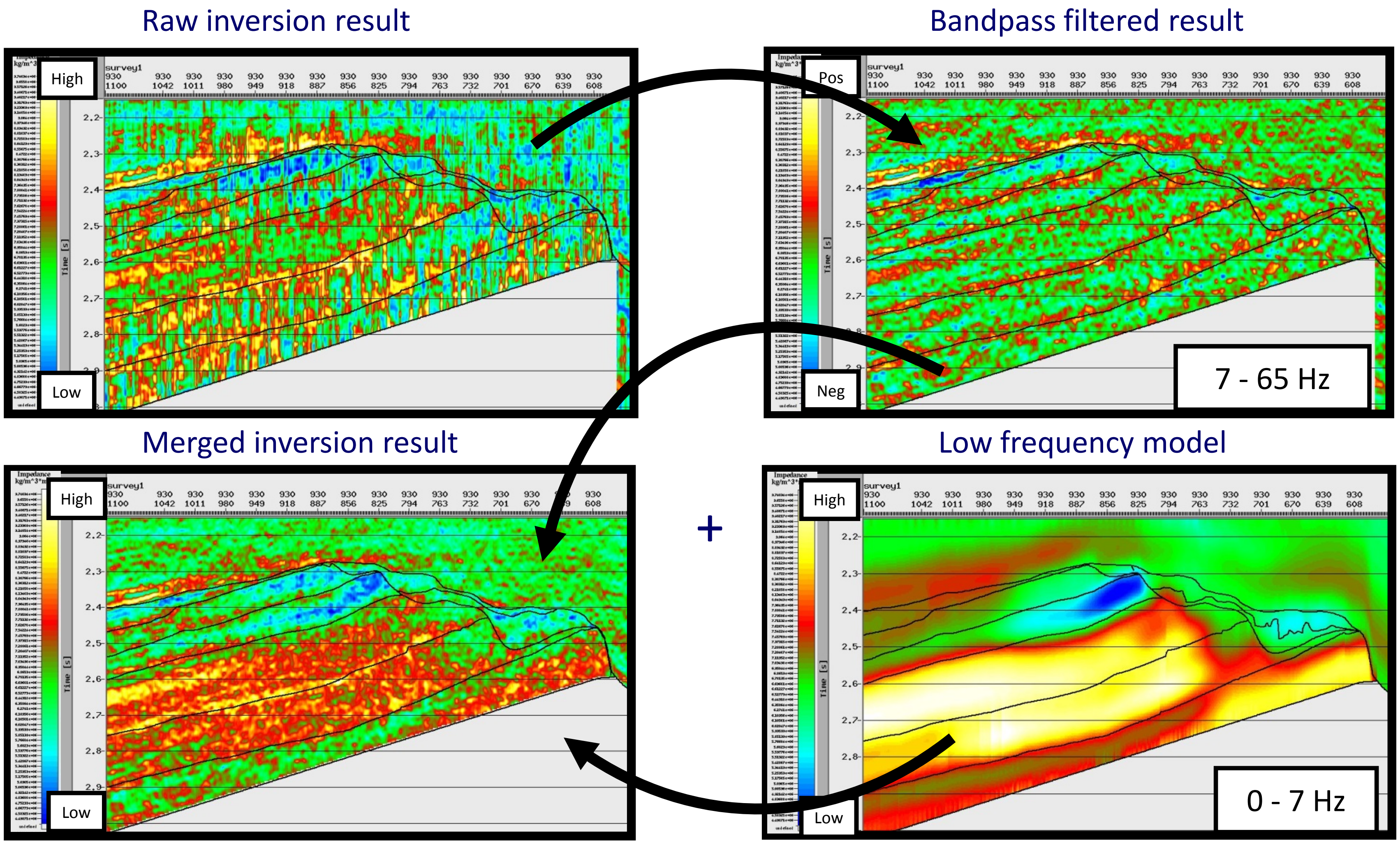
Maximizing the ultralow frequency output from air guns

Talk at ROSE meeting 2014 by M. Landrø, K. Hokstad and L. Amundsen, NTNU

Content

- Why low frequencies?
- Single, big gun test
- Proposed mechanism for generation of ultralow frequencies
- Bubble test from last week

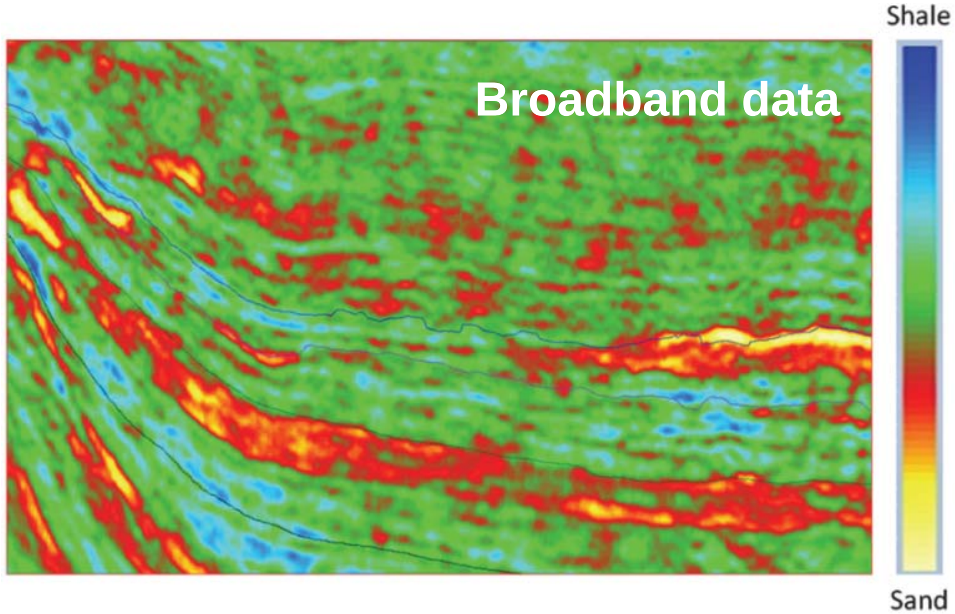
Seismic inversion: Low frequencies from well logs

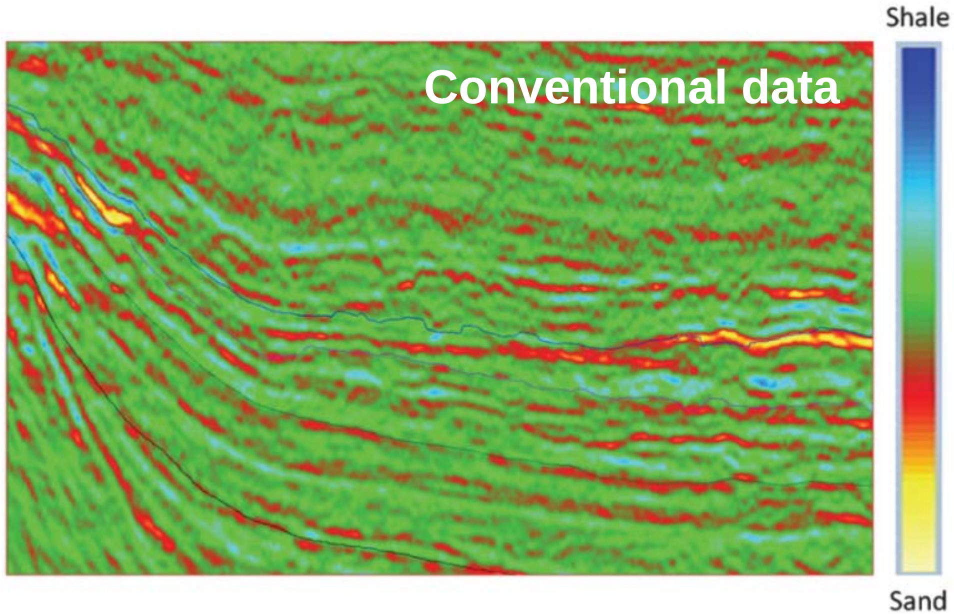


well logs + interpreted horizons + interpolation

IMPEDANCE INVERSION WITHOUT WELL INFORMATION

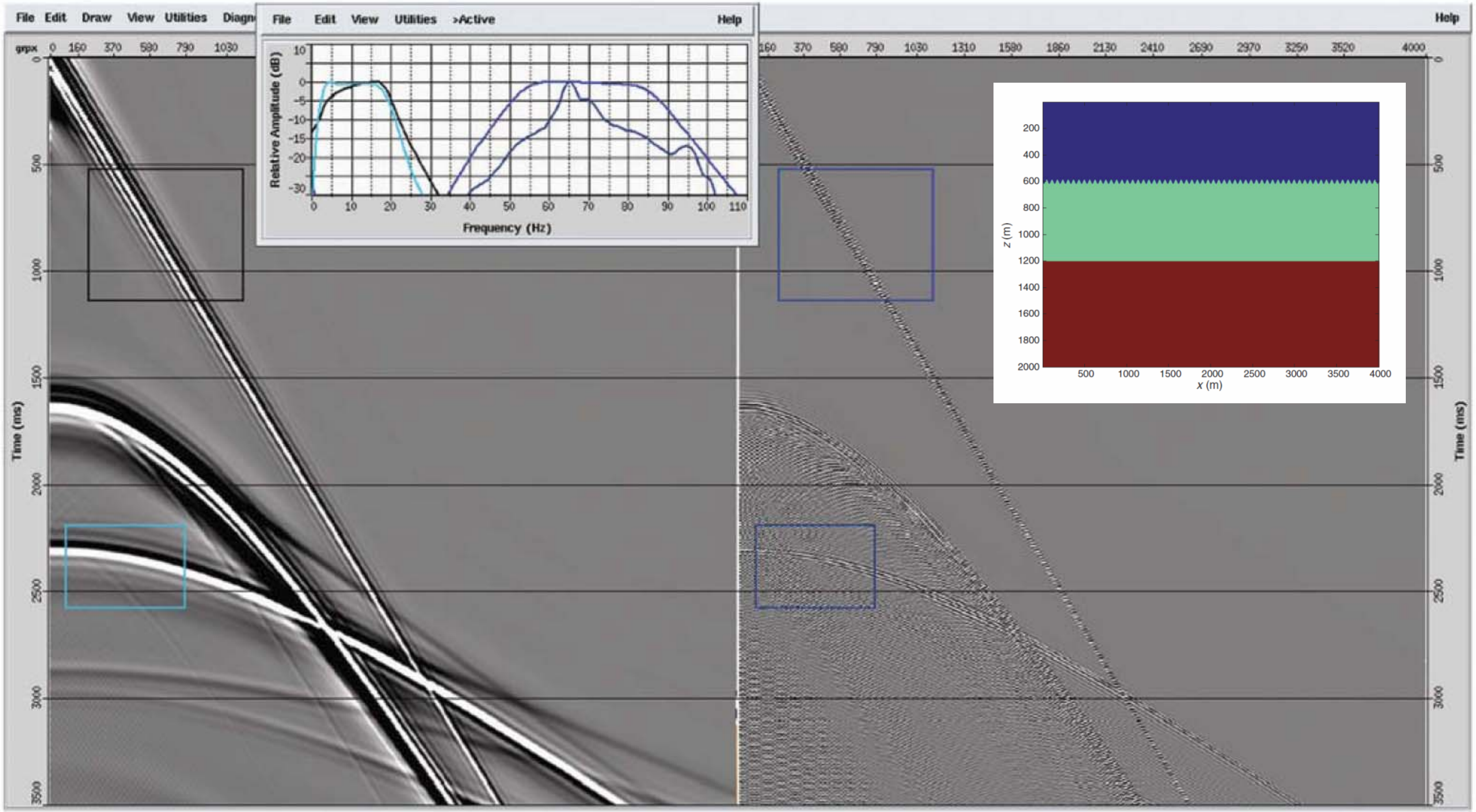
Thick sands (yellow-red) are visible on the broadband data. Shales (blue-green).





