Specific Engineering Solutions

Shuki Ronen

GAMeON 2022 meeting: https://www.globalallianceoceannoise.org/seismicexploration

Video: https://youtu.be/R14WBCPUwMQ -- minute 23 to minute 41

Report: https://www.globalallianceoceannoise.org/_files/ugd/62d341_dfc5fc6518ba4ce8b7a801f798c231ed.pdf

Updated 2023

Specific Engineering Solutions (escalating cost)

1. Modified airguns: eSource™, Bluepulse™
   - They increase rise time and reduce high frequency content
2. Complete redesign: Tuned Pulse Source (TPS)™
   - It increases rise time and reduces high frequency content
   - It also eliminates or reduces cavitation and very high frequency content (above 1500 Hz)
3. Marine Vibroseis
   - Cavitation? Never had it, never will!
   - Good 5-100 Hz signal!
   - They must be very big to get below 5 Hz—not practical

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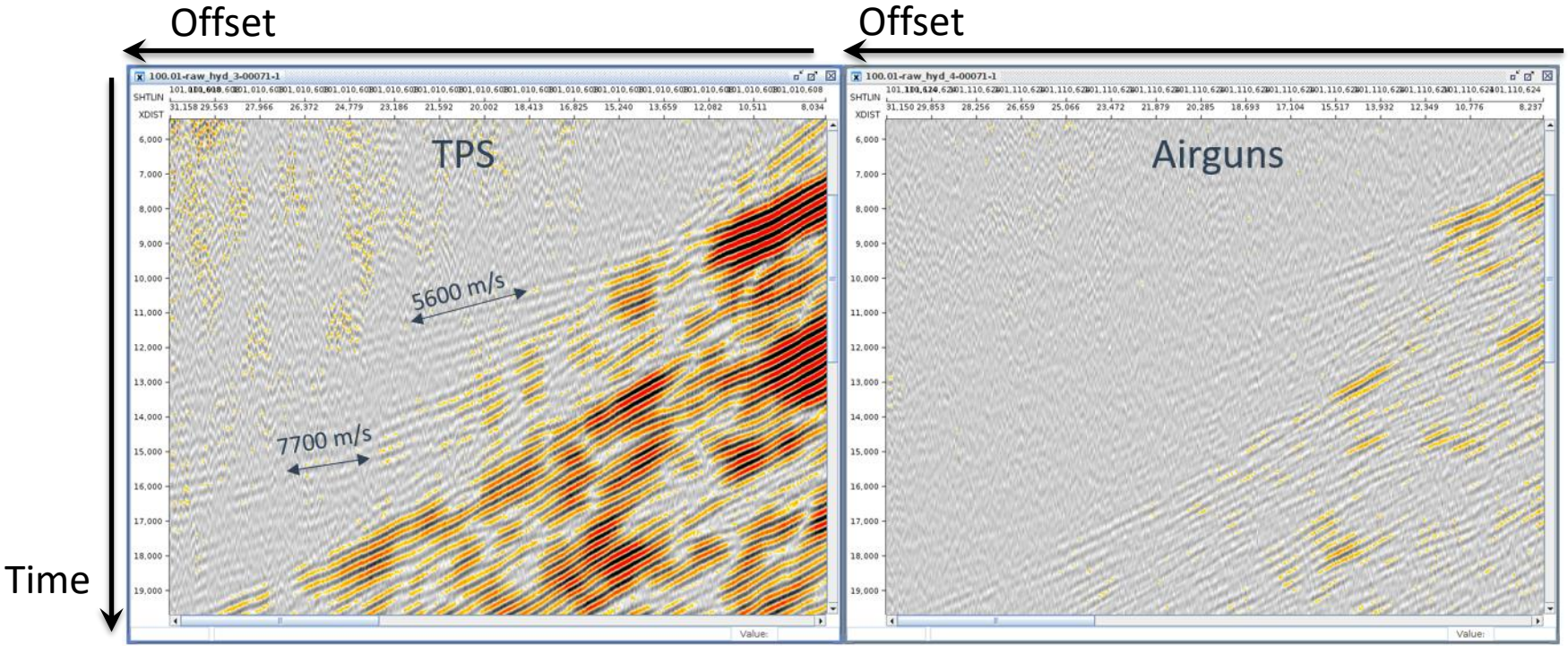
The Tuned Pulse Source

- Pneumatic, like airguns
- Lower pressure (600-1000psi vs 2000-2500psi)
- Larger range of volumes
- Substantially different Design



1. Geophysical motivation: low frequency
2. Environmental motivation: less high frequency

Geophysical motivation signal below 4 Hz hi-cut



- Much stronger low frequency signal

The TPS has two motivations

1. Very low frequency signal made possible
2. Lower environmental impact

Other new airguns have either one but not both

- Gemini™ and Harmony™ only low frequency
  - Standard airguns heads
  - Clustered or multi-head chambers
- eSource™ and Bluepulse™ only environmental
  - Modified heads
  - Less high frequency, same low frequency

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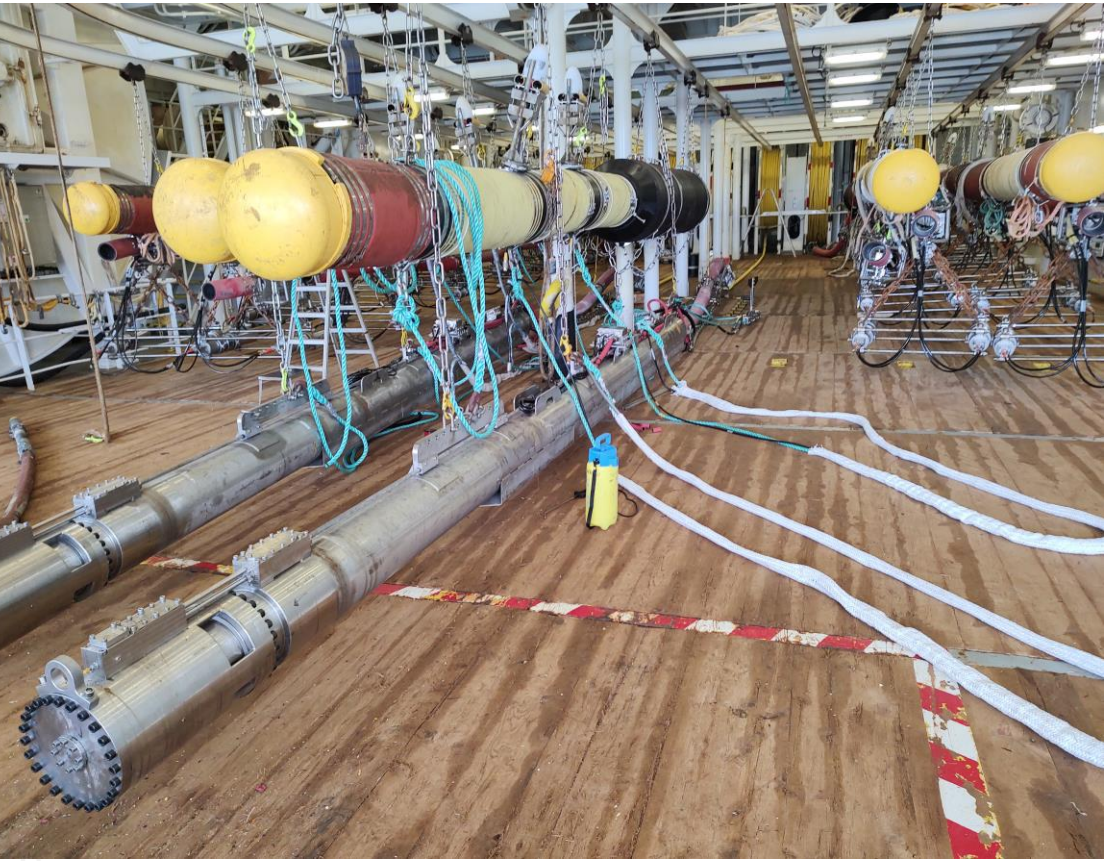
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Head
Firing Chamber (this one is 26,500 cubic inch)
TPS (mark 2)

Dual TPS and Airgun arrays (2023 survey)



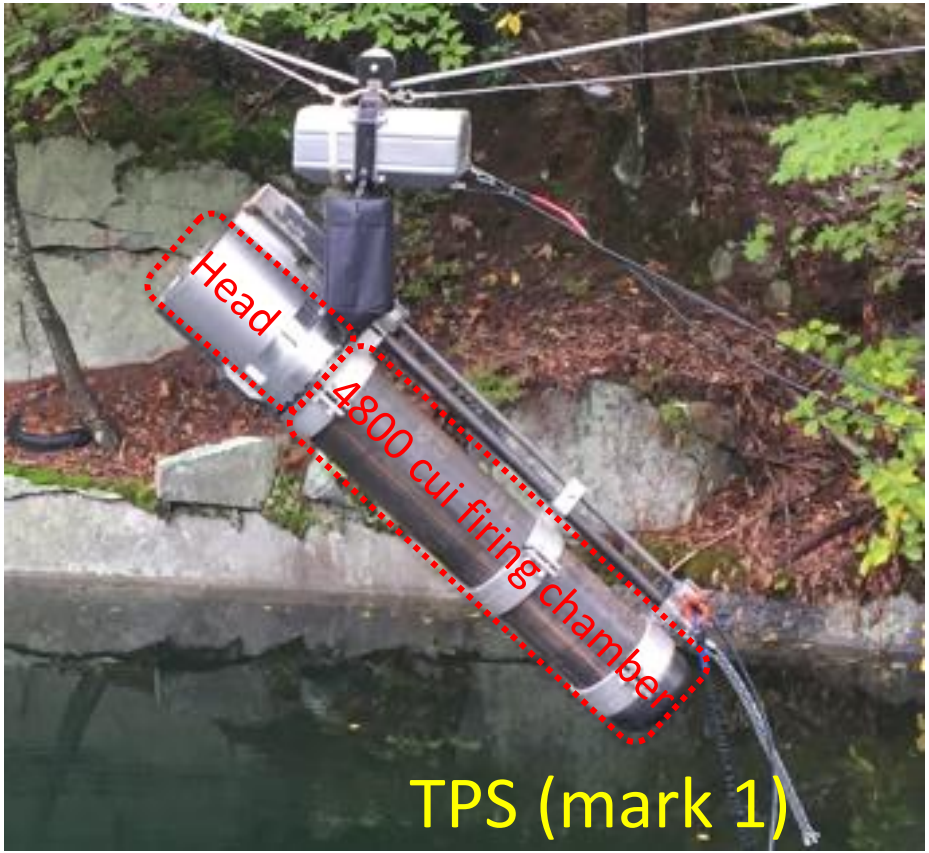
- Note
- 6 sub-arrays (standard)
- 2 converted to TPS
- 4 still with Airguns



