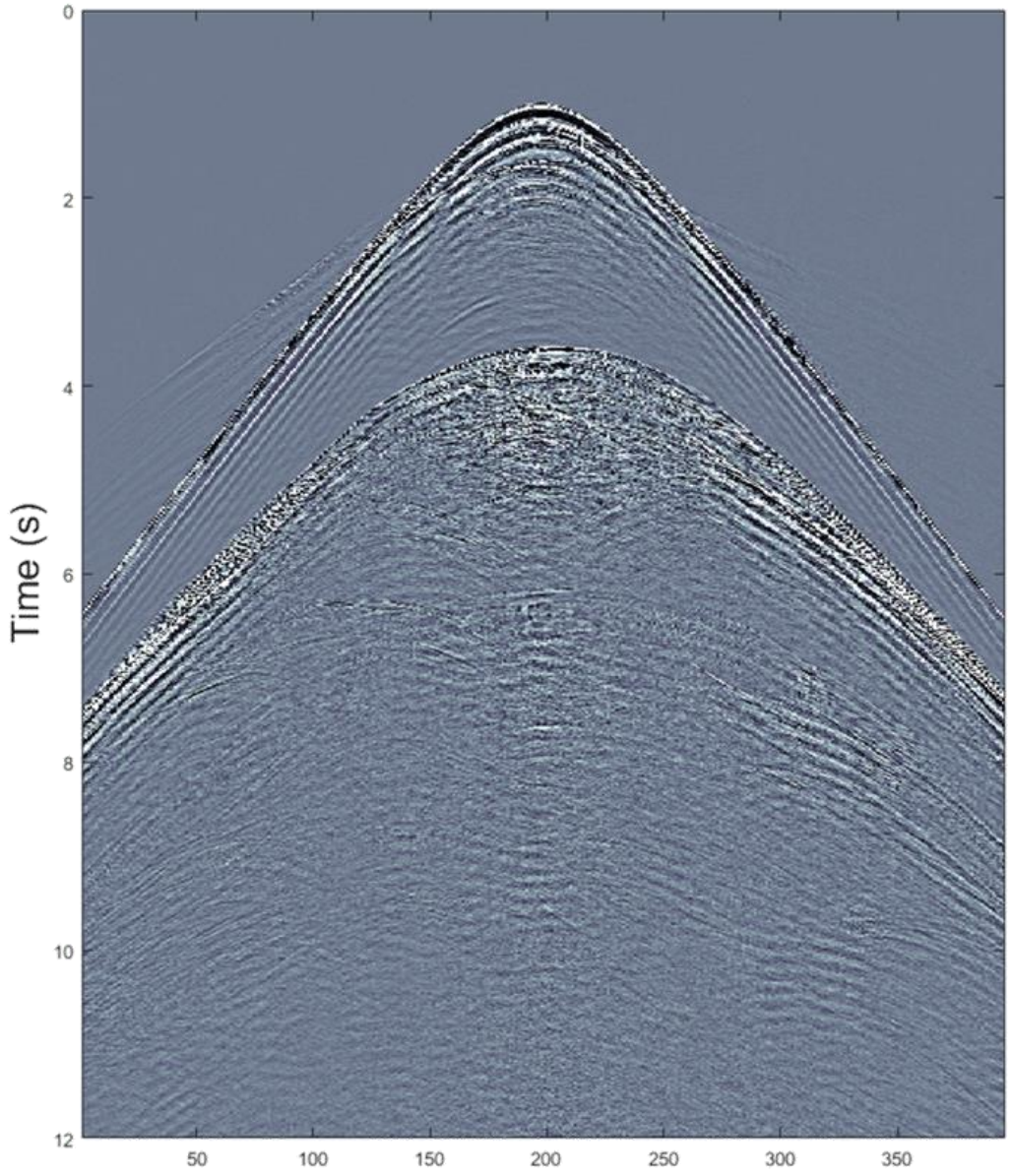
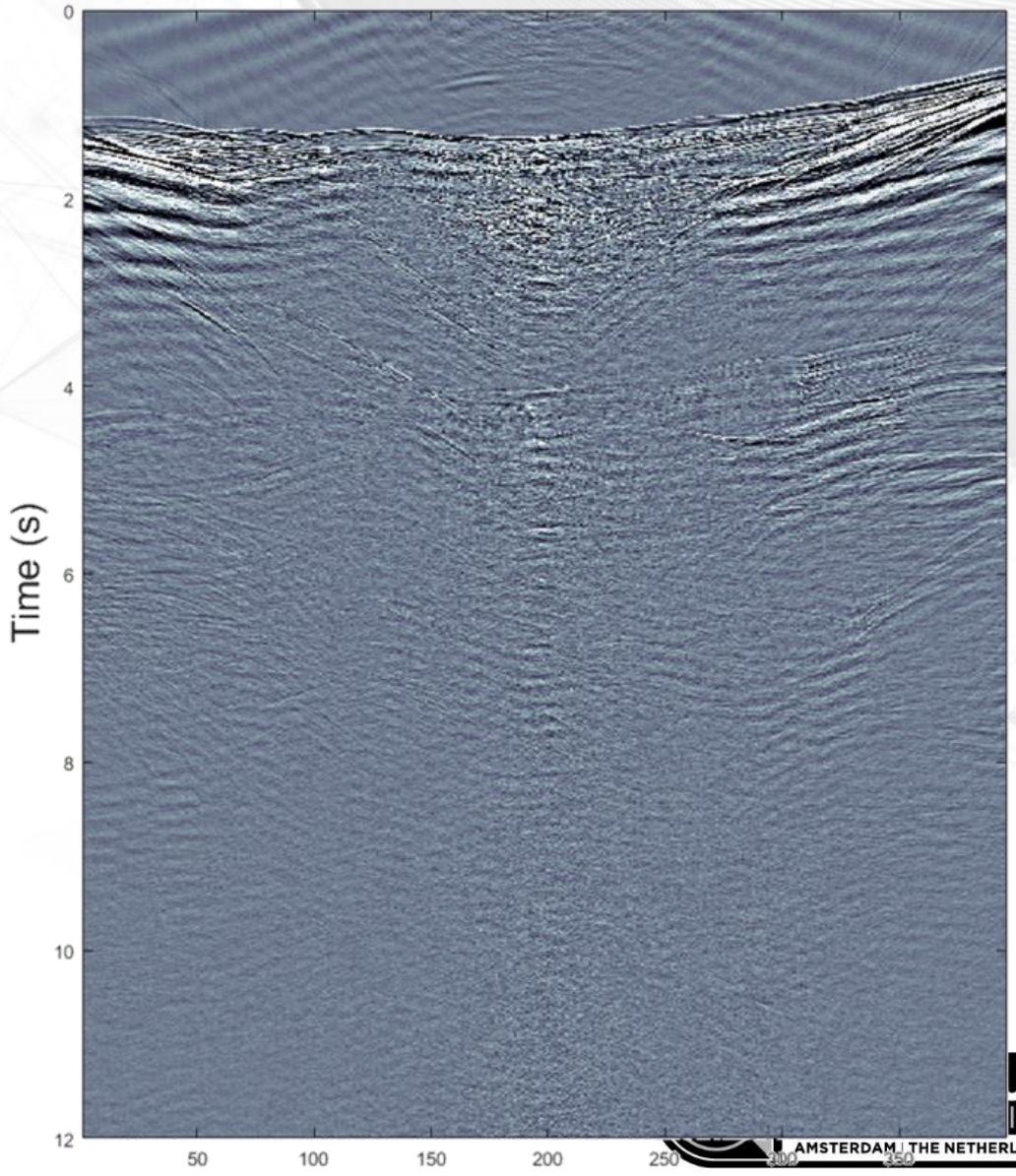
Next few slides

- (Poor man's) Mirror Imaging
- One node's common receiver gather
- One shot line
- Spherical spreading (tpow) gain
- Normal moveout (NMO)
- Select the first multiple which is the mirror image
- That's it, just display it
- Airgun array and TPS
- Full band and High cut

