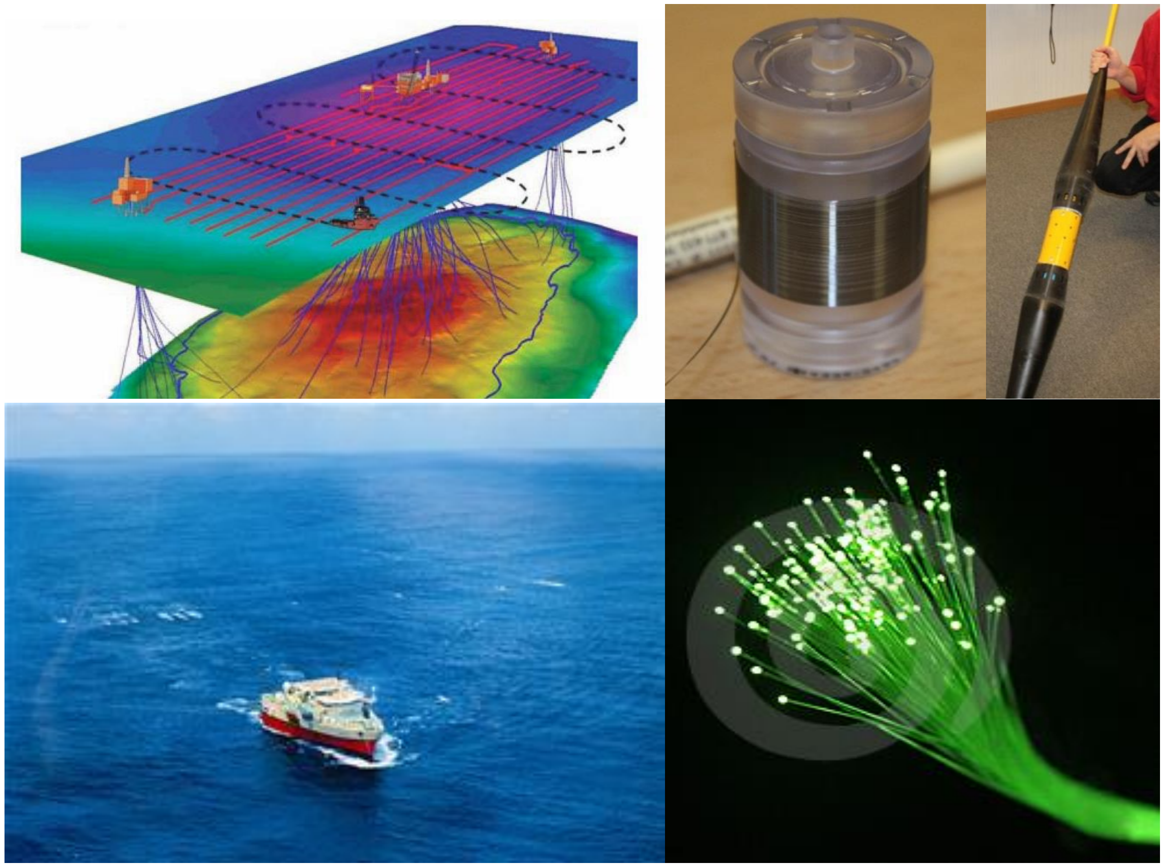
Module 3

Marine receiver systems – and noise in the water

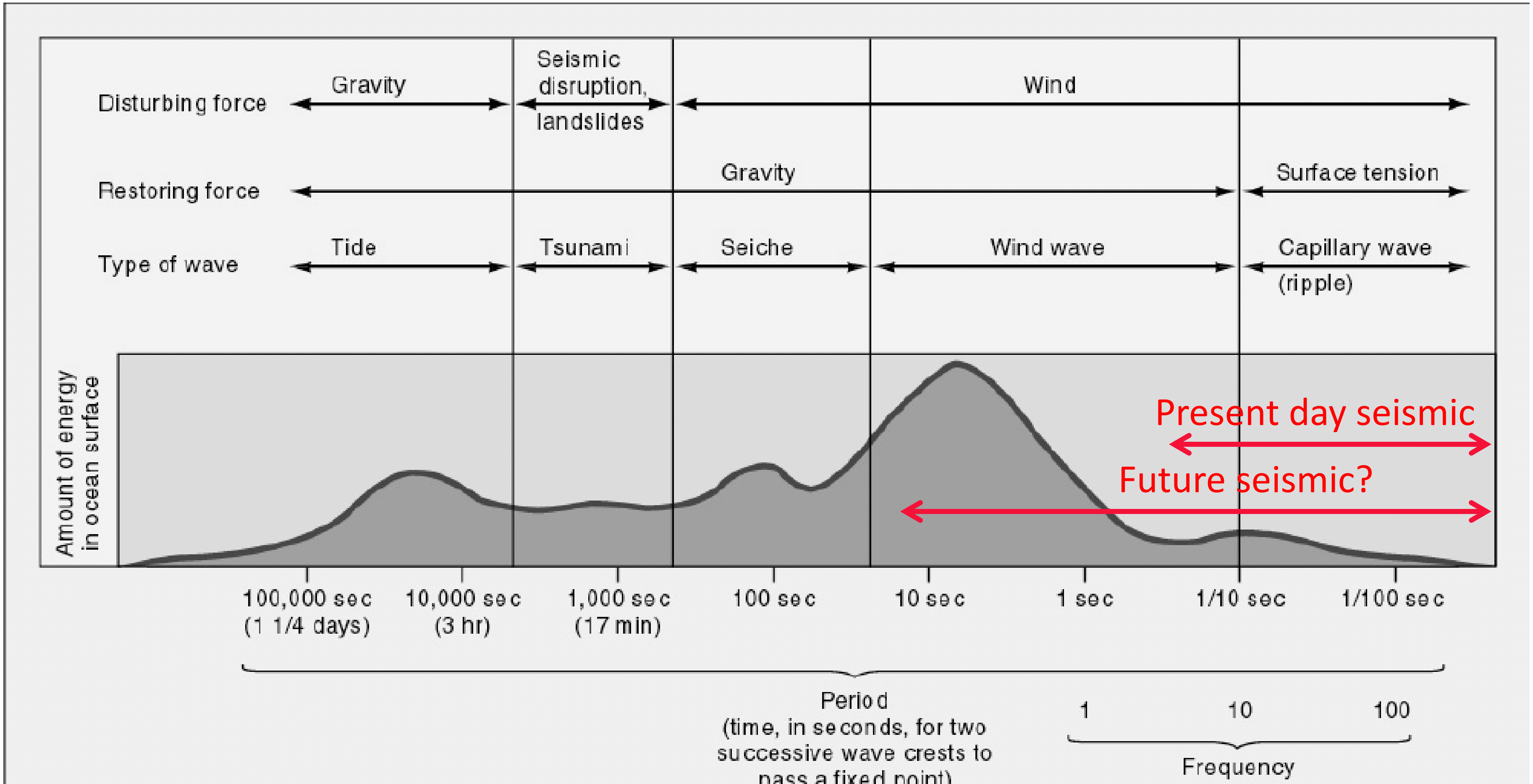


NTNU – Trondheim
Norwegian University of
Science and Technology

by Martin Landrø and Lasse Amundsen

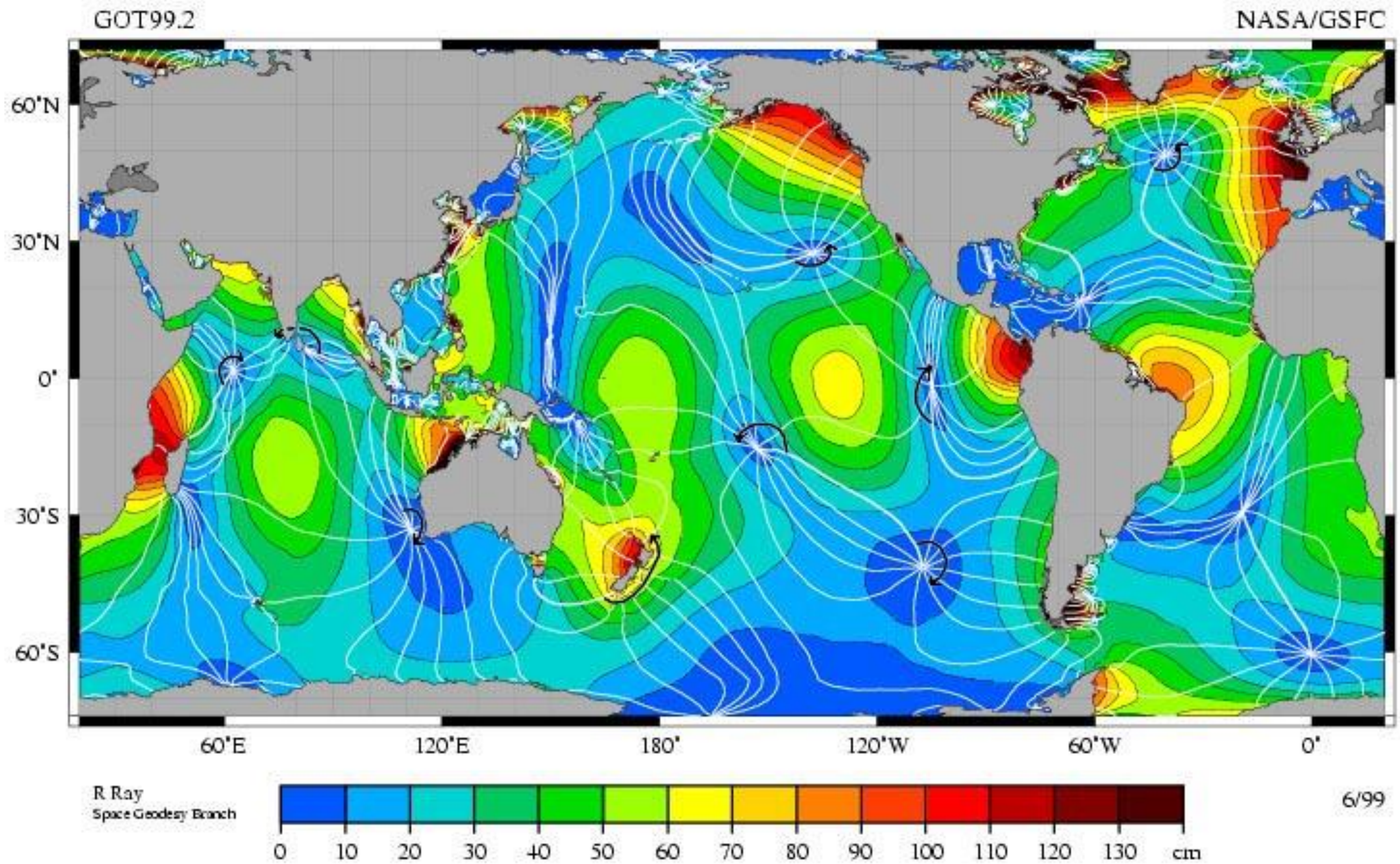
Ocean waves

Types of Waves

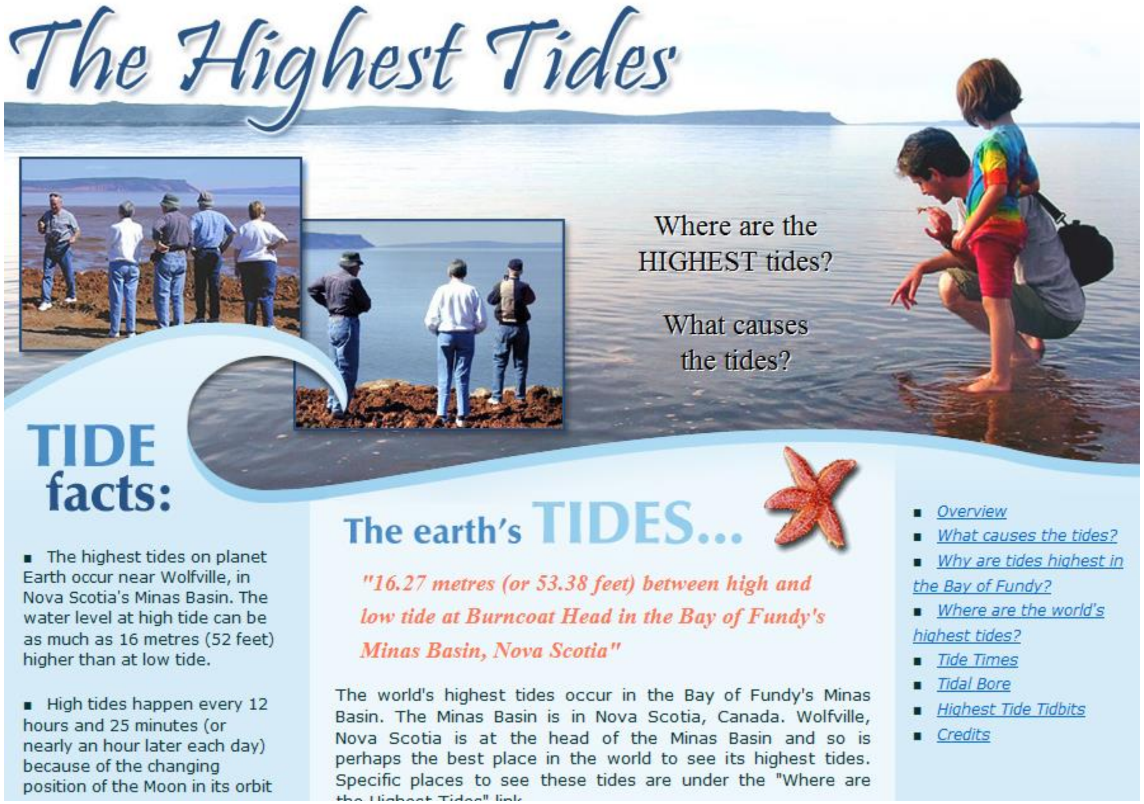


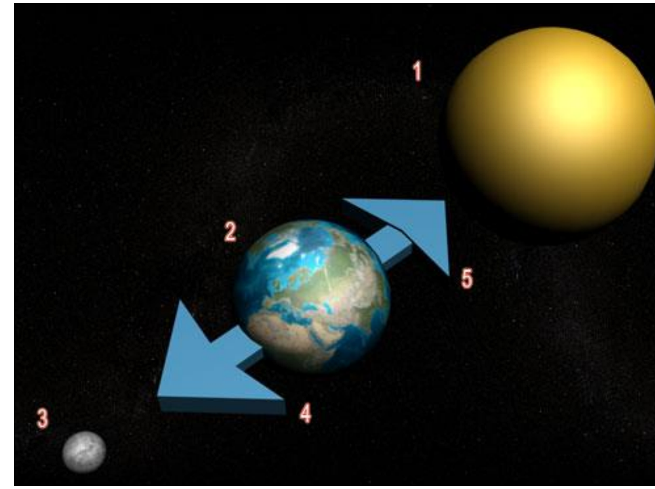
Wave Type	Typical Wavelength	Disturbing Force
Wind wave	60–150 m (200–500 ft)	Wind over ocean
Seiche	Large, variable; a function of basin size	Change in atmospheric pressure, storm surge, tsunami
Seismic sea wave (tsunami)	200 km (125 mi)	Faulting of seafloor, volcanic eruption, landslide
Tide	½ circumference of Earth	Gravitational attraction, rotation of Earth

Amphidromic points – Coriolis and interference



Nova Scotia, Canada – 16 meters difference



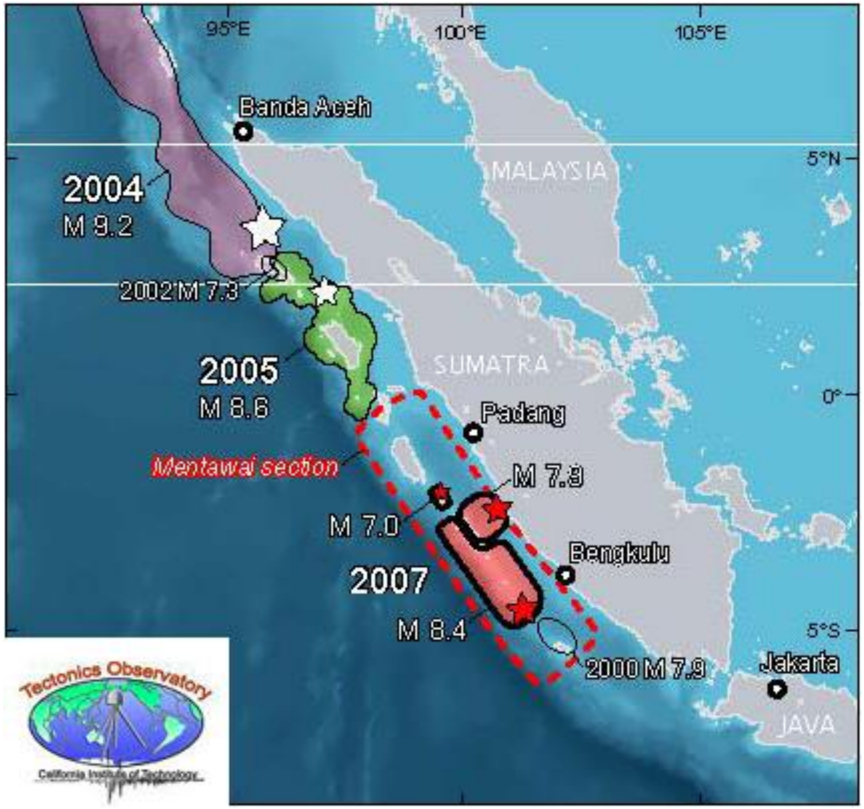


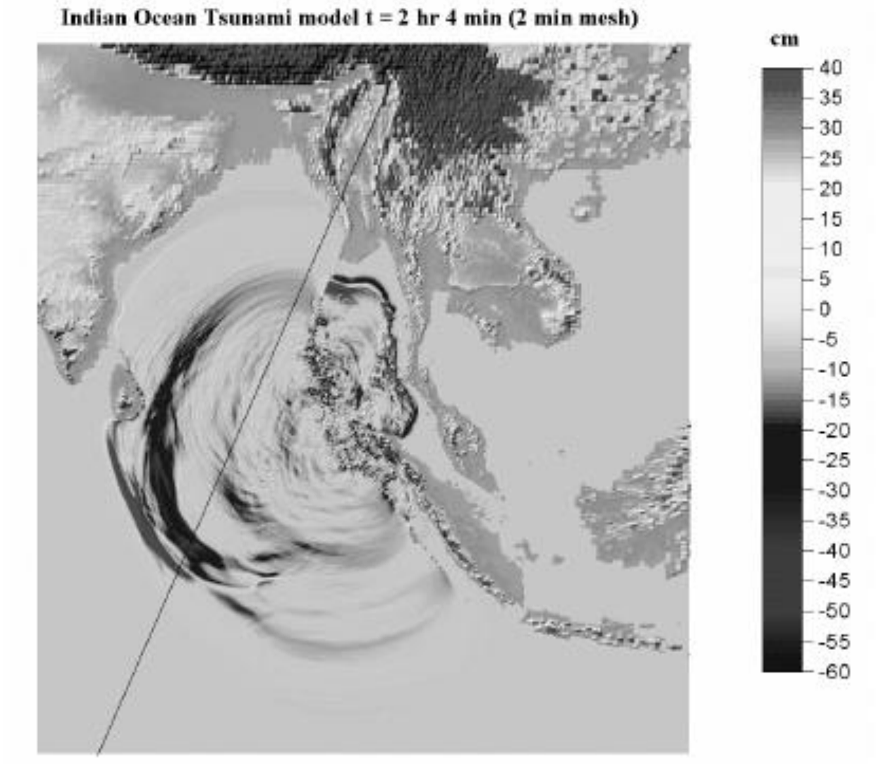
Top five (average tidal range):

- Bay of Fundy, Canada : 14.5 m
- La Rance, France : 13.5 m
- Bristol Channel, UK : 12.3 m
- Anchorage, Alaska : 9.0 m
- Liverpool, UK : 8.3 m

TSUNAMI

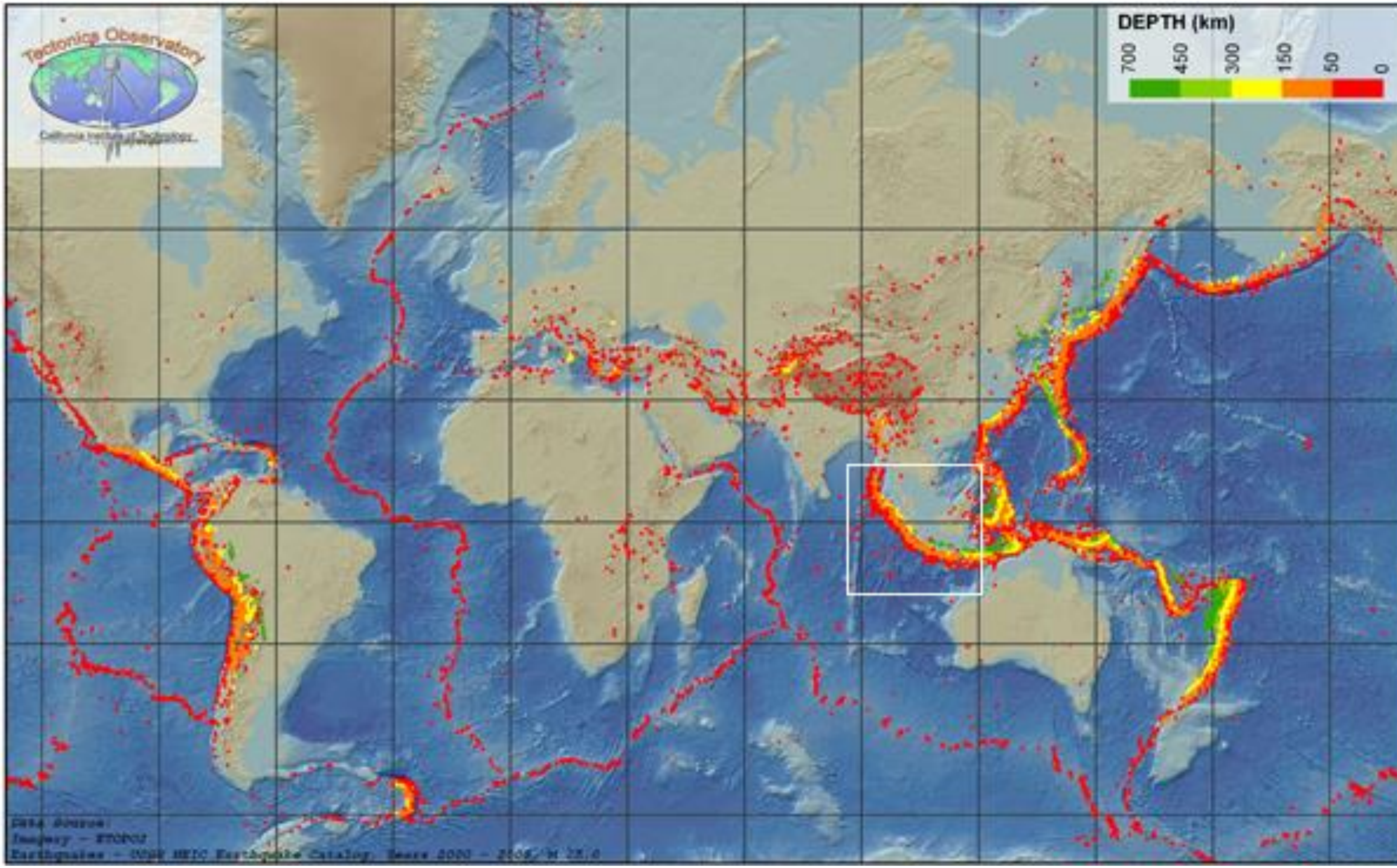
The 9.1 Sumatra-Andaman earthquake 26th December 2004