Source: Kroode et al., Geophysics 78 No. 2:

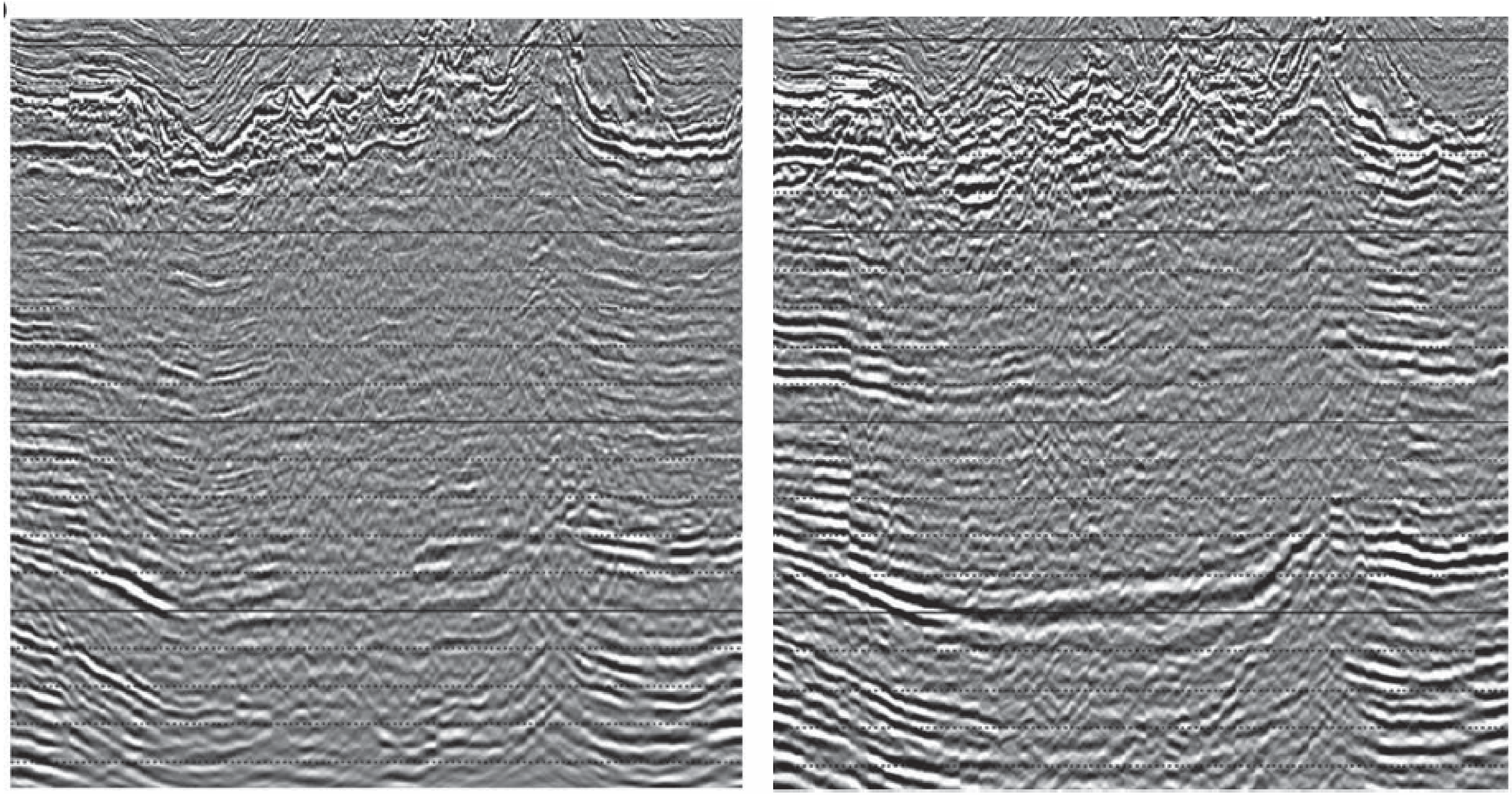
The importance of low frequencies



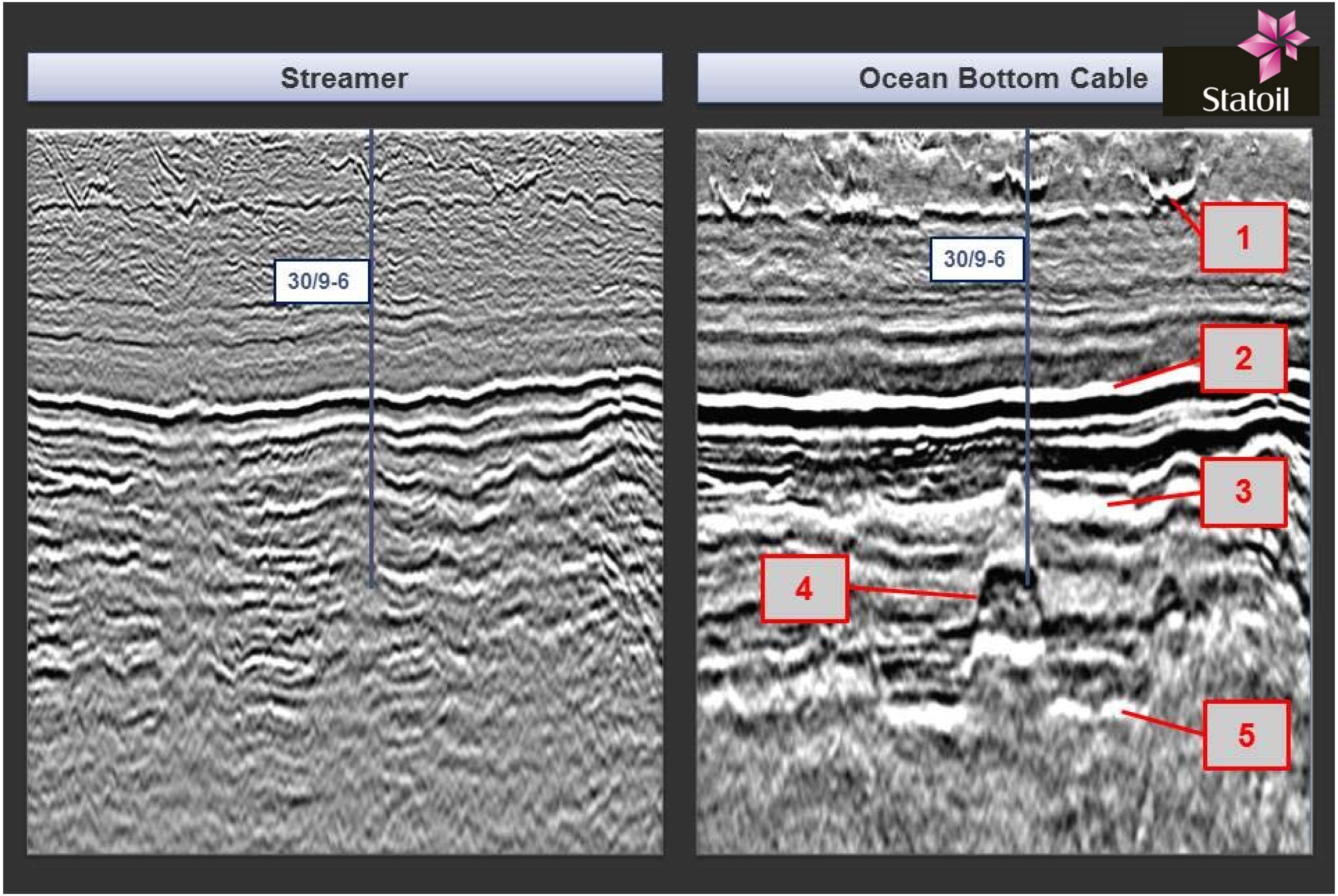
The rugosity influence high frequency data more than low frequency data