- Same flexible floats

Heads and Chambers



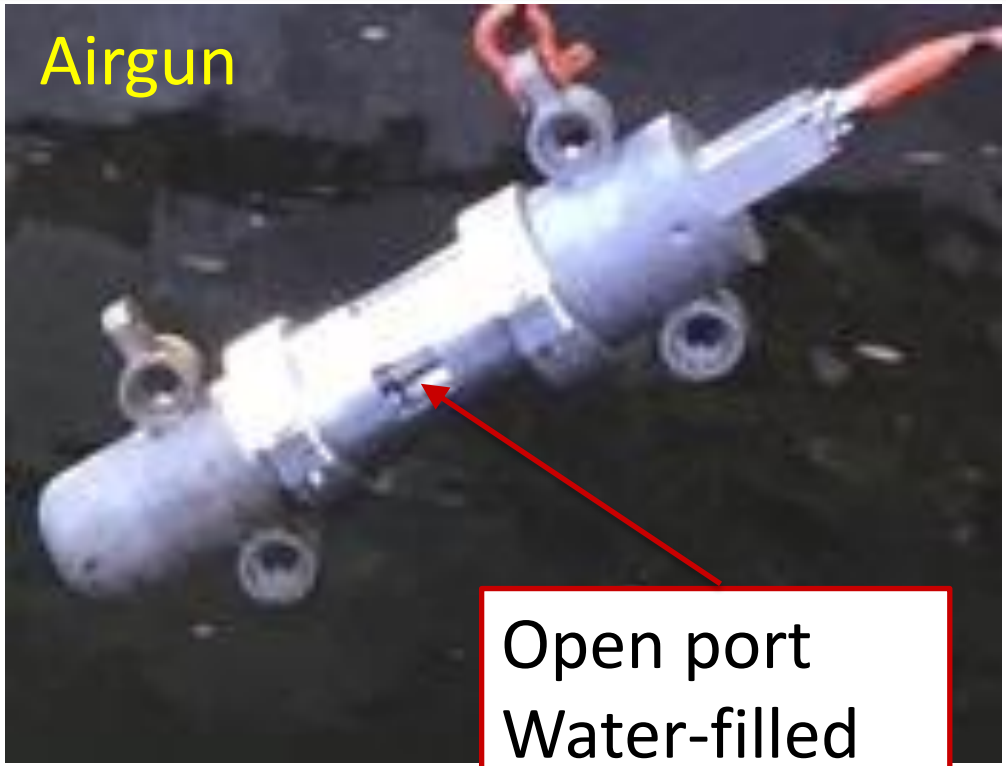


Heads and Chambers





Different design (one feature)



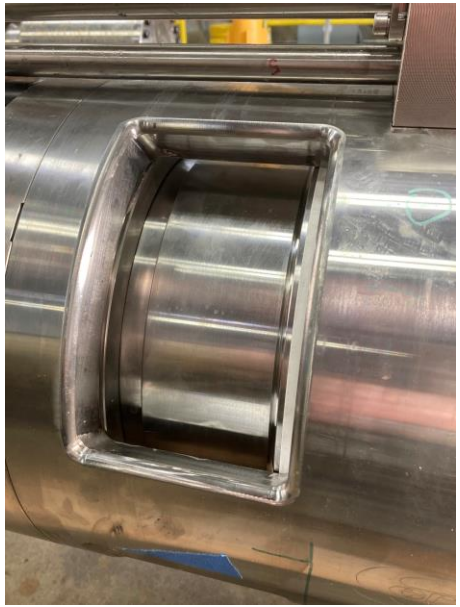


Reduce or eliminate cavitation

Air-filled mid chamber

Round edges

Avoid high-frequency cavitation



Water filled mid chamber

Sharp edges

The water coming out of the mid chamber before the air cause cavitation



The TPS is a broadband source

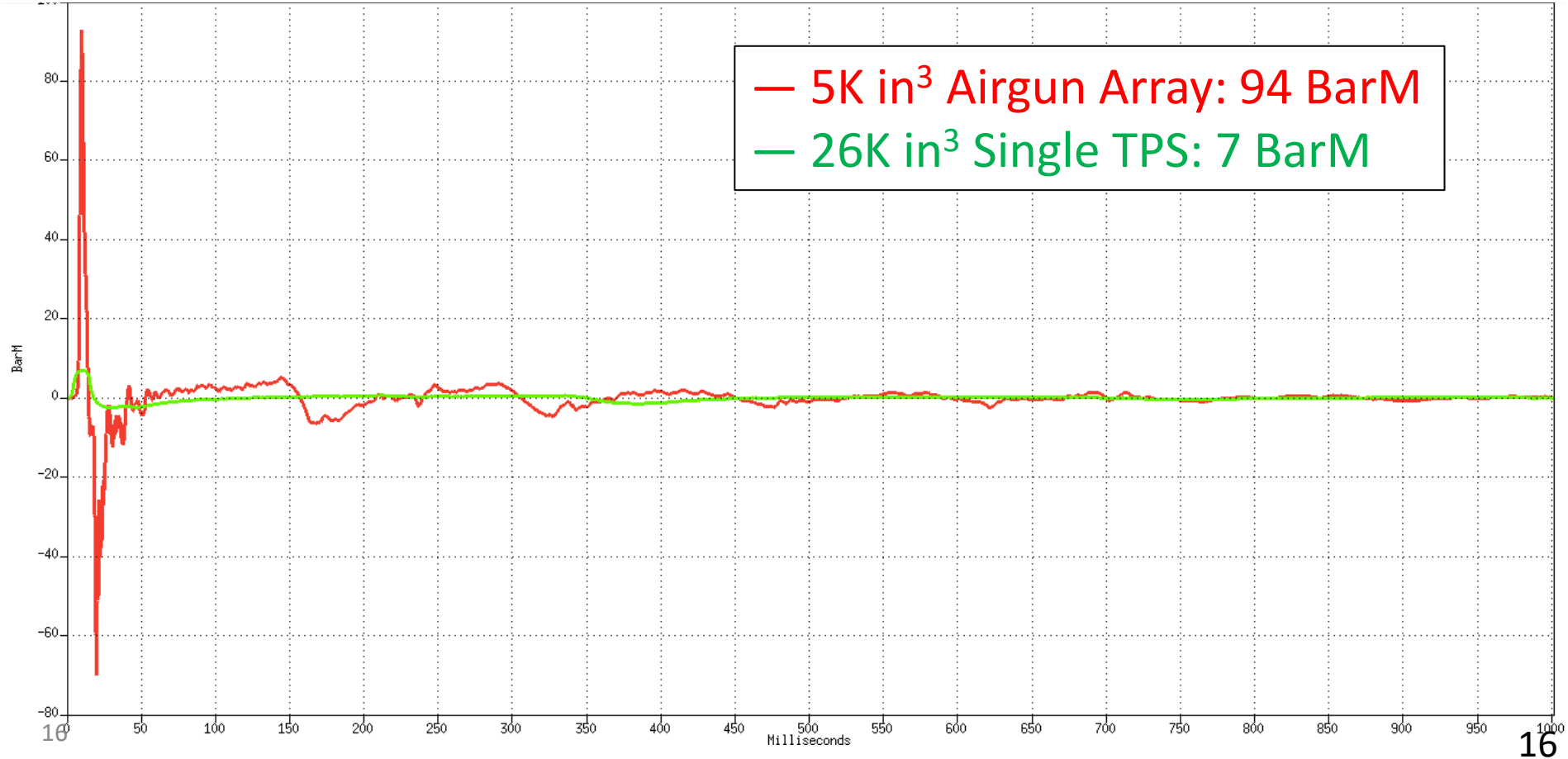
- We have tested it with volumes from 600 to 28,000 cubic inch firing chambers
  - Large volumes provide low frequency signal
  - Small volumes provide mid frequency signal
- Currently, the demand for TPS is 100% geophysical
  - Motivated by low frequency signal
- So far, no environmentally motivated demand

Let’s see some data!