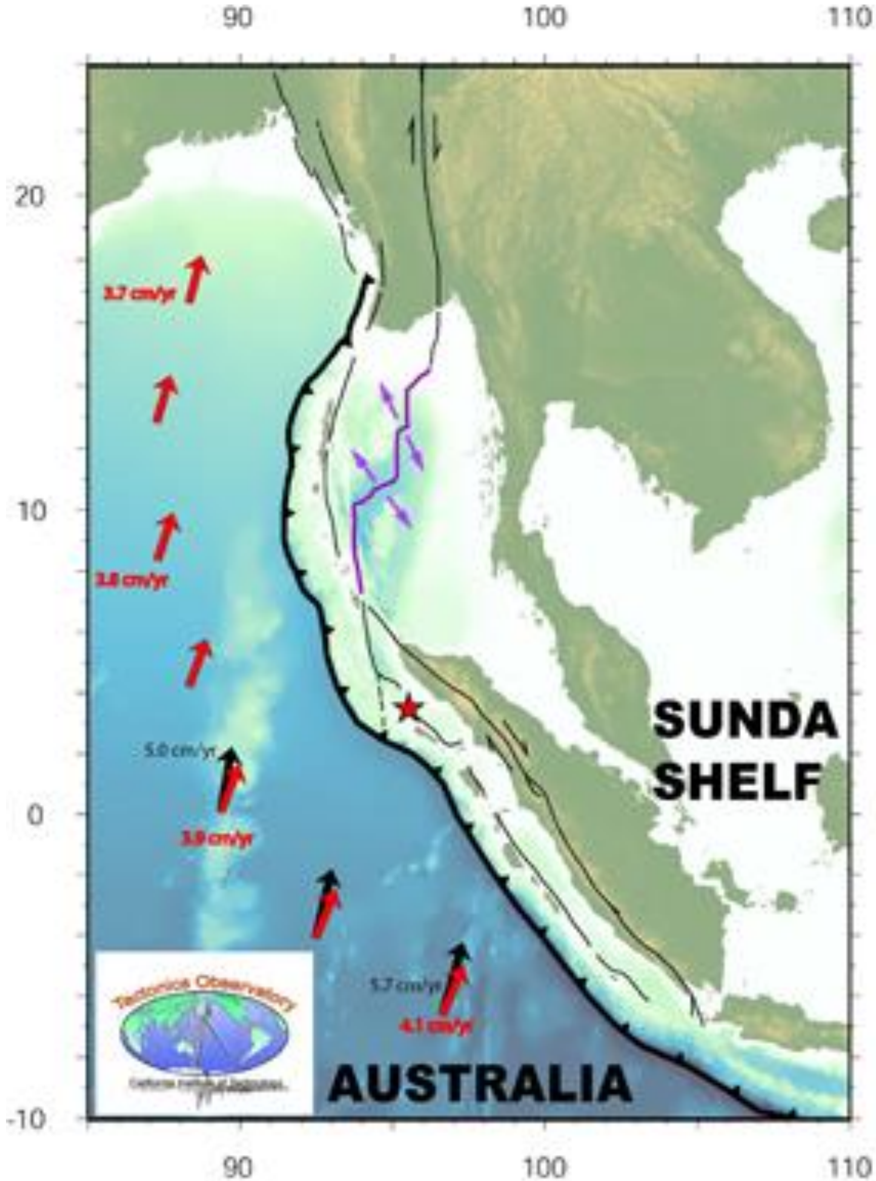
Model data at 2 hr 5 min

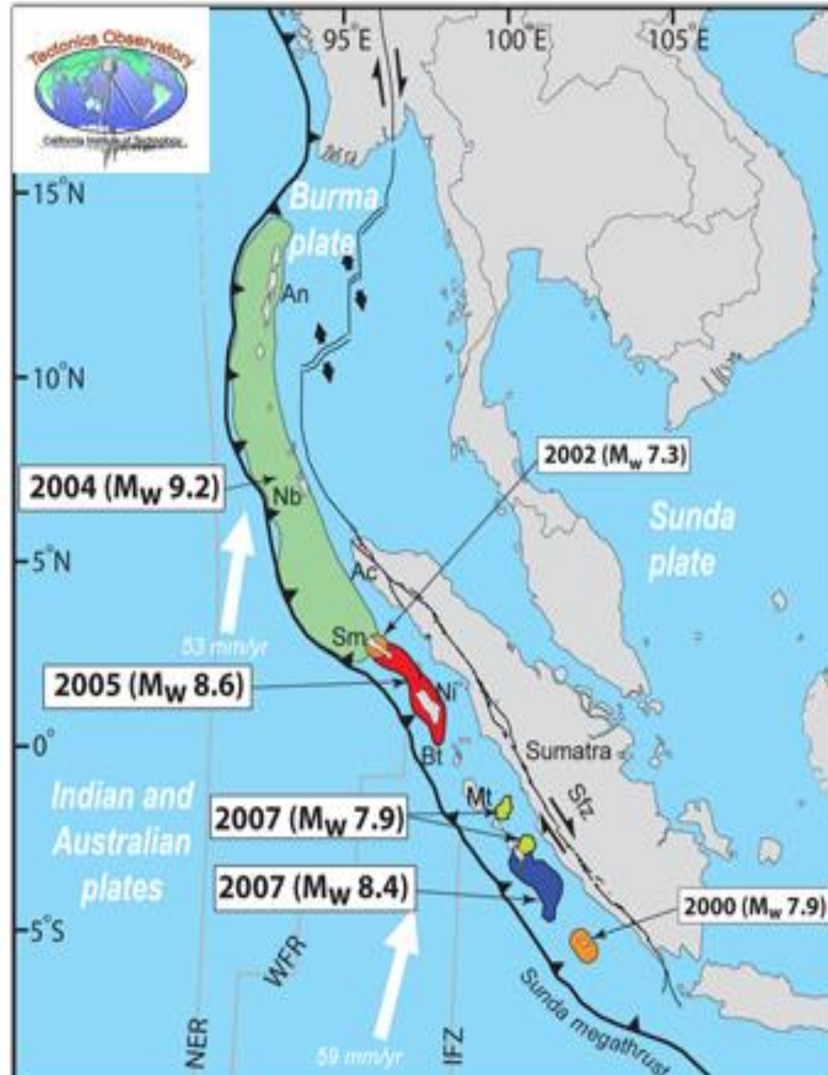
Earthquakes > 5



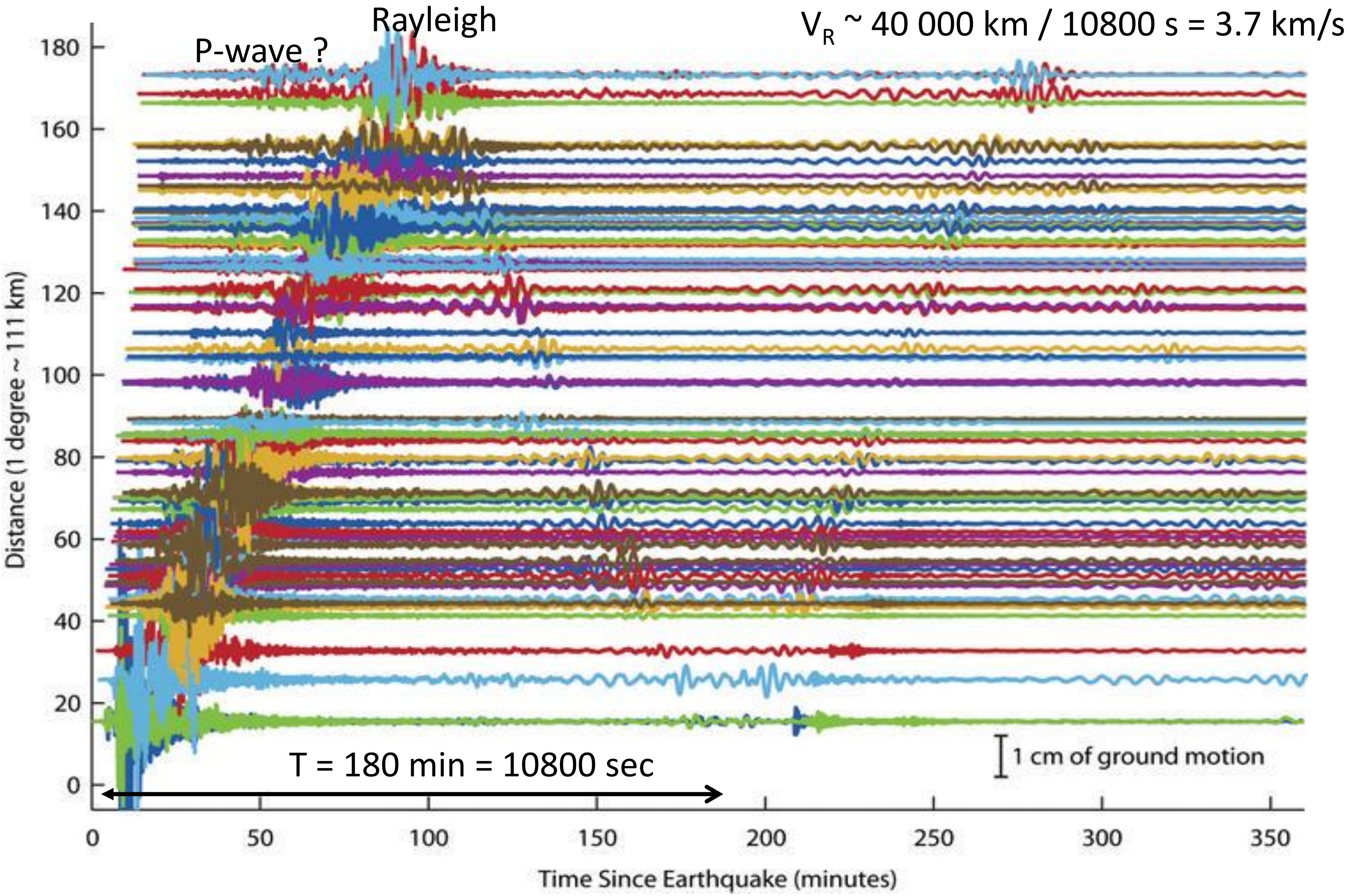
Sumatra-Andaman earthquake 26th December 2004

Techtonic movement 3-4 cm/year



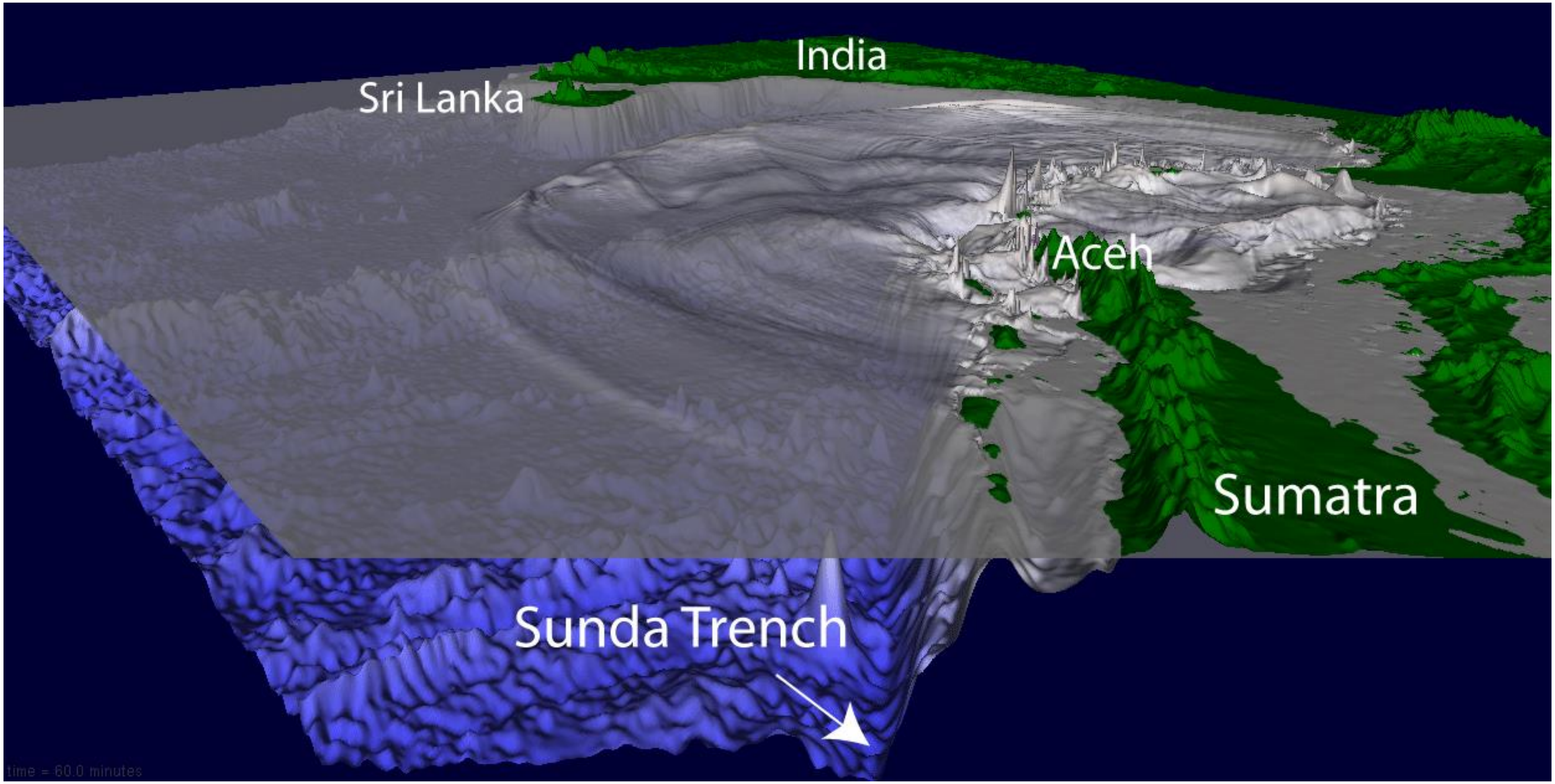


Global seismograms of the Sumatra-Andaman earthquake



Rayleigh wave: proposed by Rayleigh in 1885

Source: IRIS



Tsunami wavefield 1 hour after the 9.1 earthquake

Source: USGS

The 9.1 Sumatra-Andaman earthquake 26th December 2004

Seiche: standing waves in a closed ocean/lake caused by air pressure or wind

Suggested by hydrologist Francois-Alphonse Forel (professor in medicine) in 1890 (Lake Geneva)

$$T_{Seiche} = \frac{2L}{\sqrt{gh}}$$

Merian's formula

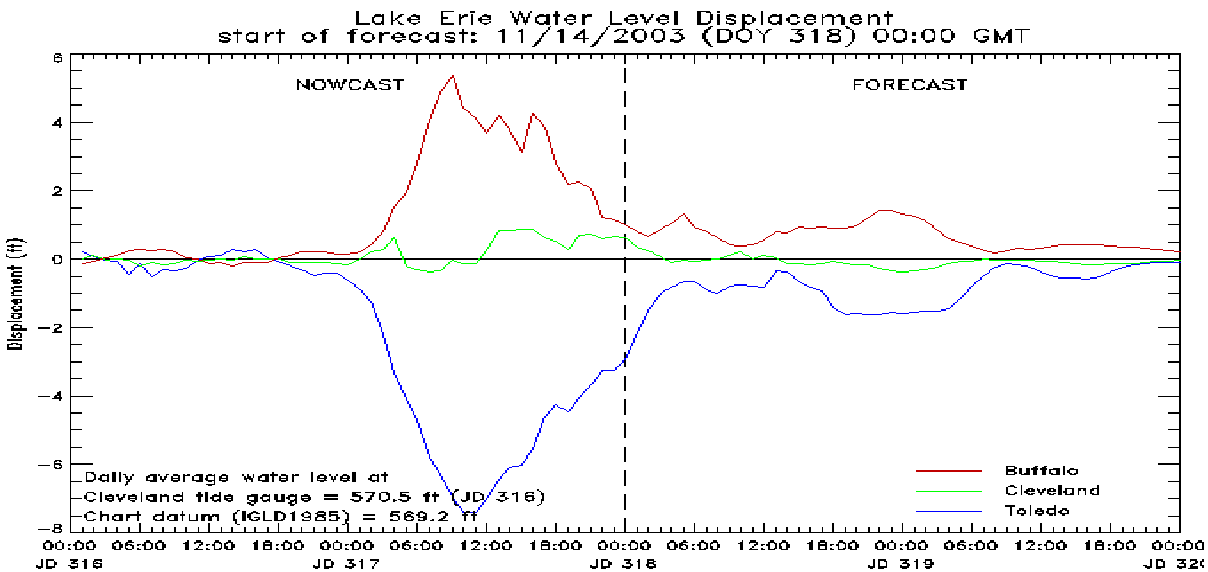
Example: L = 10 km, average height = 100 m => T = 630 seconds ; 10 minutes

Lake seiches can occur very quickly: on July 13, 1995, a big seiche on Lake Superior caused the water level to fall and then rise again by three feet (one meter) within fifteen minutes, leaving some boats hanging from the docks on their mooring lines when the water retreated.

Wikipedia:

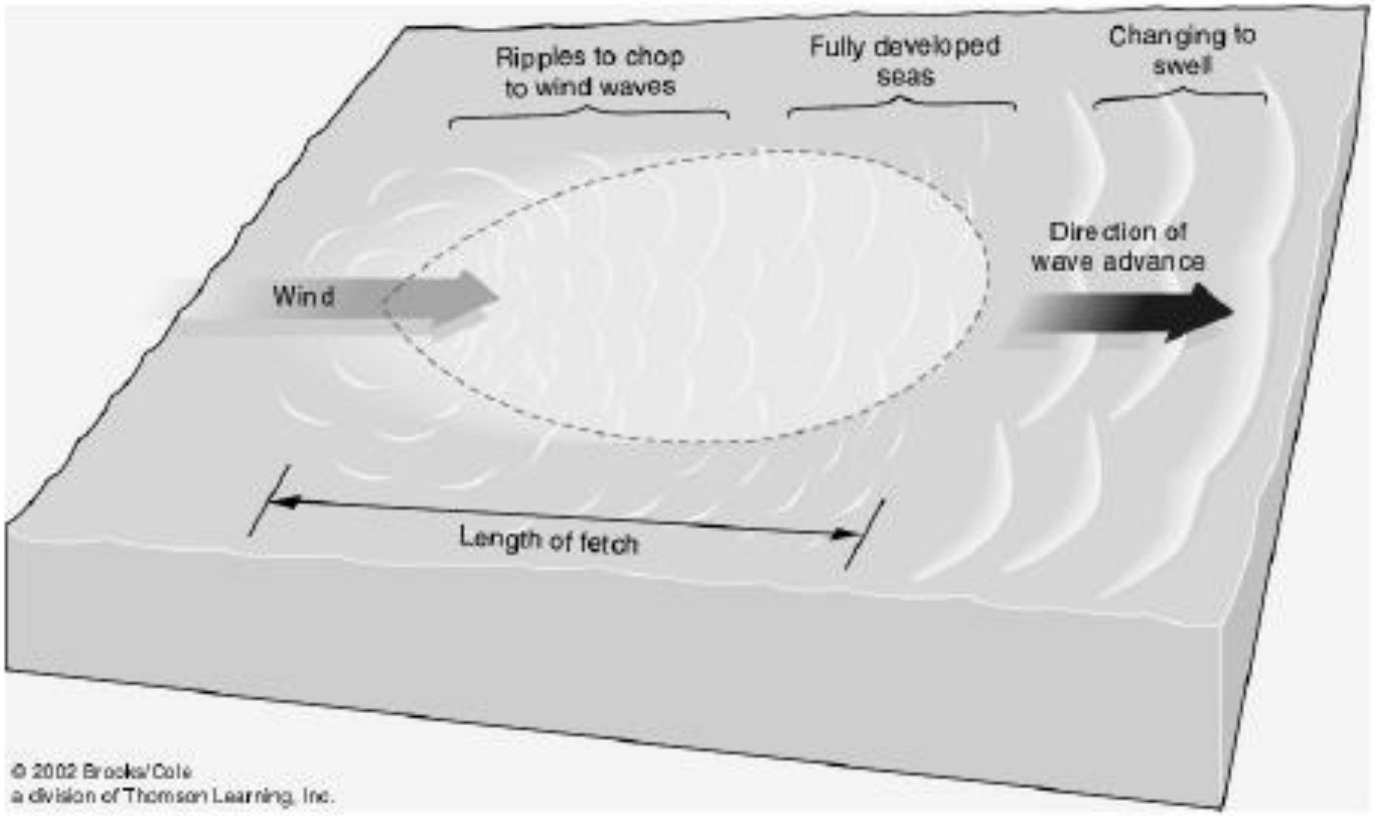
Seiches have been observed in seas such as the Adriatic Sea and the Baltic Sea, resulting in flooding of Venice and St. Petersburg respectively. The latter is constructed on drained marshlands at the mouth of the Neva river. Seiche-induced flooding is common along the Neva river in the autumn. The seiche is driven by a low pressure region in the North Atlantic moving onshore, giving rise to cyclonic lows on the Baltic Sea. The low pressure of the cyclone draws greater-than-normal quantities of water into the virtually land-locked Baltic. As the cyclone continues inland, long, low-frequency seiche waves with wavelengths up to several hundred kilometers are established in the Baltic. When the waves reach the narrow and shallow Neva Bay, they become much higher — ultimately flooding the Neva embankments.[16] Similar phenomena are observed at Venice, resulting in the MOSE Project, a system of 79 mobile barriers designed to protect the three entrances to the Venetian Lagoon.

Observed seiche at Lake Erie 2003



NOAA Great Lakes Coastal Forecasting System
Great Lakes Environmental Research Laboratory
National Weather Service

Factors Affecting Wind Wave Development



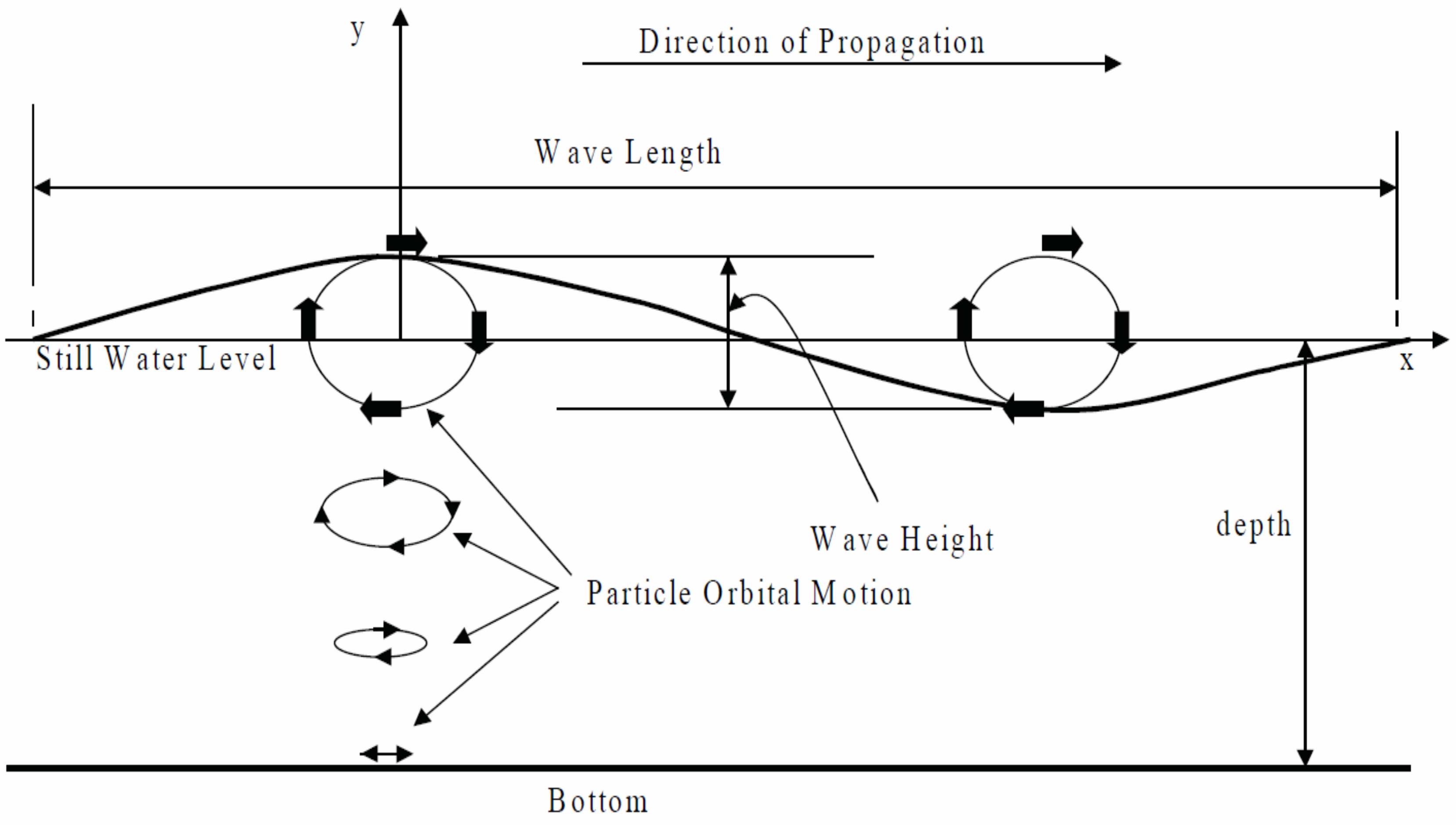
Sinusoidal waves on deep water (Lighthill, 1978)

Velocity potential $$\Phi(z) = \Phi_0 e^{-kz}$$

Velocities at depth z: $$v_x = \frac{\partial \Phi}{\partial x} = -k\Phi_0 e^{-kz} e^{i(\omega t - kx)} \quad v_z = \frac{\partial \Phi}{\partial z} = -ik\Phi_0 e^{-kz} e^{i(\omega t - kx)}$$

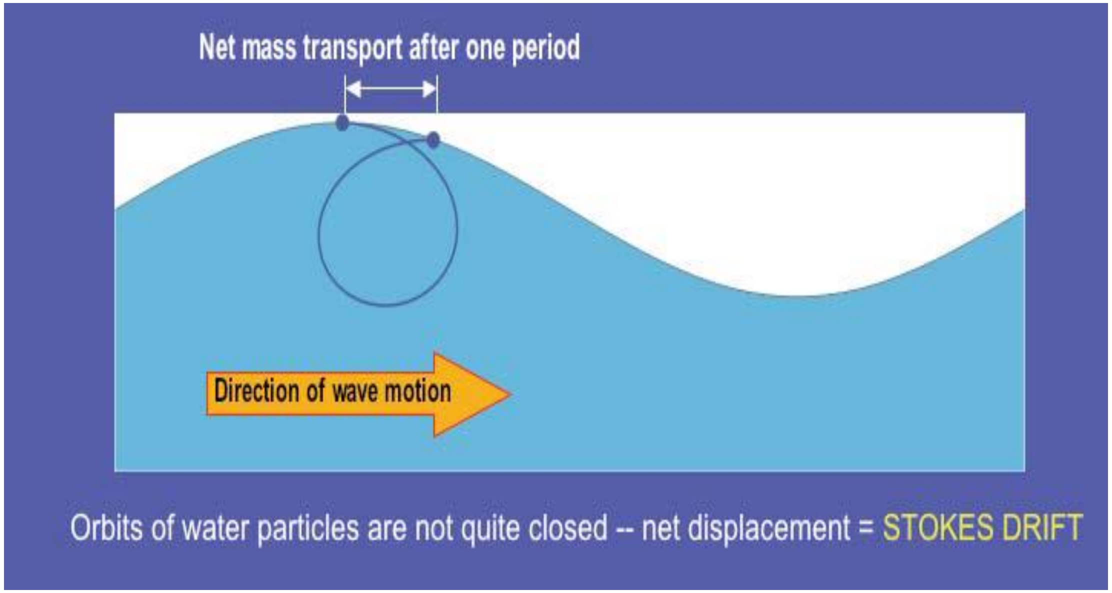
$$k = \frac{2\pi}{\lambda} \qquad \omega = \frac{2\pi}{T}$$

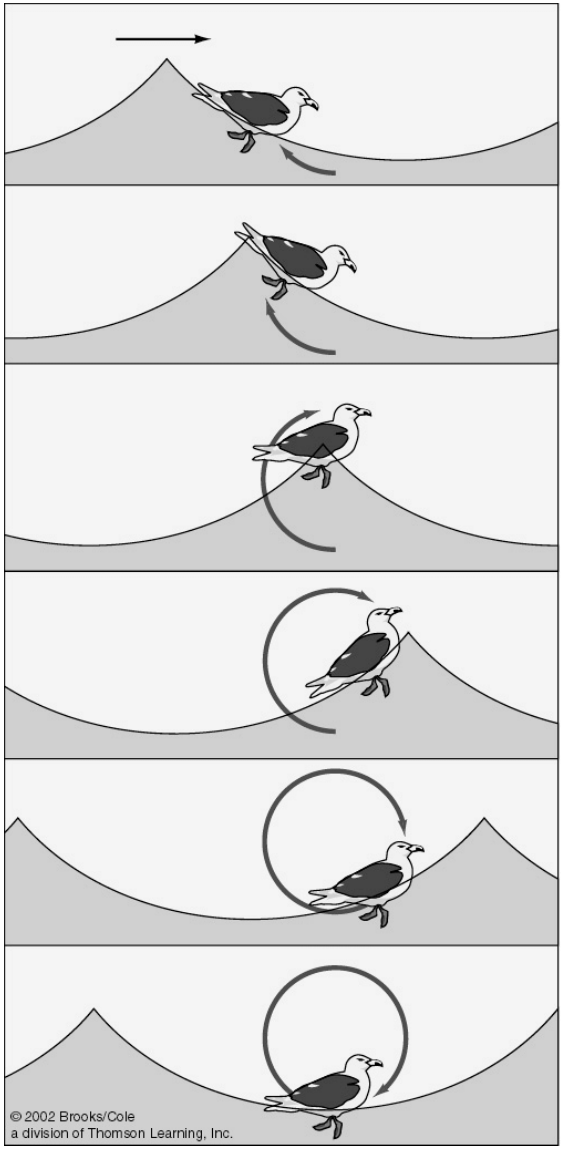
Sinusoidal waves on deep water



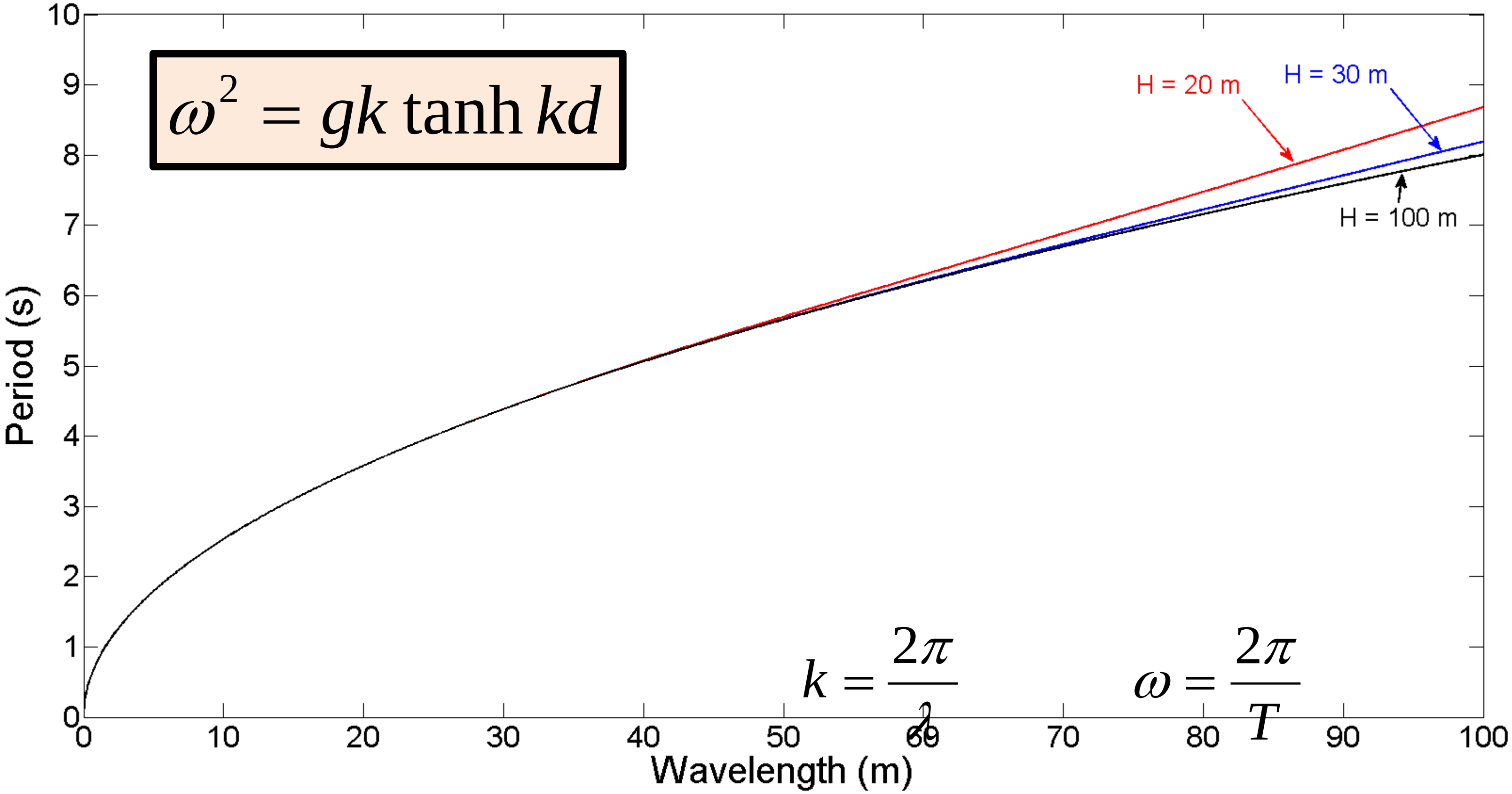
Source: Patrick Holmes, Imperial College

It is never as simple....