Airgun array—full band, NMO





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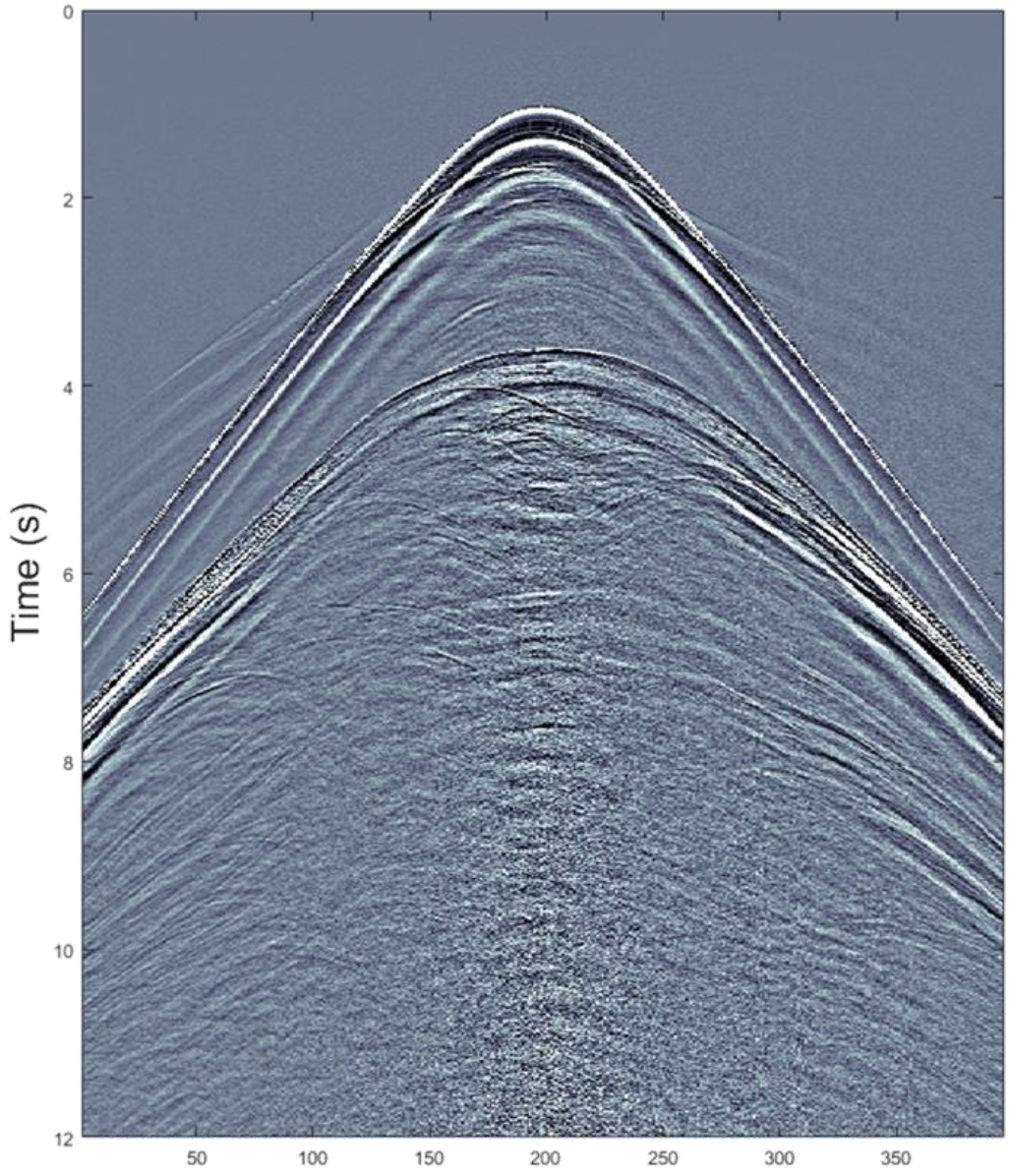
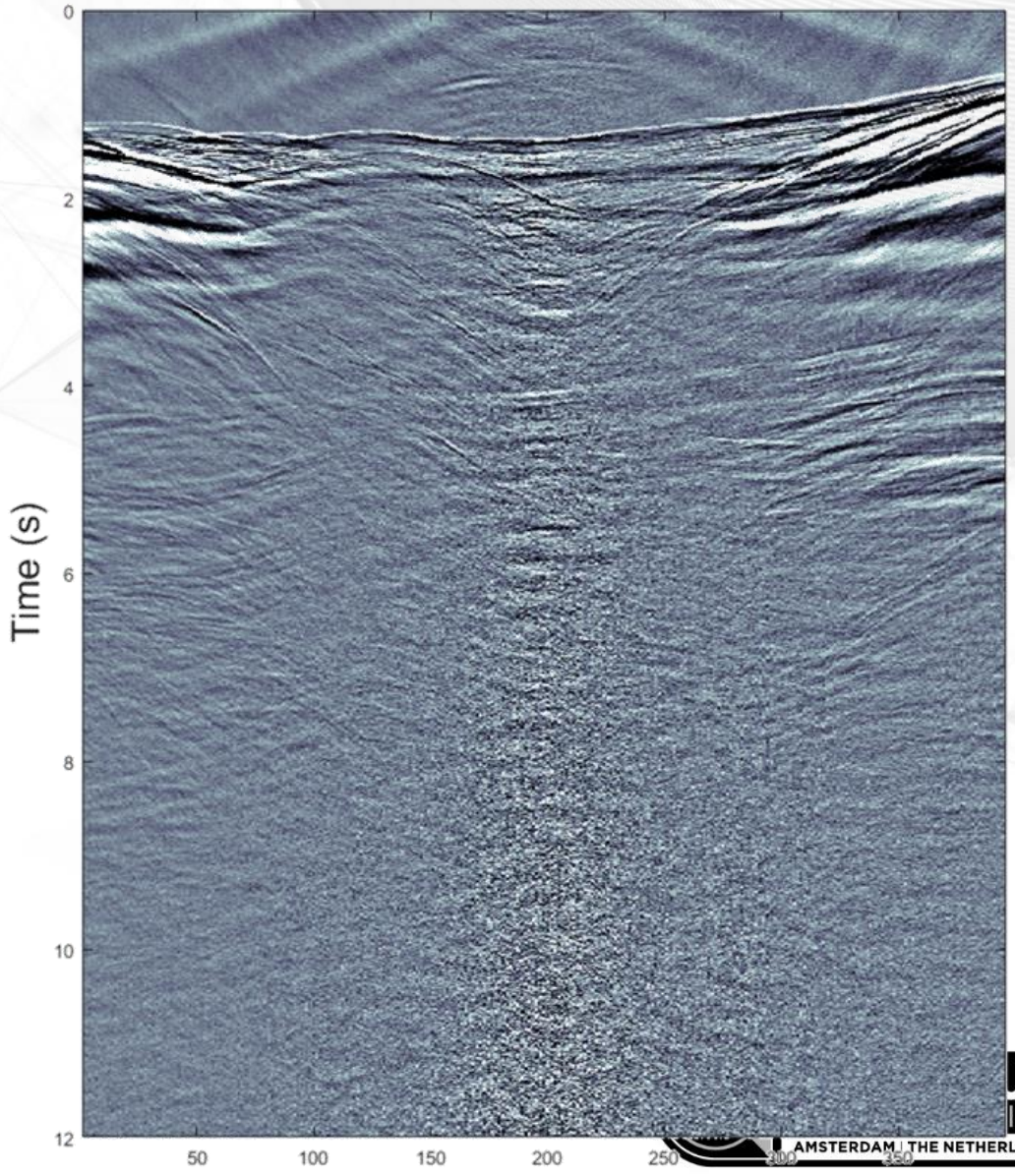
TPS—full band, NMO