- Sound Pressure Level
  - Wavelets (“Signatures”) in the time domain
  - Spectra of recorded TPS, Airguns, and passive noise
  - Common Receiver Gather
  - Time domain
  - Display the data
  - Plot the maximal SPL in every offset
- Spectra (Frequency domain)

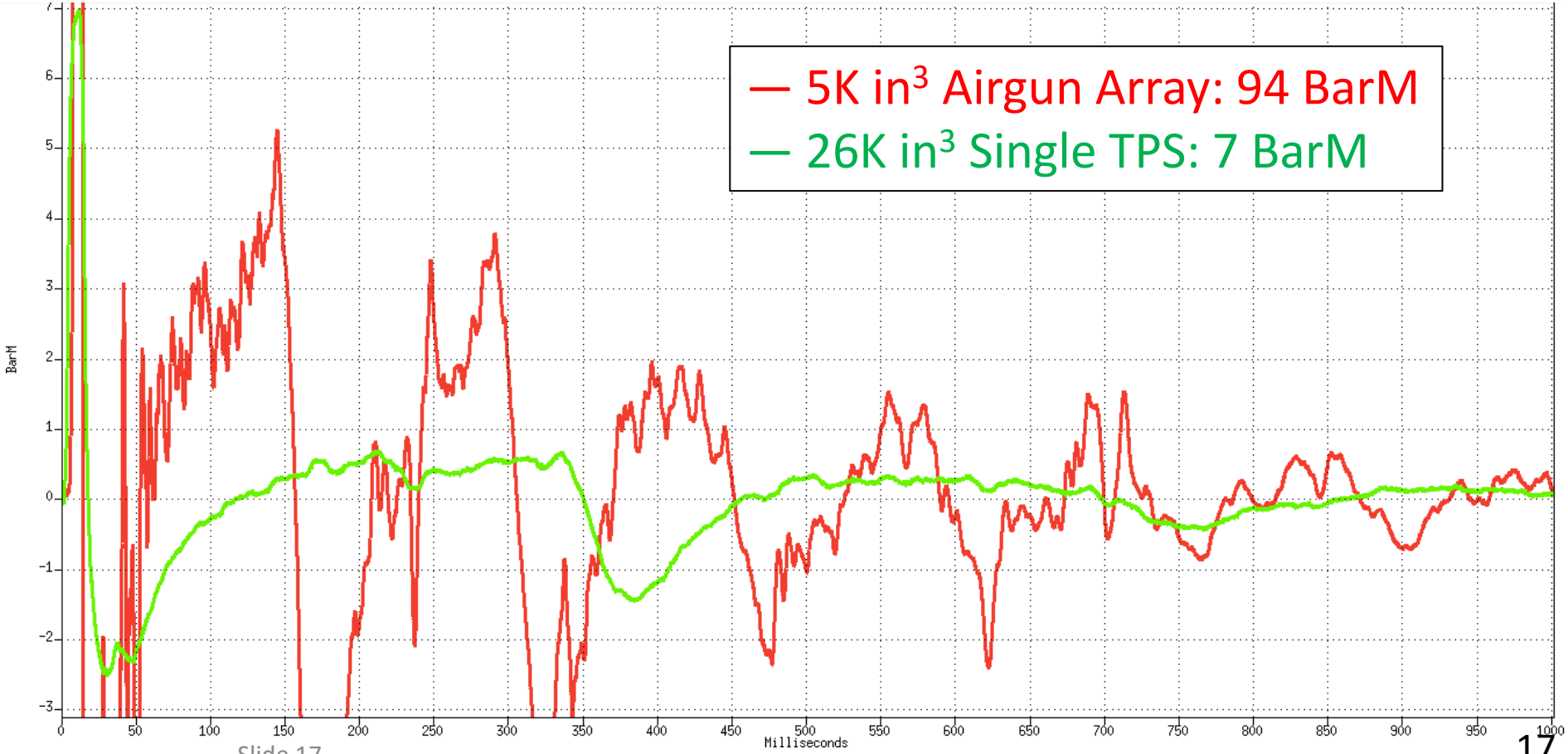
Far field data recorded by same OBN

Near offset shot



Far field data recorded by same OBN

Near offset shot

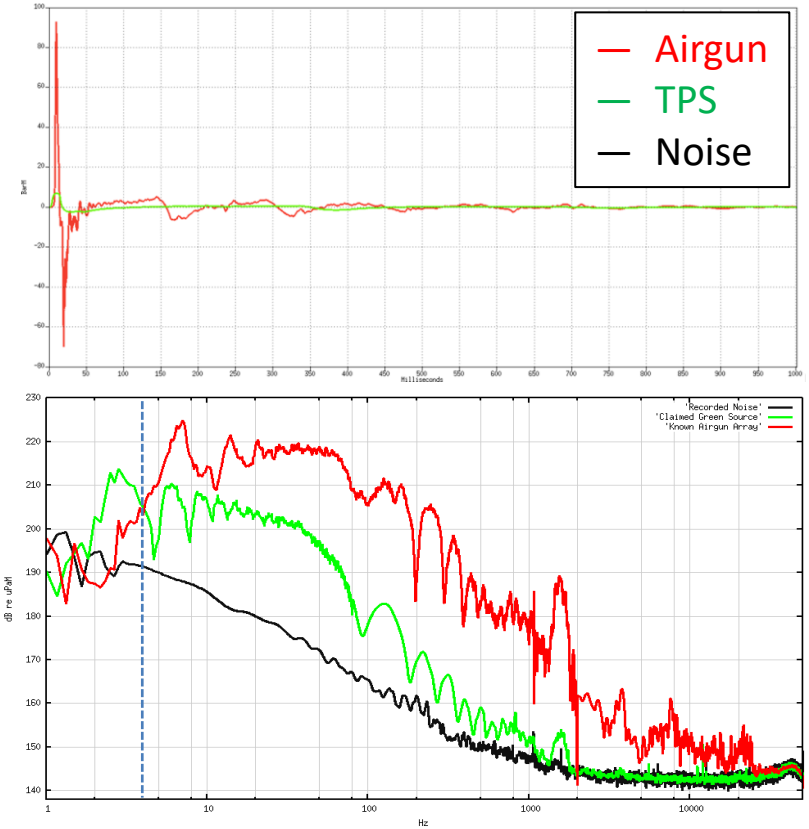


Lower environmental impact

- Time domain
  - Bar-meter: < 8 compared to > 90
- Frequency domain
  - TPS spectra ~ ambient noise at 1000-1500 Hz
  - Airgun spectra ~ ambient noise at 25 kHz