The dispersion relation for ocean waves



Ocean wave period versus wavelength for various water depths (20, 30 and 100 m)

Pressure variation below ocean waves

Surface elevation:

$$\eta = \frac{H}{2}\cos 2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)$$

λ = wave length
H = wave height
T = wave period
d = water depth
z = depth
g = gravity (9.8 m/s^2)

Pressure vary with x and z:

$$\frac{p}{\rho g} = \eta \frac{\cosh 2\pi(d-z)/\lambda}{\cosh 2\pi d/\lambda} + z$$

Source: Patrick Holmes, Imperial College

Particle velocities

λ = wave length
H = wave height
T = wave period
d = water depth
z = depth
g = gravity (9.8 m/s^2)

Particle velocities (horizontal and vertical):

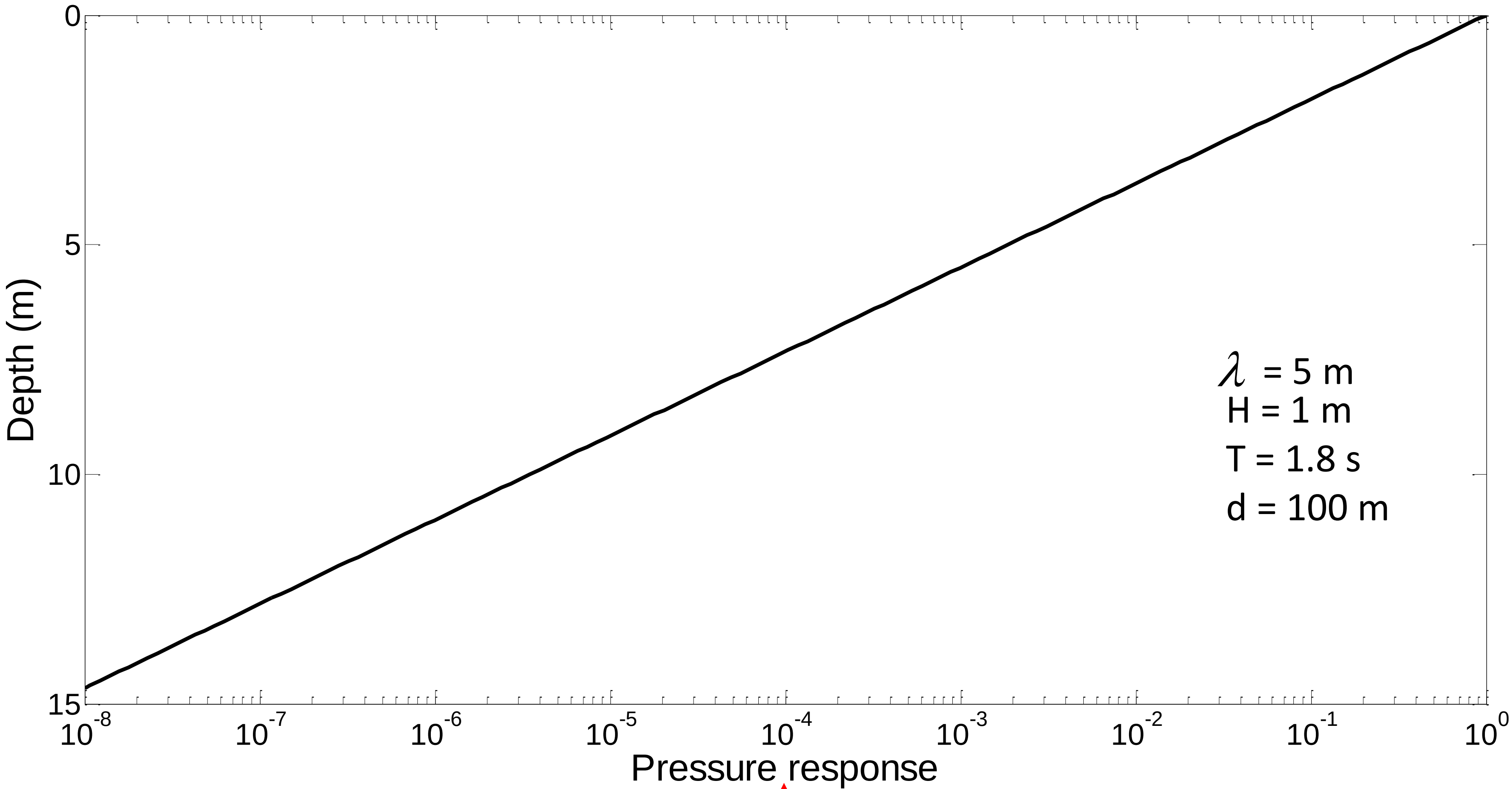
$$u = \omega H \frac{\cosh 2\pi(d-z)/\lambda}{2\sinh 2\pi d/\lambda} \cos(2\pi(x/L - t/T))$$

$$v = \omega H \frac{\sinh 2\pi(d-z)/\lambda}{2\sinh 2\pi d/\lambda} \sin(2\pi(x/L - t/T))$$

For deep water, both pressure and velocities decay exponentially and at same rate, so there is no practical differences in the decay rate between the two.

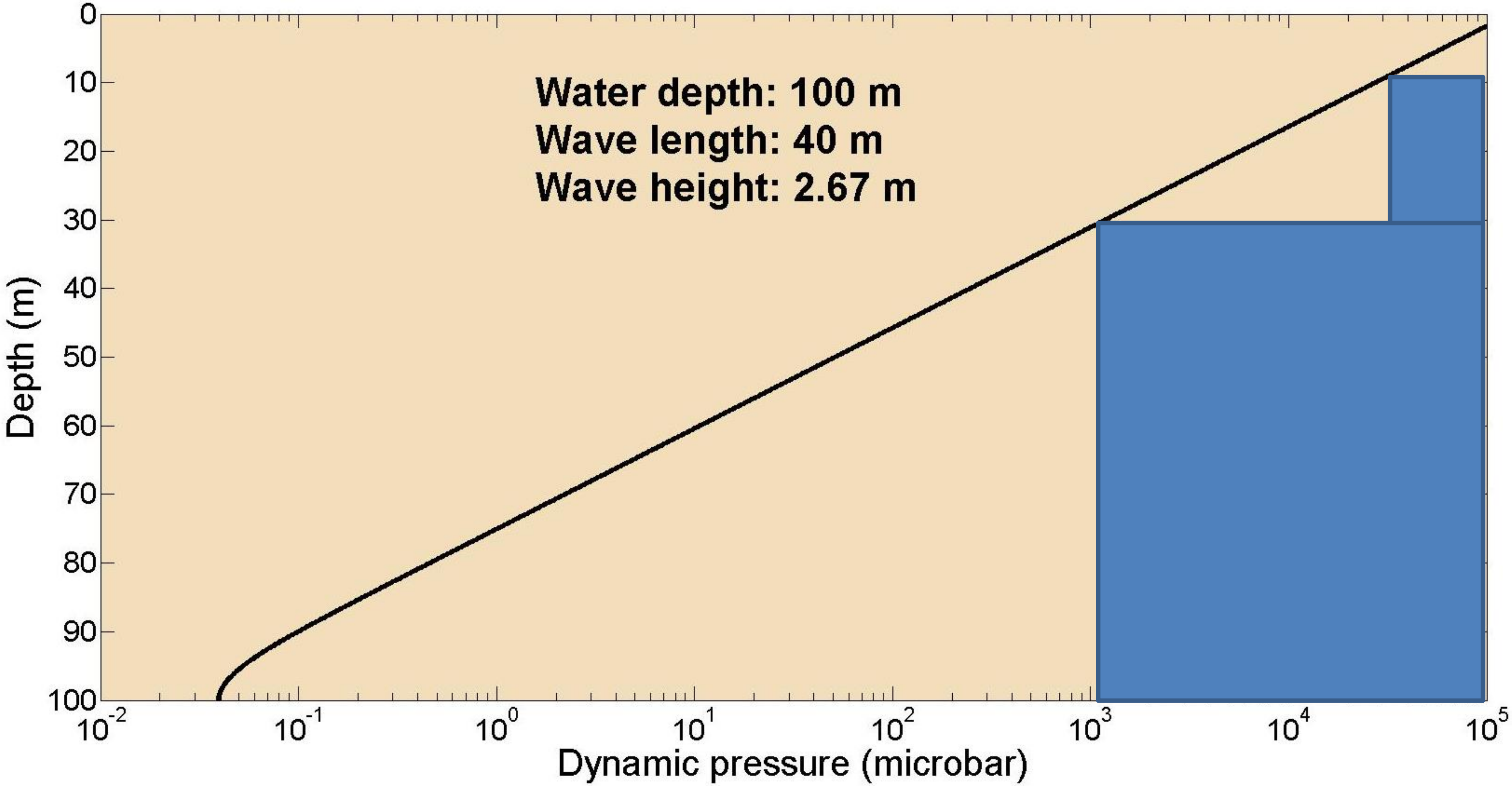
Source: Patrick Holmes, Imperial College

Pressure response factor

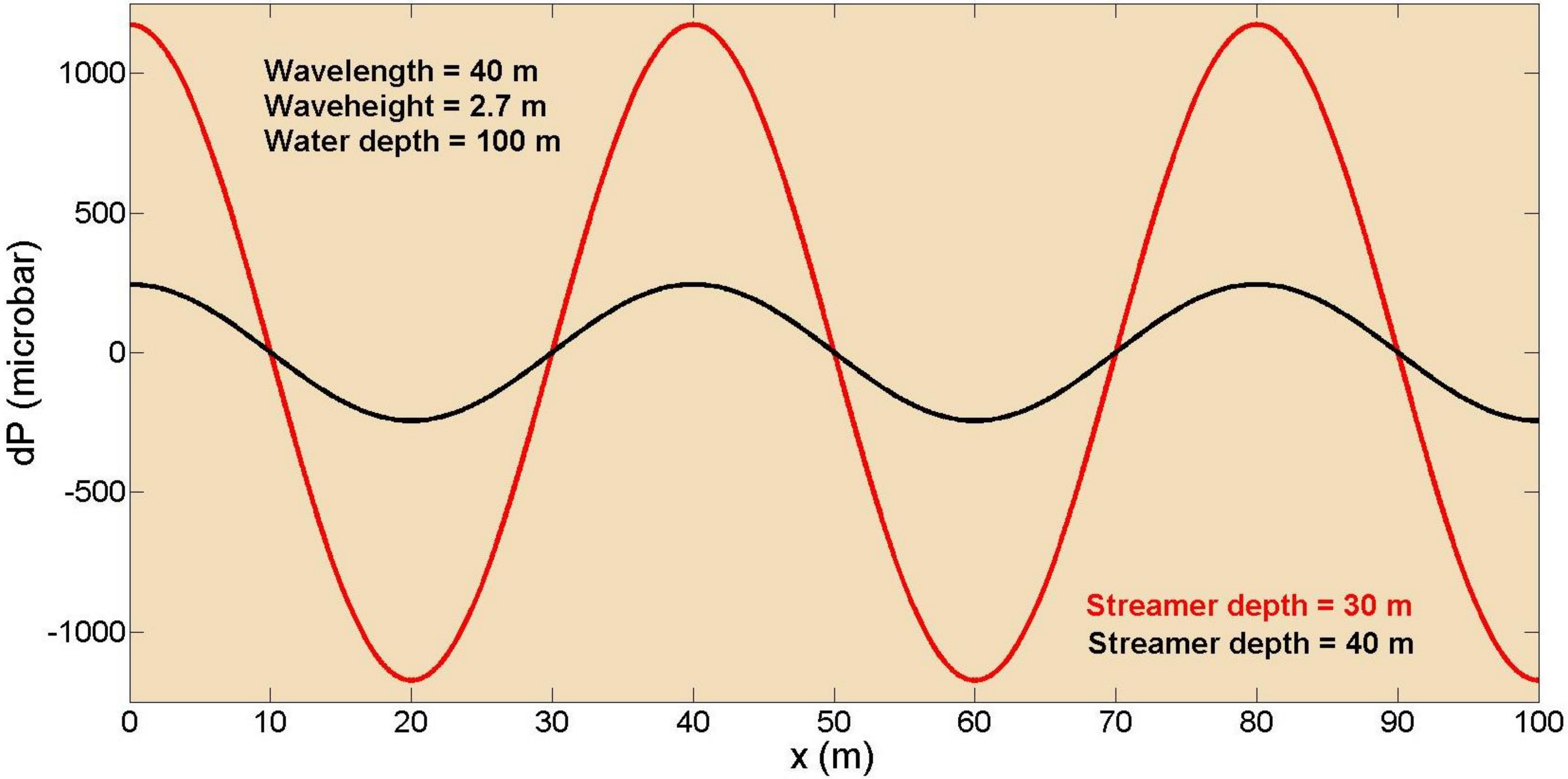


$$\frac{p}{\rho g} = \eta \frac{\cosh 2\pi(d-z)/\lambda}{\cosh 2\pi d/\lambda} + z$$

Dynamic pressure versus streamer depth assuming 40 m wavelength

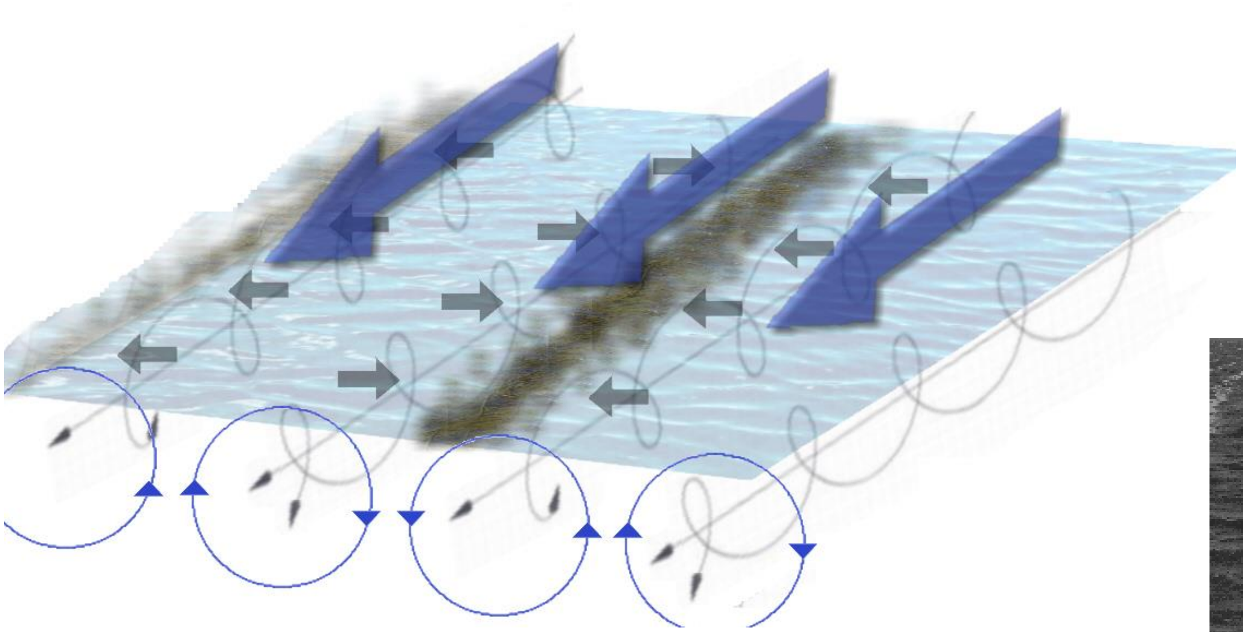


Modeled dynamic pressure below a sinusoidal ocean wave



Group summation and low cut filters will reduce the noise effect significantly

Langmuir circulation layer; Irving Langmuir 1927



Typical depth of this circualtion layer is less than **20 m**

Langmuir: Water motion is 3D

White streaks caused by Langmuir circulation

ELSEVIER

Deep Sea Research Part A. Oceanographic Research Papers

Volume 35, Issue 5, May 1988, Pages 711–731, 733–737, 739–747

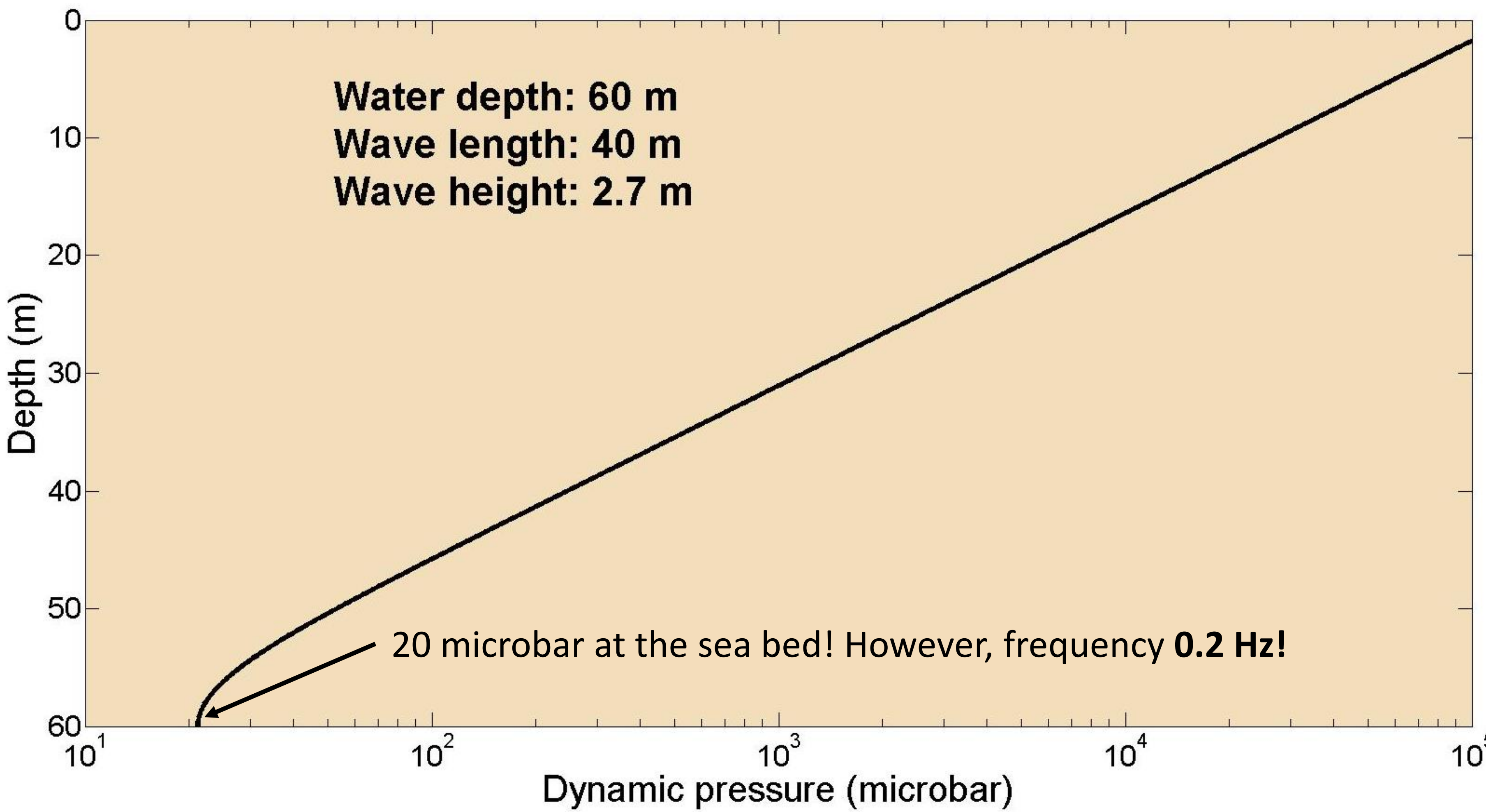
Langmuir circulation within the oceanic mixed layer

Robert A. Weller[*], James F. Price[*]

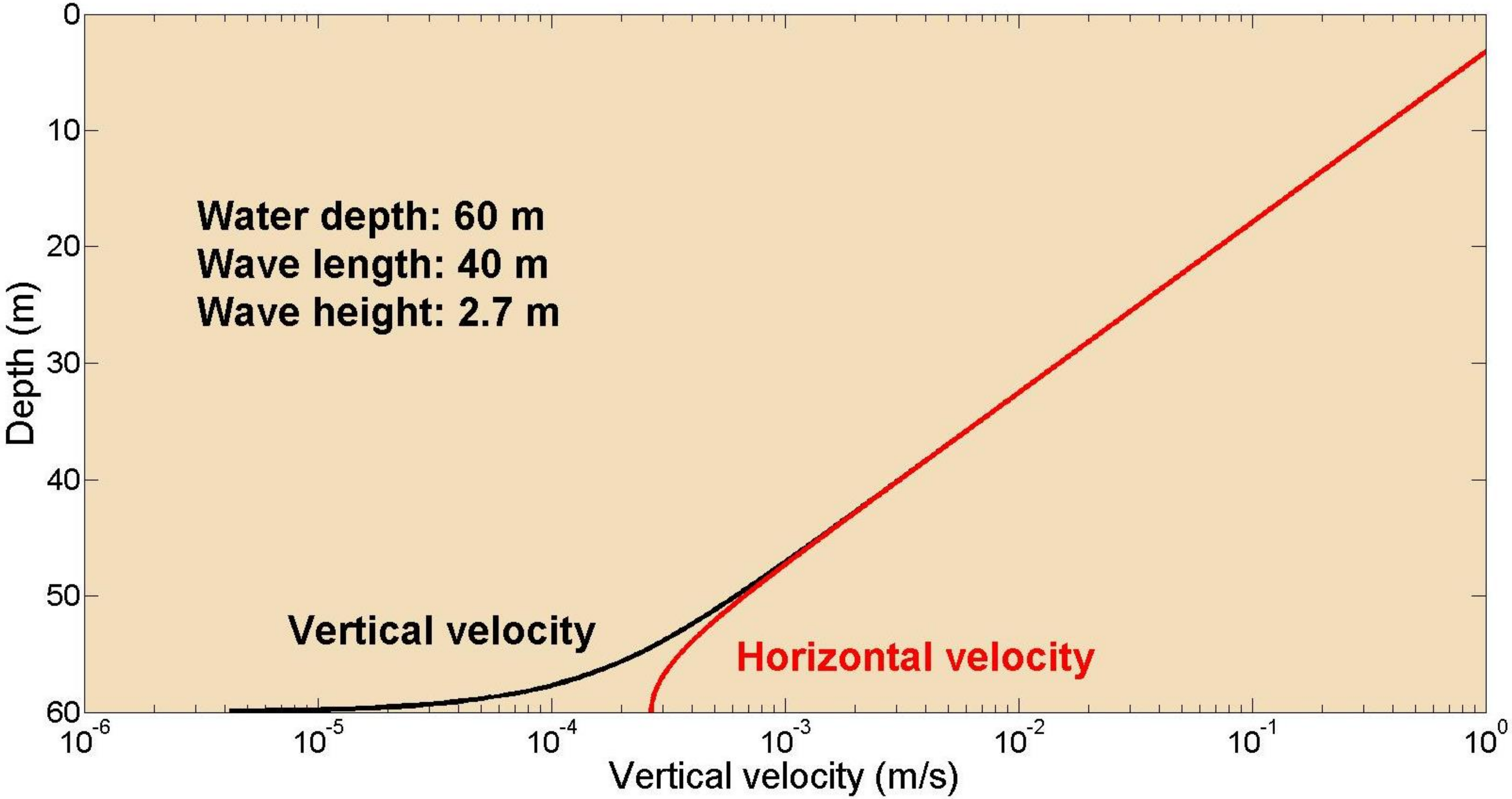
[*] Woods Hole Oceanographic Institution, Woods Hole, MA 02543, U.S.A.

Regions of convergent surface flow were located with surface drifters. In these regions the downward vertical and downwind horizontal components of the flow were comparable in size and, at times, in excess of 20 cm s^{-1}. This downwind, dowmwelling flow was jet-like in structure, with the maximum velocity located below the surface. Away from the downwelling regions and in the lower half of the mixed layer below the convergence zones, the flow associated with the Langmuir cells was an order of magnitude smaller and not well resolved in these experiments.