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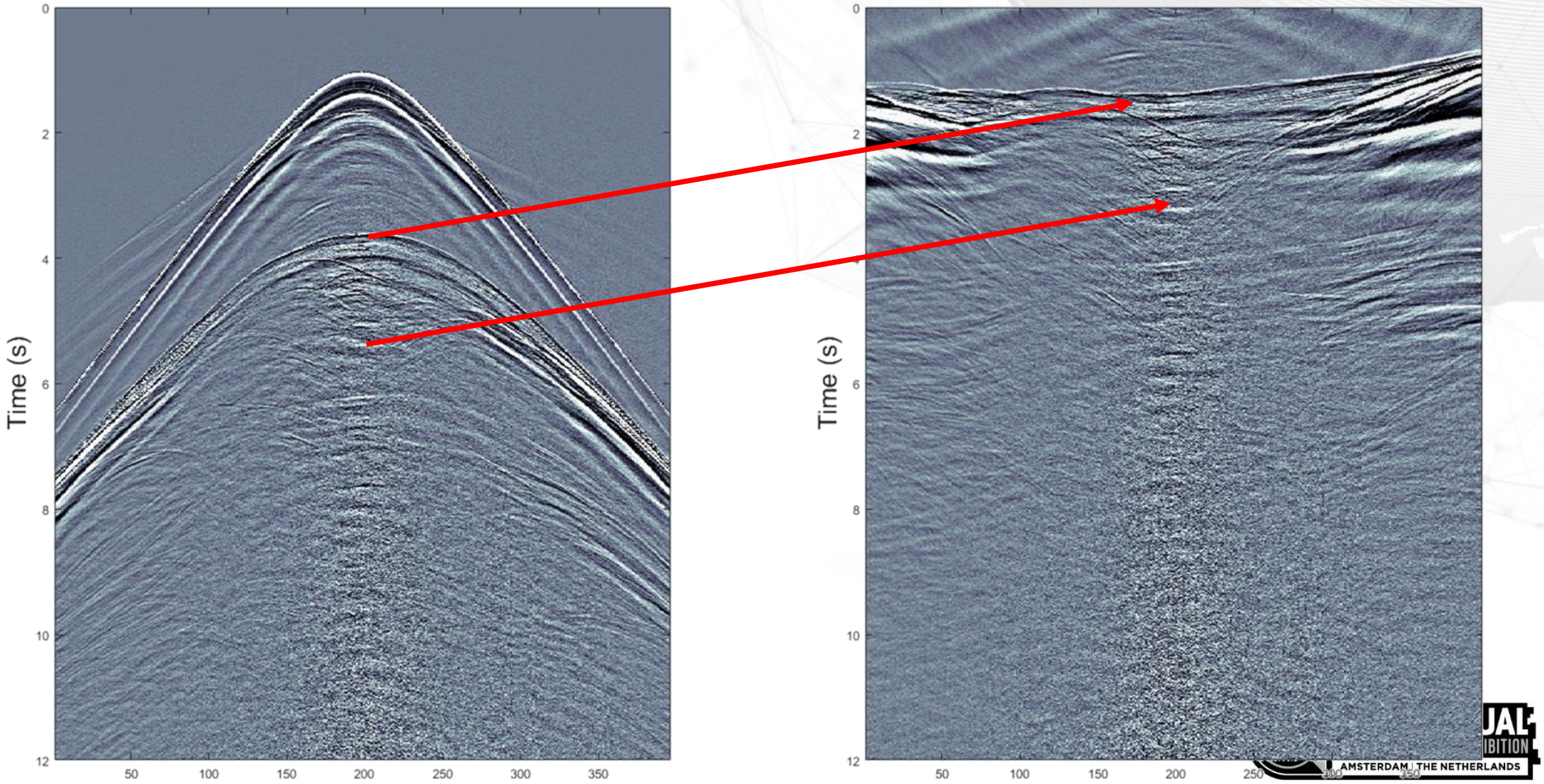
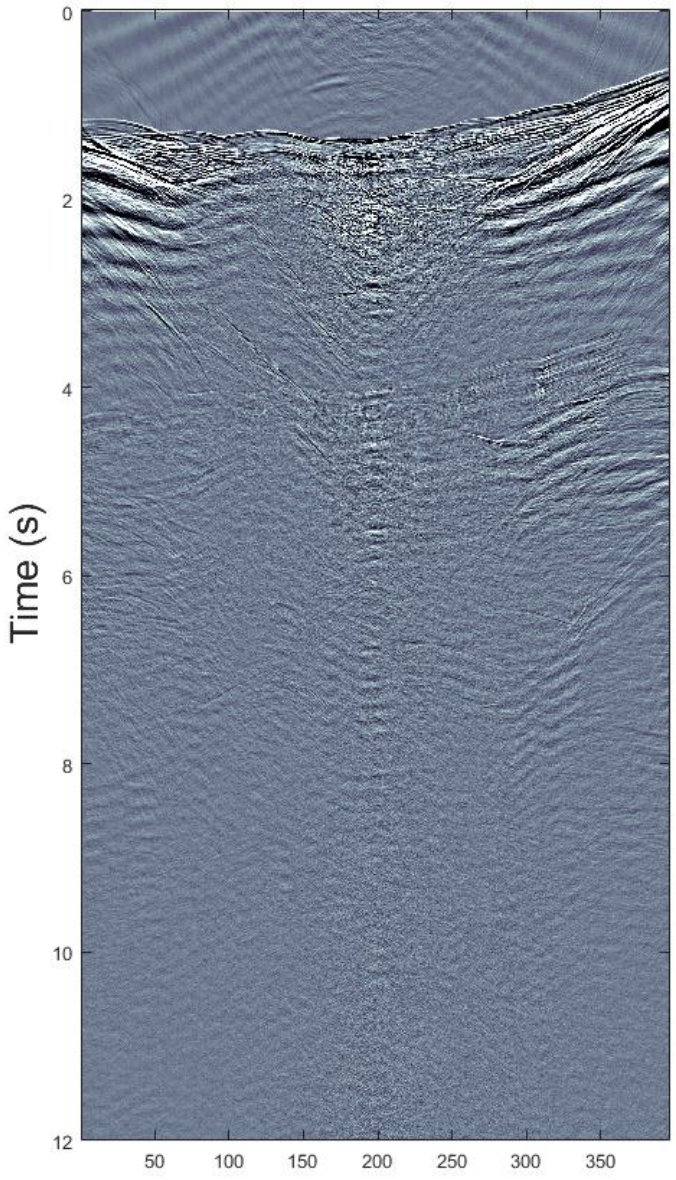
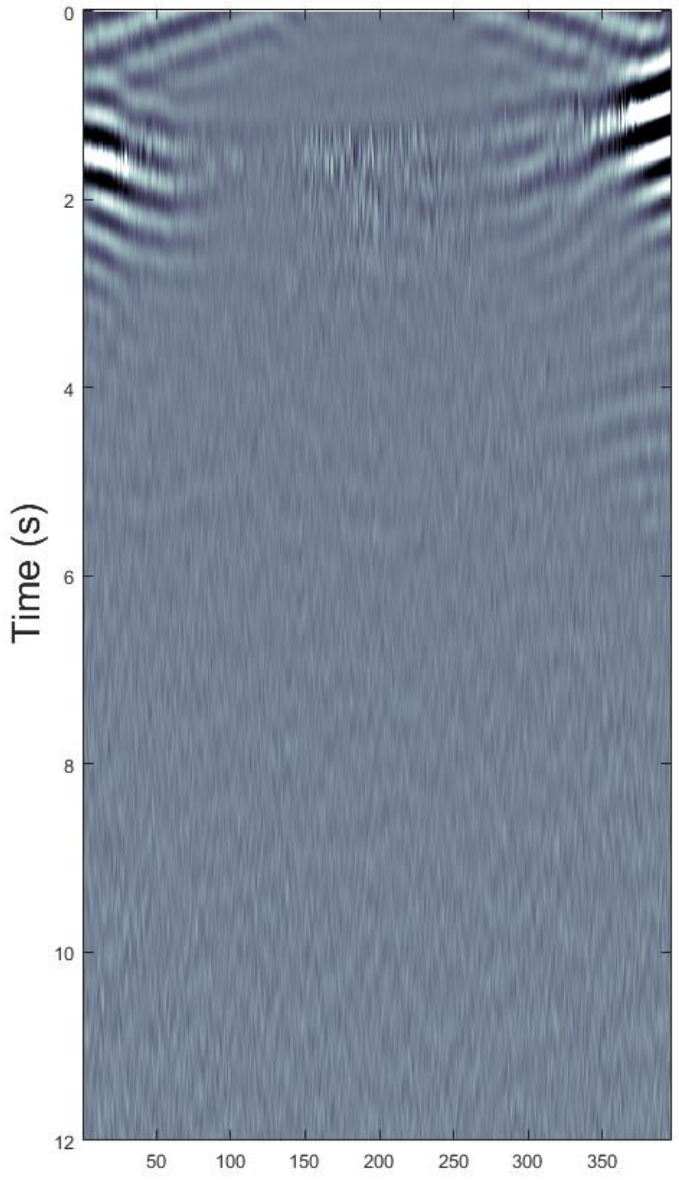
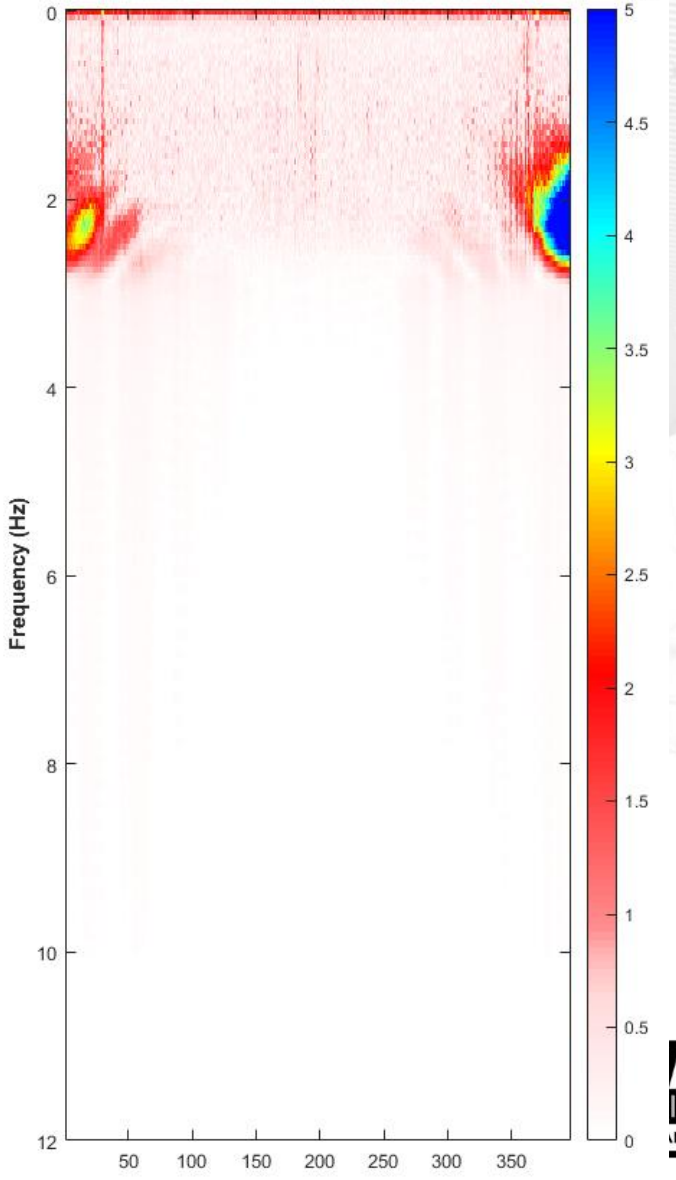
TPS—full band, NMO