Source: Kroode et al., Geophysics, 2013

Conventional (left) and broadband (right) data



Source: Kroode et al., Geophysics, 2013

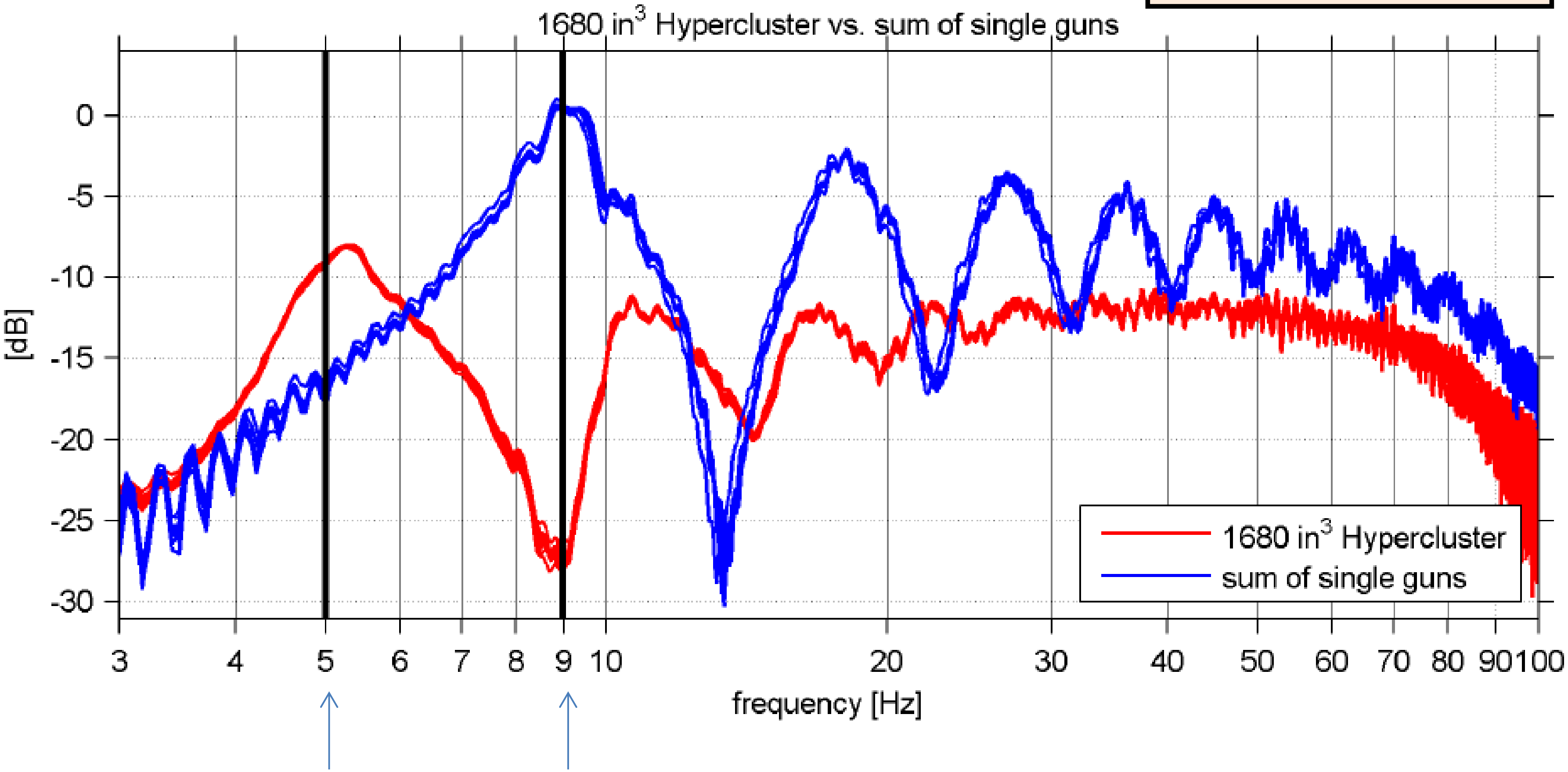


1) Oligocene sands 2) Shetland 3) Reservoir 4) Improved fault imaging 5) Improved imaging of deeper, prospective sands

Size matters: Big guns give more low frequency

Airgun hyperclusters:

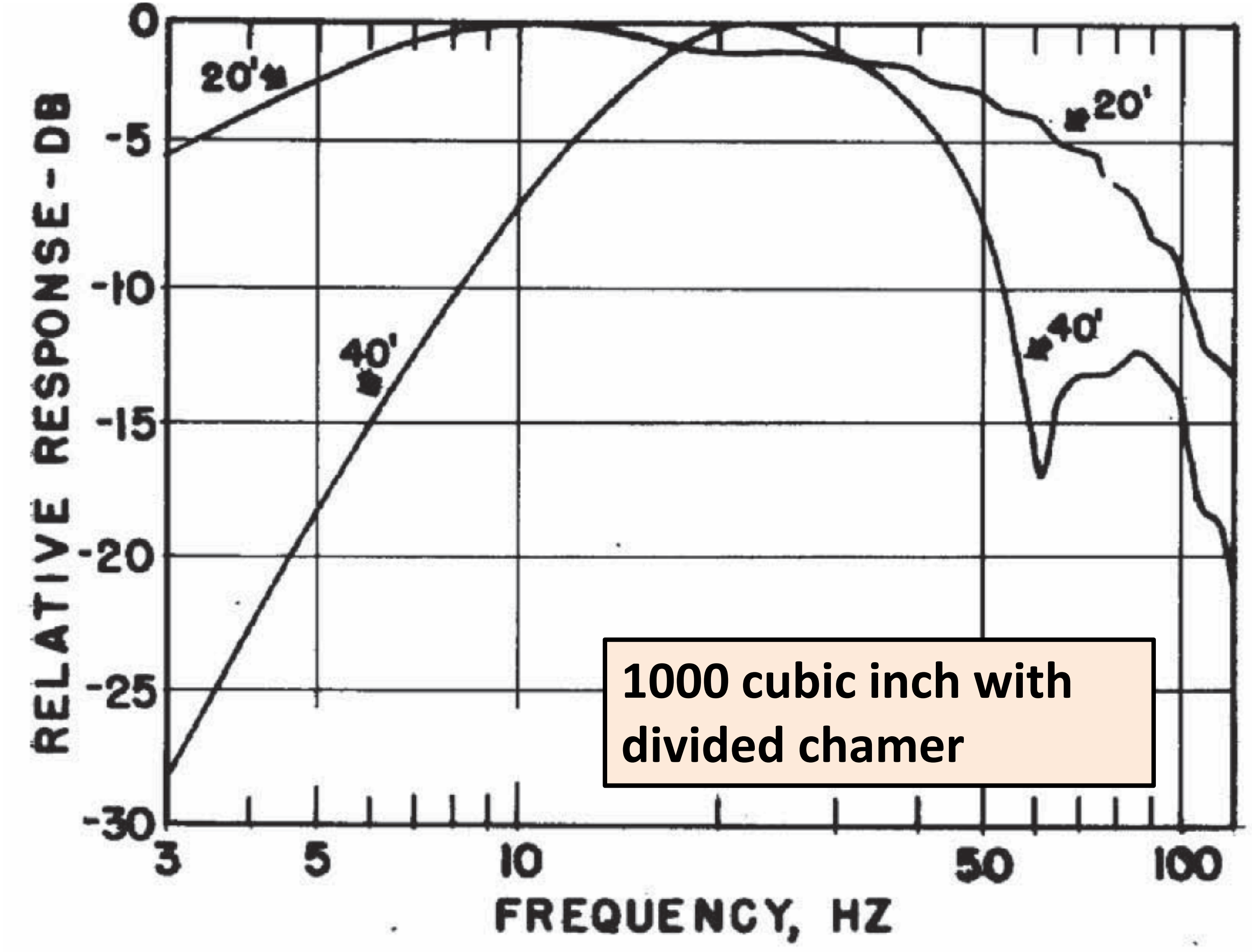
$$\tau = const \frac{P^{\frac{1}{3}} R_0}{p_h^{\frac{5}{6}}}$$



Theoretical bubble frequecies fit nicely with measured data

Hopperstad et al. EAGE 2012

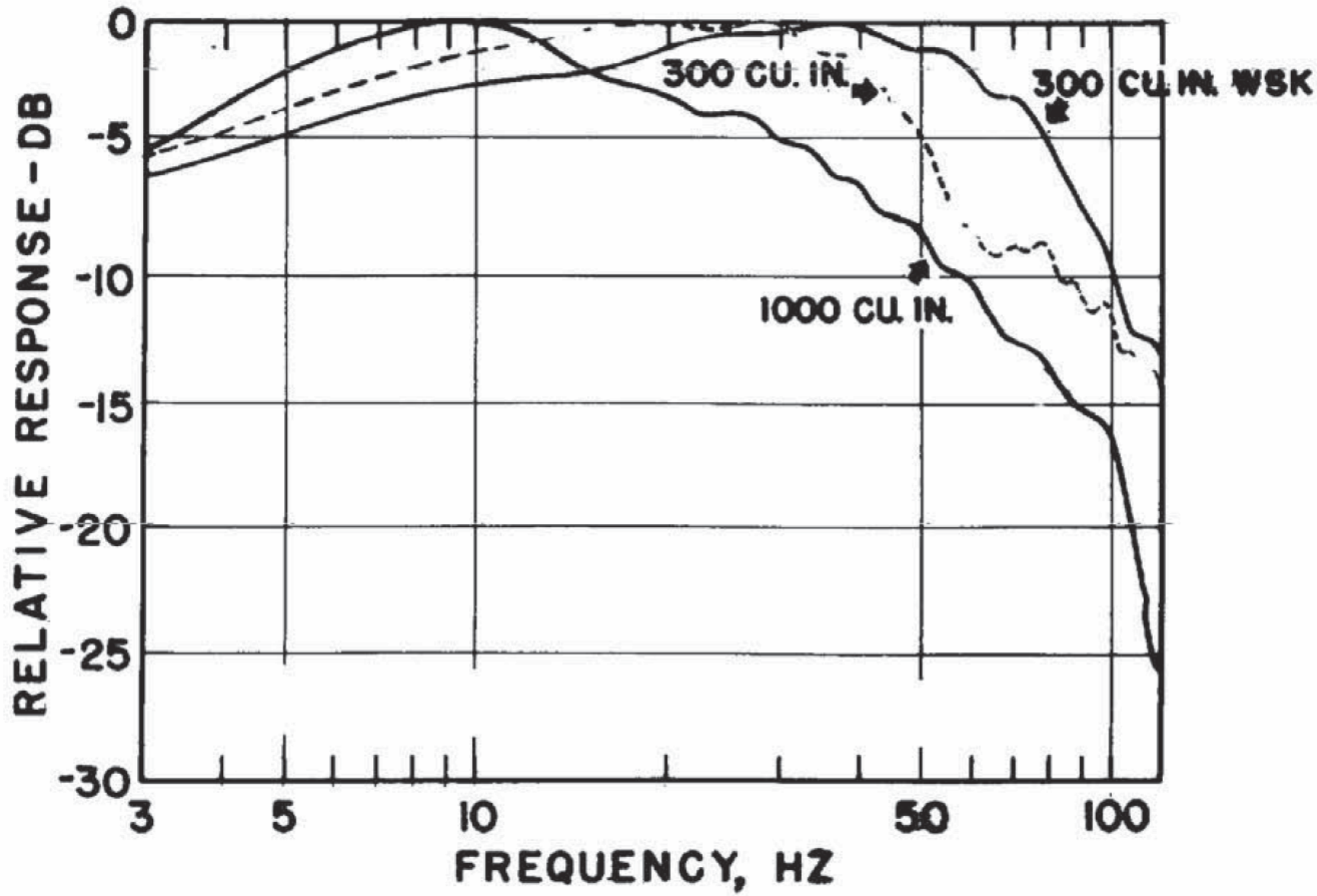
Early observations by Mayne and Quay, 1971