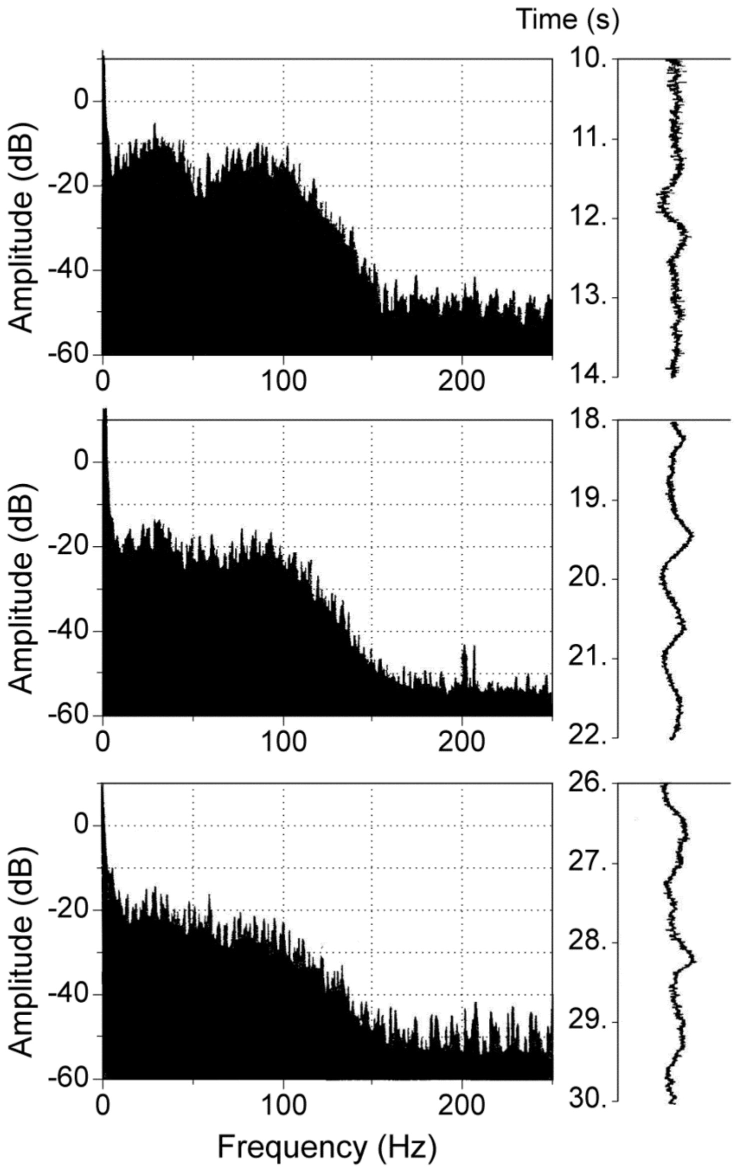
Dynamic pressure versus streamer depth assuming 40 m wavelength (5 sec period) – water depth 60 m



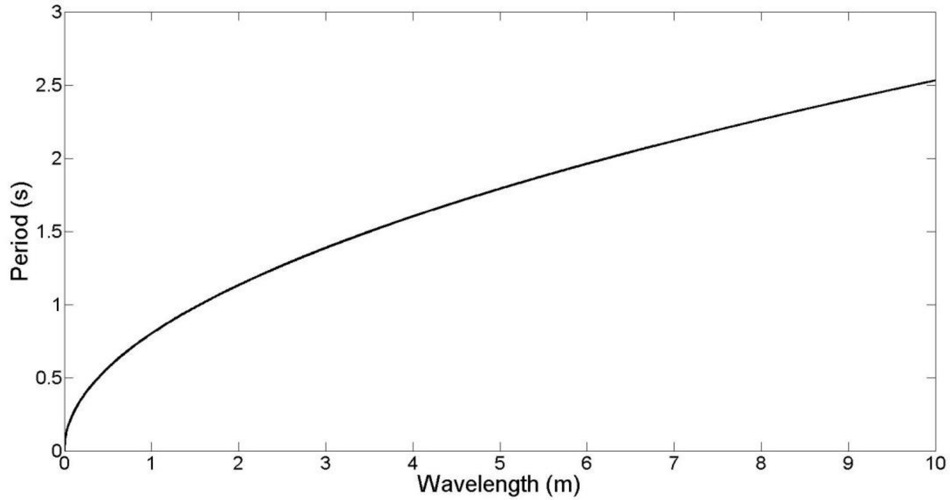
Particle velocity versus depth assuming 40 m wavelength – water depth 60 m



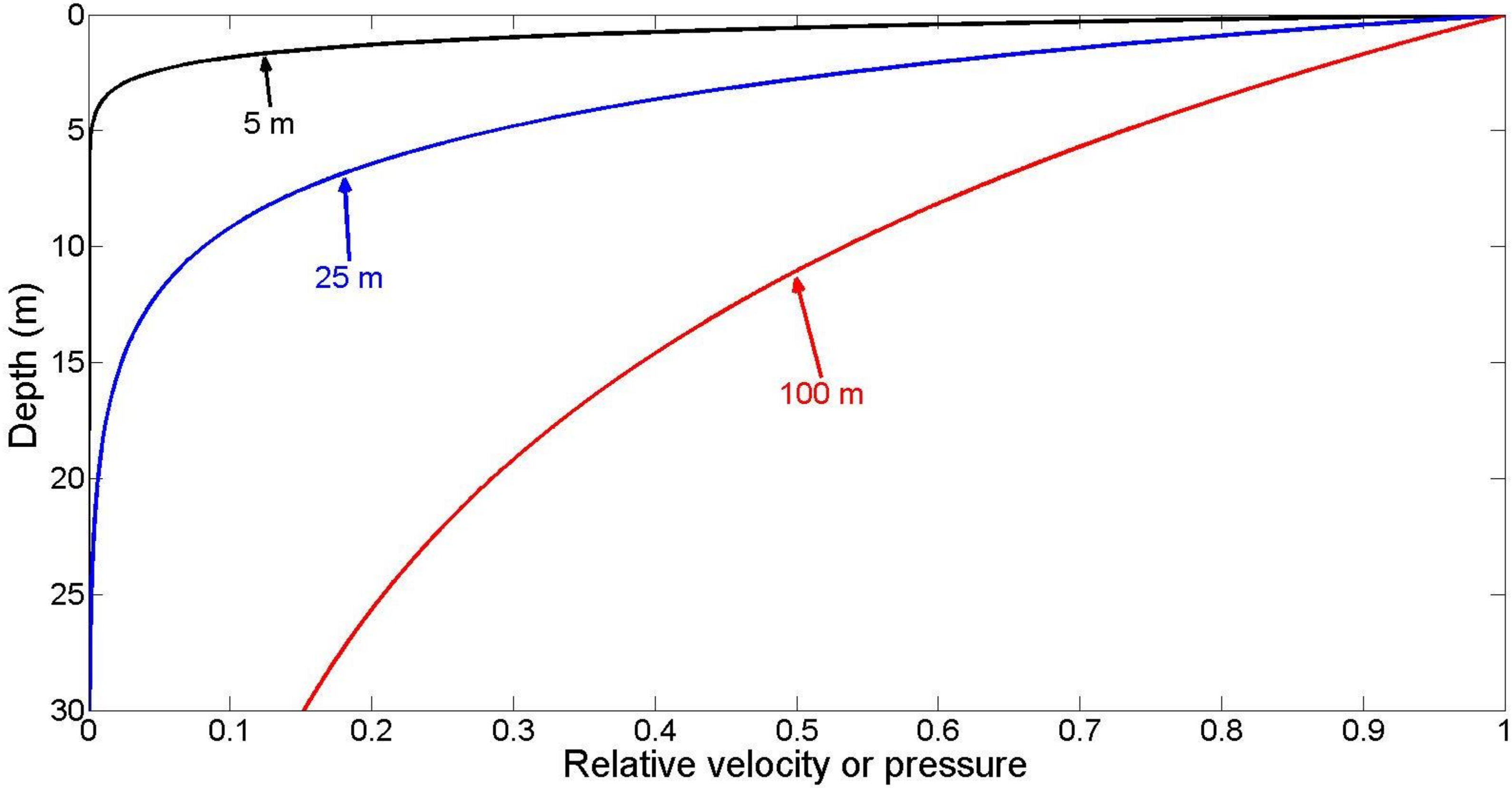
Typical swell noise observed on seismic data has a period of 1 s



Ocean waves with 1 second period => wavelength of 1.6 m

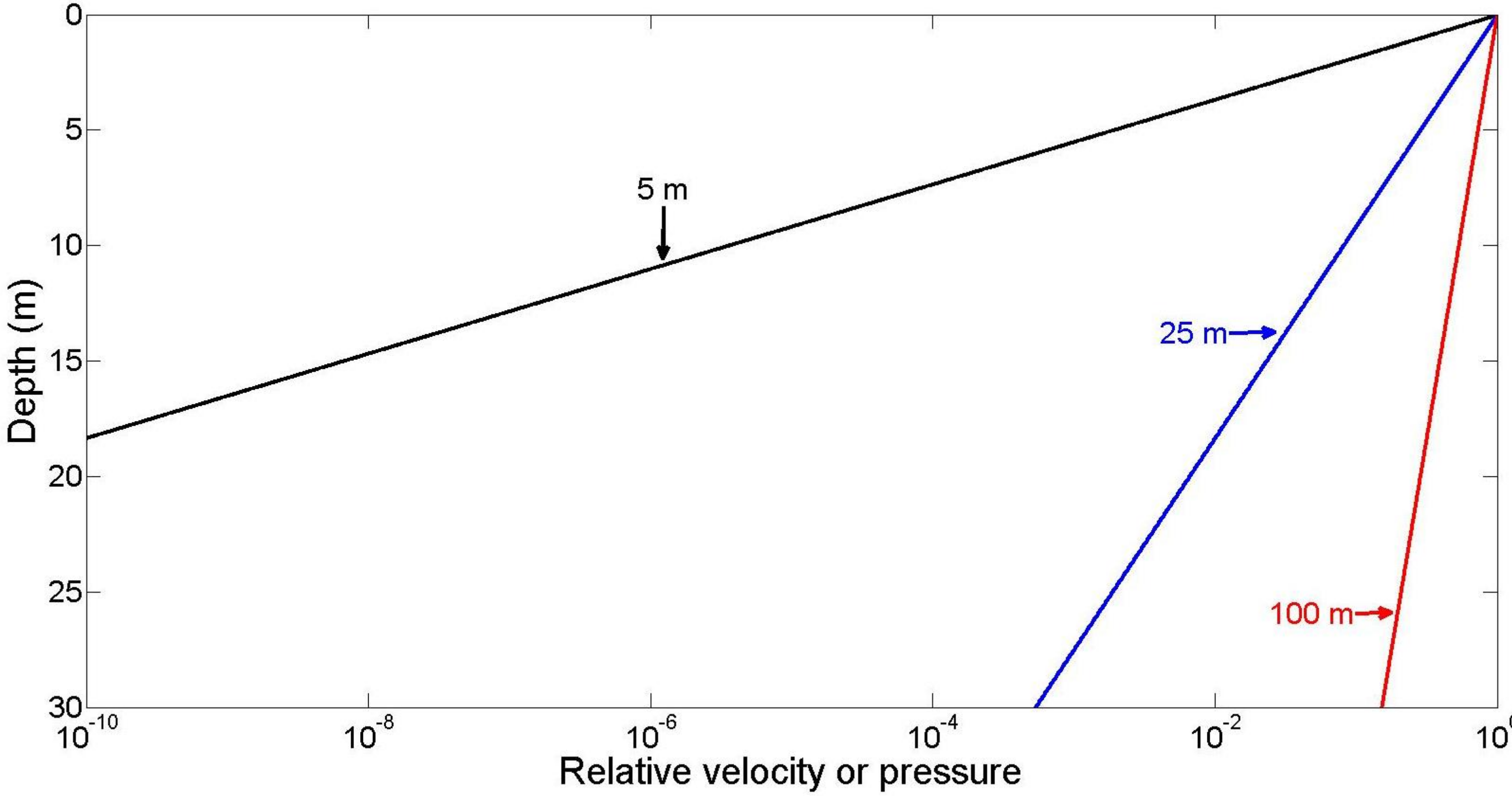


Dynamic pressure and velocity fields decay exponentially as a function of water depth

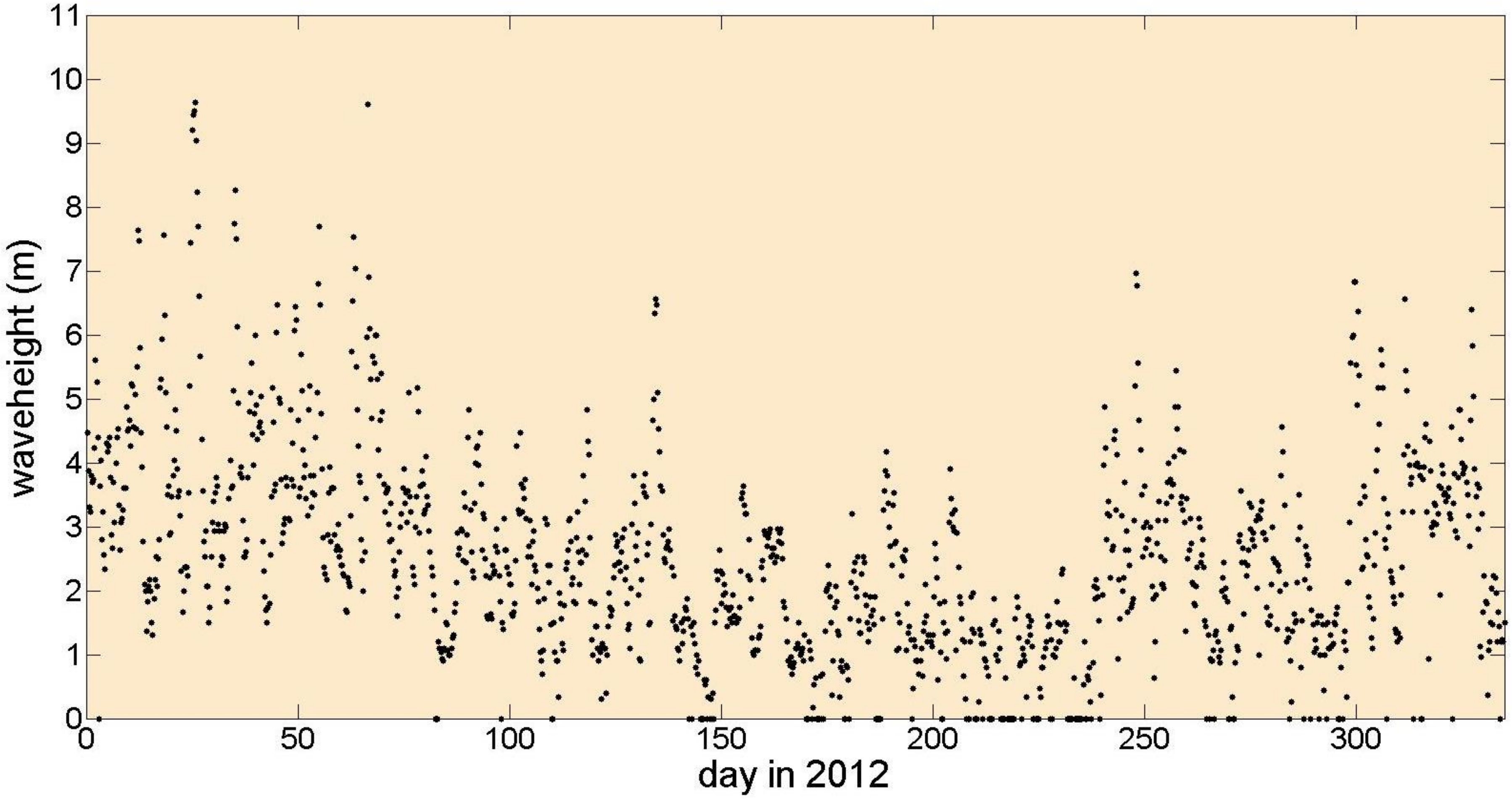


Strongly dependent on ocean wavelengths (5, 25 and 100 m shown above)

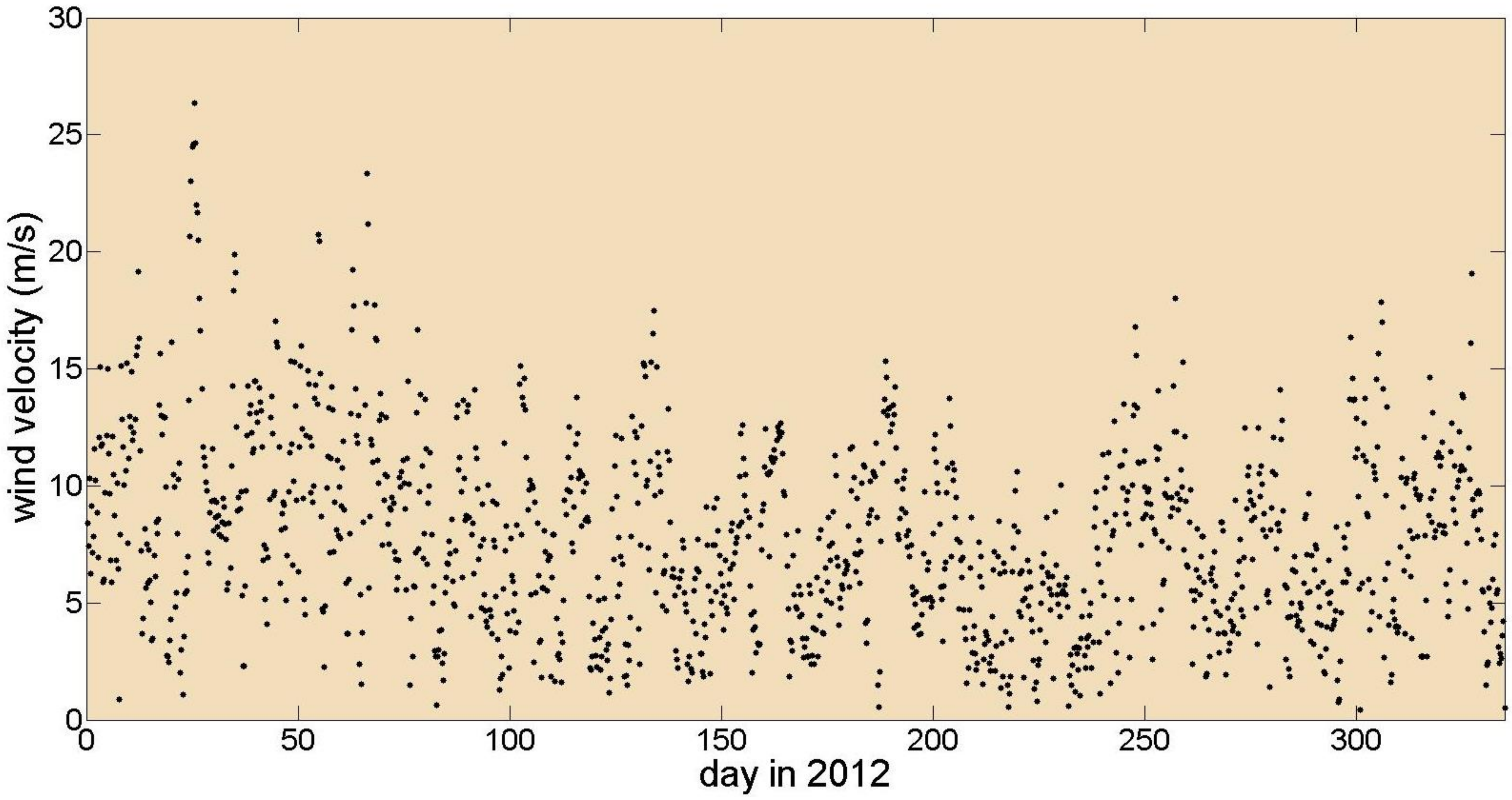
Logarithmic version of previous plot



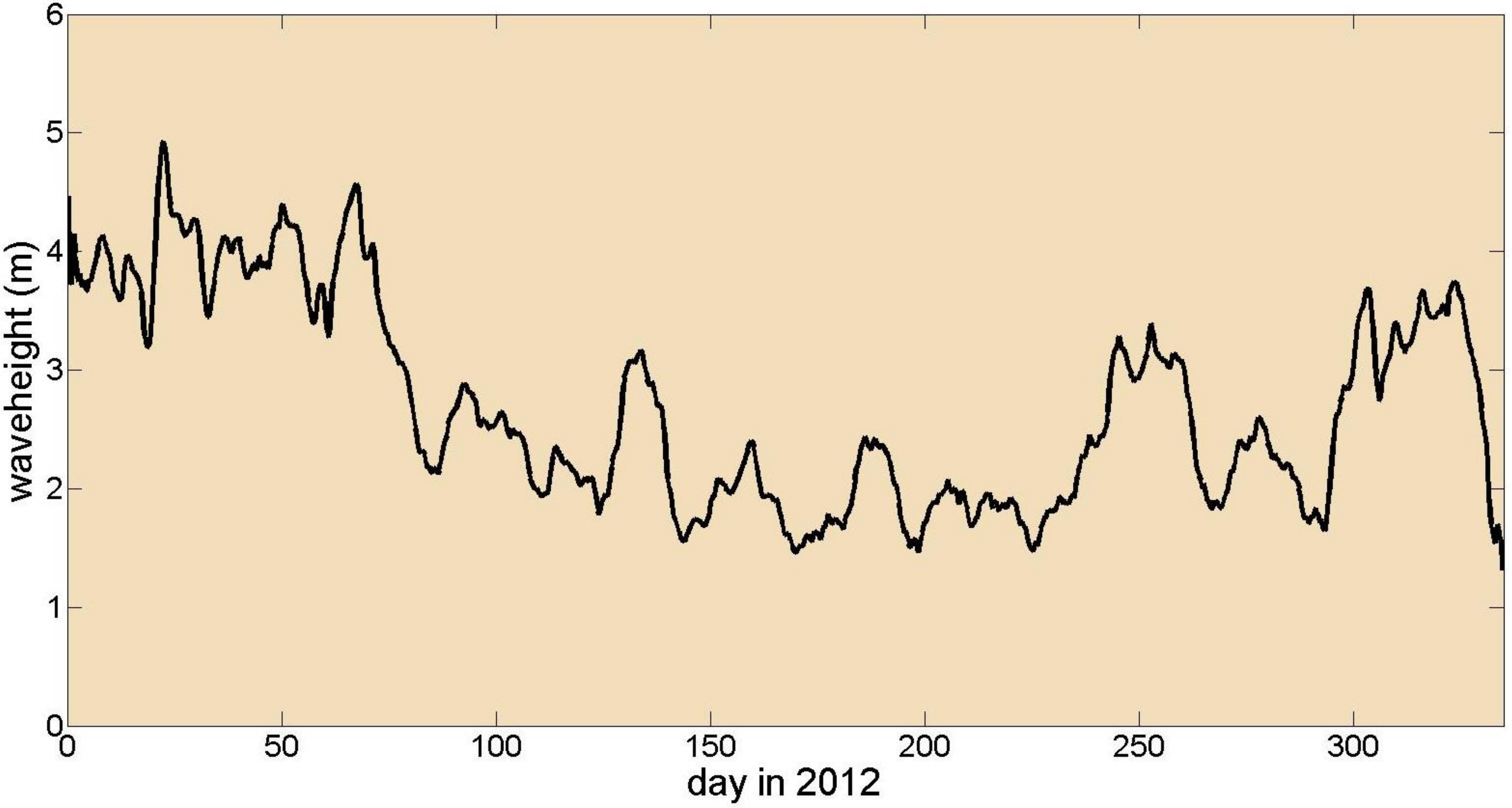
Waveheights at Gullfaks 2012



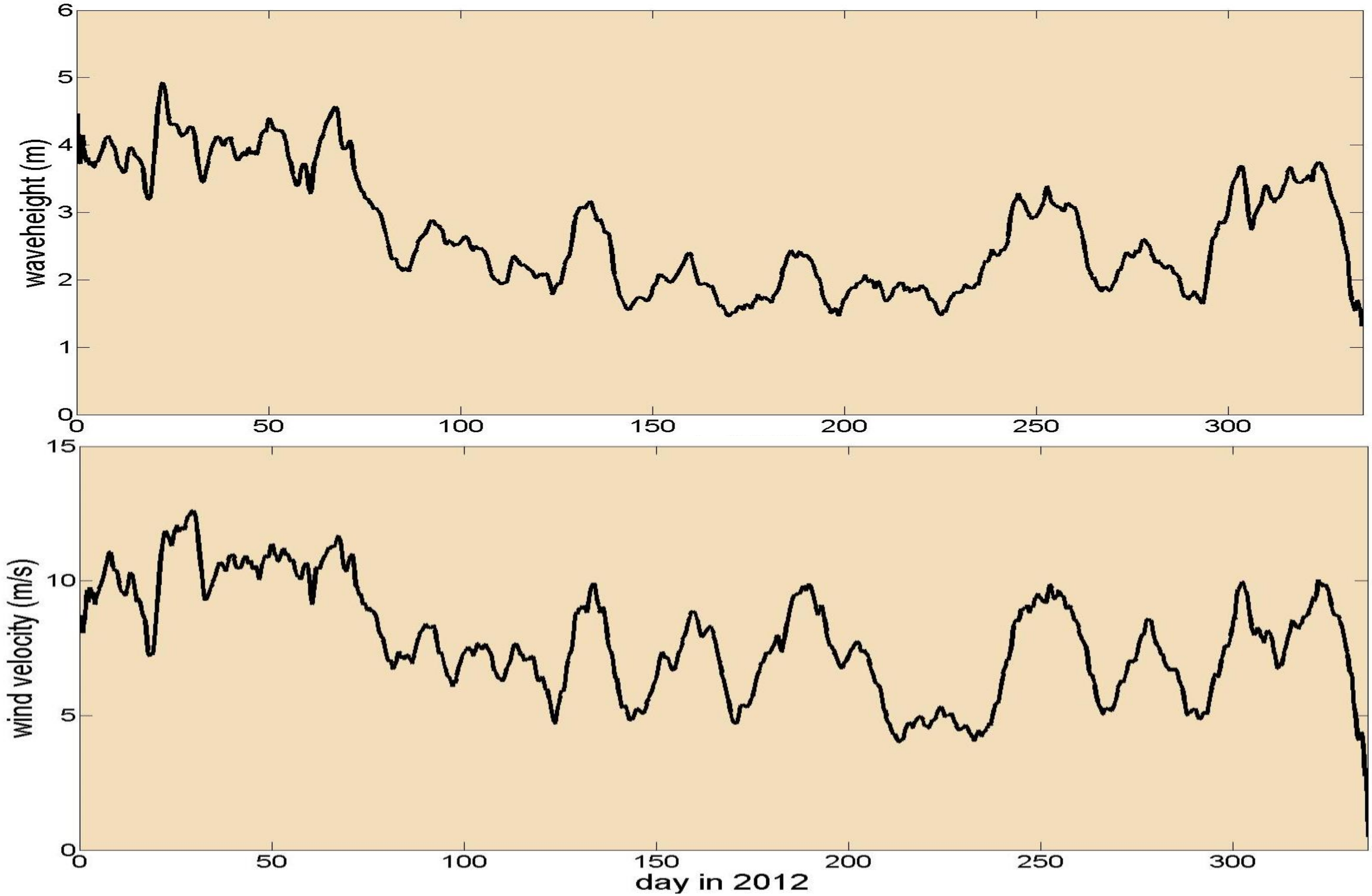
Wind speed at Gullfaks 2012



Waveheights at Gullfaks 2012 – smoothed (operator length: 14 days)