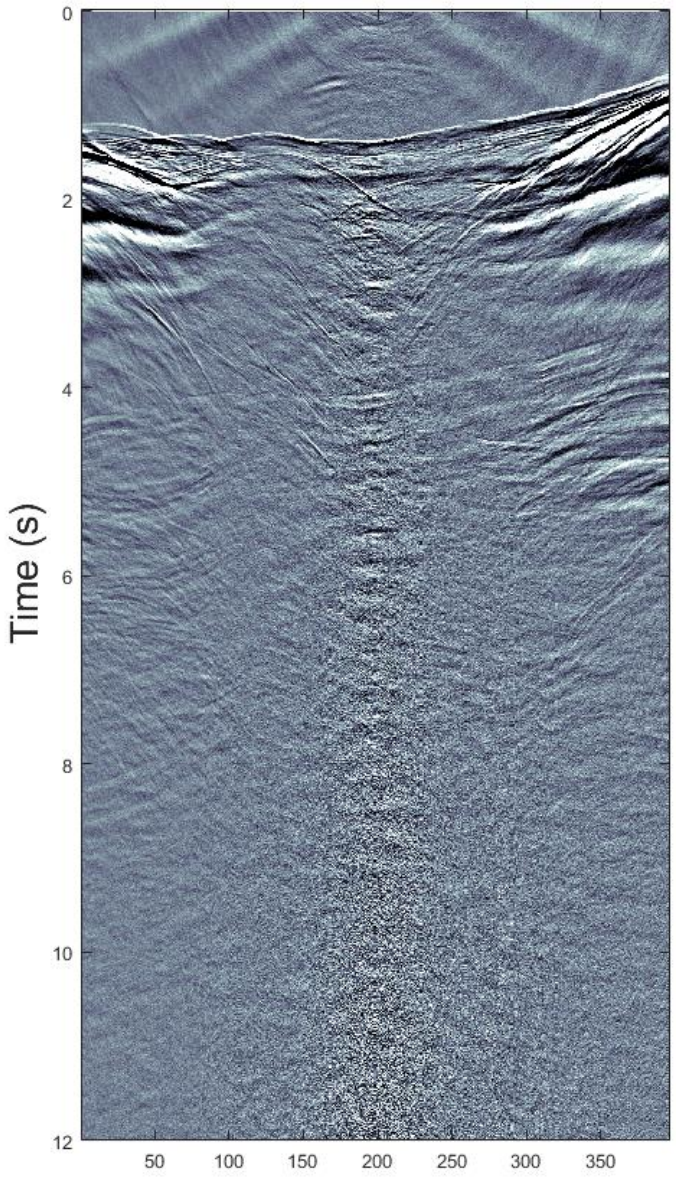
Airgun array—2.8 Hz High Cut

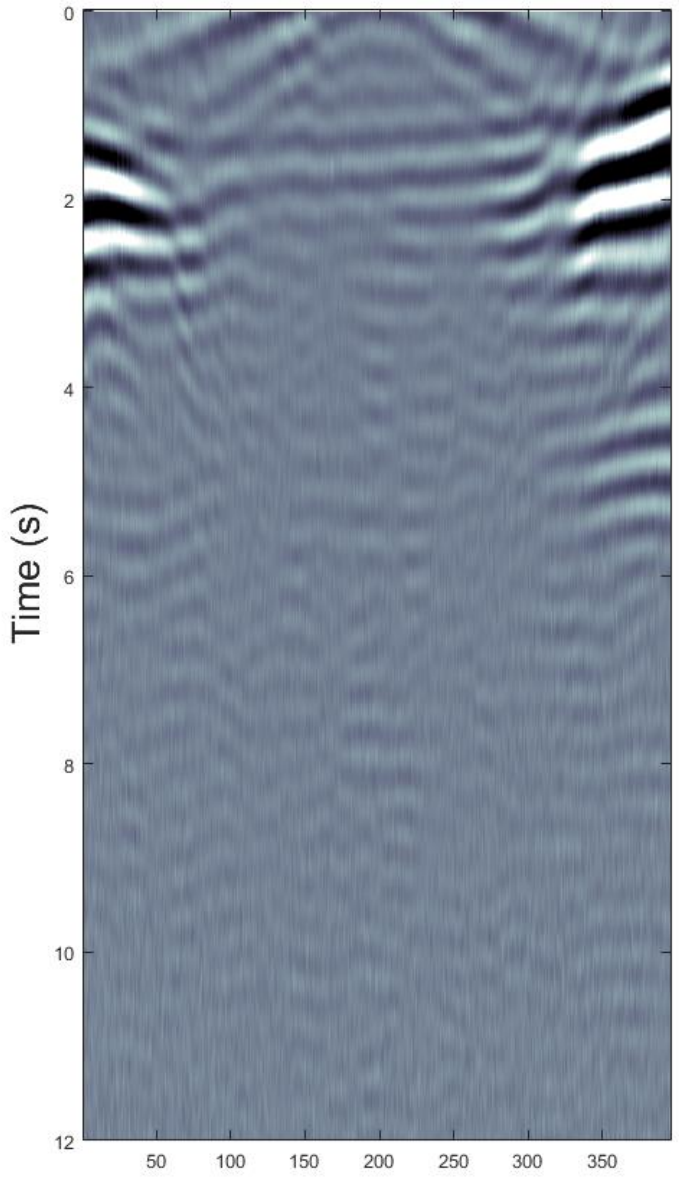


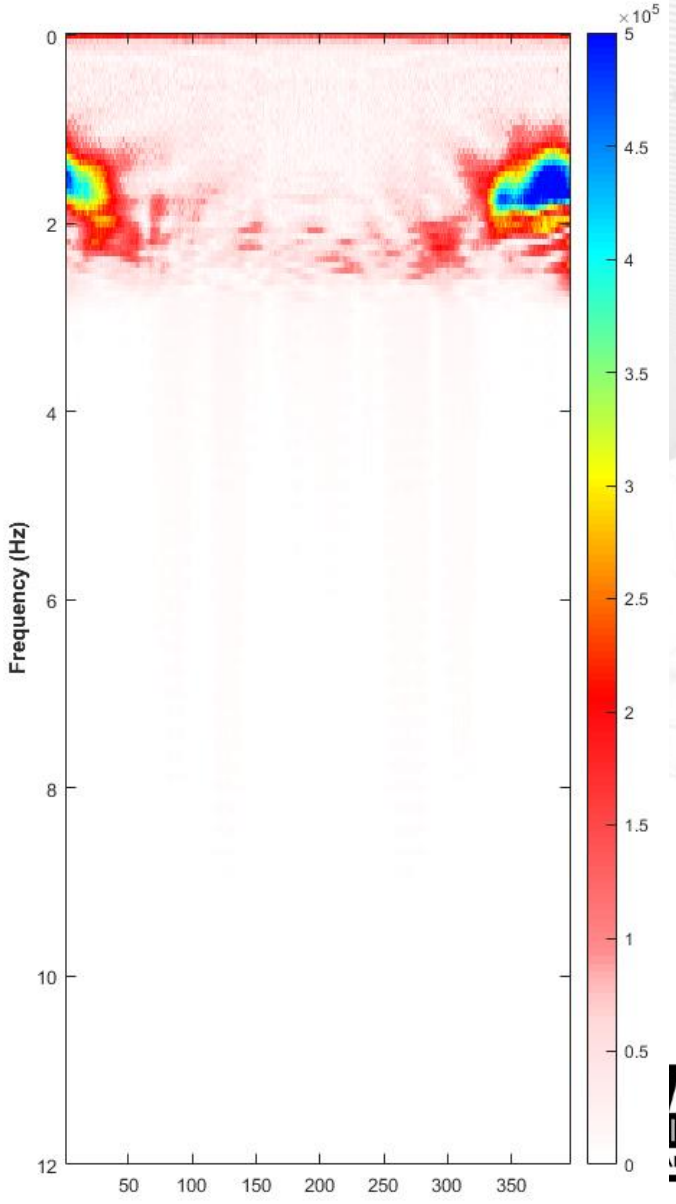




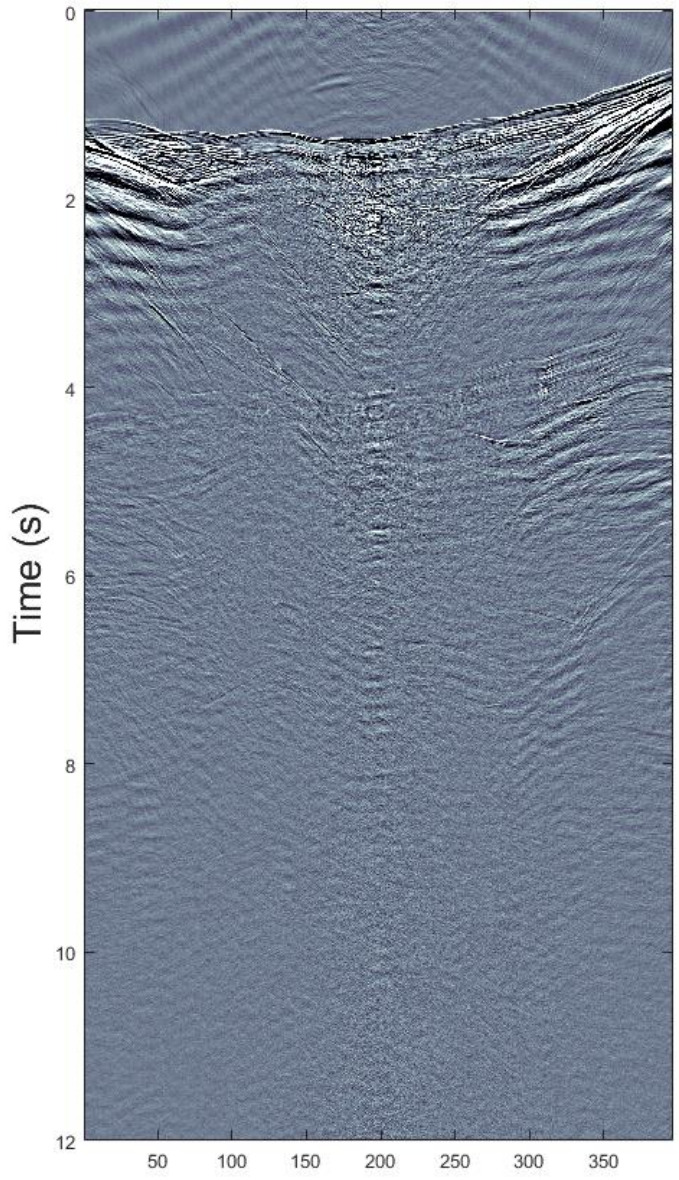