Data from a special node Δt=10 micro-seconds

Nyquist frequency = 50 kHz

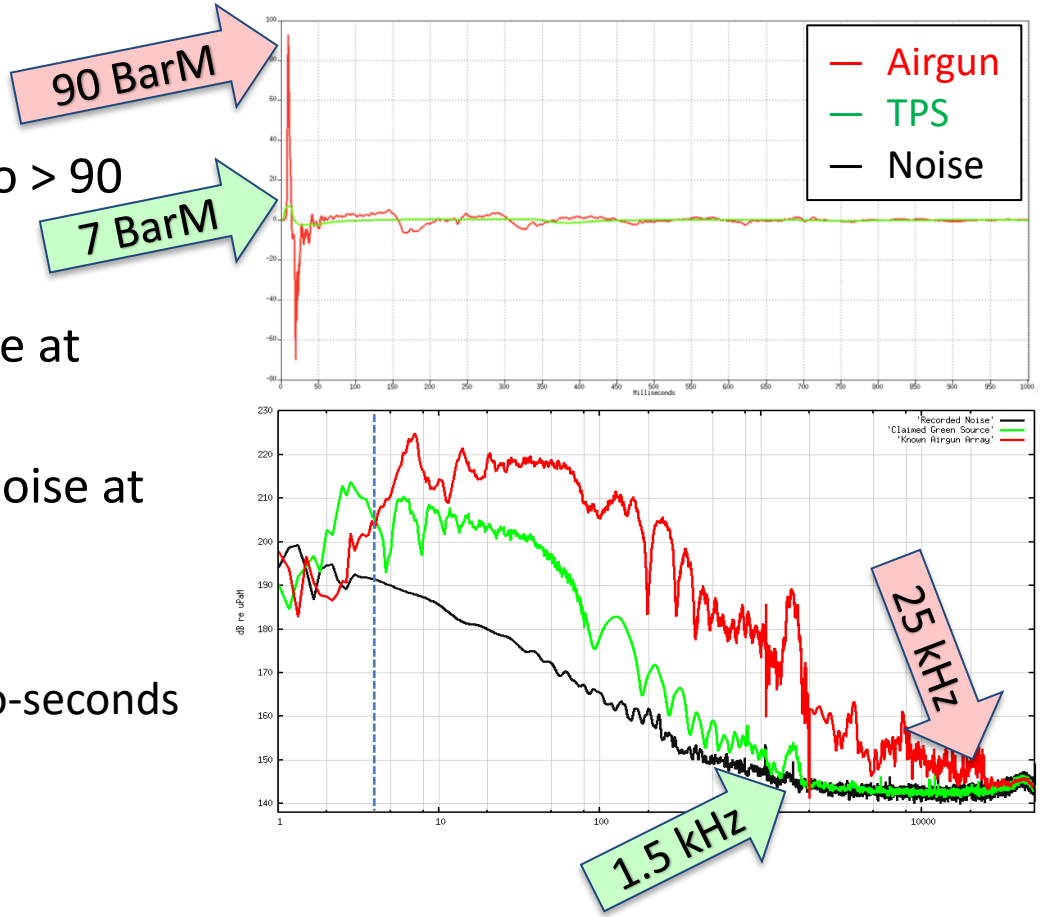


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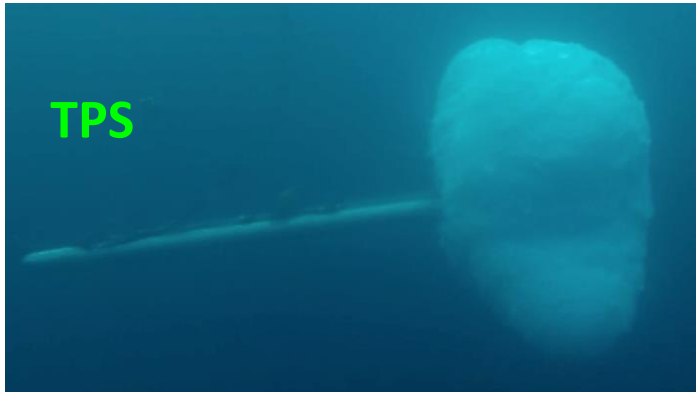
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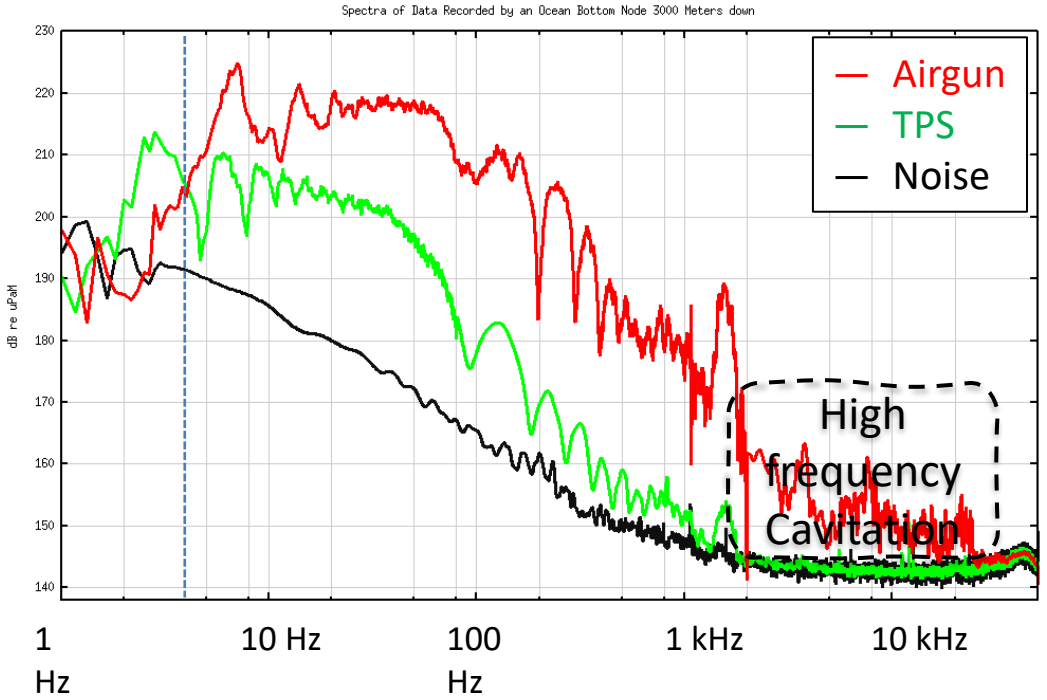


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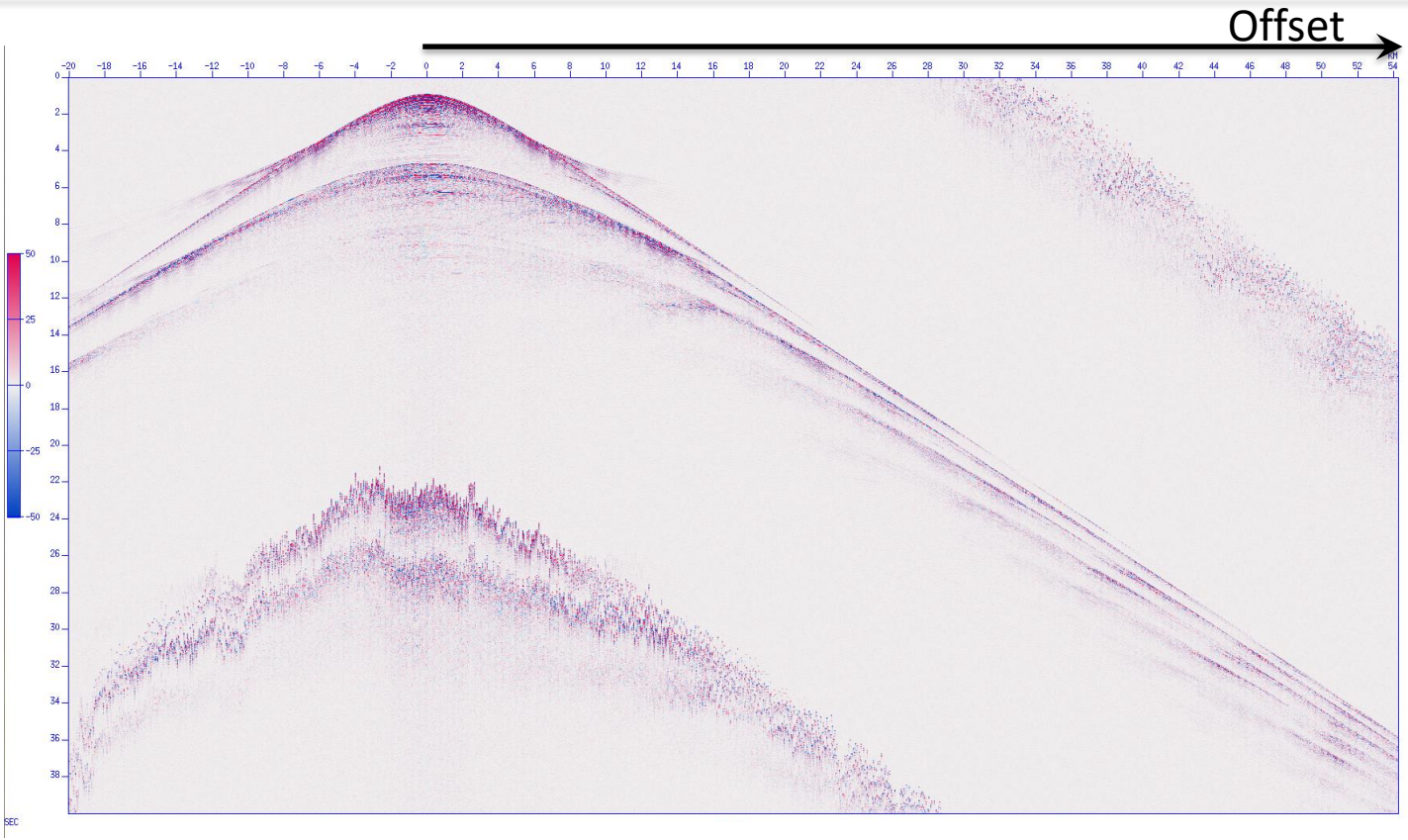
Spectra summary







Common Receiver Gather—Airguns (full band)