Comparing waveheights and wind velocity at Gullfaks 2012

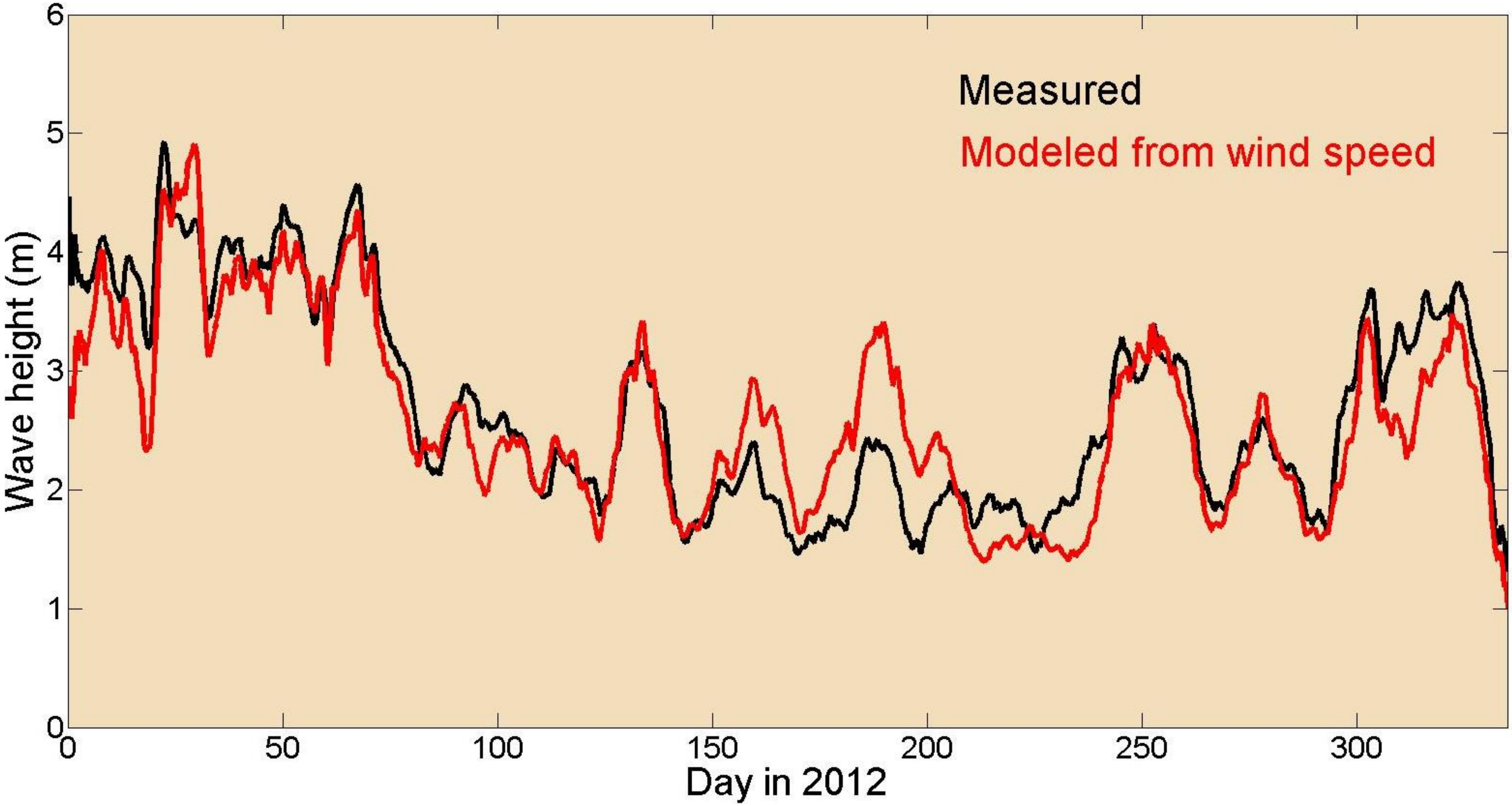


Gullfaks 2012 – correlation between wind speed and wave heights

Relation between waveheight and wind velocity (modified from Kinsman, 1965):

$$H = aU^2 + b$$

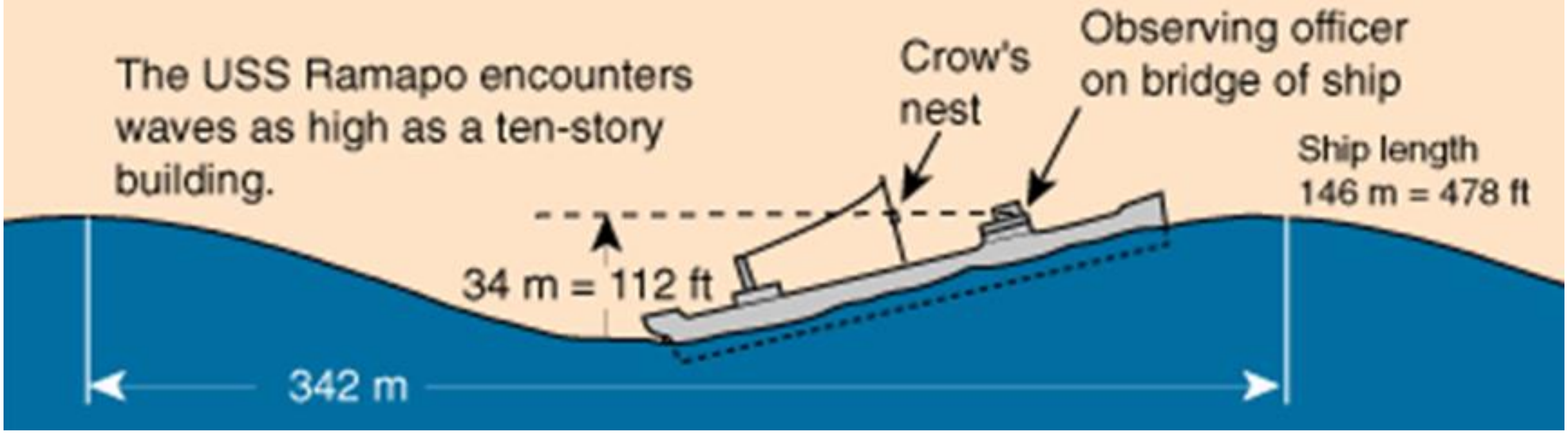
a = 0.0246; b= 1.0 m



Mountain waves: USS RAMAPO – 1933 Pacific Ocean

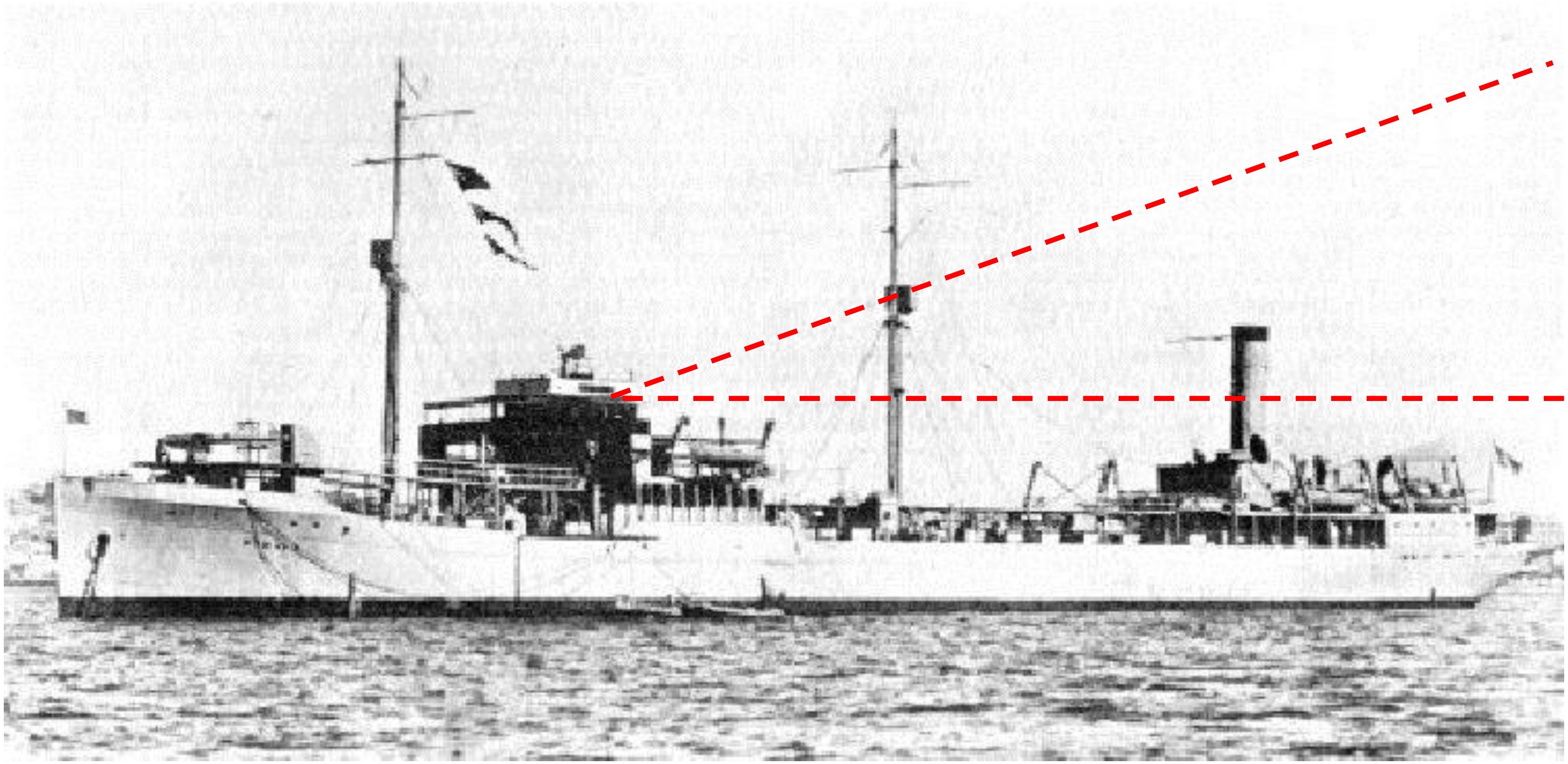
Source: Ned Mayo

In February, 1933, the USS Ramapo, a 146 meter (478 ft) Navy oiler found itself in an extraordinary storm on its way from Manila to San Diego. The storm lasted 7 days and stretched from the coast of Asia to New York, producing strong winds over thousands of miles of unobstructed ocean. Driven from behind by winds on the order of 60 knots, the crew had time to carefully observe the nearly sinusoidal mountainous waves. An officer on the deck observed the crest of the wave approaching from behind just over the level of the crow's nest while the stern of the ship was at the trough of the wave. Subsequent scaling yielded the height of 34 meters for the wave.



Wavelength/waveheight ratio = 10

USS RAMAPO



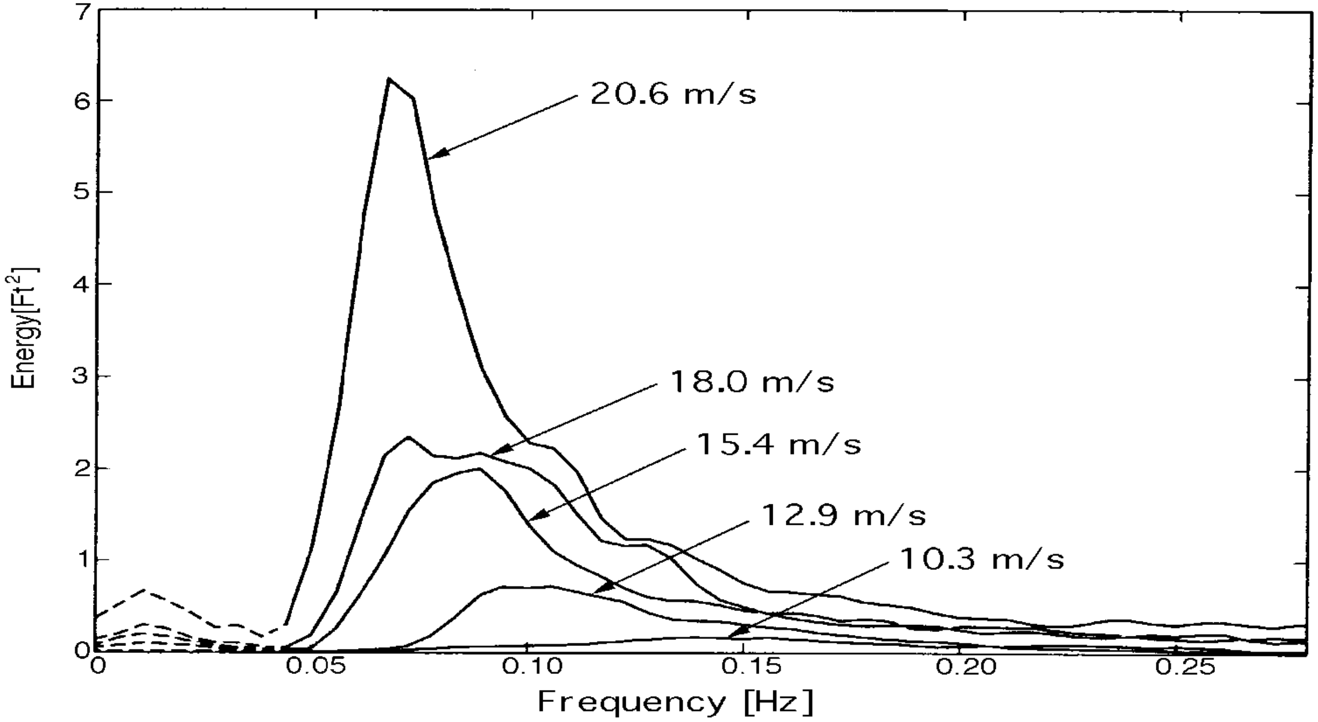
Low frequency part of wave spectra

Pierson-Moskowitz spectrum:

$$S(\omega) = \frac{\alpha g^2}{\omega^5} e^{-\beta\left(\frac{\omega_0}{\omega}\right)^4}$$

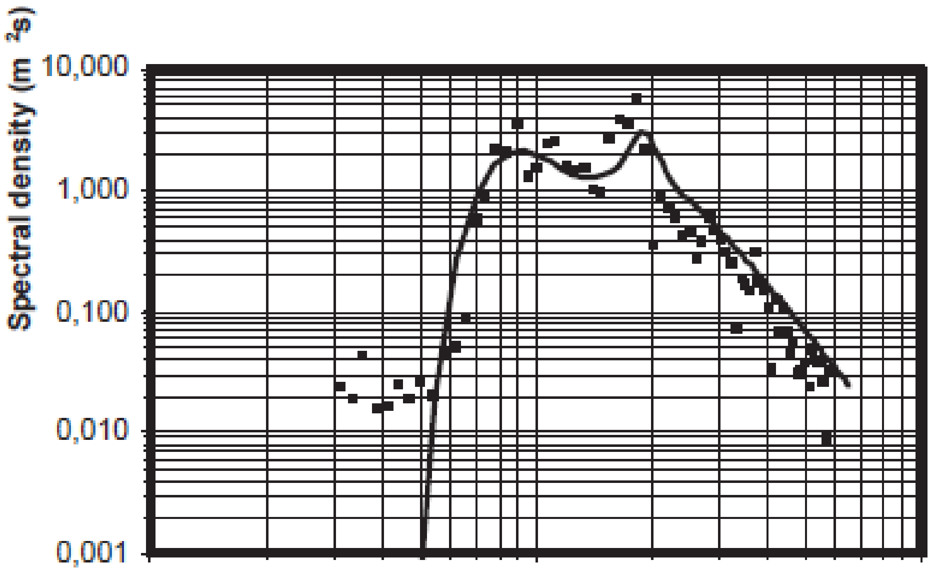
Peak frequency decreases with wind speed:

$$f_P = \frac{0.9g}{U}$$



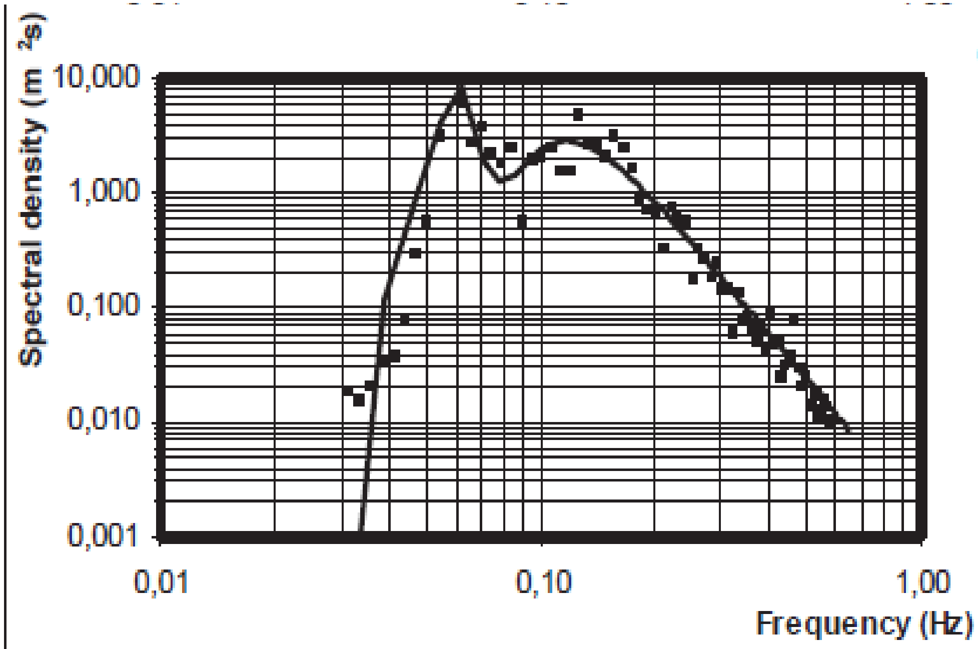
Wave spectra of a fully developed sea for different wind speeds according to Moskowitz (1964).

Torsethaugen, 1993: double peak model



Statfjord data: Hs=2.5 m; T=5.3 s

Wavelength: 44 m
Steepness = 2.5/44 = 0.057



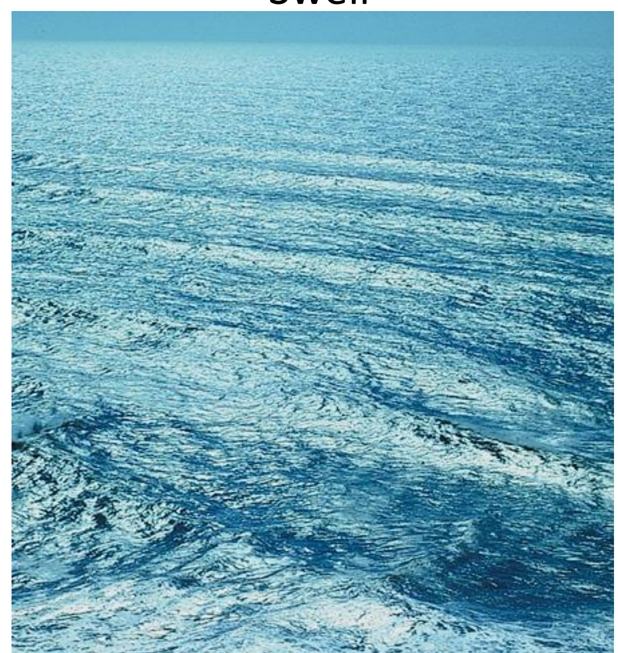
Statfjord data: Hs=2.6 m; T=16.8 s

Wavelength: 450 m
Steepness = 2.6/450 = 0.0057

Foam (mixture of water and sand) on shore after a storm in Aberdeen

Chaotic sea

Swell



Source: Columbia University and other

Observations

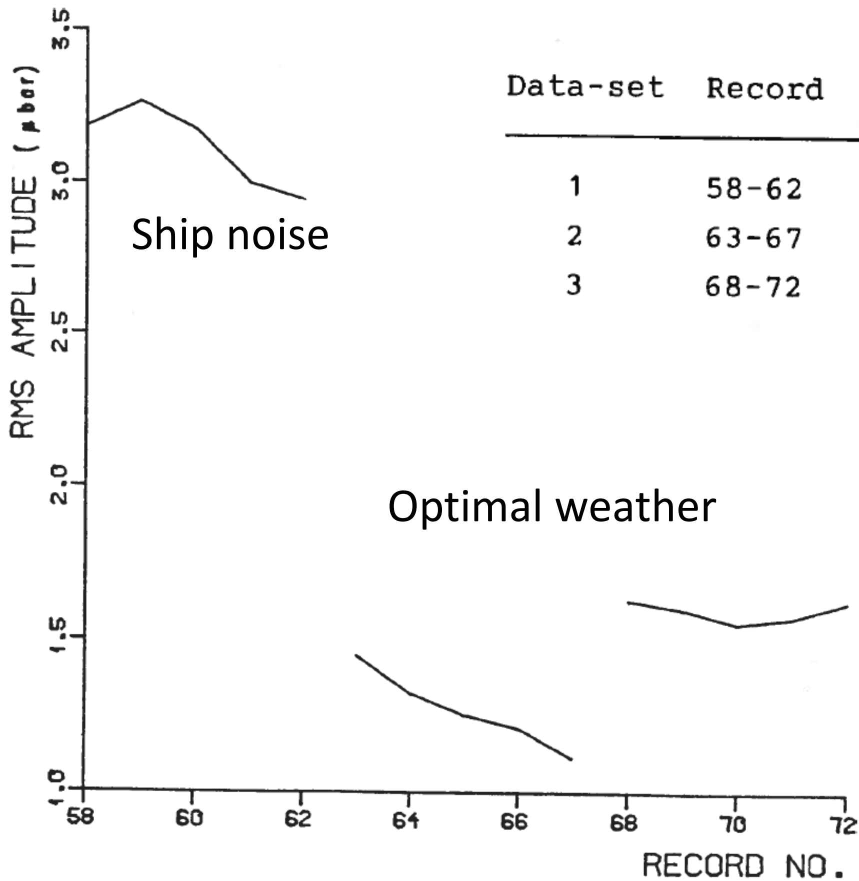
- The noise created by the mass distribution effects of a sinusoidal surface wave decays exponentially and is negligible for frequencies above 1-2 Hz
- Langmuir layer extends down to 20 m, and create helix type of water circulation

Measuring noise on streamers

Photo: Kongsberg Maritime

Marine seismic noise – field experiment Haltenbanken, Seres project 1988-1989

Streamer depth: 9-12 m, 3 km streamer, 120 channels, birds at traces: 1,13,25,37,49,61,73,85,97,109



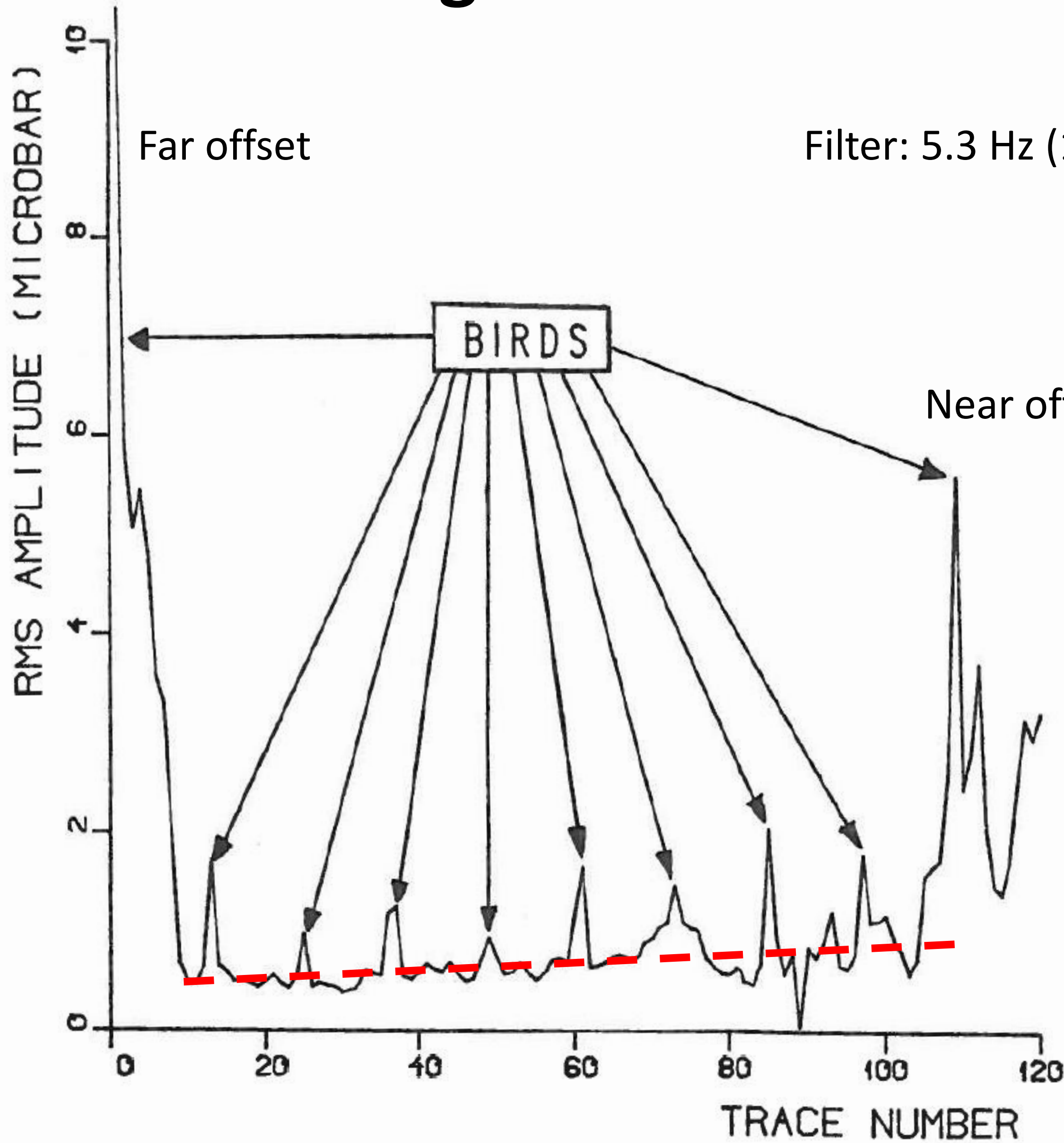
Data-set	Record	Swell	Wind	Sea state	Low cut Filter
1	58-62	1 m	no	0.5	in
2	63-67	1-2 m	16 kts	4	in
3	68-72	0.5 m	17 kts	3	in

RMS-average for records 63-67 good weather

Far offset

Filter: 5.3 Hz (18 dB/oct to 128 Hz (72 dB/oct)

Near offset



Notice the sligth decrase (red dashed line) in noise level away from the ship (trace 120 is closest to the vessel)

Conventional fluid filled streamer

Ambient noise on midstreamer traces is ~ 0.5 microbar !