Hydrophone suspended at 100 feet

Mayne and Quay, Geophysics, 1971

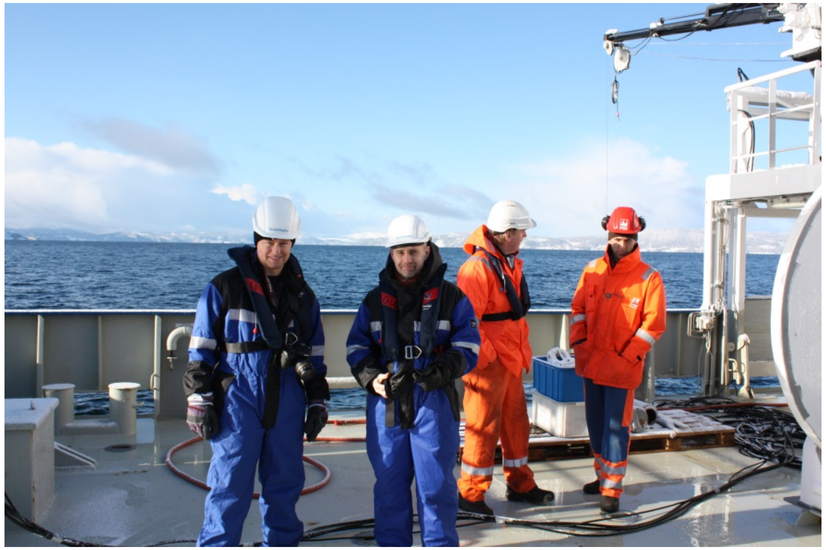
Bigger guns: Better low frequency response

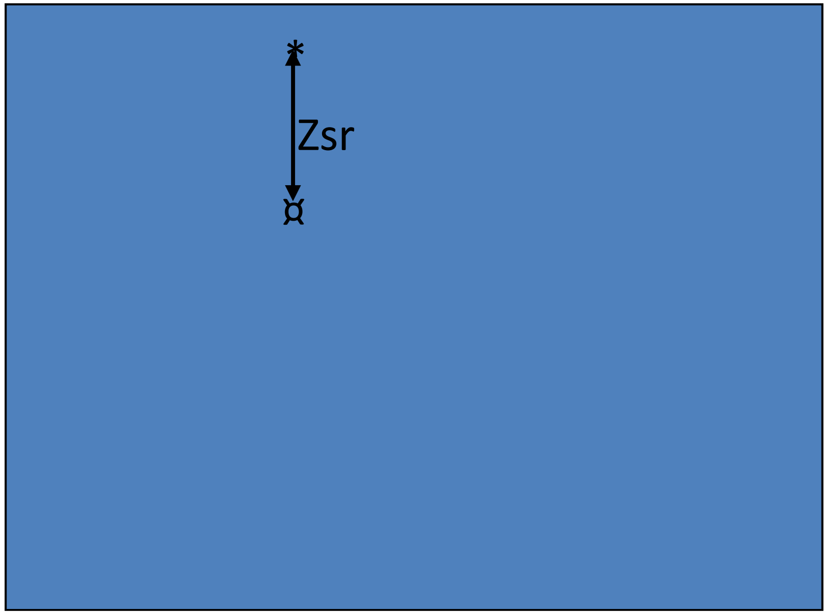


Hydrophone suspended at 100 feet

Mayne and Quay, Geophysics, 1971

Gunnerus test –February 2009 Trondheimsfjorden

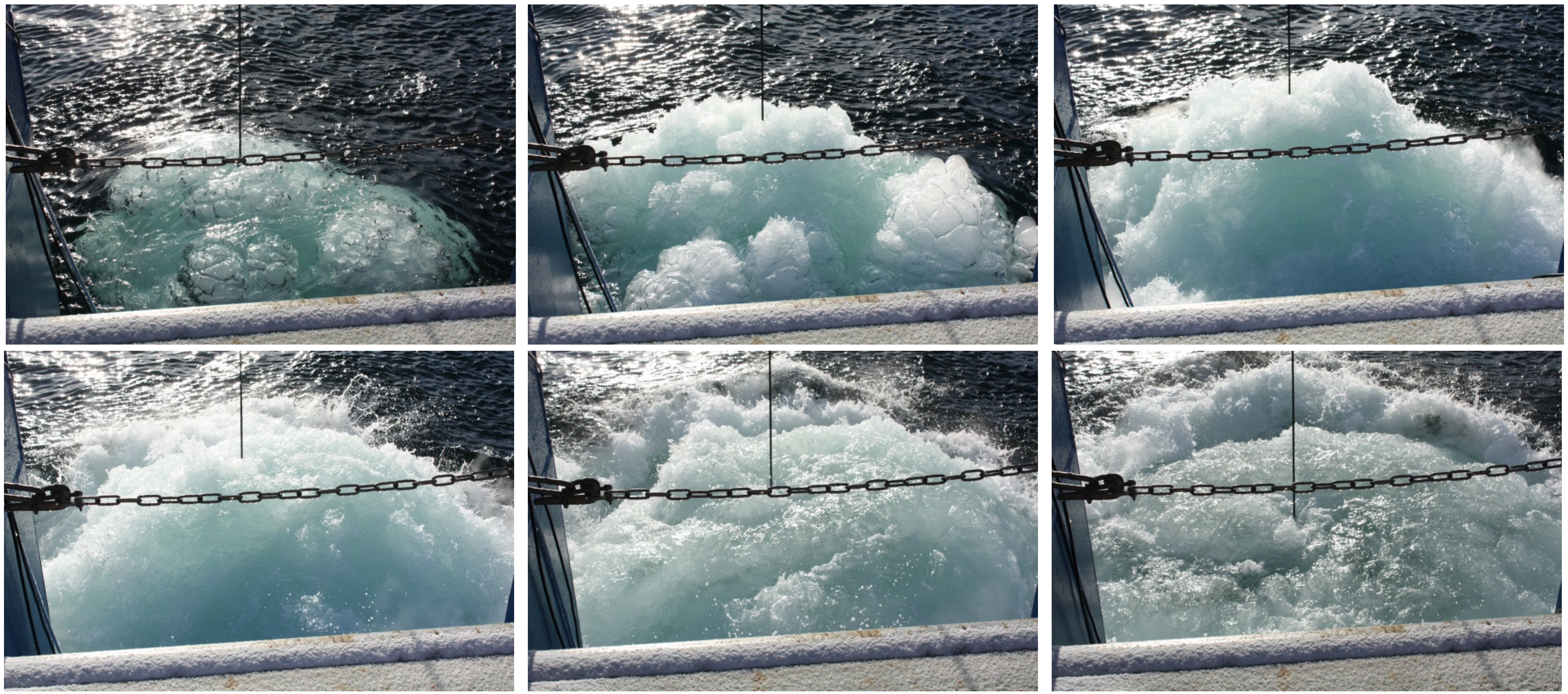




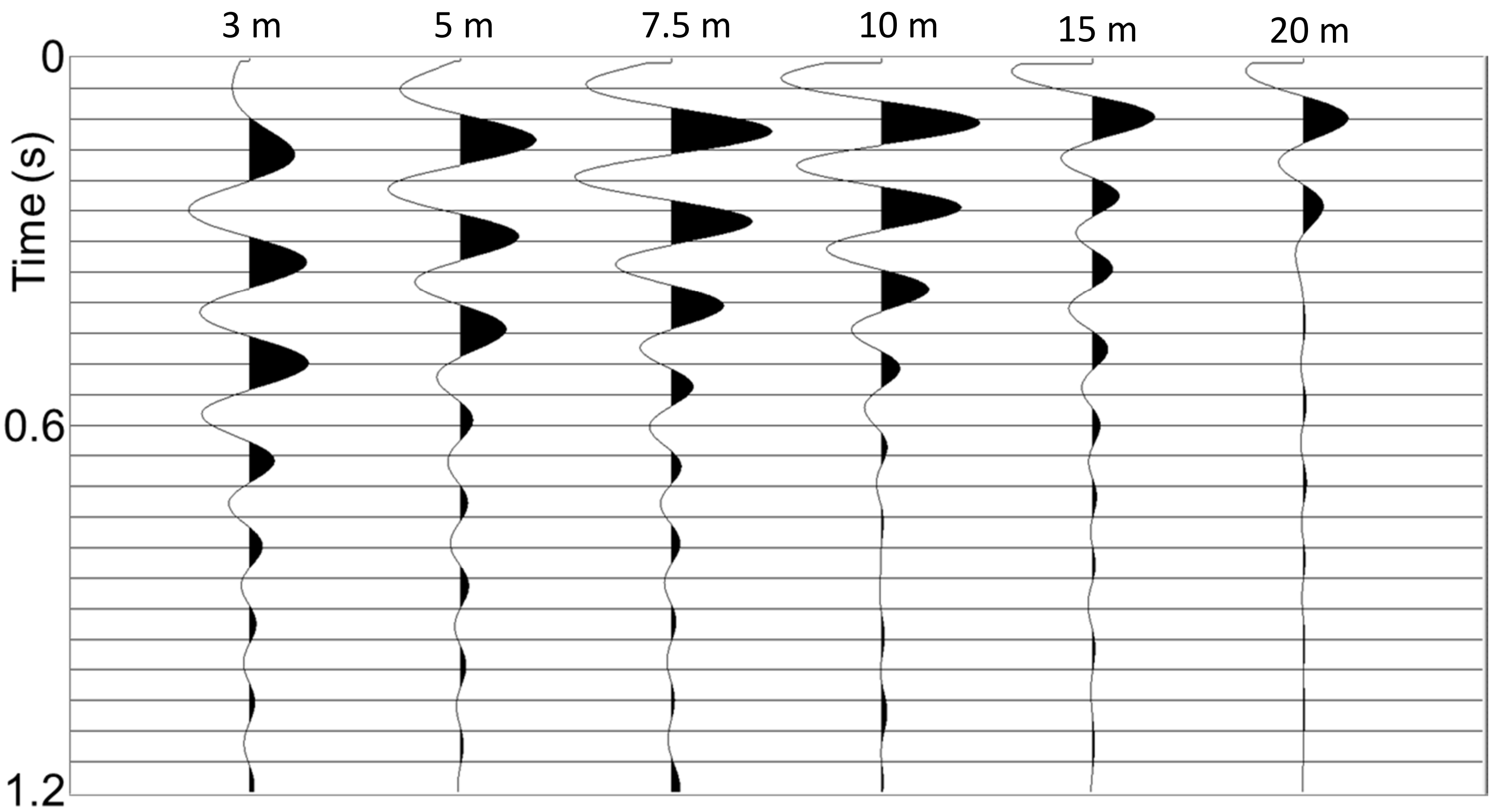
The source depth is varied from 3 to 40 m, and the distance between the source and the hydrophone is kept constant: Zsr = 20m. Water depth is ~300 m .