TPS—2.8 Hz High Cut

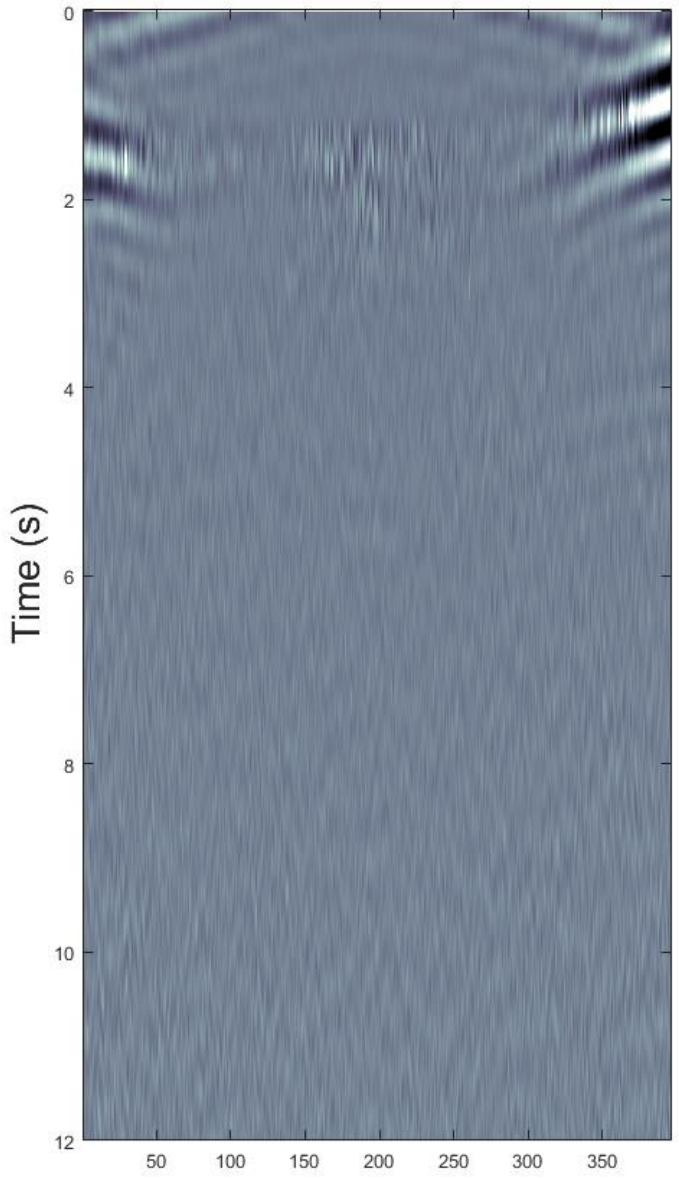


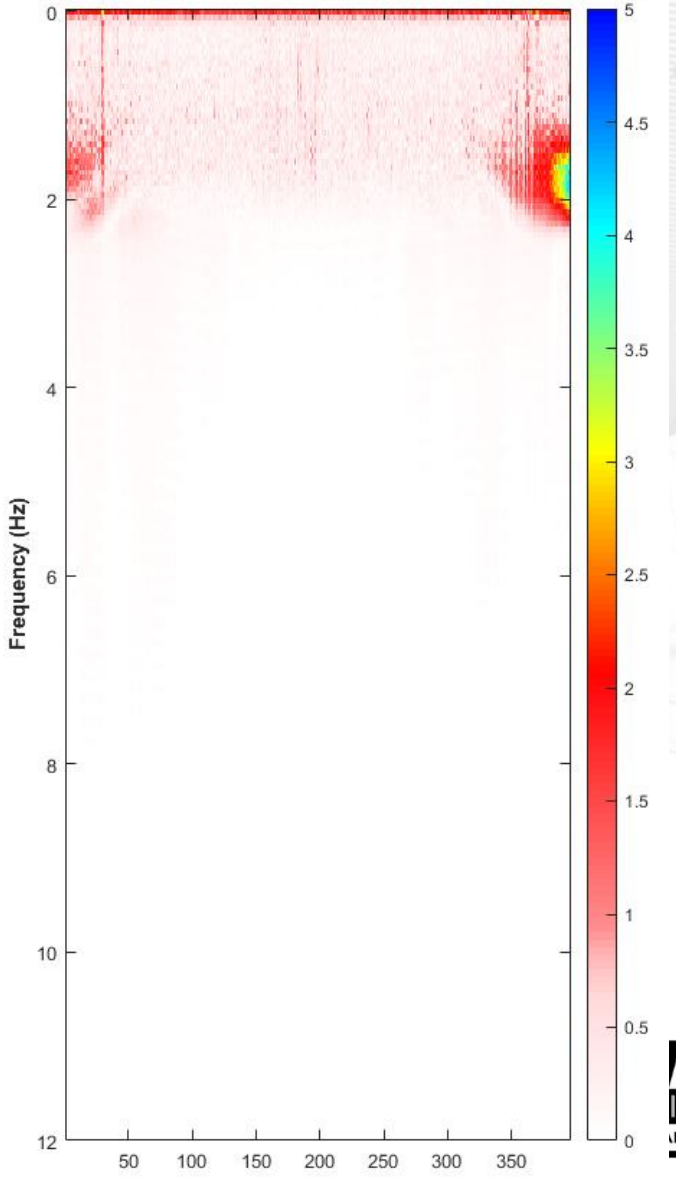




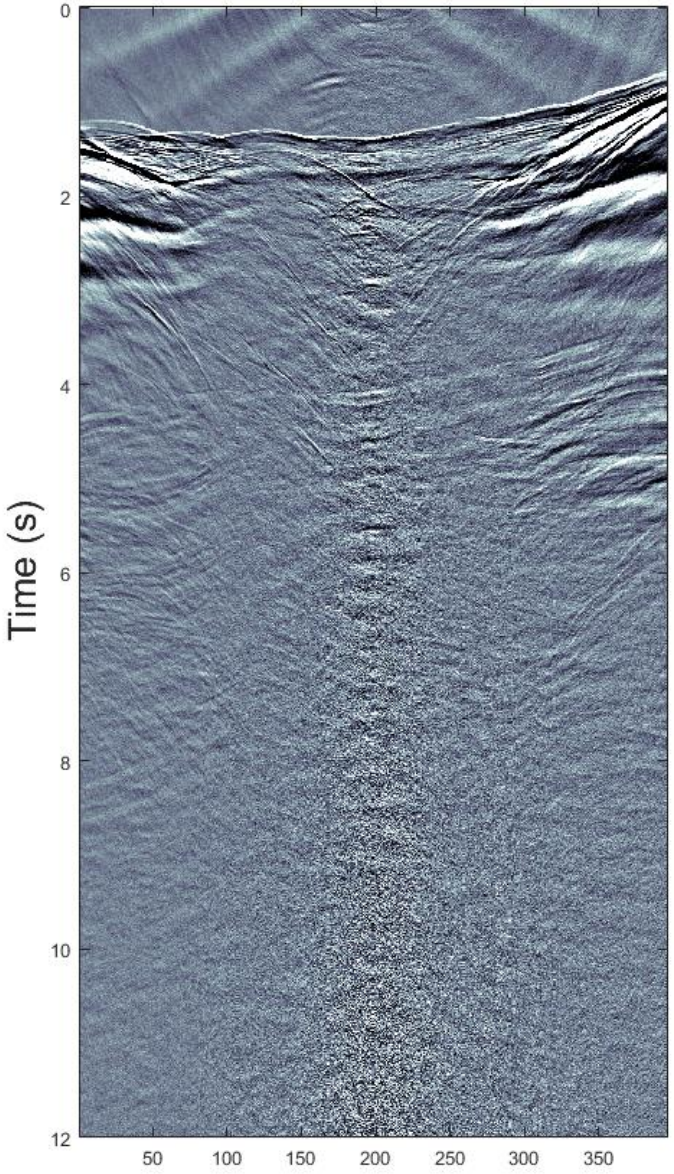
Airgun array—2 Hz High Cut

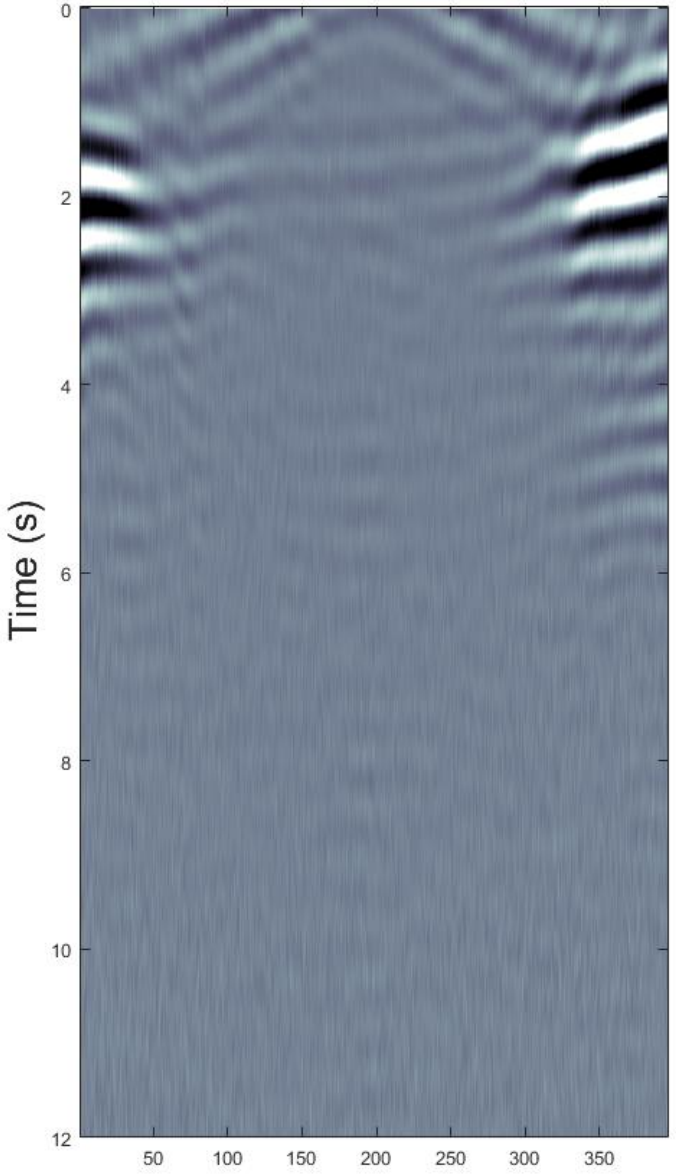