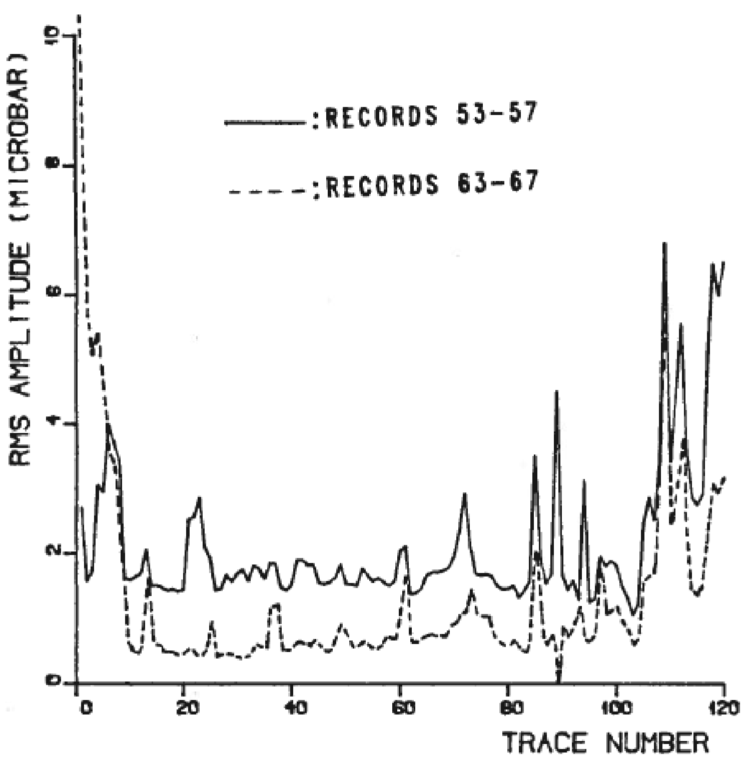
Data from the SERES Marine Seismic Noise Project 1989

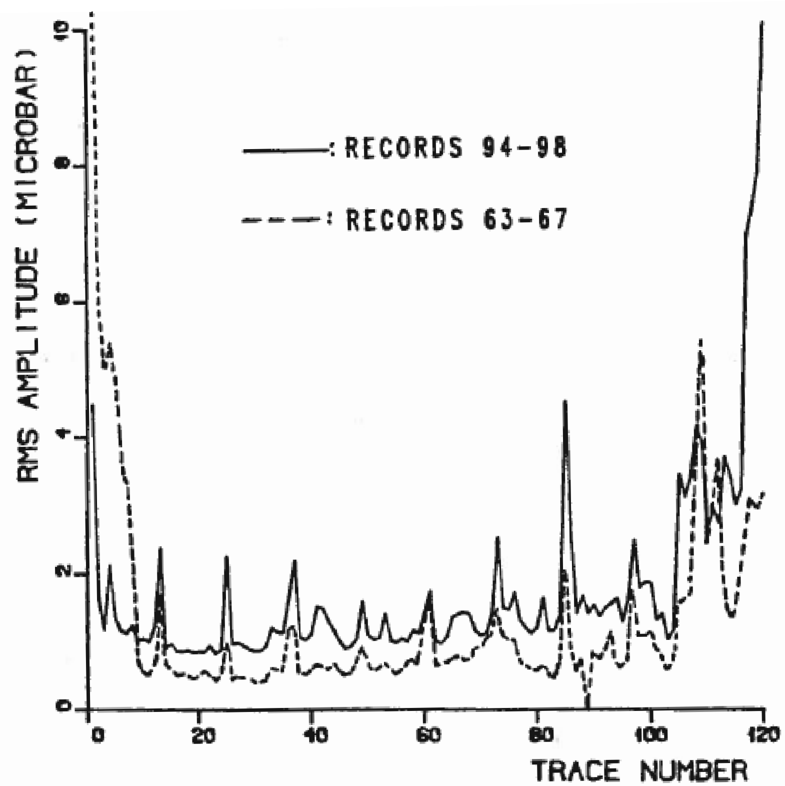
Comparing the optimal noise records with some weather noise records:

Bird noise is still visible

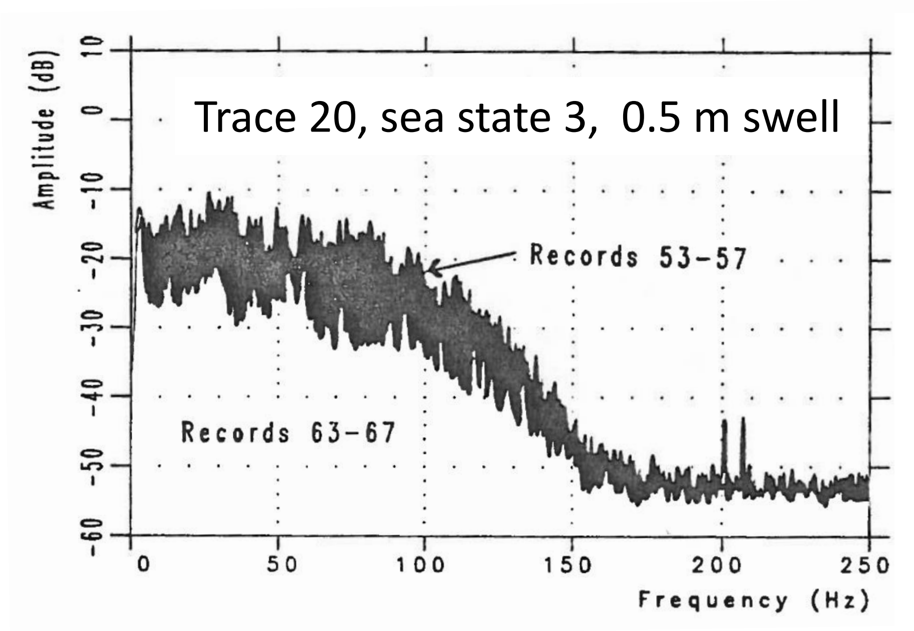
Data-set	Record	Swell	Wind	Sea state	Low cut Filter
1	53-57	0.5 m	12 kts	3	in
2	94-98	2 m	12 kts	2	in

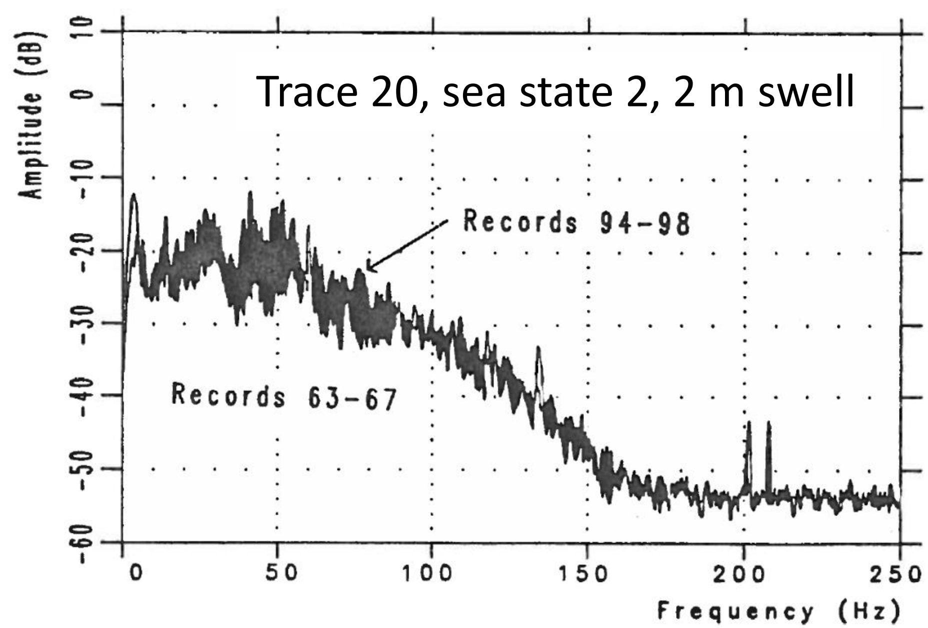
RMS AMPLITUDE





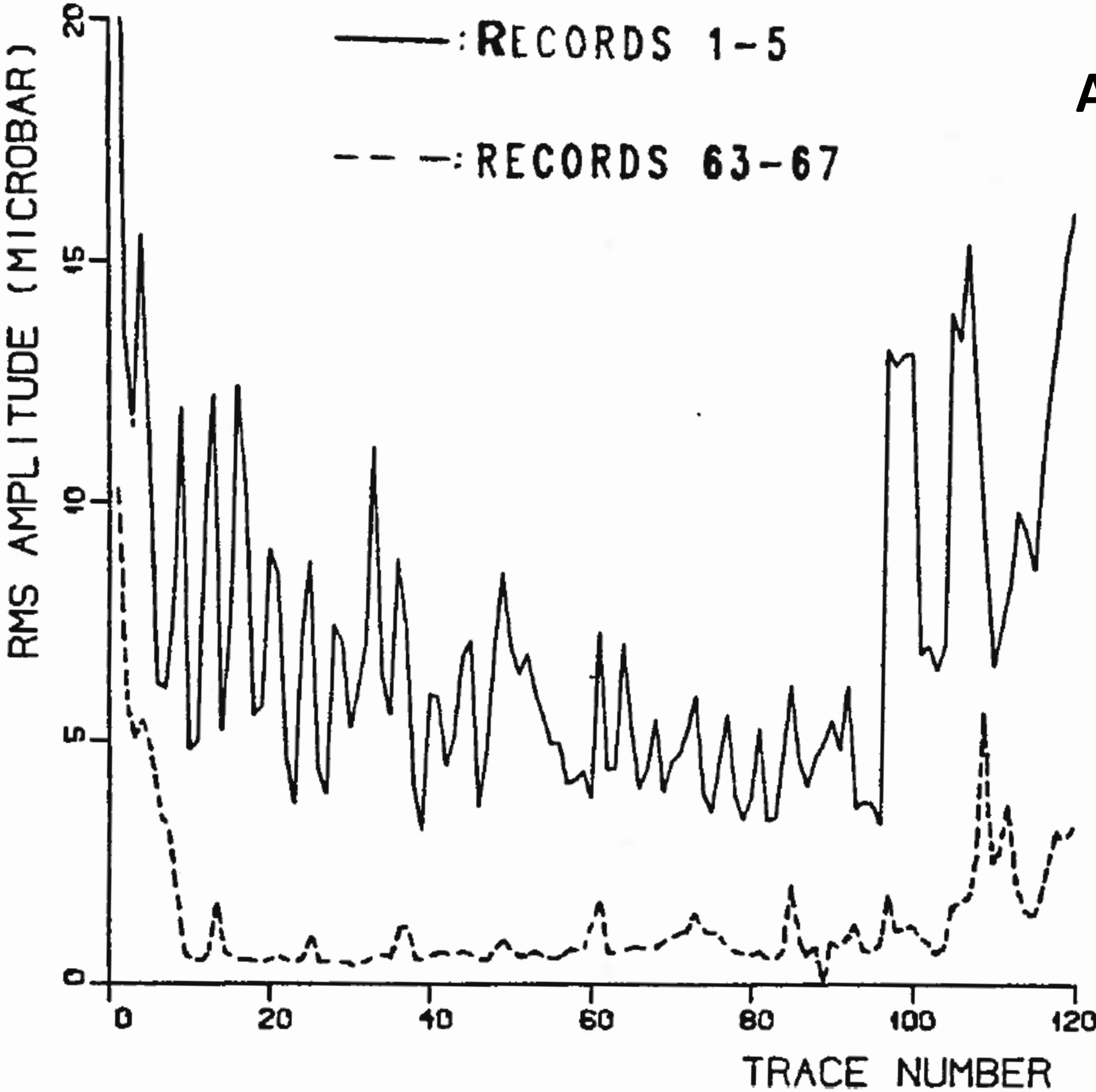
Sea state is more important than swell size





- Indication that rough seas with relative small wave heights create more noise than a calmer sea with larger swells
- Same wind speed for the two measurements
- Noise generated by motion and cavitation close to sea surface?

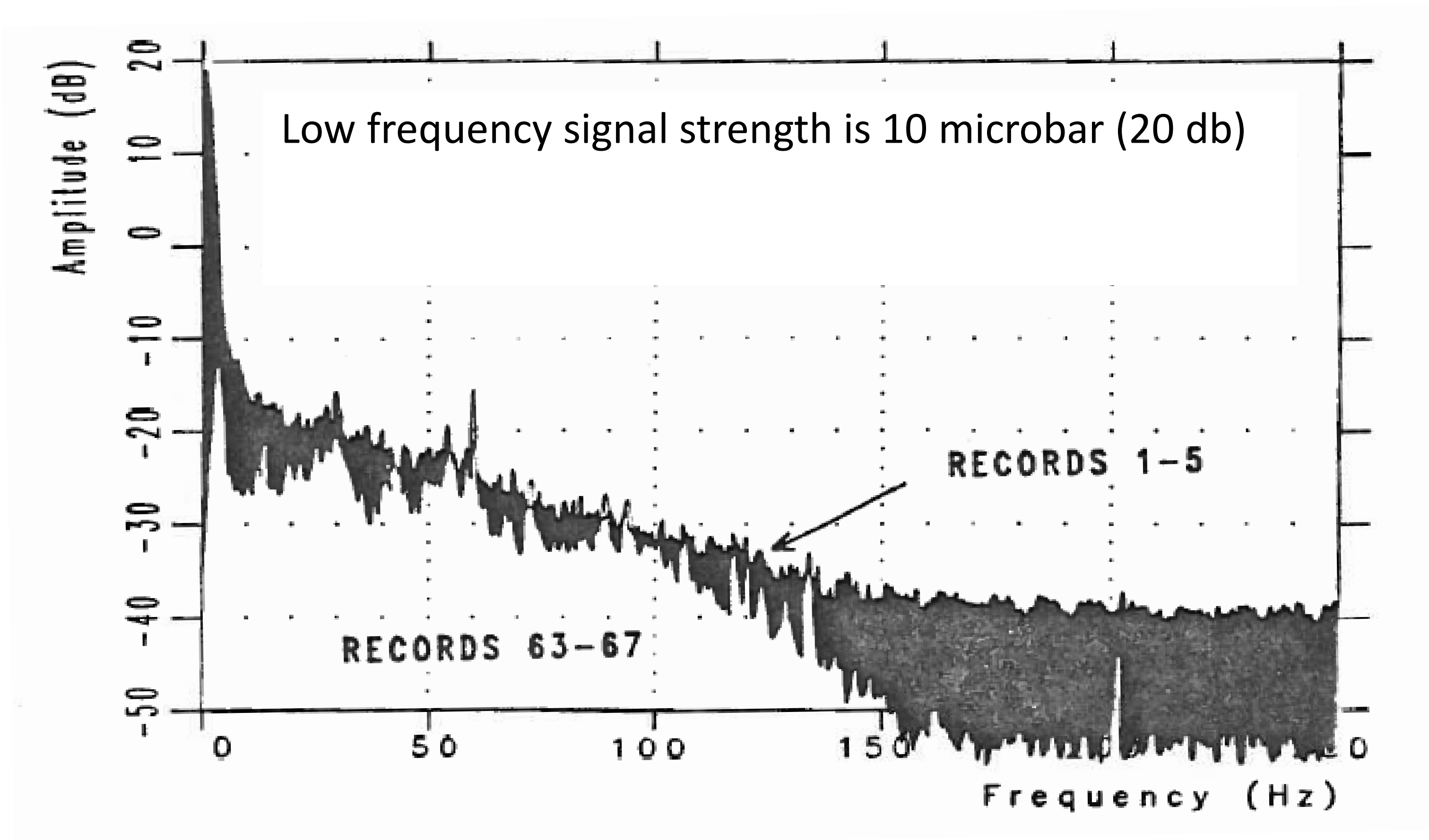
Strong weather noise – 33 knots sea state 6-7



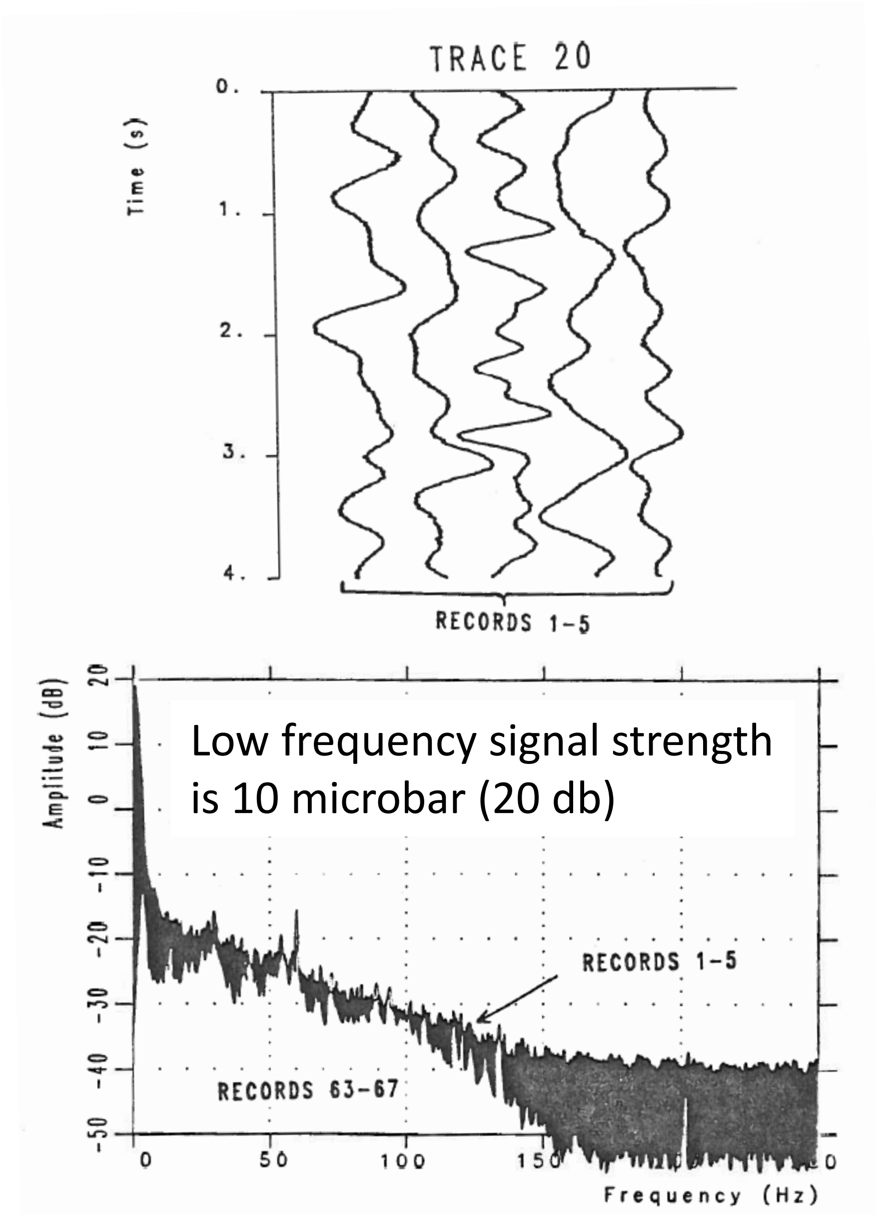
Average 10 microbar

Bird noise not visible, more head and tail noise

Typical weather noise (black) compared to the ambient noise (white)



Records in rough weather (wind speed 33 knots, gale)

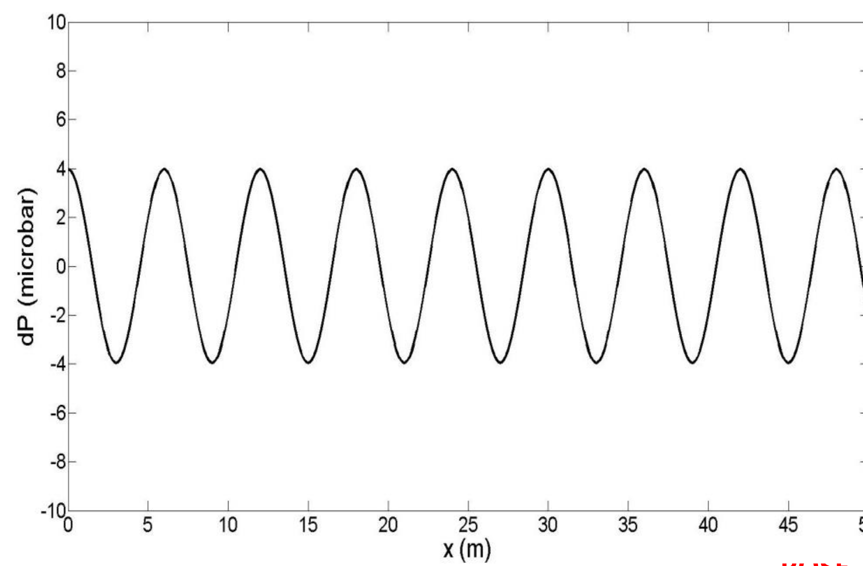


Low frequency signal strength is 10 microbar (20 db)

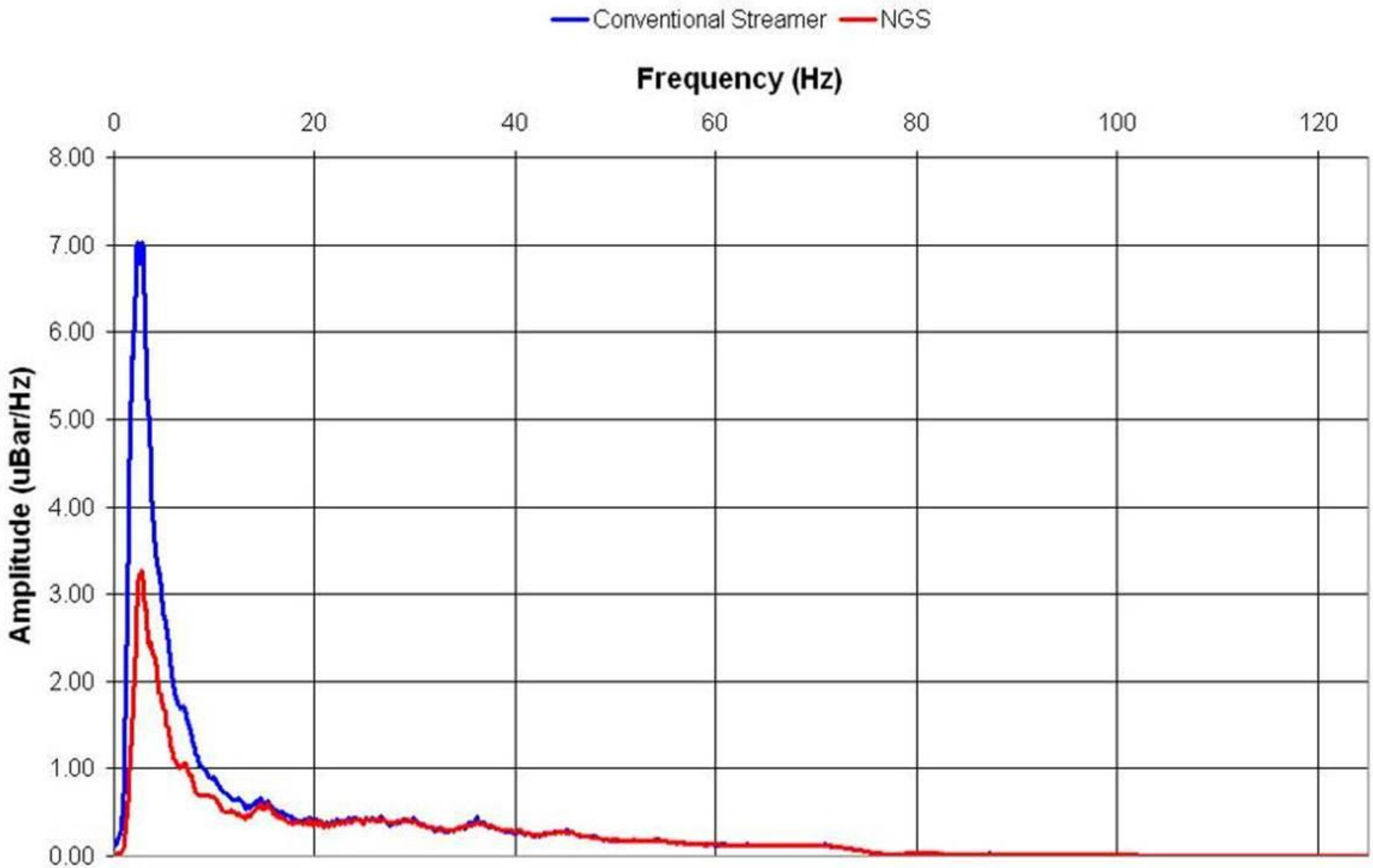
Observe periods up to 2 seconds => 6 m wavelength

Modeled response at 9 m streamer depth

λ = 6 m
H = 1 m
T = 2 s
d = 100 m

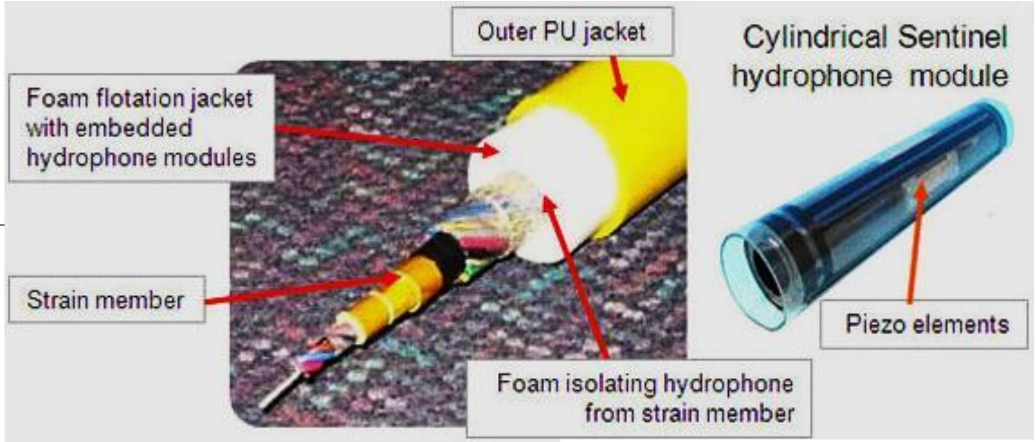


Noise records at 6 and 15 m, conventional and new streamer

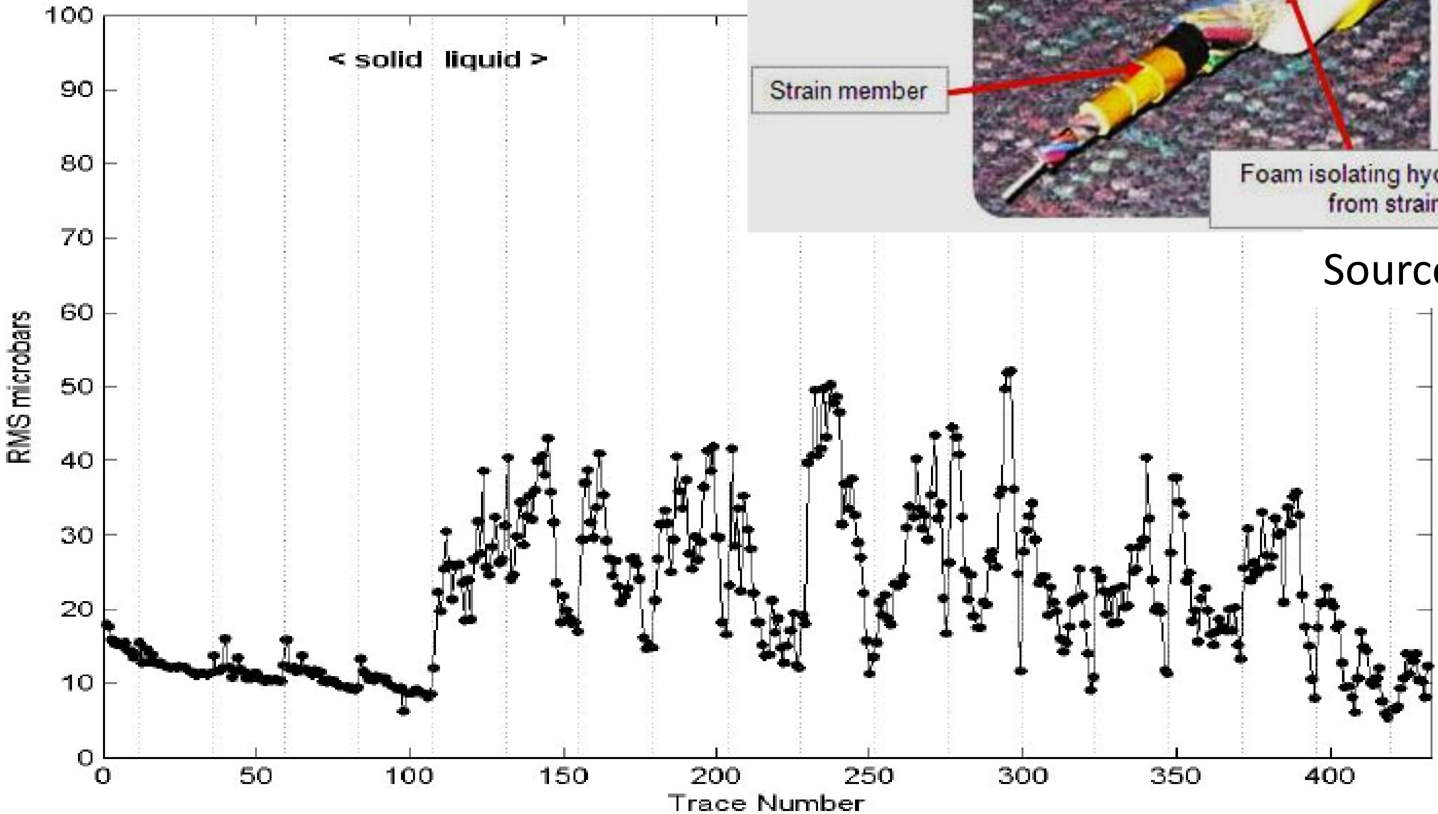


Courtesy of PGS

Solid streamers



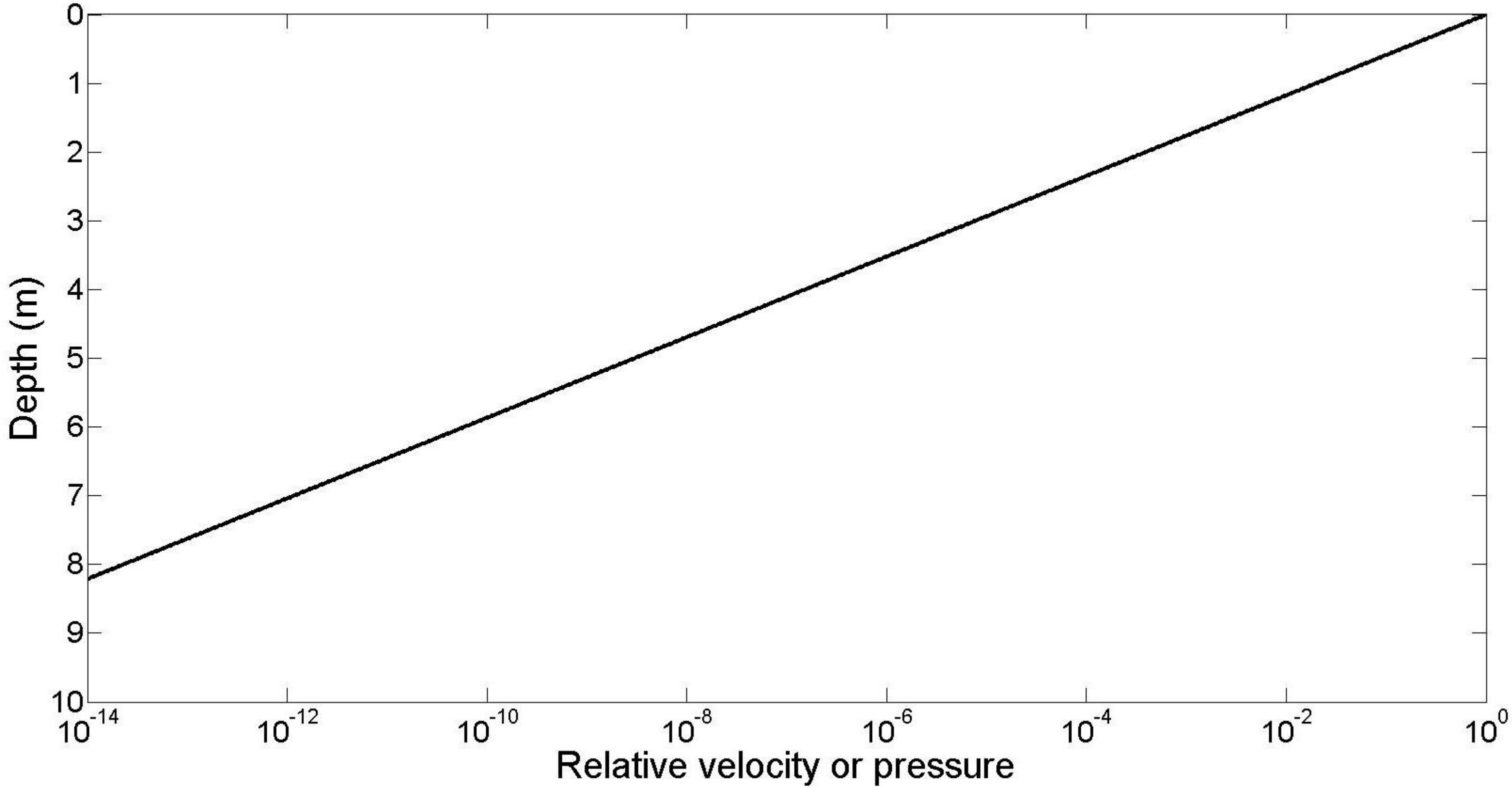
Source: www.cgg.com



Noise comparison of solid streamer (left) and fluid filled streamer (right) measured for moderate seas. From Dowle, SEG, 2006.