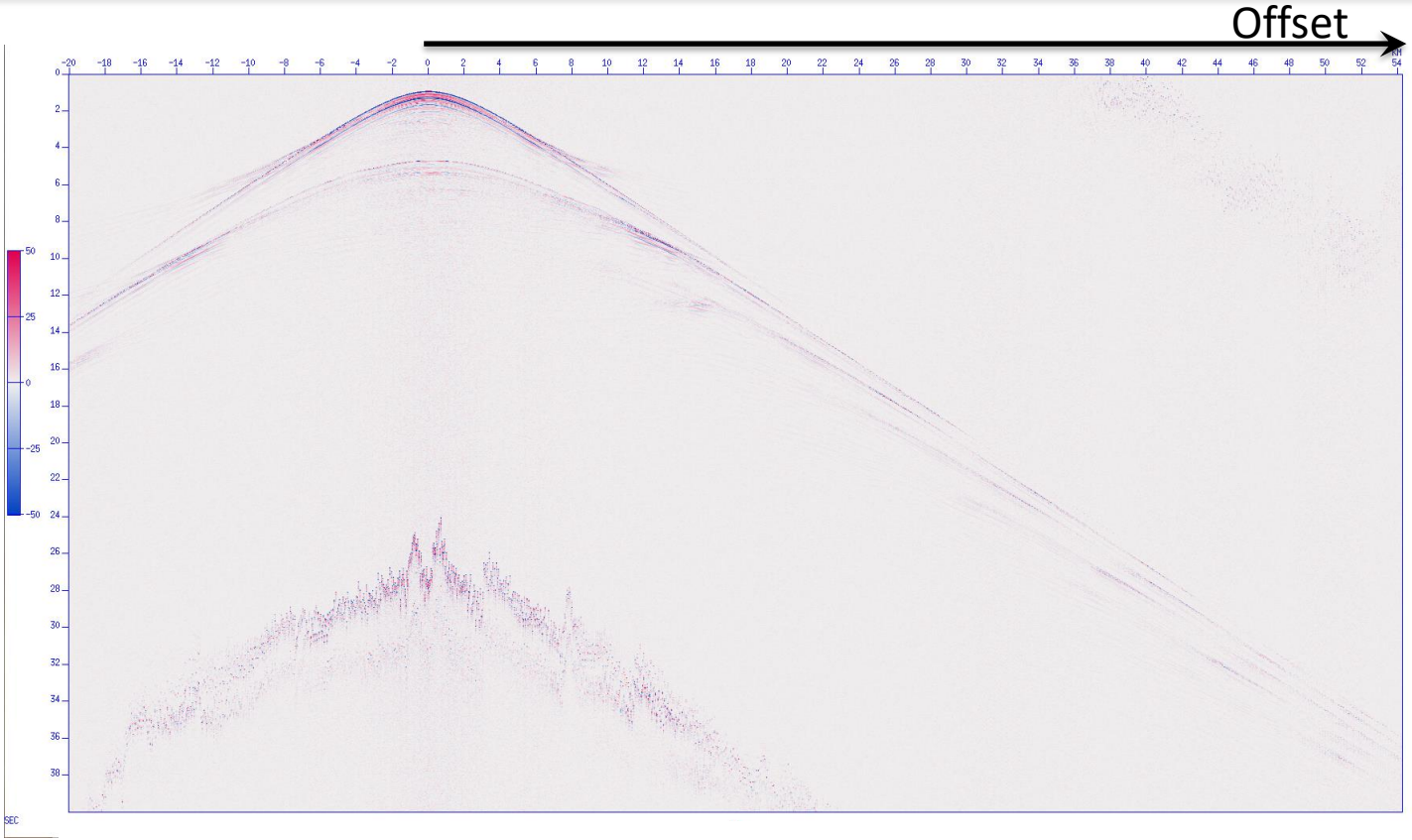


Clip at 50 Pa

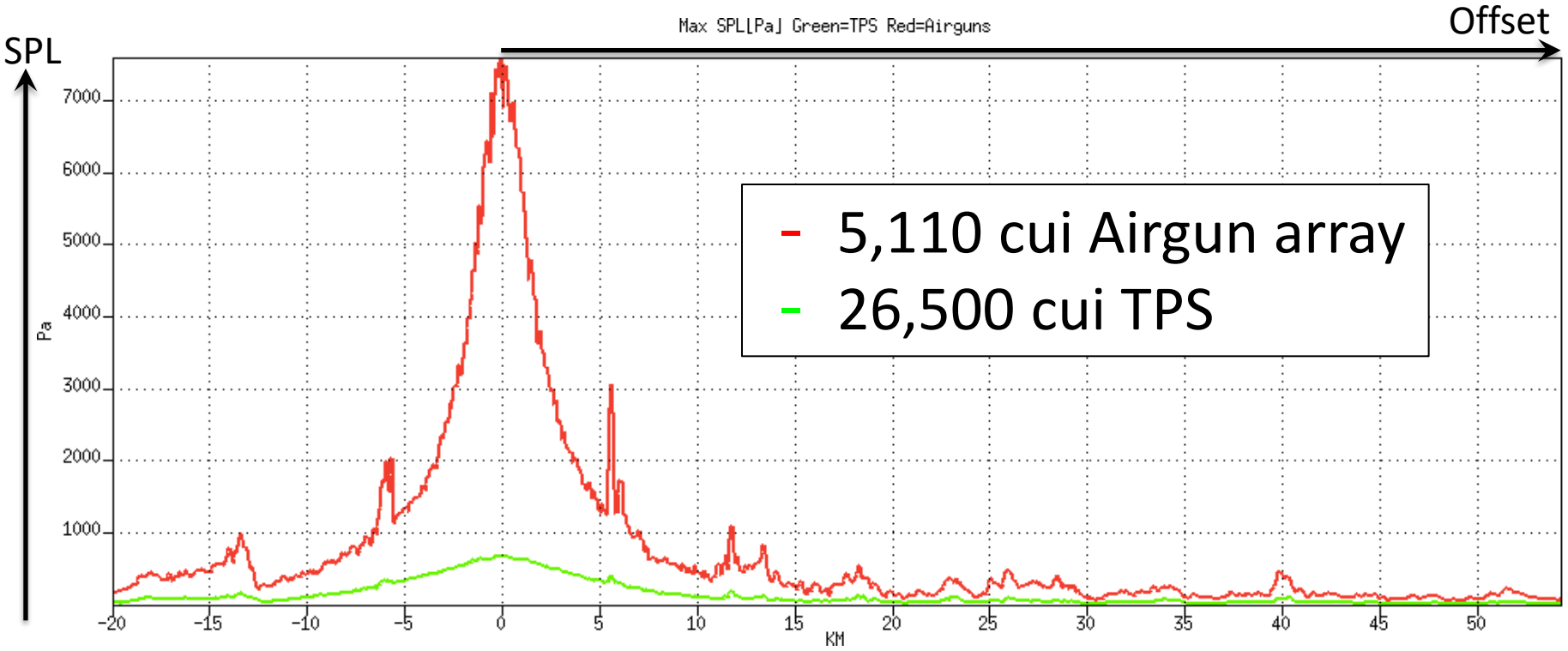
Node deployed 3 km vertically down

horizontal offset to 54 km

Common Receiver Gather—TPS (full band)



Maximal Sound Pressure Level



Node deployed at 2800 meter depth

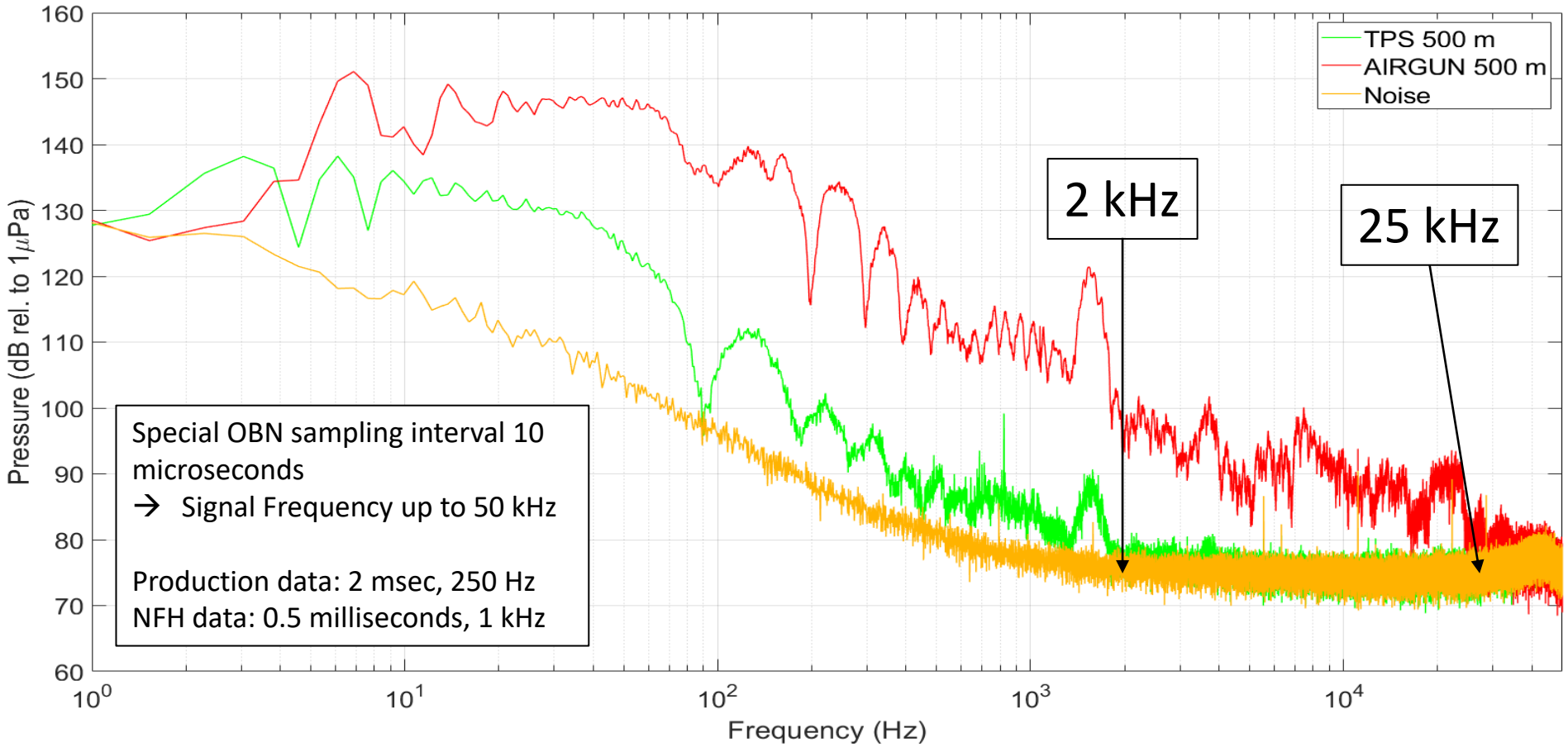
Offset in km

Data Analysis

- Sound Pressure Level (Time domain)
- Spectra (Frequency domain)
  - Overlay Airgun array, single TPS, noise
  - Watch the frequency at which the source signal is the same as the noise level