Source volume: 600 cubic inch Bolt
Firing pressure: 2000 psi

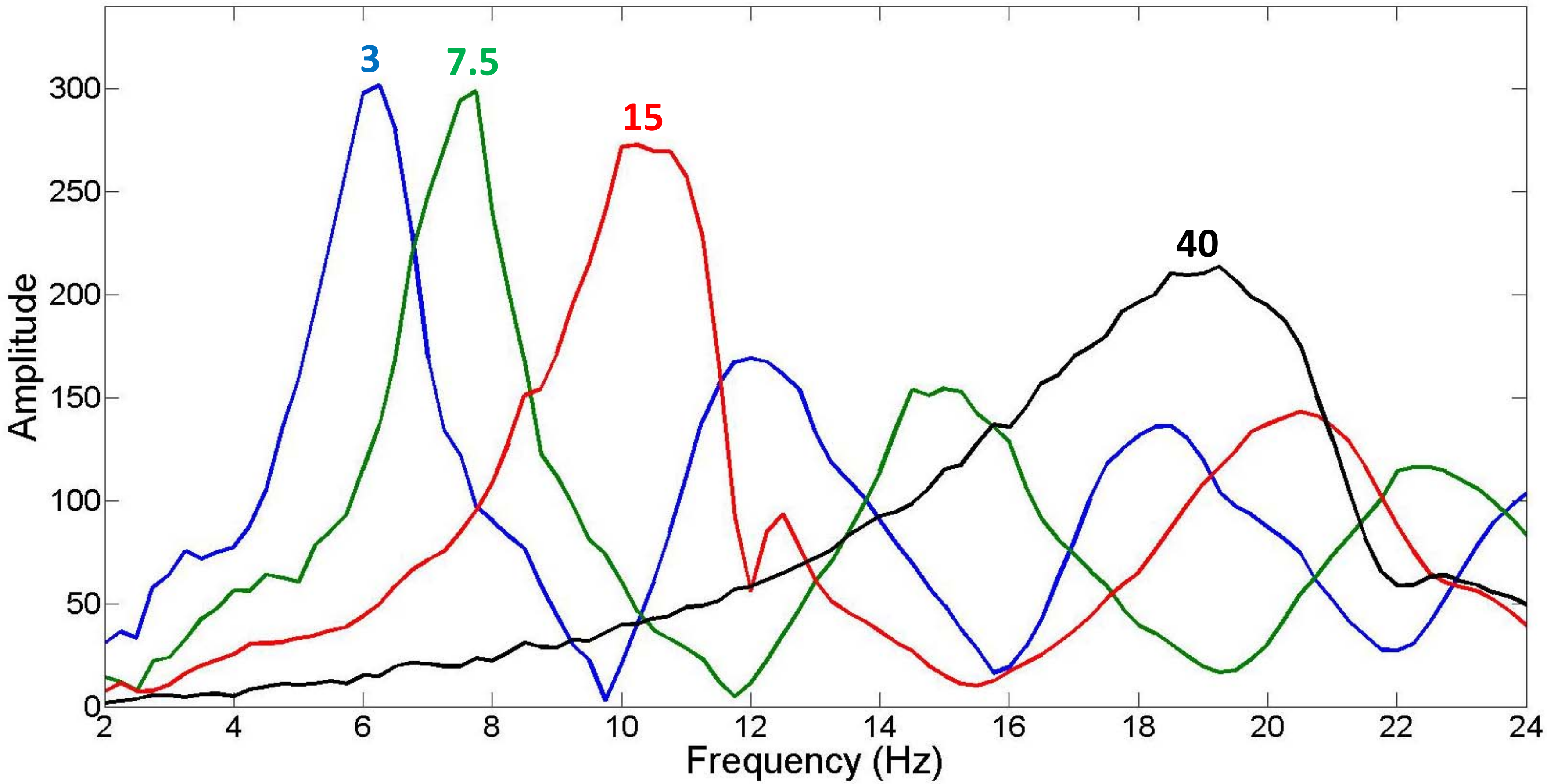
Bubble of 600 cubic inch gun breaking the water surface



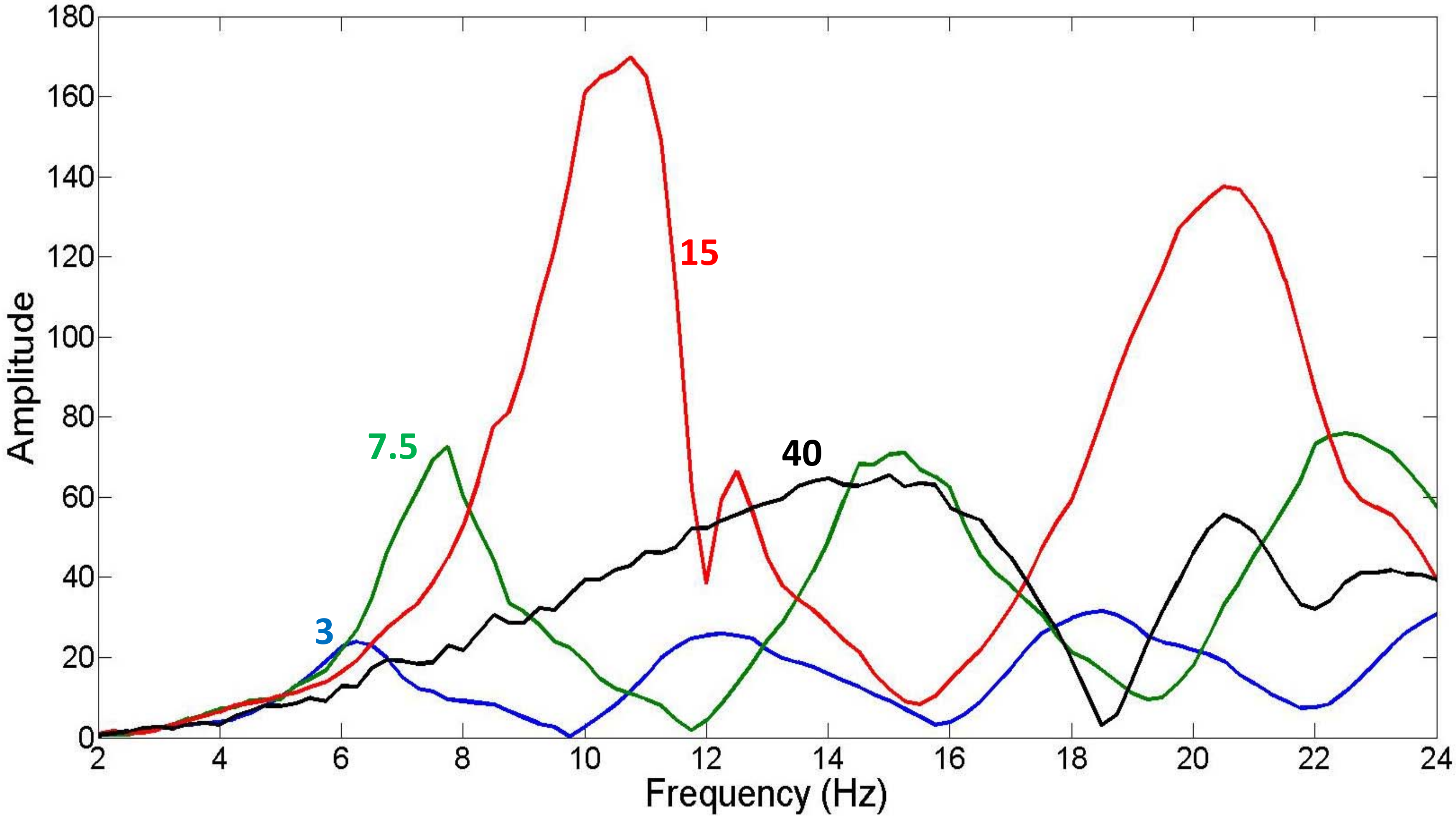
7 Hz low pass filtered field data



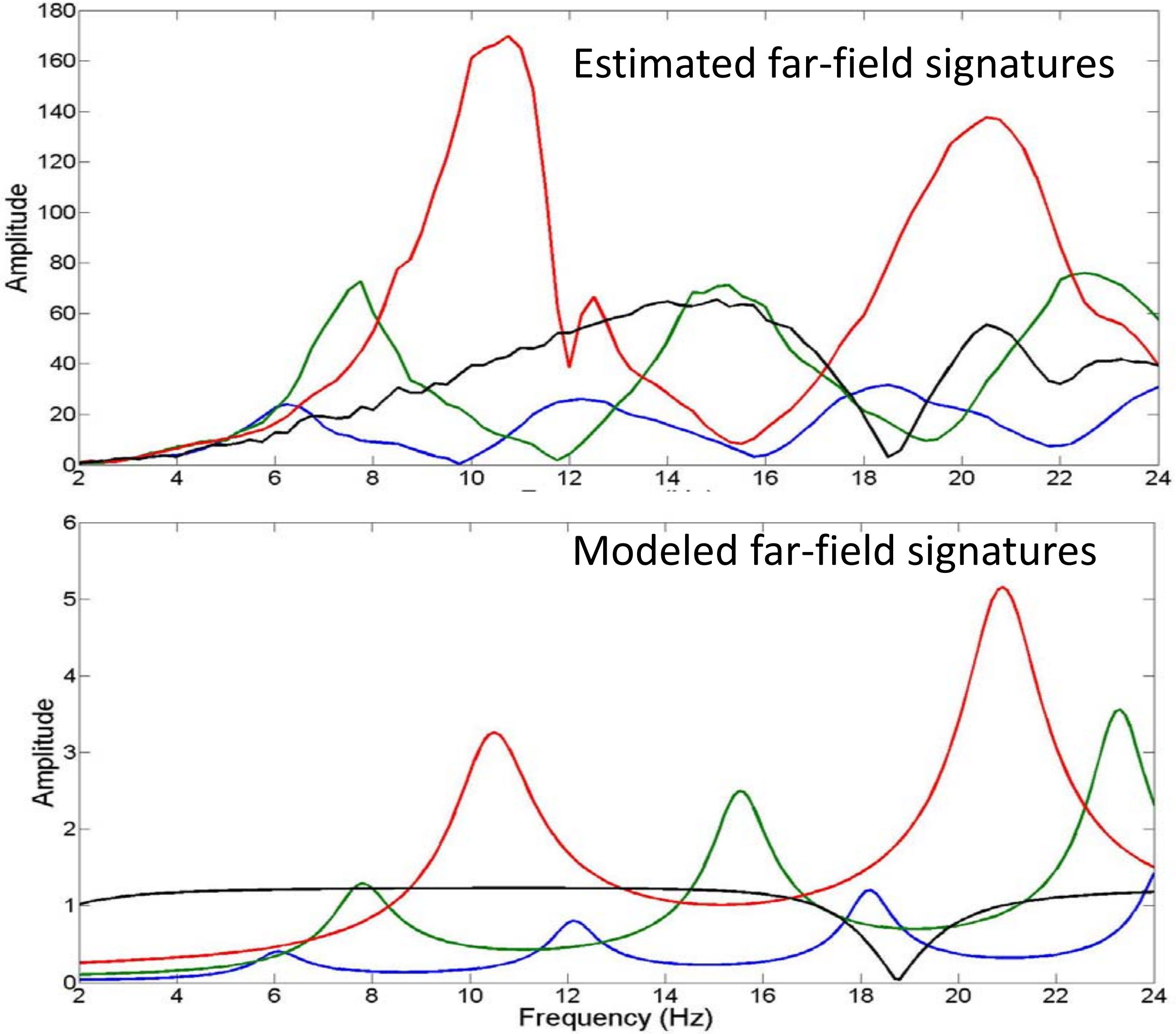
Estimated notional source signatures (de-ghosting)