Ocean wavelength of 1.6 m (1 s period) decay with depth

Assume that noise level at surface is 0.1 bar => 10^{-15} bar at 8 m



CONCLUSION: This type of noise is rarely observed in seismic data, because the period is rarely larger than 1 second..

Turbulent flow around a streamer (Elboth et al., Geophysics 2010)

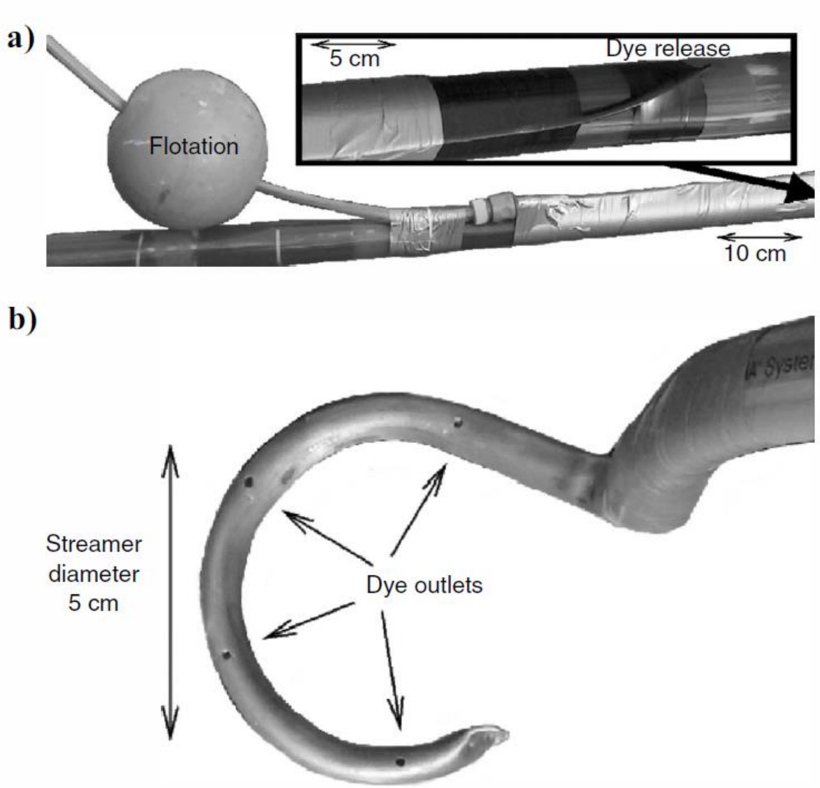


Figure 2. (a) The single hole outlet arrangement. A slight bend toward the nozzle is imposed to release the dye in an area where we hope there are minimal flow interactions with the arrangement (cf. the zoomed inset). (b) The four-hole nozzle outlet, which was hooked onto the streamer cable.

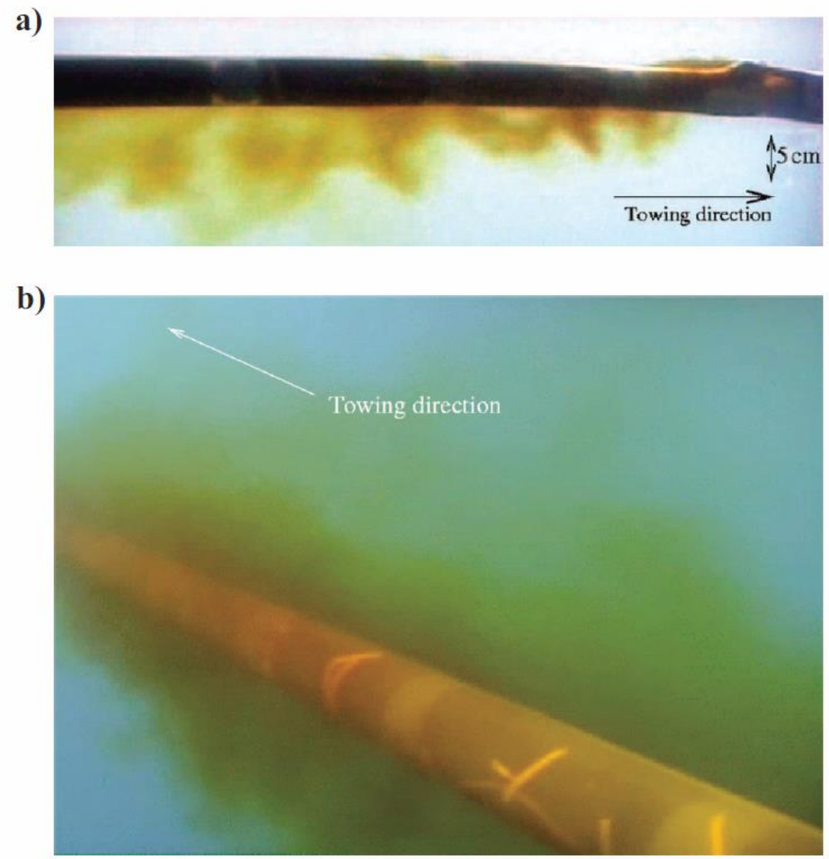
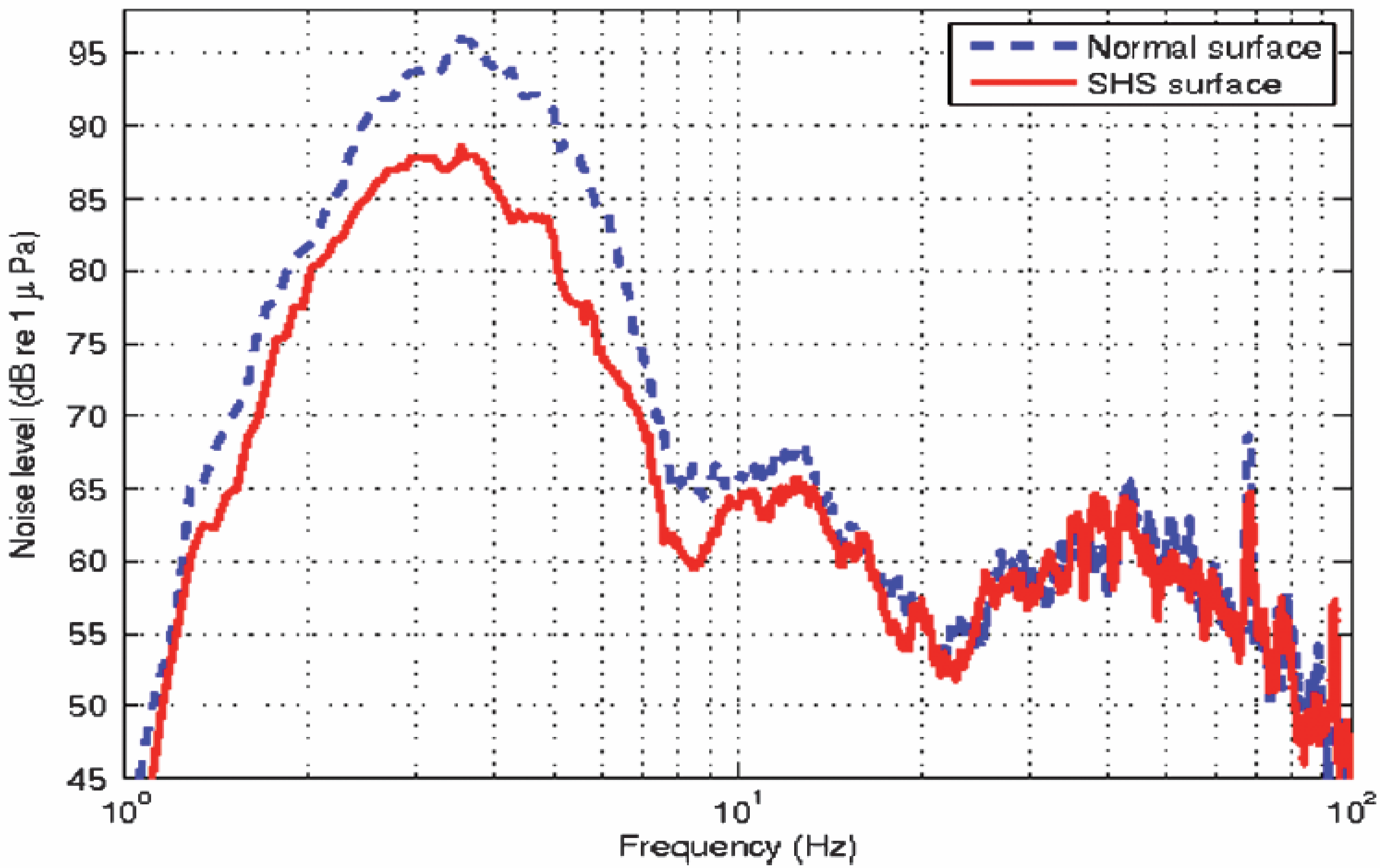


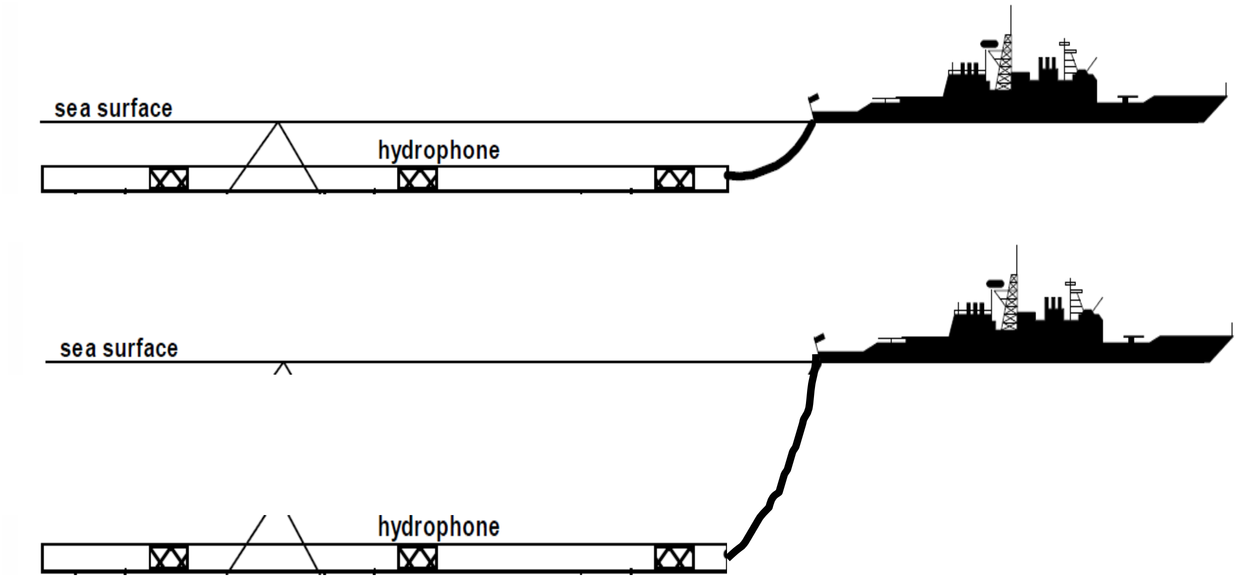
Figure 3. Snapshots of a seismic streamer cable in the ocean. (a) Cross-section view visualized by a single hole dye release. (b) Three-dimensional view by a multihole dye release.

Flow noise reduction from superhydrophobic surfaces Geophysics, 2012

Thomas Elboth[1], Bjørn Anders Pettersson Reif[2], Øyvind Andreassen[2], and Michael B. Martell[3]



Tug noise – increase with increasing towing depth?

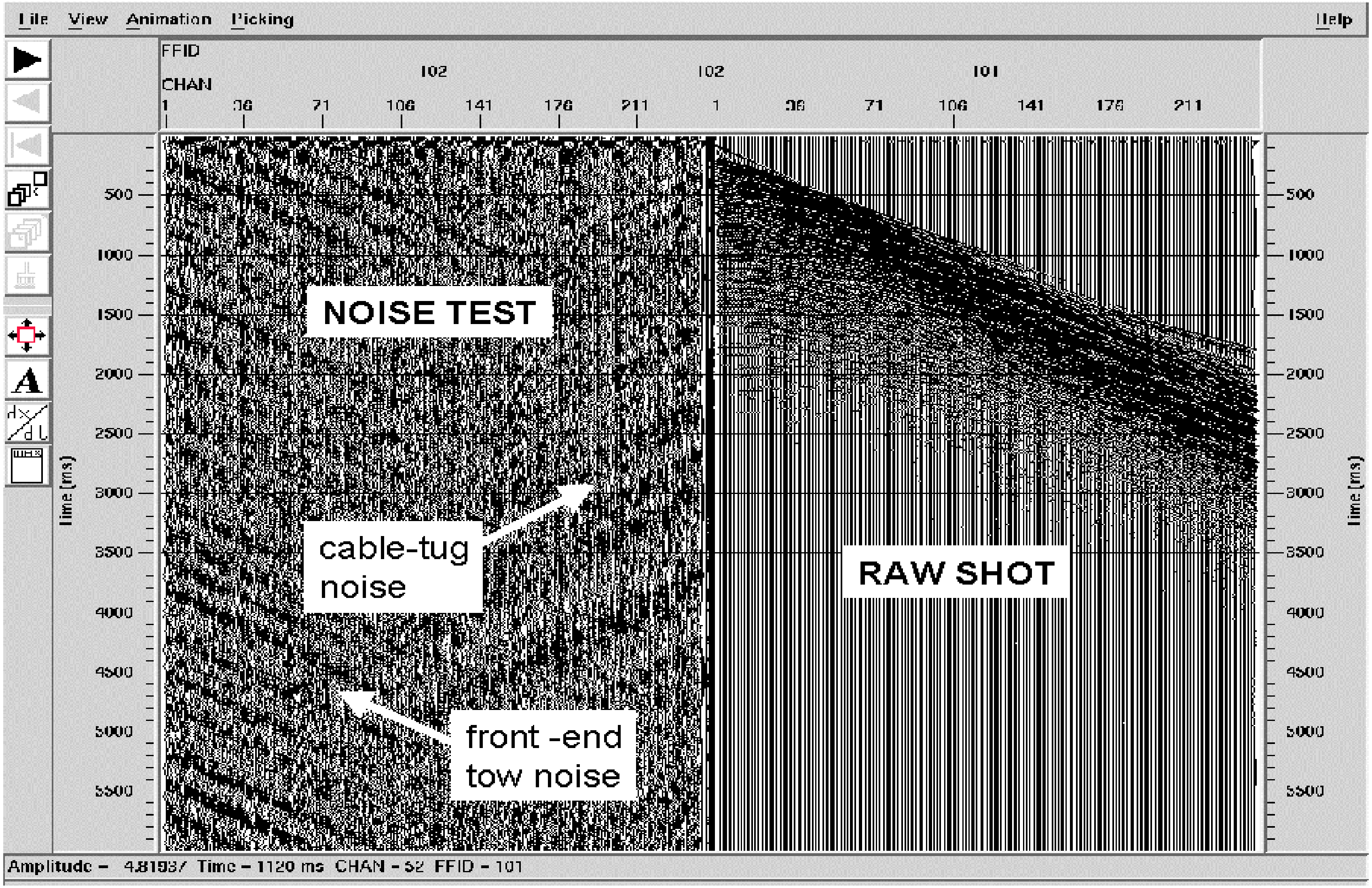


Increased angle between lead ins and the streamer => more tug noise

- Use of lead ins to decrease the angle => less near offset coverage?