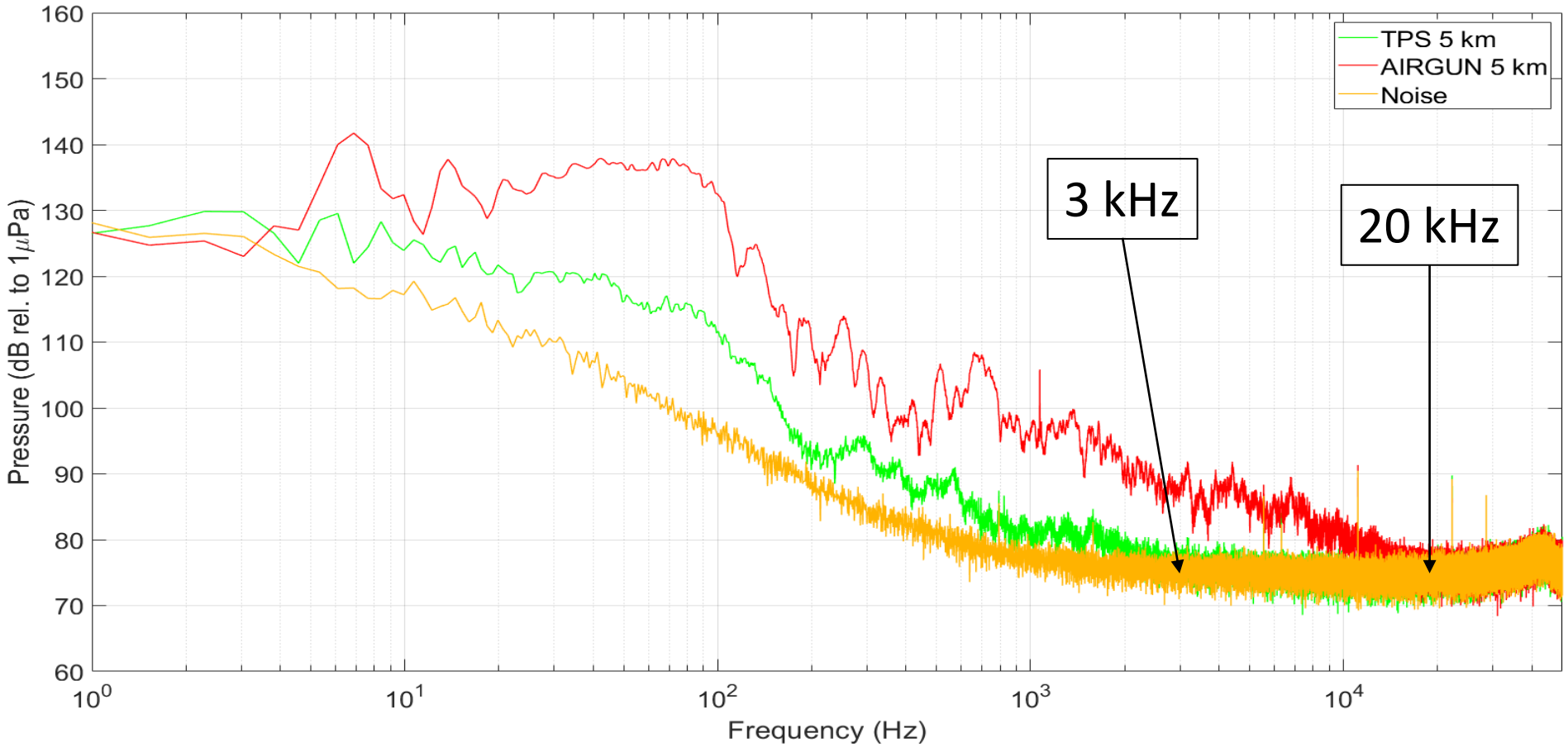
Amplitude spectra – OFFSET 500 m

Node depth: 2814 m, Distance: 2858 m



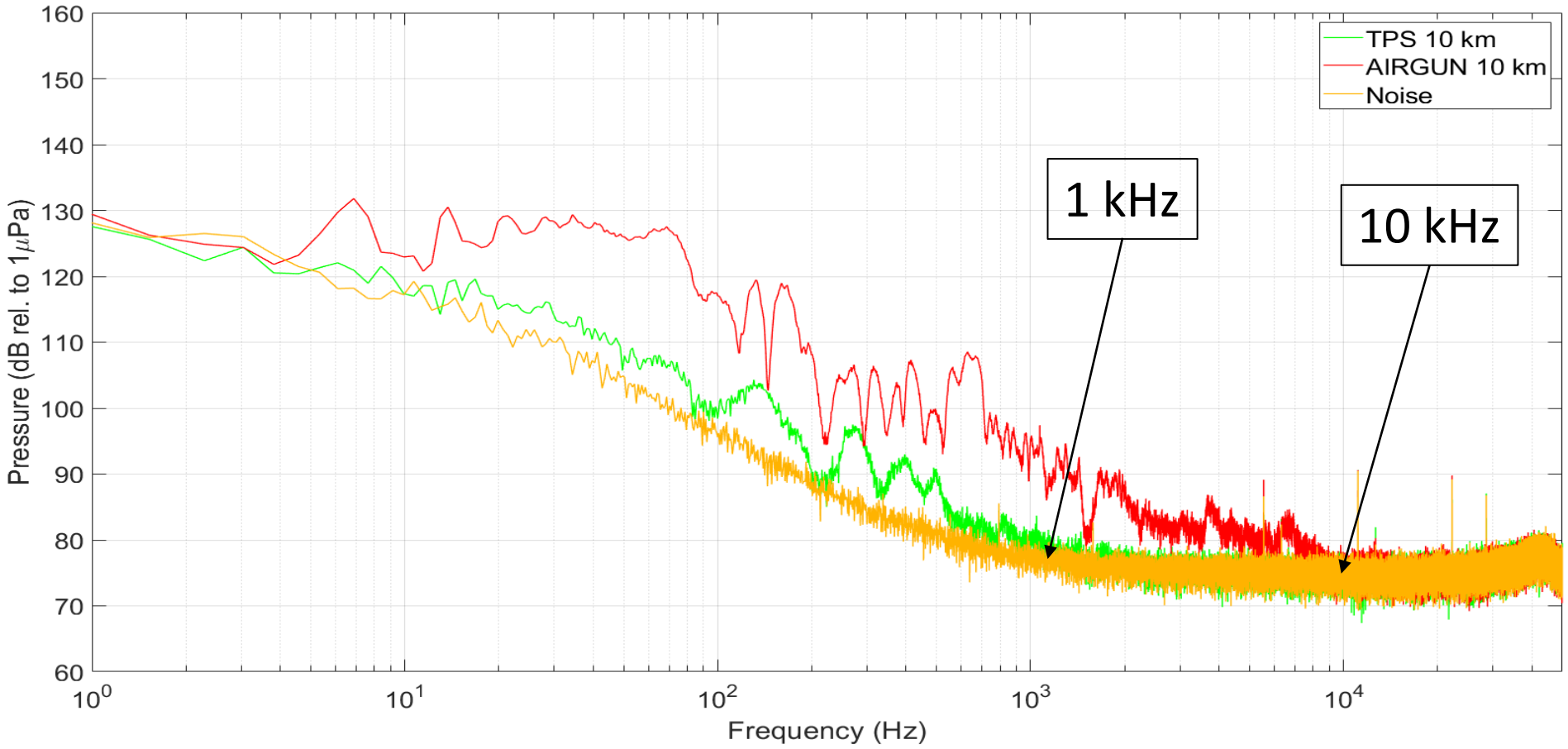
Amplitude spectra – OFFSET 5 km

Node depth: 2814 m



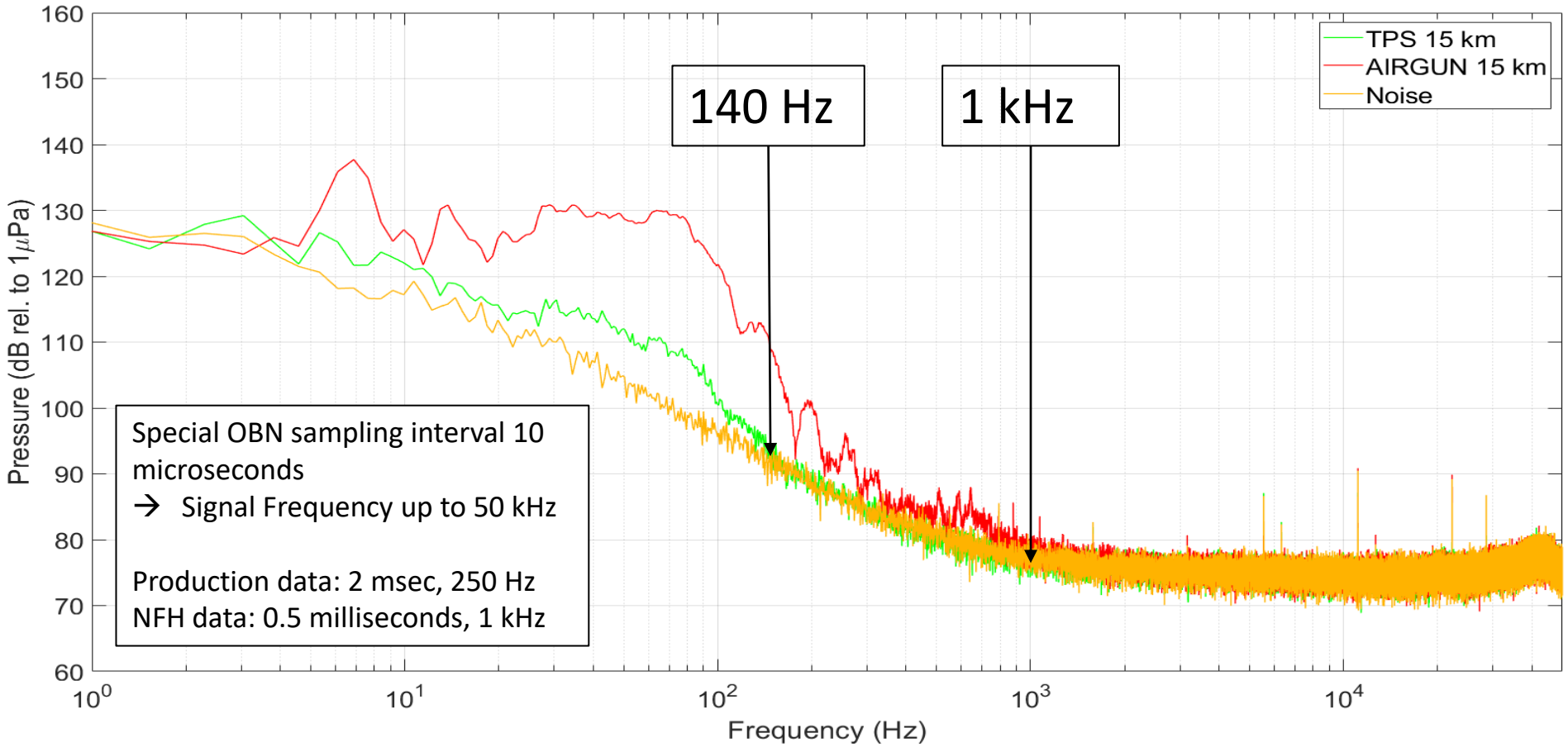
Amplitude spectra – OFFSET 10 km

Node depth: 2814 m



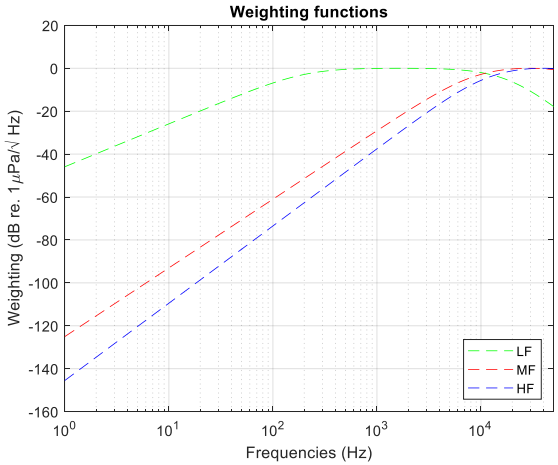
Amplitude spectra – OFFSET 15 km

Node depth: 2814 m, Distance: 15.26 km



Duty Cycle (from the Δt=10 usec data)