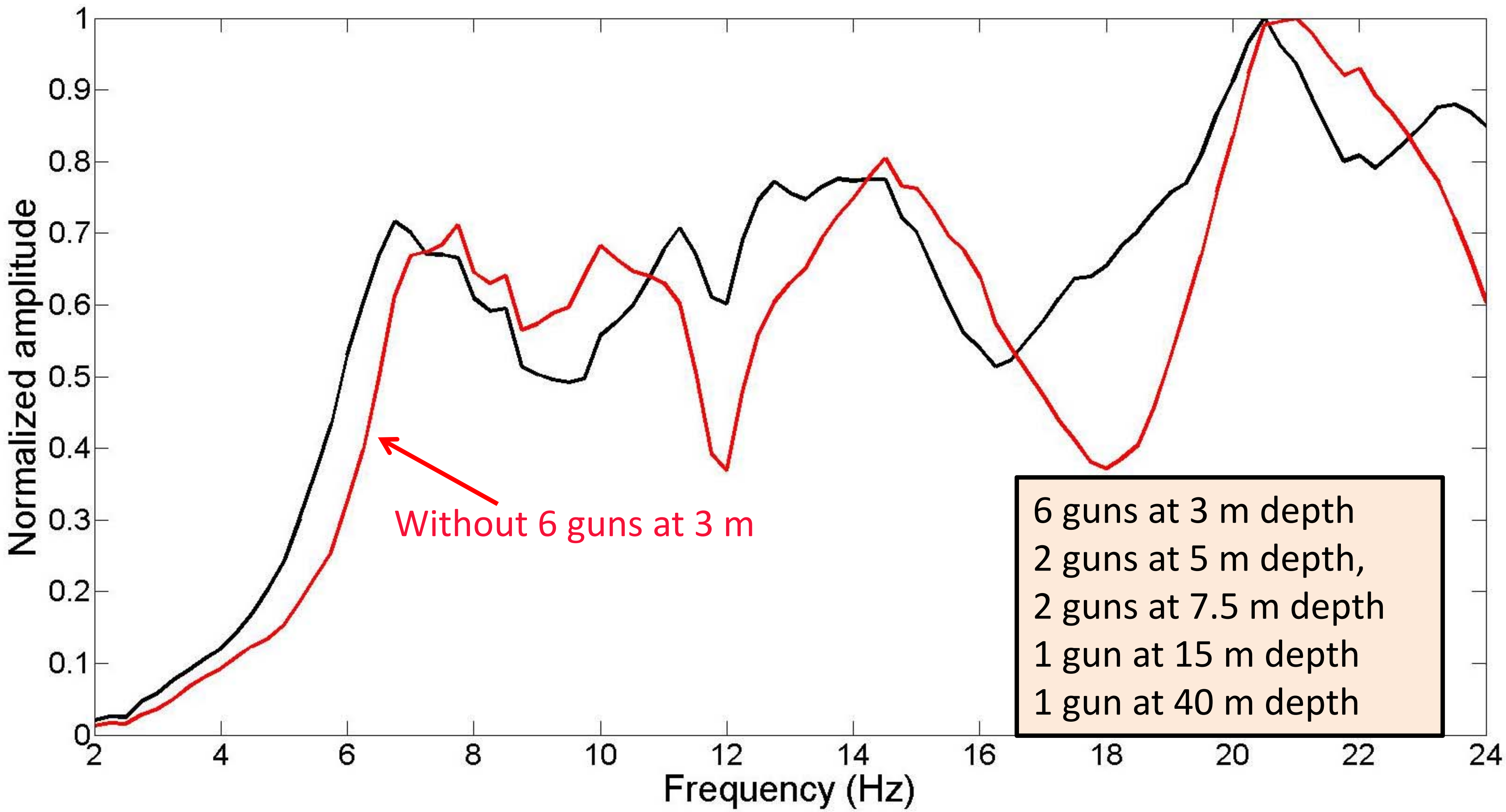
Estimated far-field signatures (de-ghosting+ghosting)



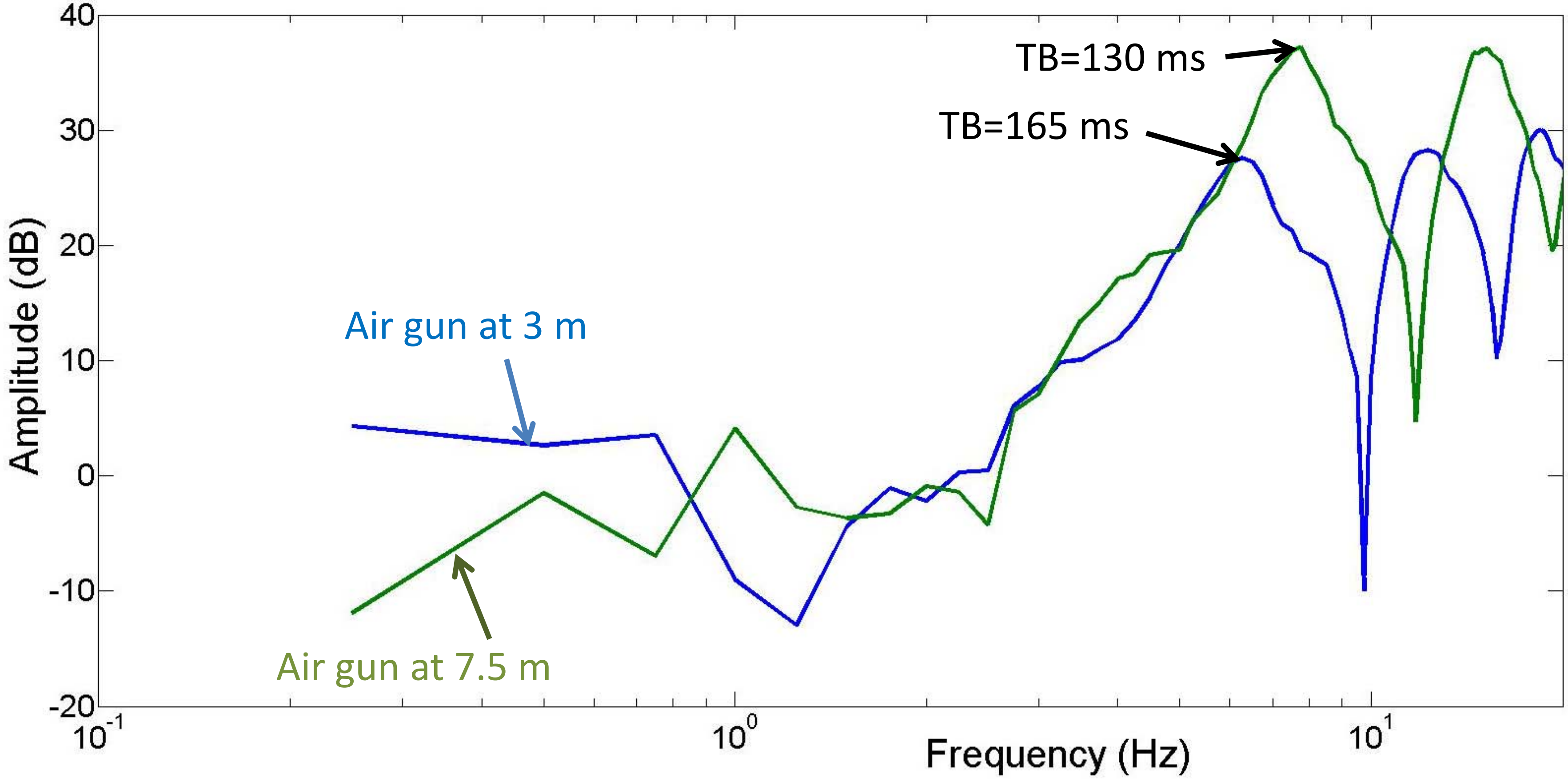
Comparison of «measured» and modeled far-field signatures



Farfield amplitude spectrum of twelve 600 cu. in. guns at various depths (sum of notional sources and addition of source ghost)



Estimated far-field spectra 3 and 7.5 m depth



Notice the 10 dB difference for frequencies between 0.25-0.8 Hz

Landrø and Amundsen, Geophysics, 2014

A possible mechanism for ultralow frequencies from air guns

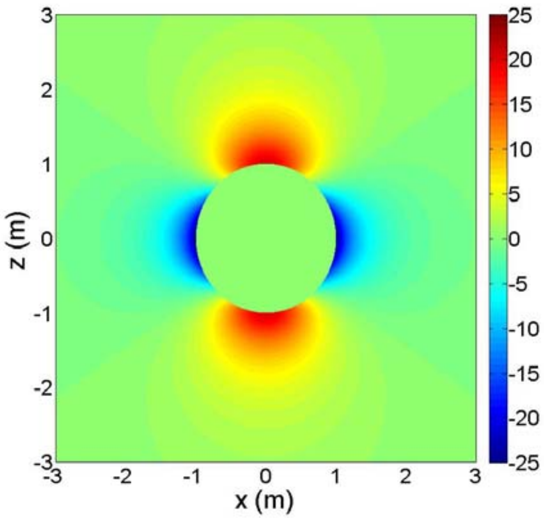
Bubble rise velocity:

$$U_B = \frac{2}{3}\sqrt{gR}$$

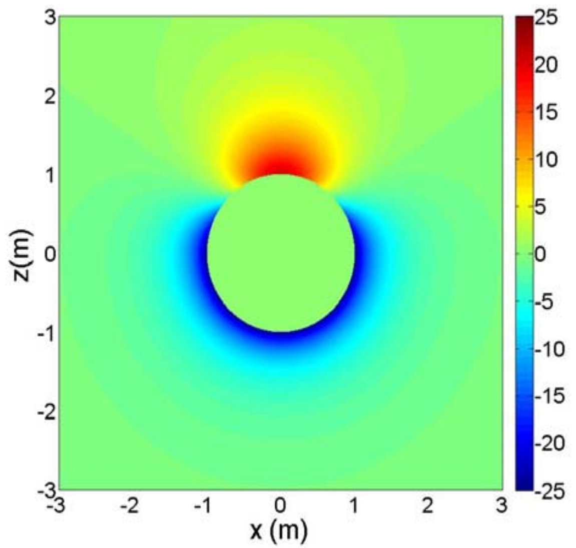
Davies and Taylor, 1950

Pressure around a sphere in a moving fluid:

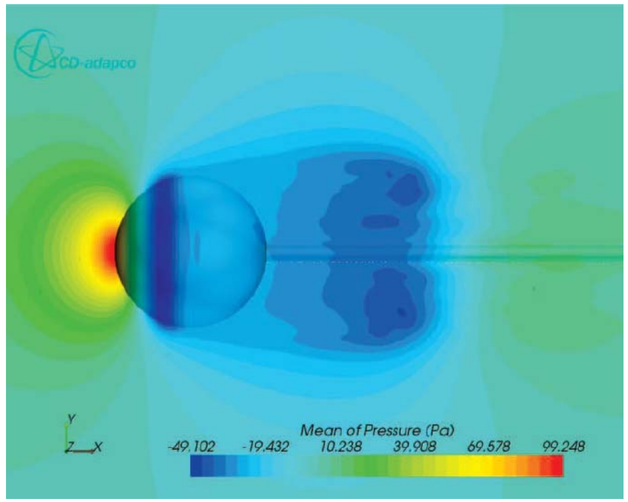
$$p - p_h = \frac{\rho U_B^2}{2}\left(2\frac{R^3}{r^3} - 3\frac{R^3}{r^3}\sin^2\theta - \frac{R^6}{r^6}\cos^2\theta - \frac{R^6}{4r^6}\sin^2\theta\right)$$



Pressure in mbar-m



Guess of pressure field
around rising bubble in water



Simulation: Mean pressure (source: Sajn)

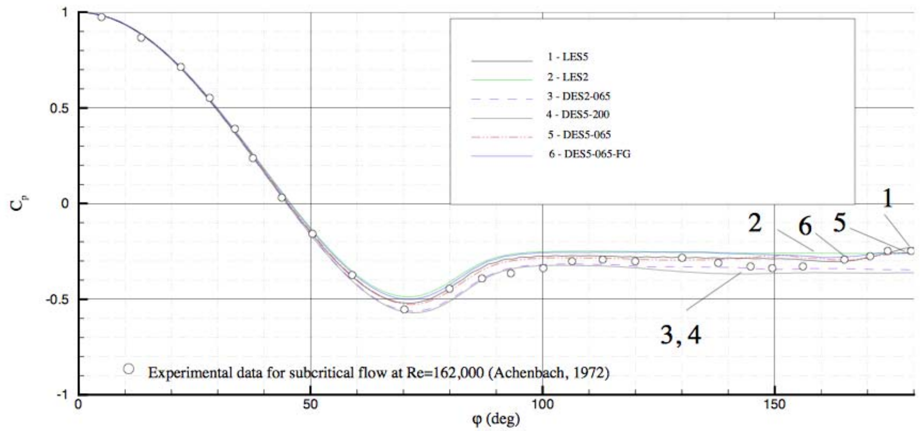
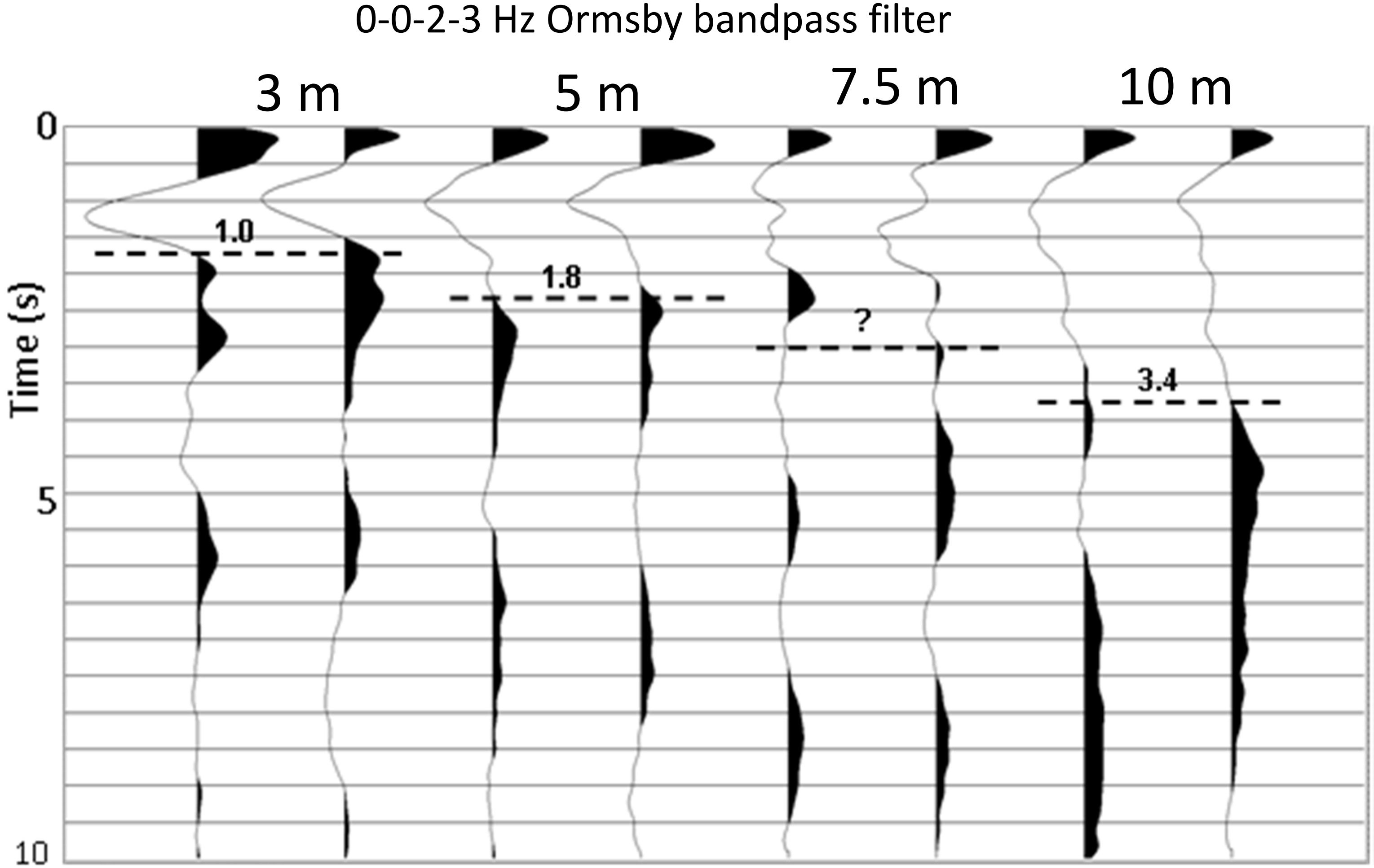


Figure 2: Mean pressure coefficient distribution over the sphere.

Experimental data (Achenbach, 1972)

Comparing signatures for various source depths



- Duration of negative pressure increases with source depth
- Amplitude of negative pressure decreases with source depth

Simple estimates:

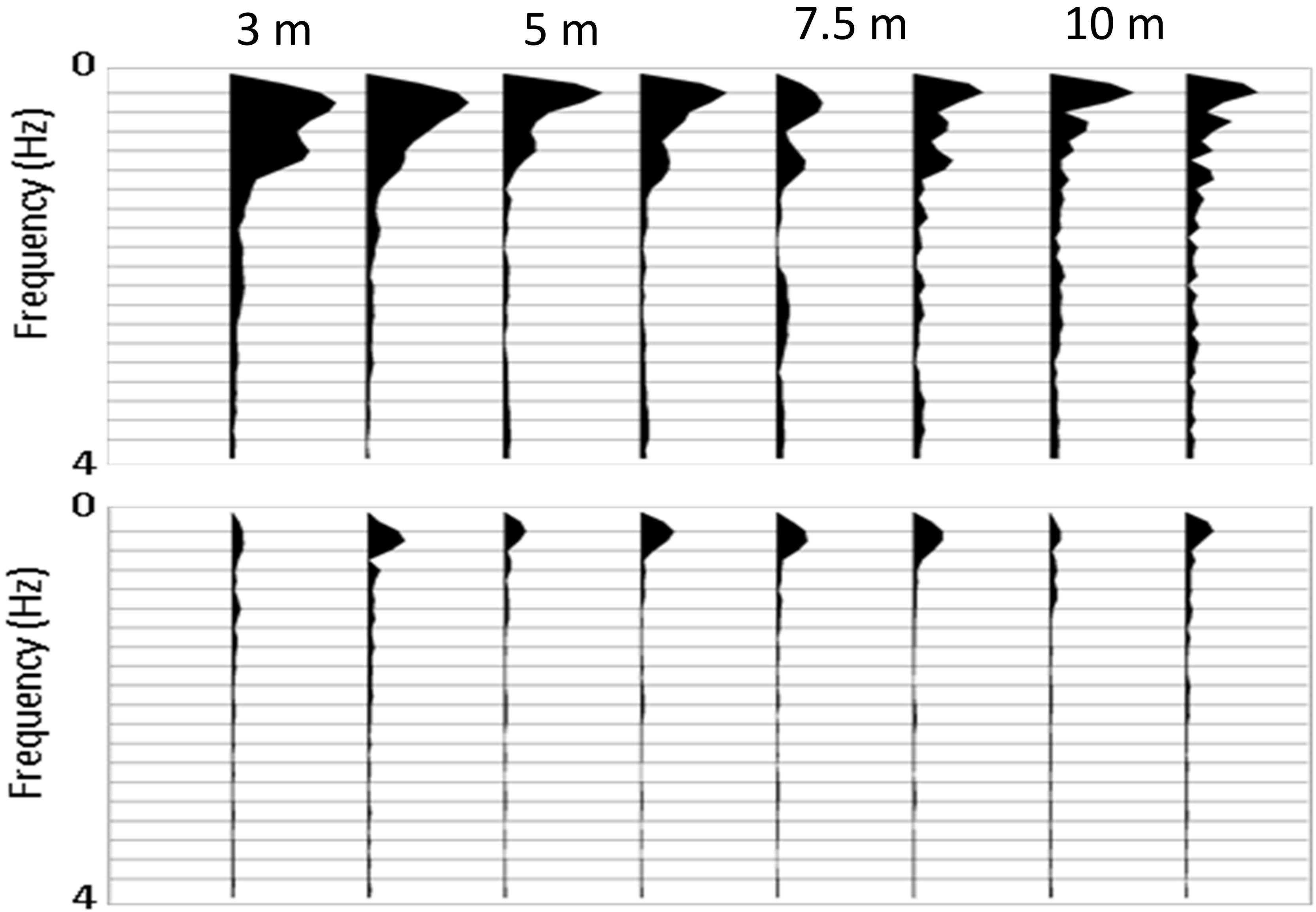
$$\tau_L \approx (z - R)/U_B$$

$$f_L \approx \frac{2\sqrt{gR}}{3(z-R)}$$

$$p - p_h \approx \rho \frac{RU_B^2}{r} = \frac{4\rho g R^2}{9r}$$

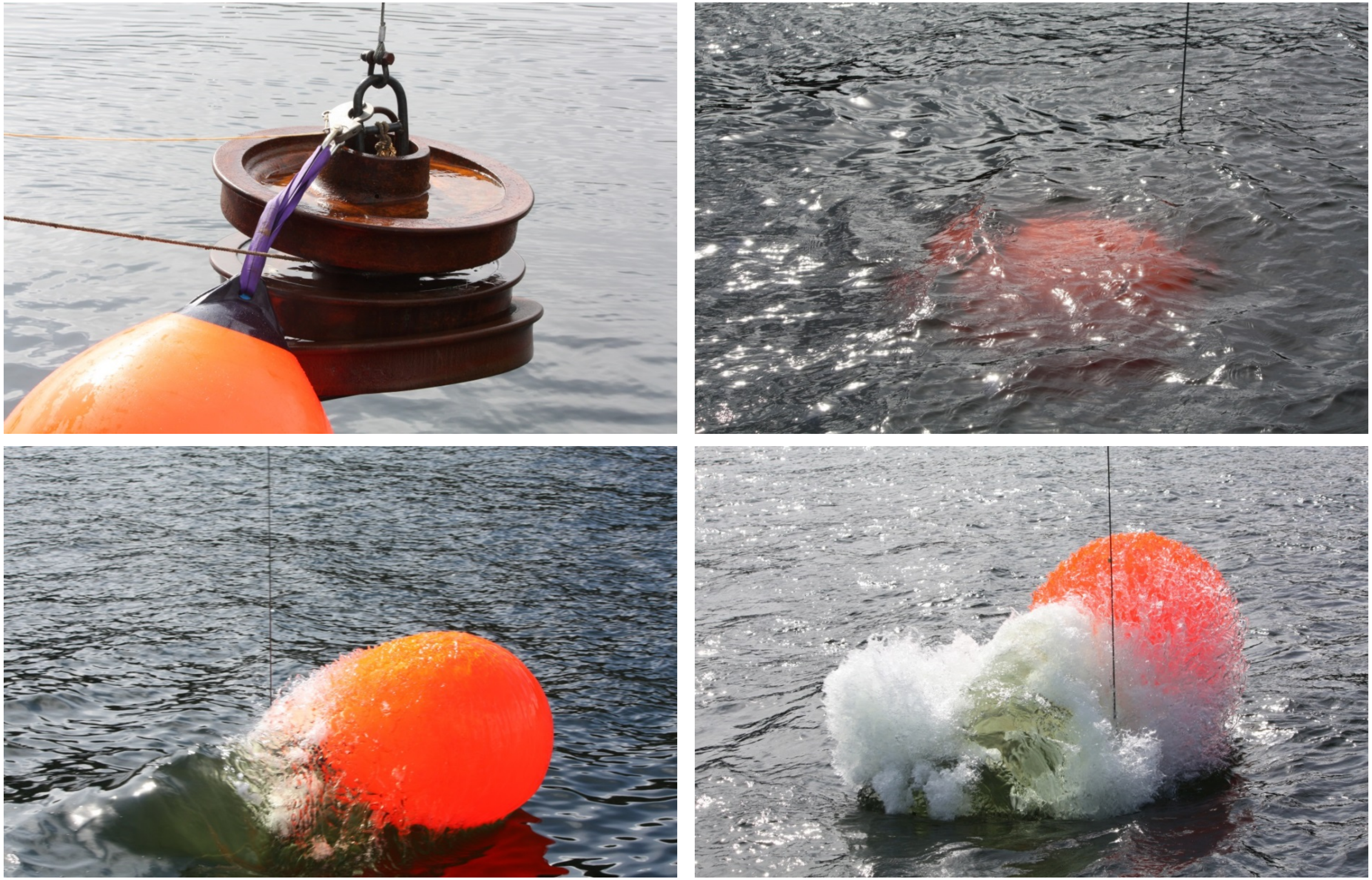
z = source depth
R = average bubble radius
g = 9.82 m/s^2
r = distance to observation point
p-ph = dynamic pressure

Amplitude spectra for 0.5-4.5 s and 6-10 s

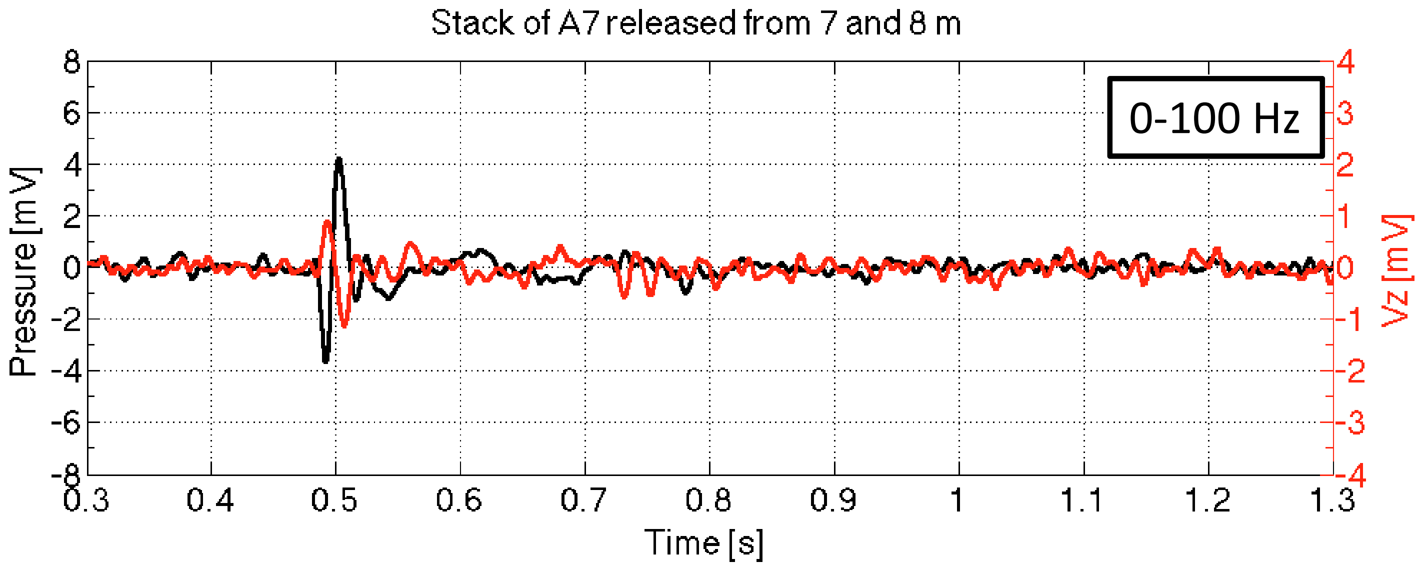


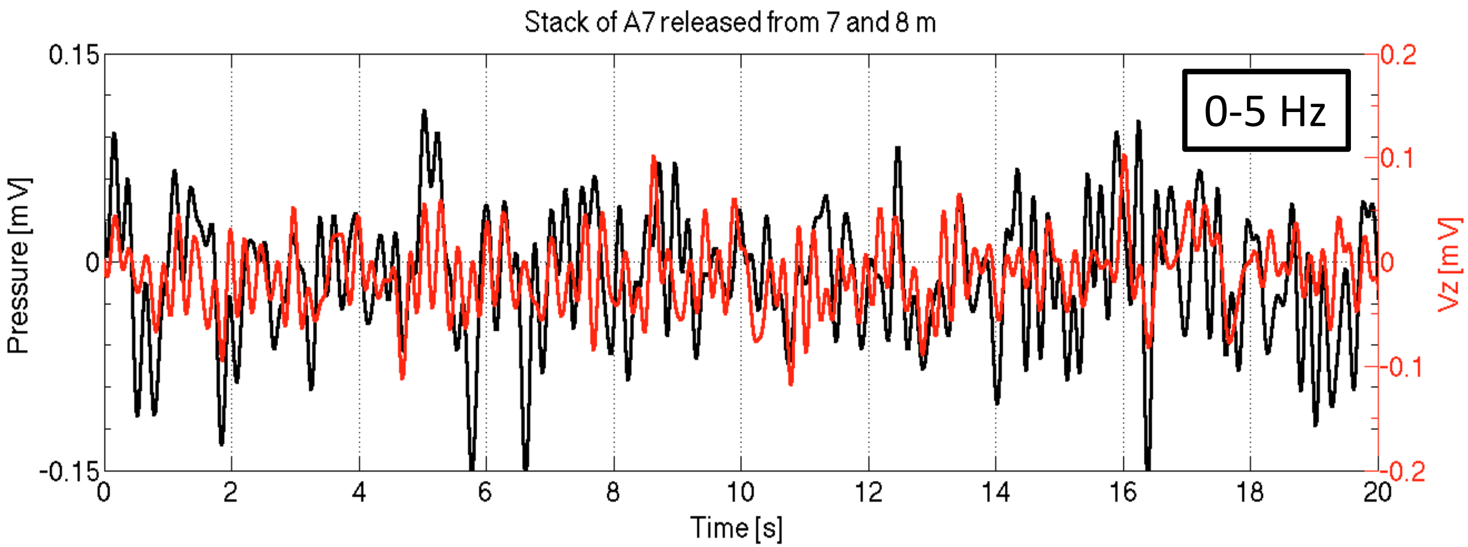
Gunnerus bubble test – last week

Big bubbles released from various source depths. Recording by a conventional hydrophone/geophone and an OBS located at seabed (50 m).



Initial measurements from conventional seabed hydrophone and geophone





Summary

- **Ultralow frequencies observed for big air gun**
- **A negative pressure signal where the duration is increasing with source depth is observed**
- **Peak frequency of the ultralow signal decreases with source depth**
- **Bubble test might help to understand the mechanism behind low frequency air gun behaviour**