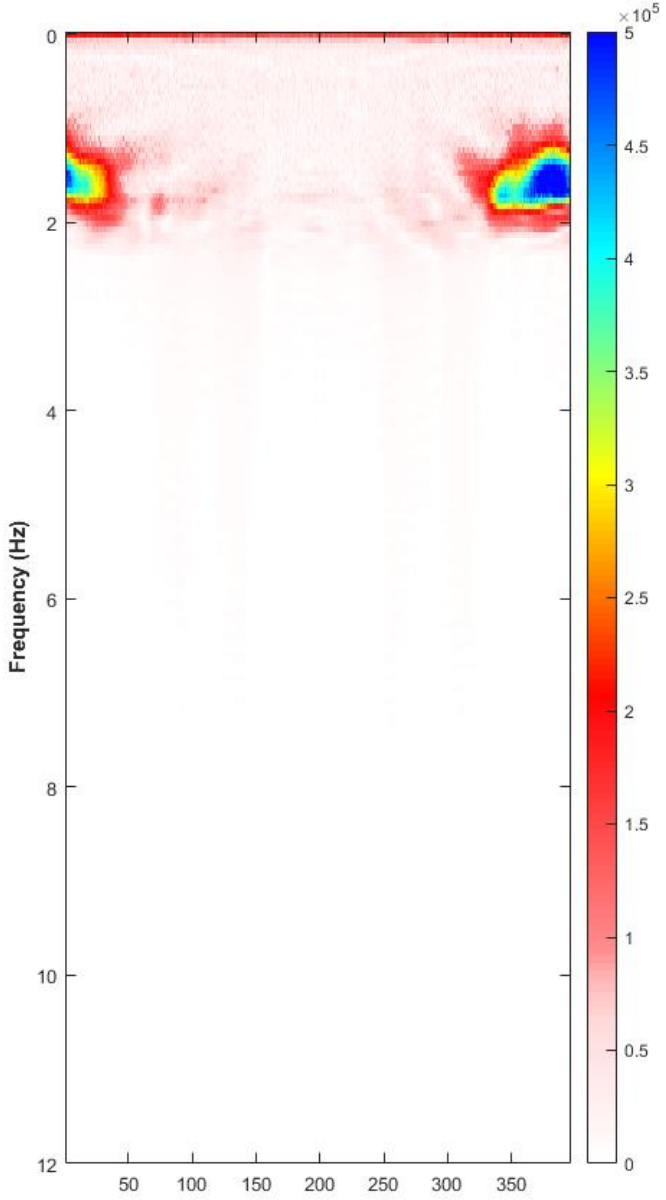




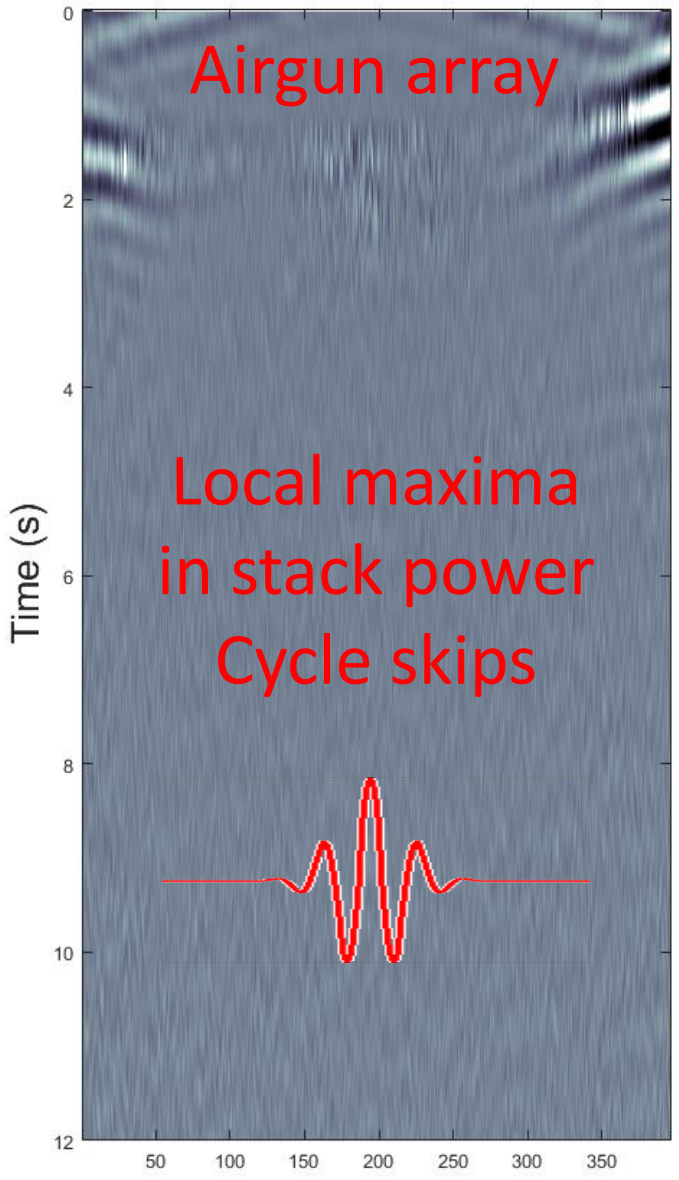
TPS—2 Hz High Cut

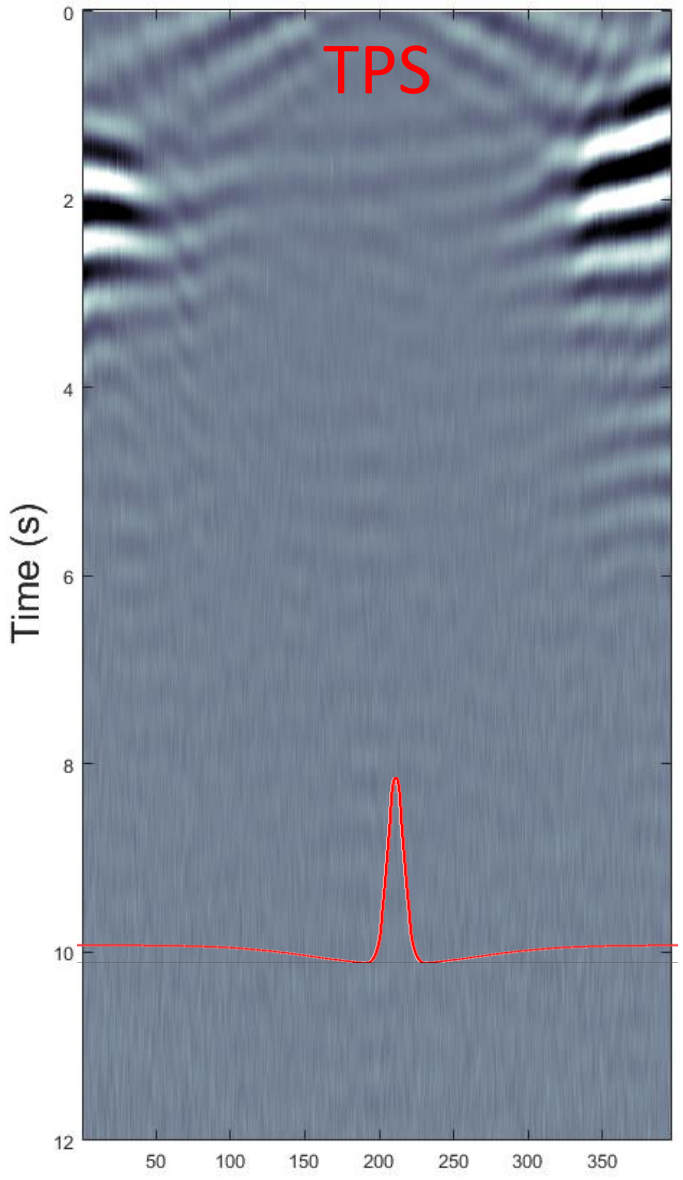






TPS Vs AG—2 Hz High Cut





This is single fold, single shot line, trace by trace NMO and tpow gain. No migration, no demultiple, no stacking

Full CRG: 50x50 meters shot carpet, 3D migration → Fresnel zone stacking, improved S/N

Stacking OBNS:

→ Improved S/N

→ FWI = find the optimal velocity model to maximize the tack power

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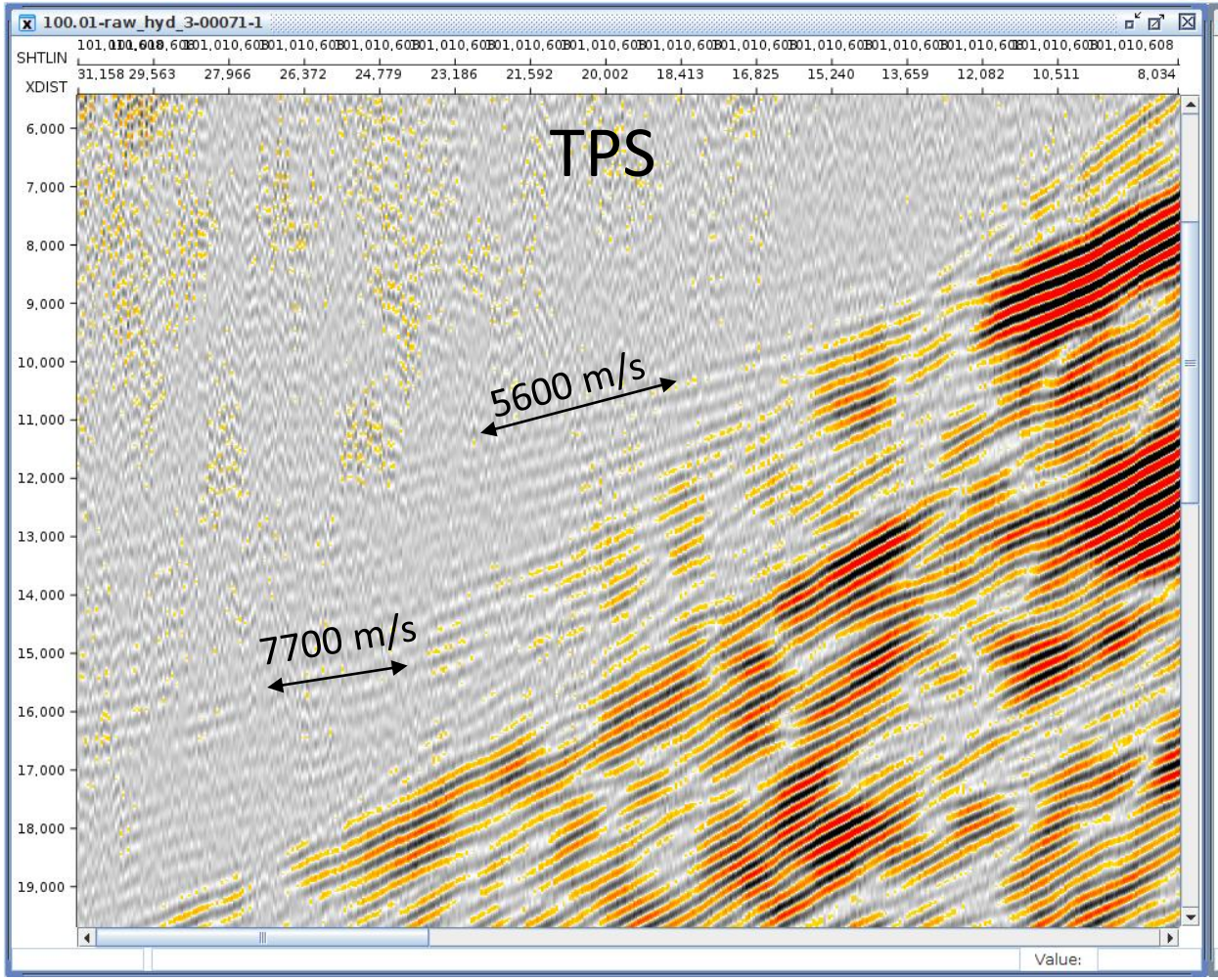
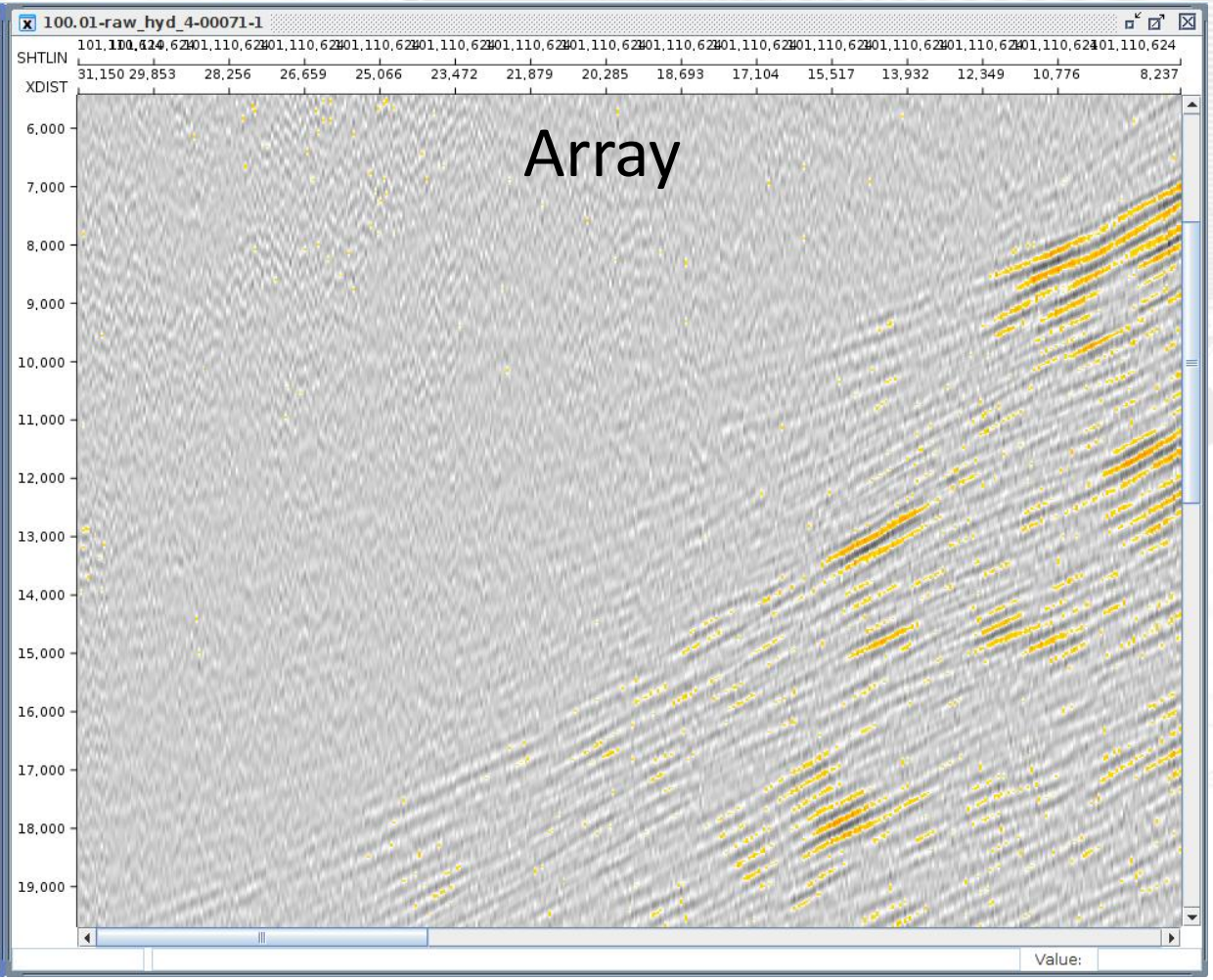
Maybe one interpretation slide





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Summary: How low can we go?

- Hard number: the bubble frequency was 2.6-2.8 Hz
  - The difference was the source depth (8 meters, 10 meters)
  - Same volume (26,500 cubic inch) and same pressure (1,000 PSI)
- Soft number: what is the lower limit of useful signal? (26Kcui)
  - Waves in the water (not very useful)—under 1 Hz
  - Refractions and reflections (useful signal)—under 2 Hz
- 26Kcui is not the upper limit. We will go much higher in volume (and cubic root of much lower in frequency)
- Expecting significant improvement in sub-salt, sub-basalt, FWI (Full Waveform Inversion), blocky model building, and resolution

Acknowledgements

- Shell for funding LISS and providing support in physics and geophysics
- George Steel who took LISS to a successful delivery
- TGS and WesternGeco and the crew of the Sanco Atlantic
- Sercel who bought LISS and quickly got on top of the technology
- MagseisFairfield and the crew of the Artemis Atlantic

- Special thanks to data analysis by Zijian Tang and Stephane Laroche

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