- There is a concern that non impulsive source may block communication because of high duty cycle
- Impulsive sources have lower duty cycles
- The duty cycle calculation depends on the threshold of the level that is loud enough to block communication
- The calculation is after bandpass by audio-band



- Duty cycle > 1%
  - only Airguns
  - only Low Frequency band
  - only up to 5 km offset

Duty cycle calculation

1. Bandpass to audio-band
2. Calculate the envelope (Hilbert method)
3. Count the % of the data above a certain threshold

Duty Cycles (10 Pa threshold)

500 m offset 2814 m depth		
Band	Airguns	TPS
LF	3.46%	0.21%
MF	0.13%	0.0001%
HF	0.10%	0.0001%

5 km offset 2814 m depth		
Band	Airguns	TPS
LF	1.07%	0.11%
MF	0.02%	0.0001%
HF	0.01%	0.0001%

Above 1%

10 km offset 2814 m depth		
Band	Airguns	TPS
LF	0.69%	0.06%
MF	0.001%	0.0001%
HF	0.0001%	0.0001%

15 km offset 2814 m depth		
Band	Airguns	TPS
LF	0.44%	0.05%
MF	0.0001%	0.0001%
HF	0.0001%	0.0001%

Summary (1)

- Size does not matter *environmentally*
  - 28Kcui cubic inch much friendlier than 5Kcui
  - (It matters *geophysicaly*: much better low frequency signal)
- Design matters!
  - It is the design of the head that matters environmentally
  - Low frequency sources that are clusters of standard airguns have the same cavitation and high frequency content, just fewer guns in a cluster than the number of guns in a standard array
- TPS compared to standard airguns
  - Longer rise time, much lower slope
  - Less/no cavitation: max frequency 25 kHz → 2 kHz
    - Modeling and 0.5 msec data do not capture 1kHz and above

Summary (2)

- We should take the design and the number of the heads into account, environmentally
  - not the total volume of the chambers
  - Should record high frequency data: max frequency 25 kHz or 2 kHz ?
  - SPL, RiseTime, Slope = SPL/RiseTime = Impedance✱acceleration
- Consequences on permitting and mitigations
  - First come first serve permitting?
  - Exclusion radii (always 500m?)
  - Permit time limit (always 65 days in the USA?)
  - Permit spatial limitations (60 km minimum distance)

Summary (3)

- When testing any new source that claims to be environmentally friendlier than conventional Airguns
  - Near field hydrophone and streamer data are not enough
  - We also need Ocean Bottom Node data because
    - Low ambient noise
    - To provide far offsets data for SPL and Duty Cycle as a function of offset
  - We need data from high frequency recorders with 10 usecs or less sampling interval (50kHz or more Nyquist frequency)
    - This is possible with special OBN, special NFH, PAM, and some special streamers that are used as passive acoustic monitoring (PAM)

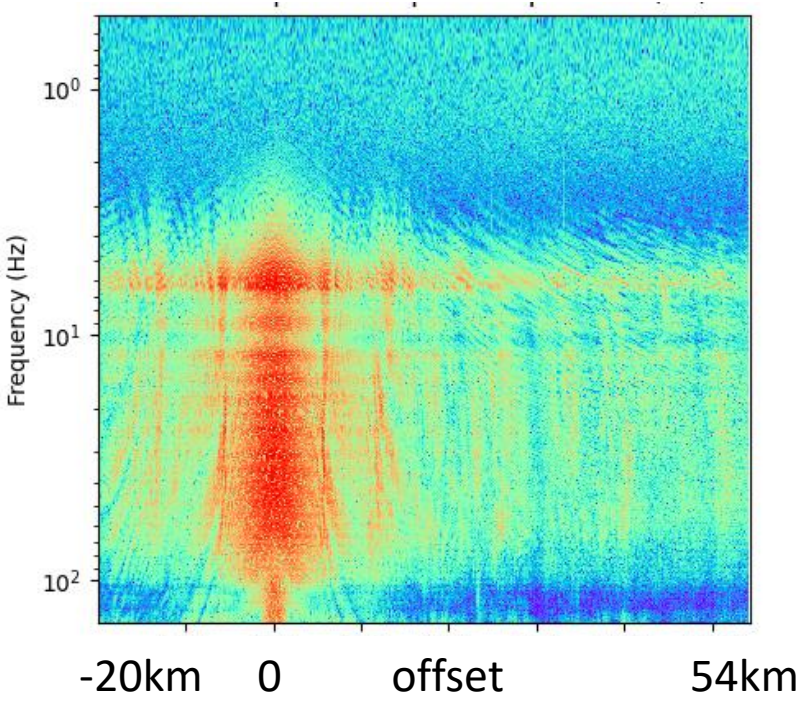
Spare Slides

that were moved back for lack of time

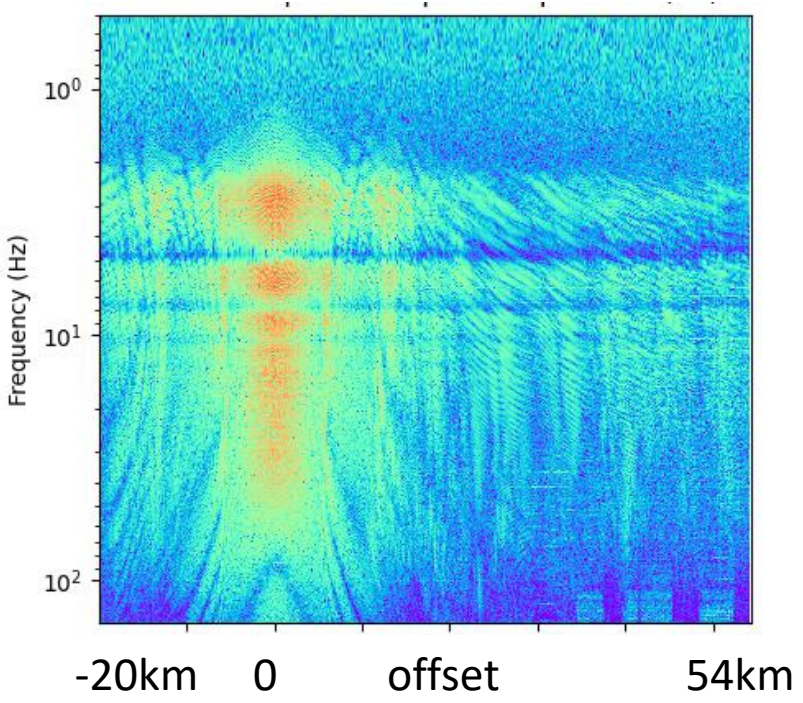
kept for discussion and handout

Side by side spectra (Frequency, Offset)

5Kcui Airgun Array

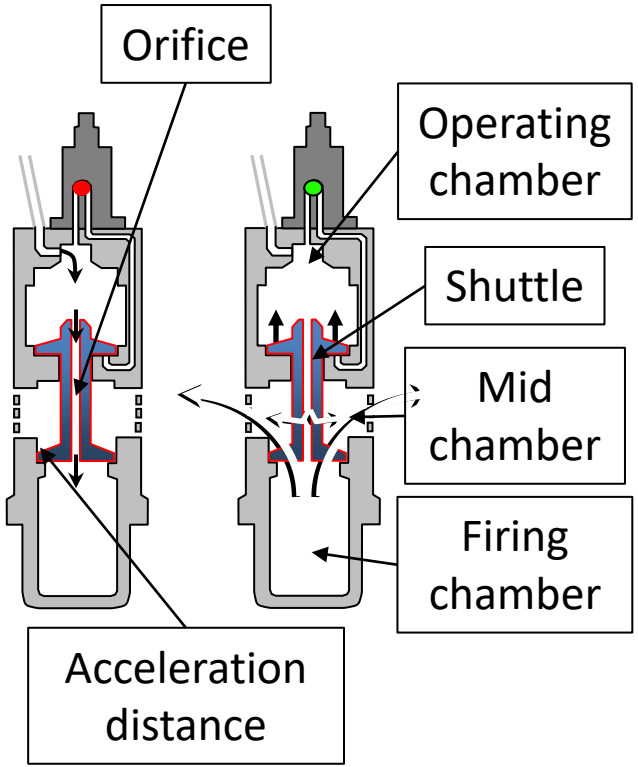


26Kcui Single TPS



Common Receiver Gathers: same node, two co-located shot lines

Airguns' 60-year-old design

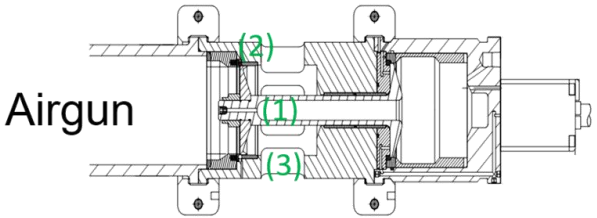


Low HSE ambition level

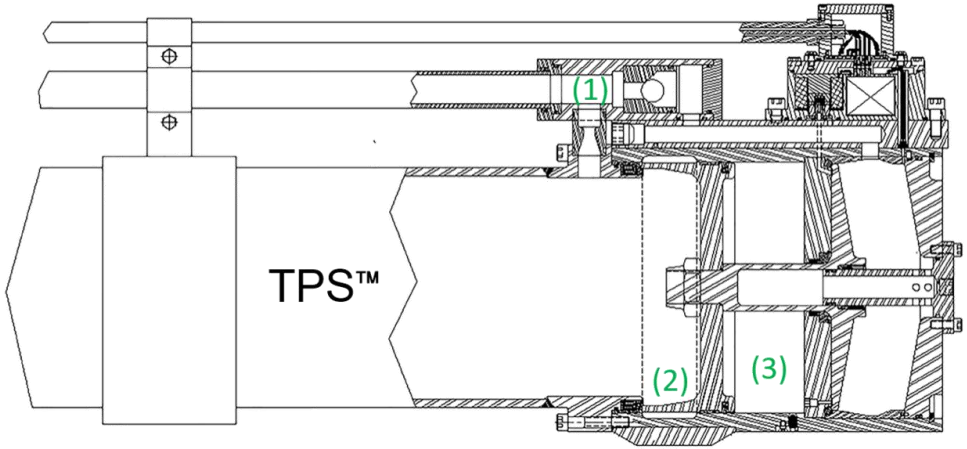
- **Acceleration Distance**
  →short rise time
- Water flooded **mid chamber**
  →cavitation
- **Orifice** through the shuttle
  →Autofires

Important TPS design features

1) No orifice → safer air draining method
2) Zero acceleration distance → longer rise time and lower slope
3) Air filled mid chamber → reduces cavitation

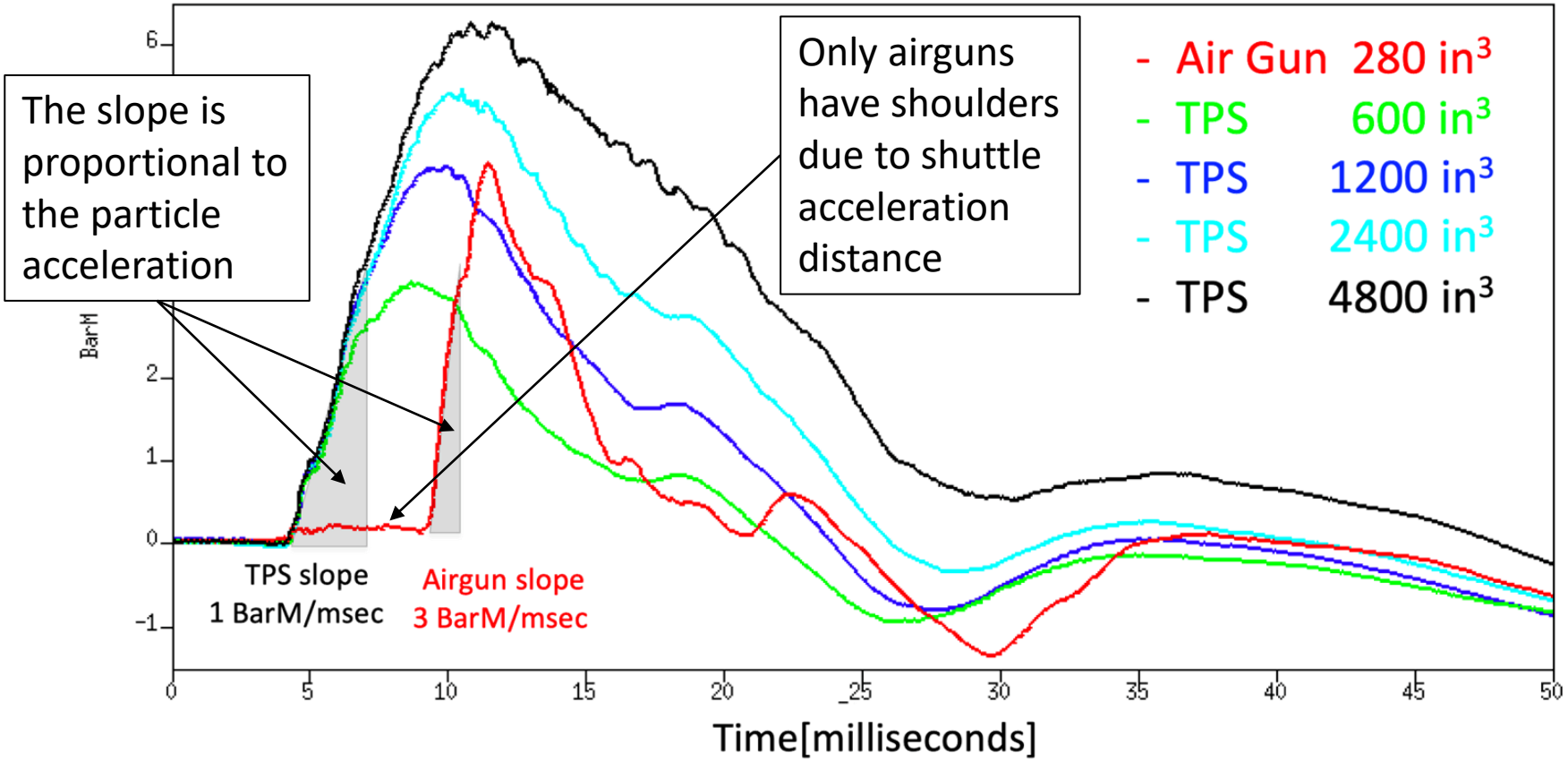


Feature	Airgun	TPS	
Air fill/drain	via shuttle	direct	(1)
Flange	Flat piston	Cup-shaped	(2)
Acceleration distance	A few cm	Zero	(2)
Mid chamber	Water-filled	Air-filled	(3)

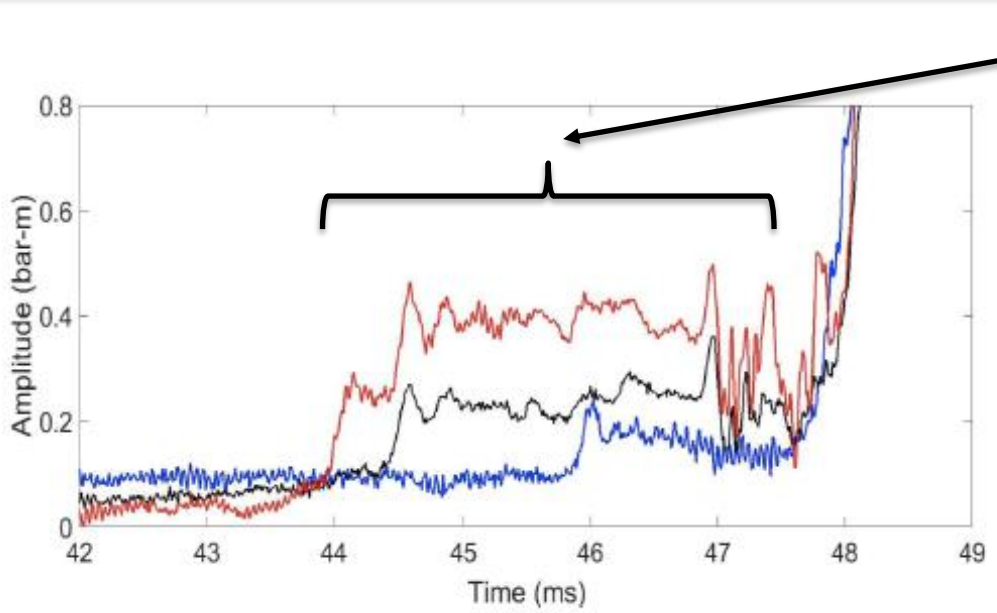


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Lower slope and no “shoulder” with TPS



Acceleration distance: Airgun “shoulder”



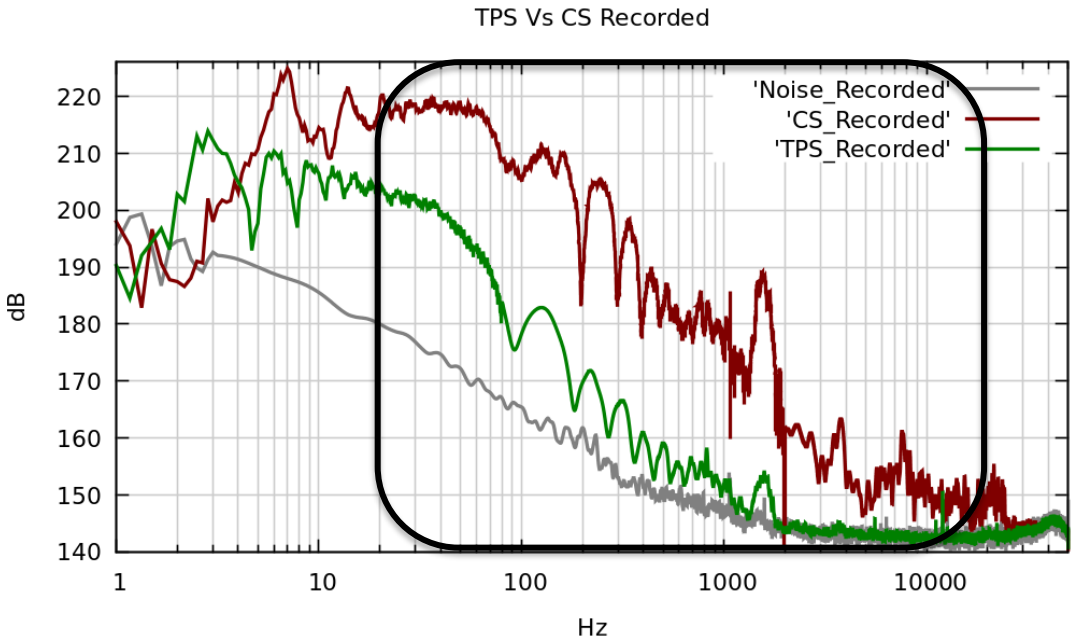
— Cluster 2X300 cui
— Single 300 cui
— Single 70 cui

Comparing the broadband acoustic frequency response of single, clustered and arrays of marine air guns (Martin Landro, 2016)

Water coming out of the mid chamber before the air causes cavitation and high frequency waves

Human Audio-band 20 to 20K Hz

- The crew does not hear the TPS
- They can feel “it” through the hull. Through the feet and when they touch something
- The TPS is mostly below 20 Hz, so it is infrasound for humans



- The same happened before in quarry testing

Array Vs point source directivity