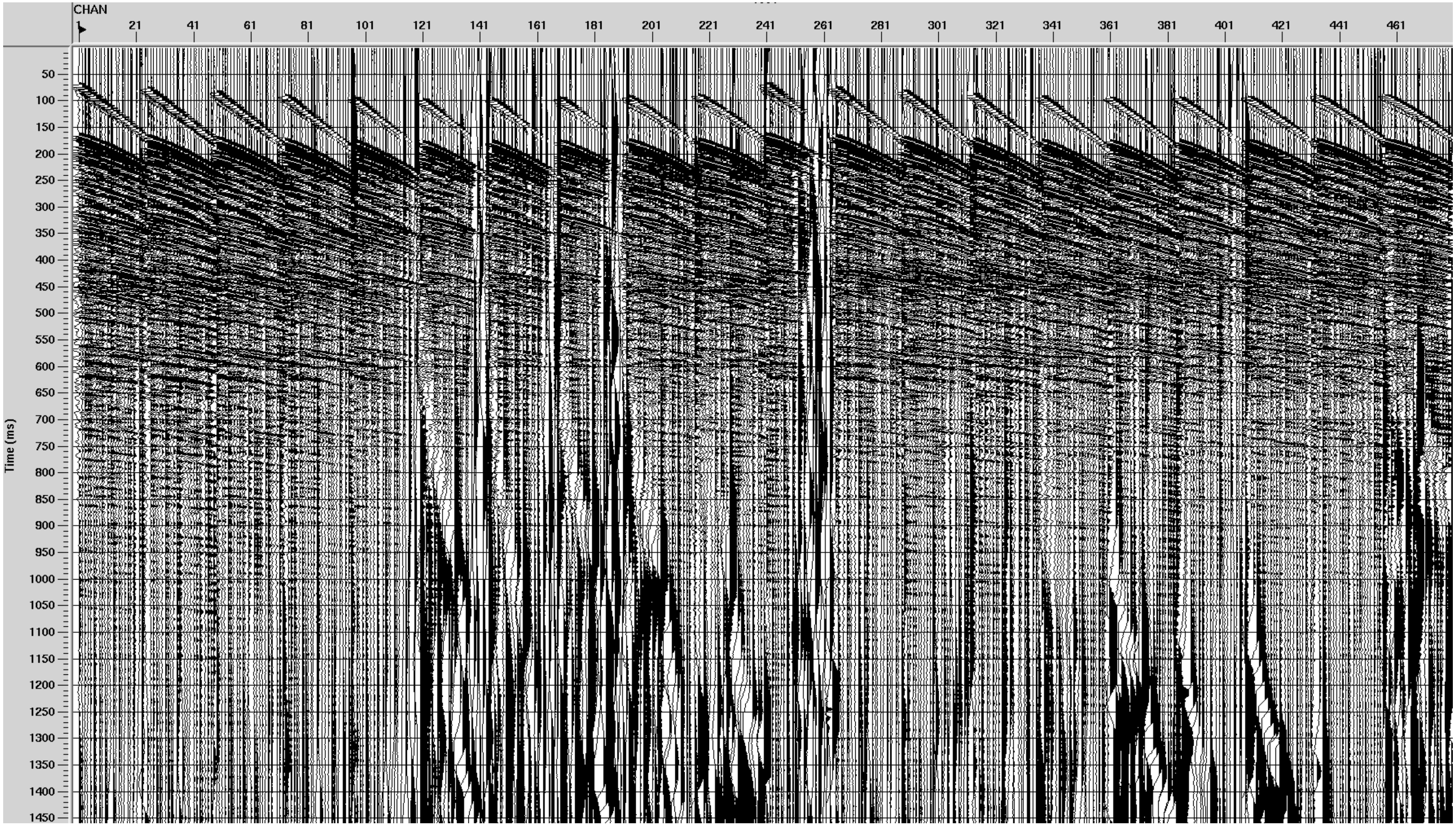
TUG NOISE

RAW SHOTS

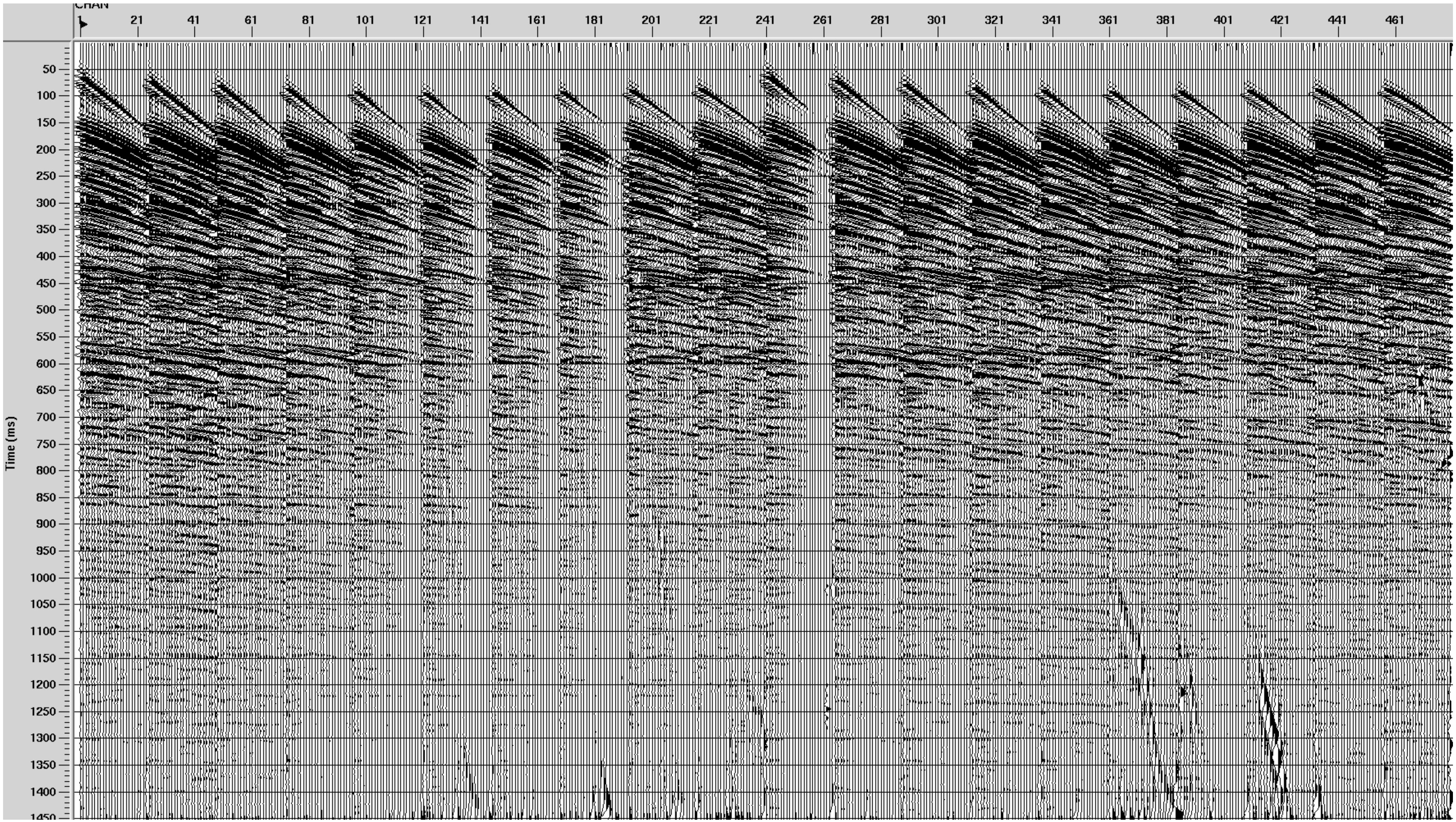


http://www.xsgeo.com/course/acq.htm

Site survey data – «random» swell noise

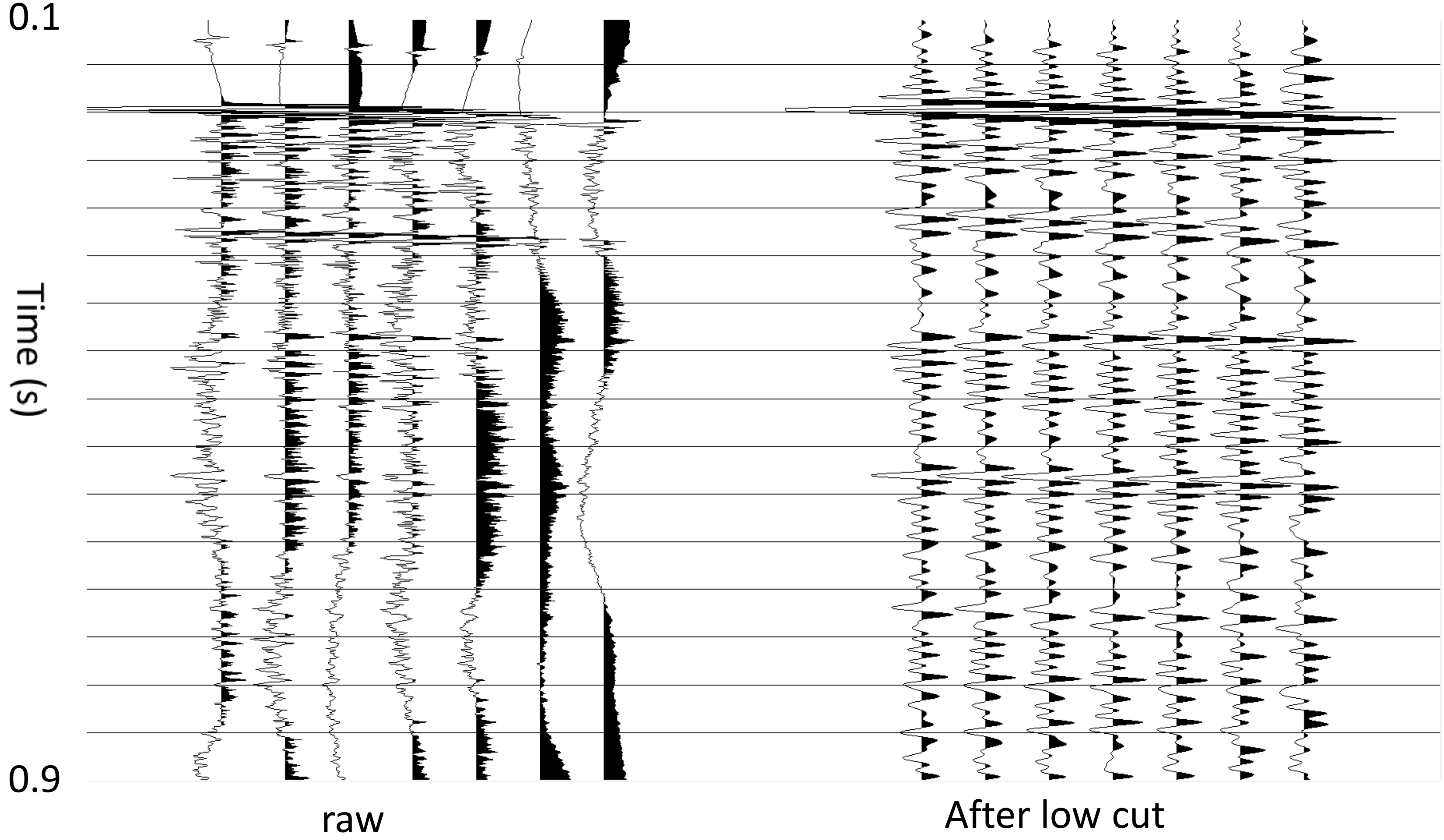


5-15-100-130 Hz band pass filter

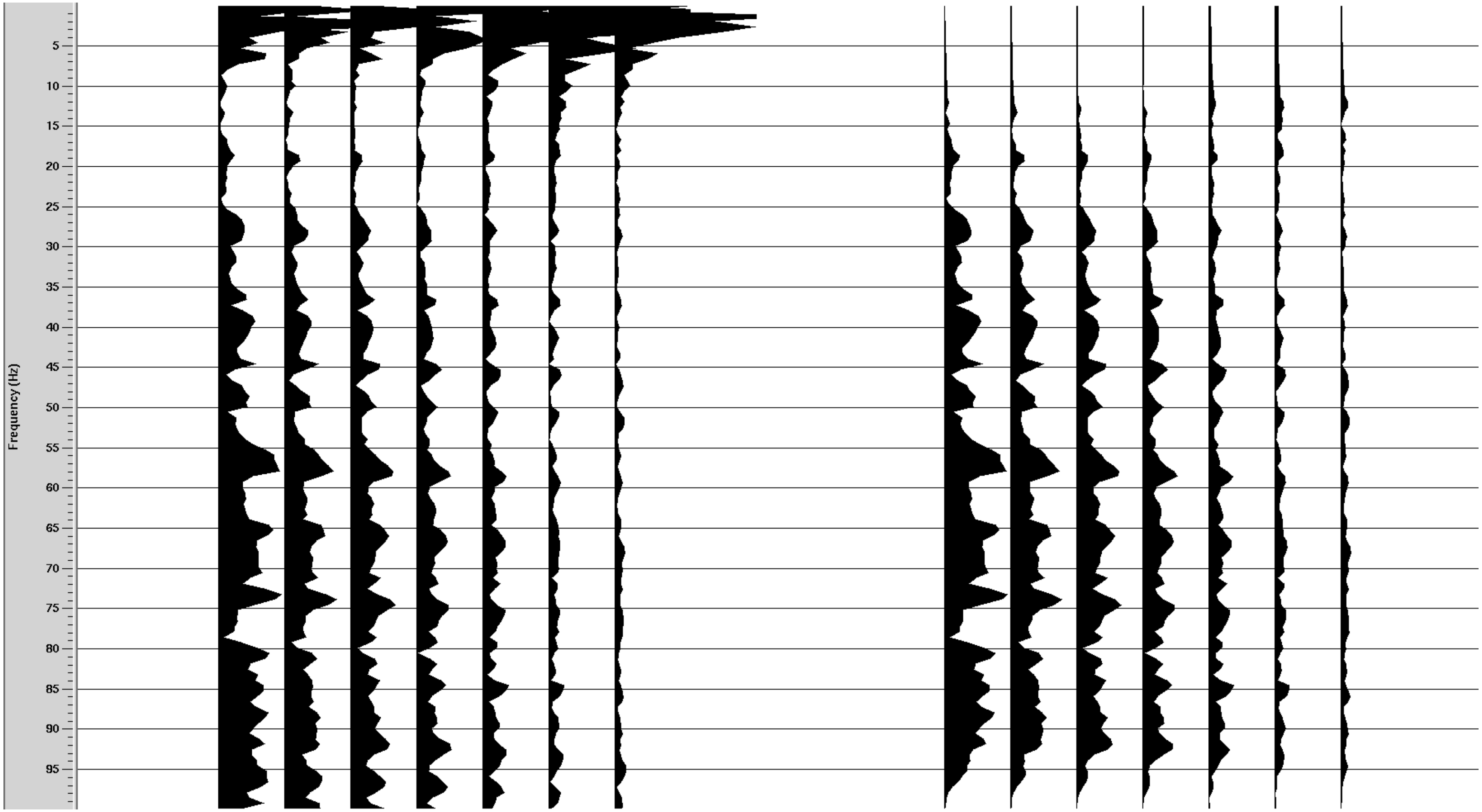


Still some swell noise visible

Swell noise on site survey data

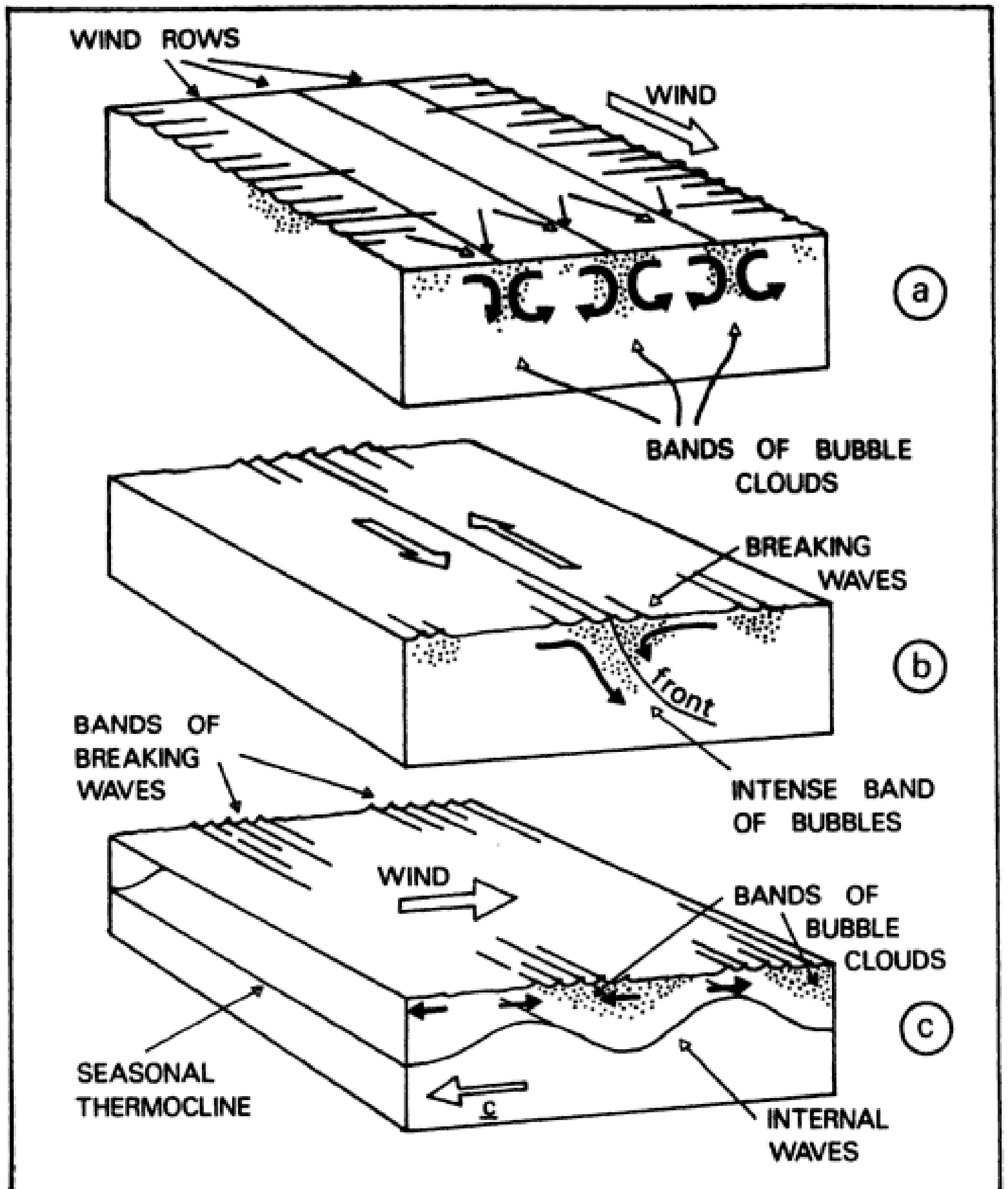


Frequency spectra



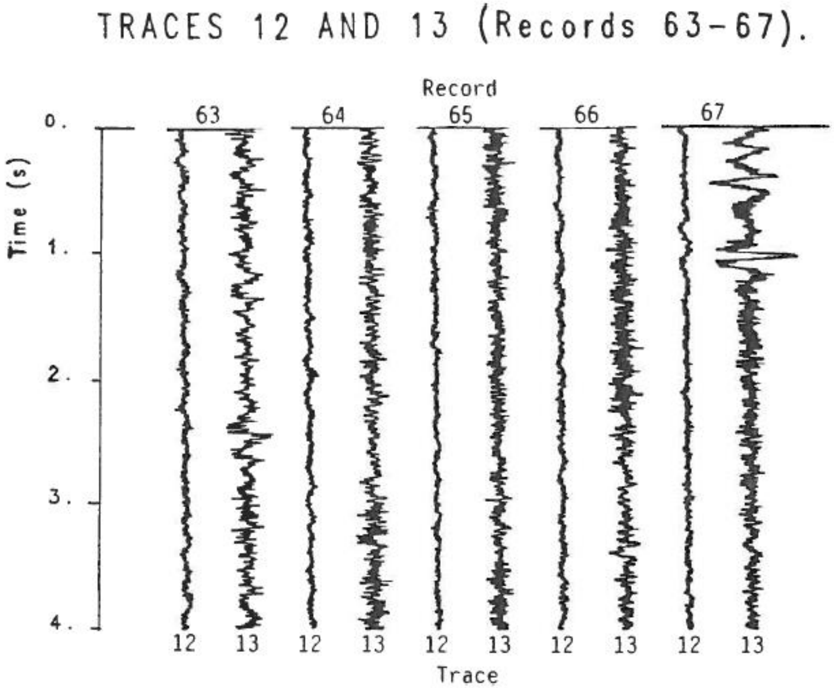
Another problem for streamers: Barnacle growth…

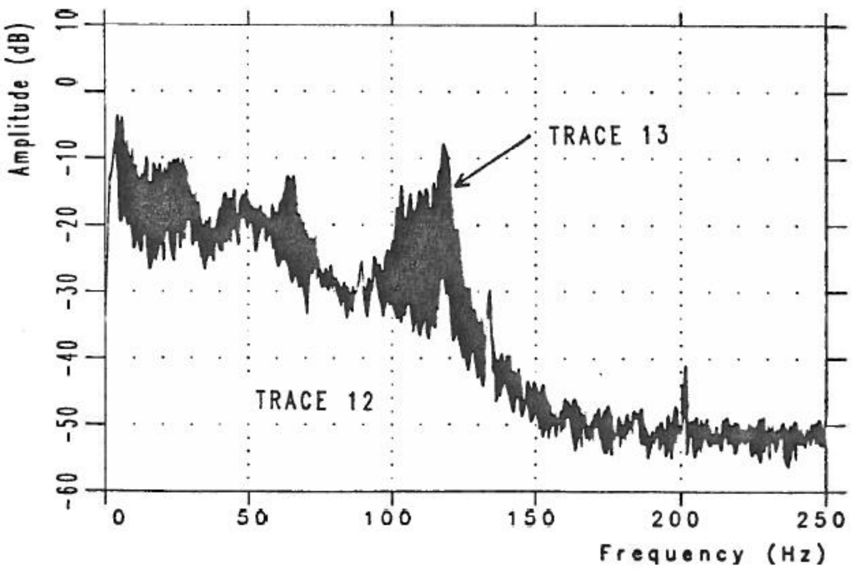
Bubbles as mechanism for noise



Sea surface sound, ed. Kerman

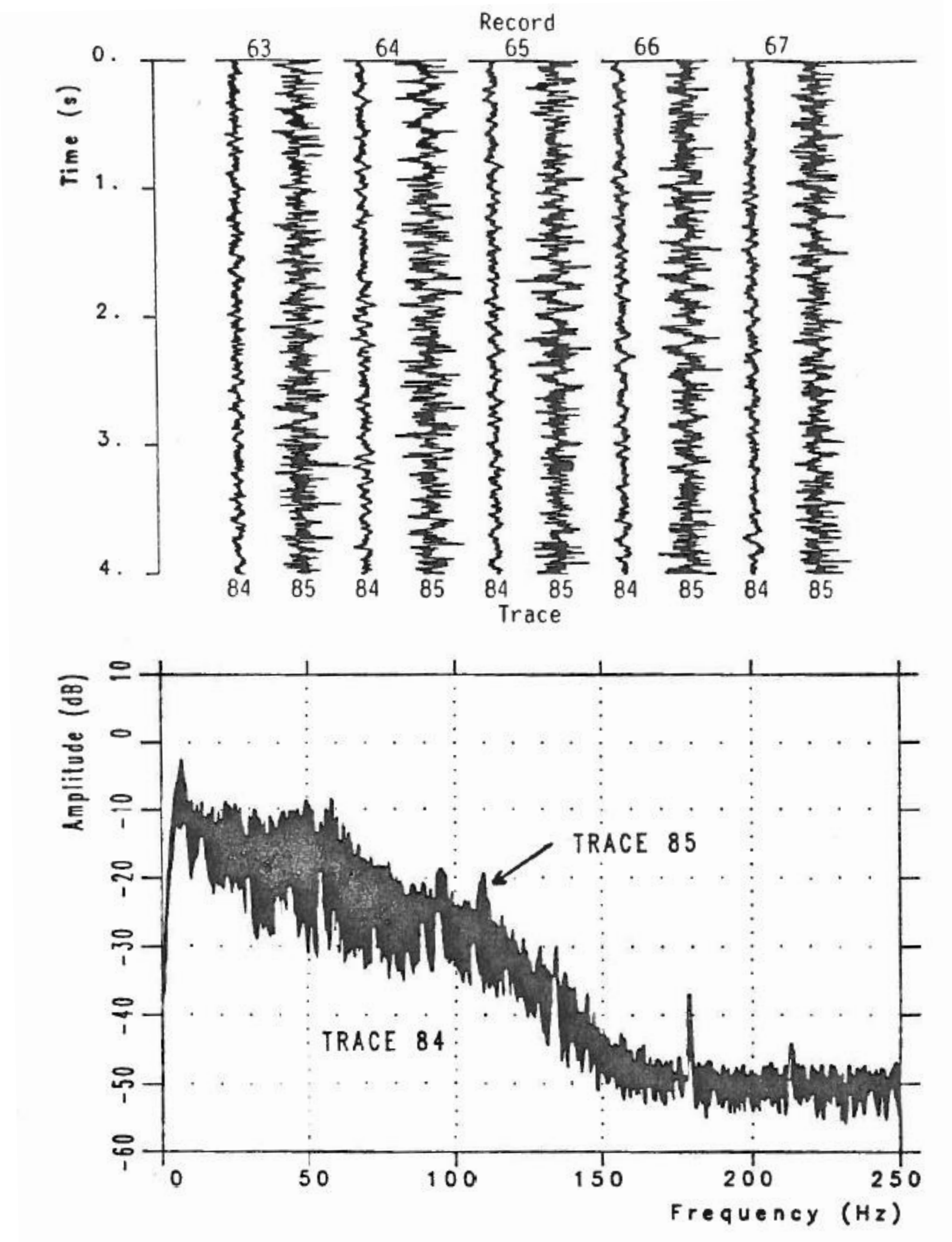
Bird noise





Comparison between a bird trace (13) and the neigbouring trace (12) – in time and frequency domain.

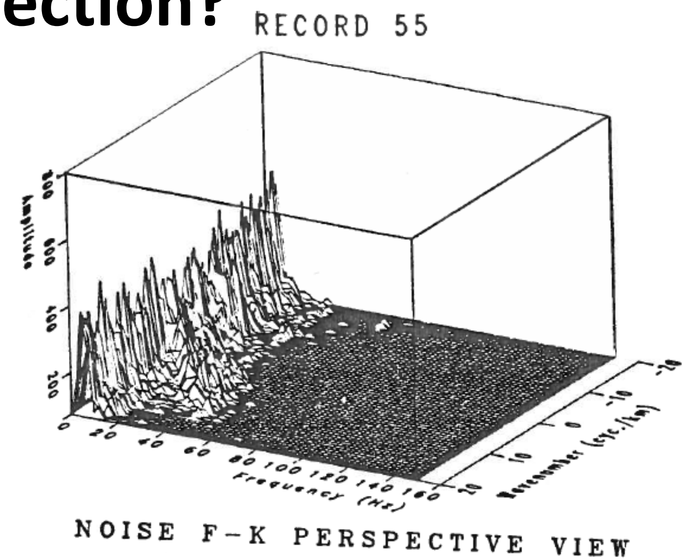
Significant bird noise between 5-35 Hz and 100-130 Hz…

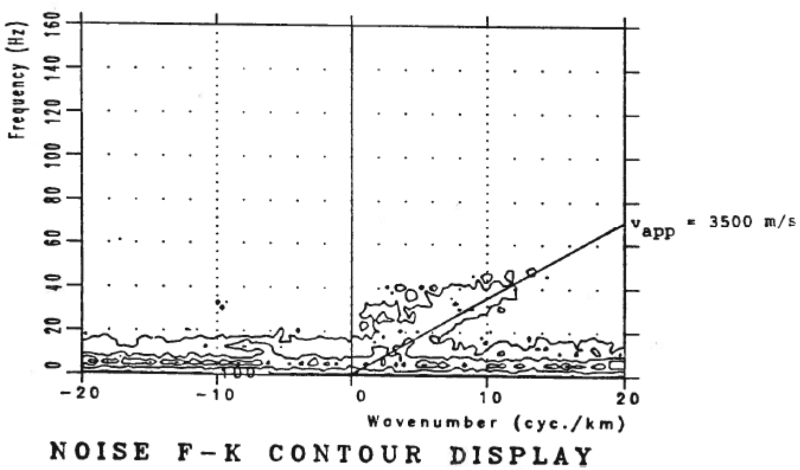


… and bird trace 85 versus trace 84.

Directional effects caused by wind direction?

All for science!!





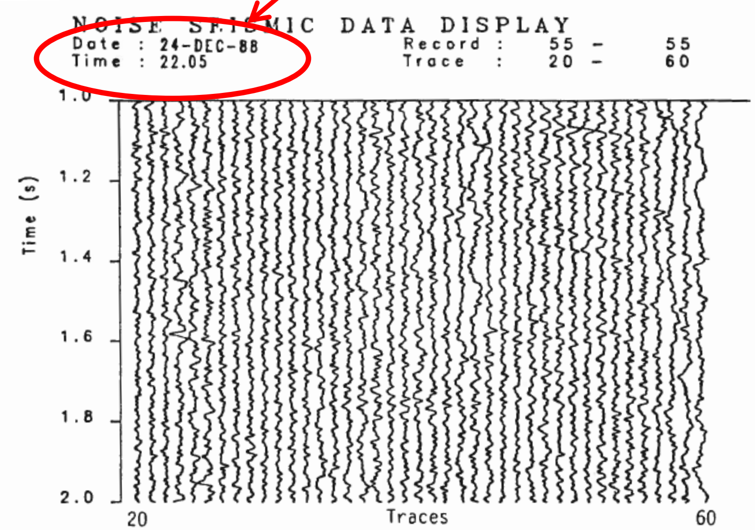
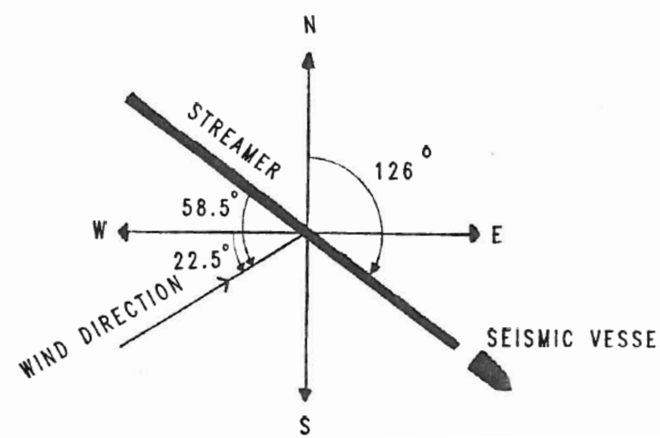
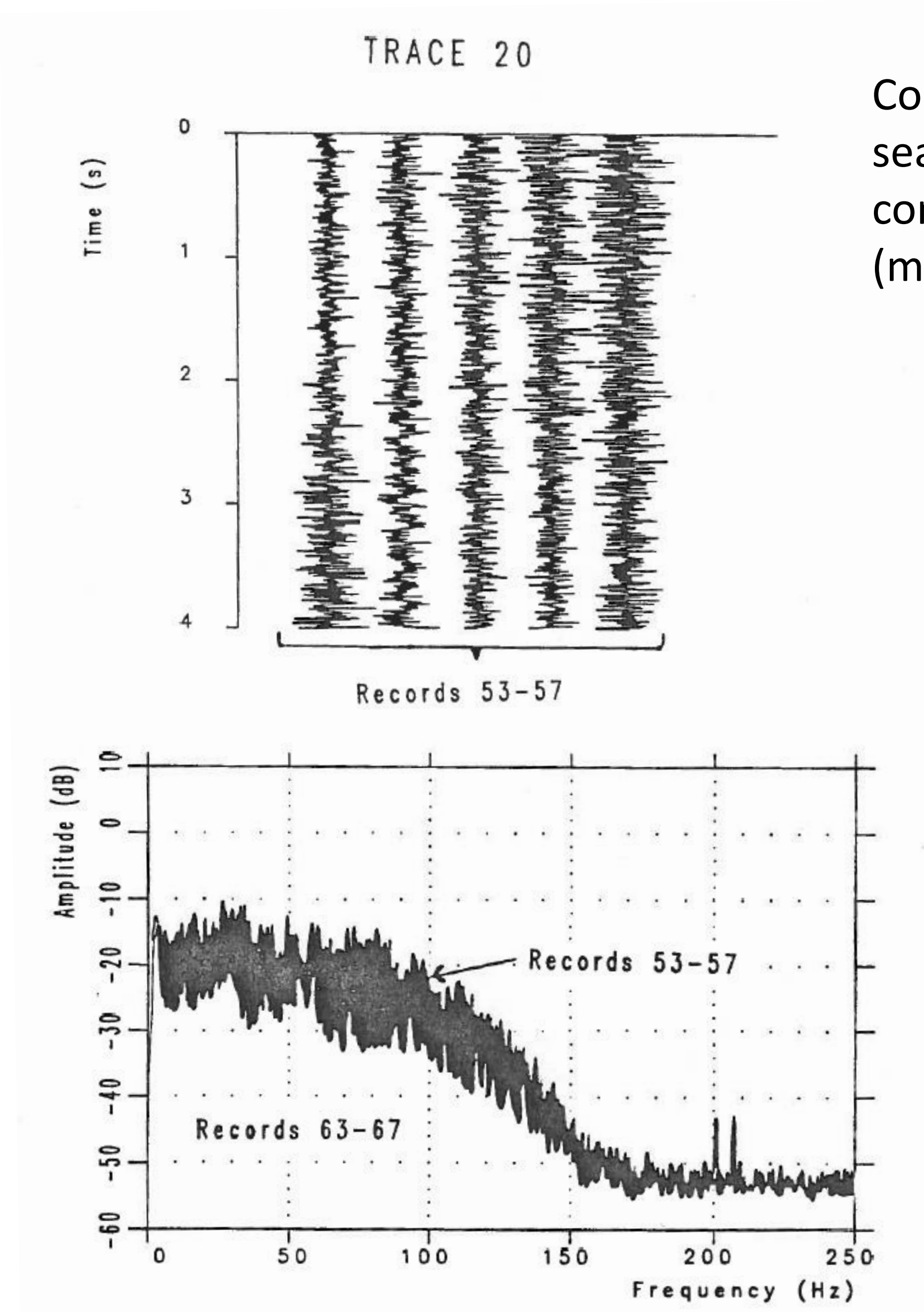


Fig. 4.5: Seismic data display of record 55 showing that some of the noise is coherent.



$$\cos\theta = \frac{c_0}{c_{app}} = \frac{1500}{3500} \Rightarrow \theta = 65^o$$

Observed angle: 59°



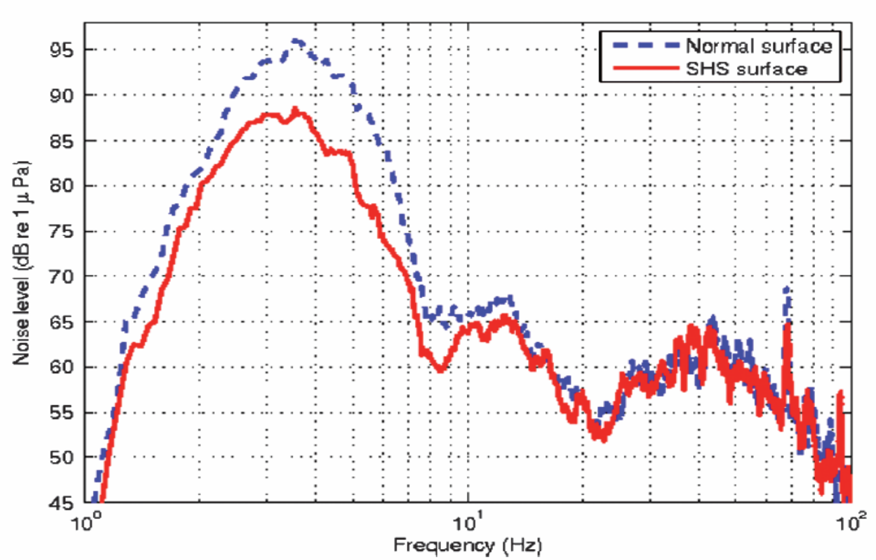
Comparison between optimal noise gather and seastate 3 (12 knots wind speed) weather conditions - this is WEAK weather noise (moderate breeze; moderate swell (1m))

- Weather noise is ~ white
- 10 dB increase

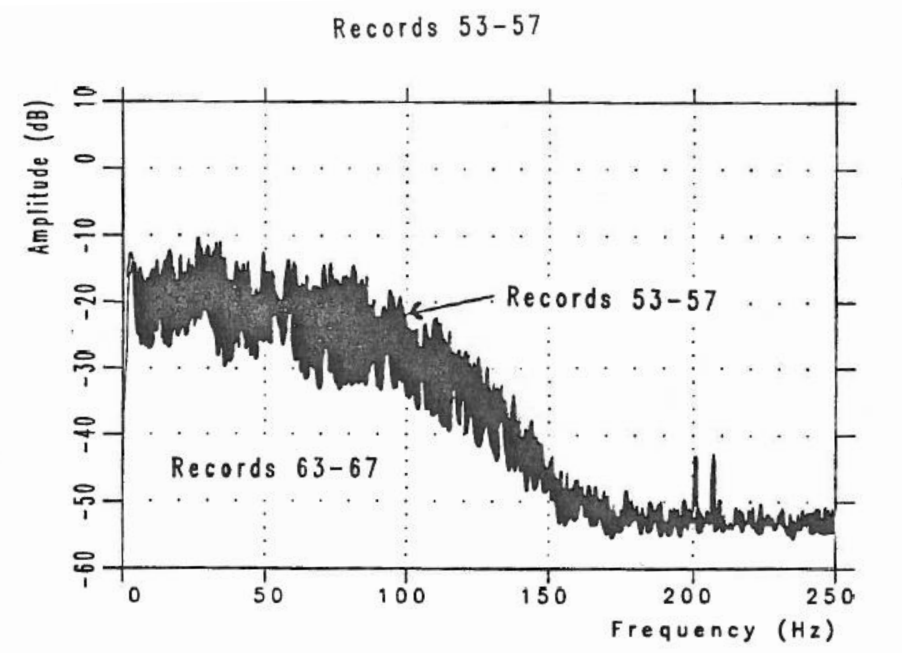
Mechanism: Rapid wave motion acts as acoustic sources at the ocean surface – TWO ways to attenuate this type of noise: WAIT for perfect weather or tow DEEPER

Comparing towing noise and weather noise

Changing the surface properties of the streamer attenuates noise below 10 Hz, while weather noise is white

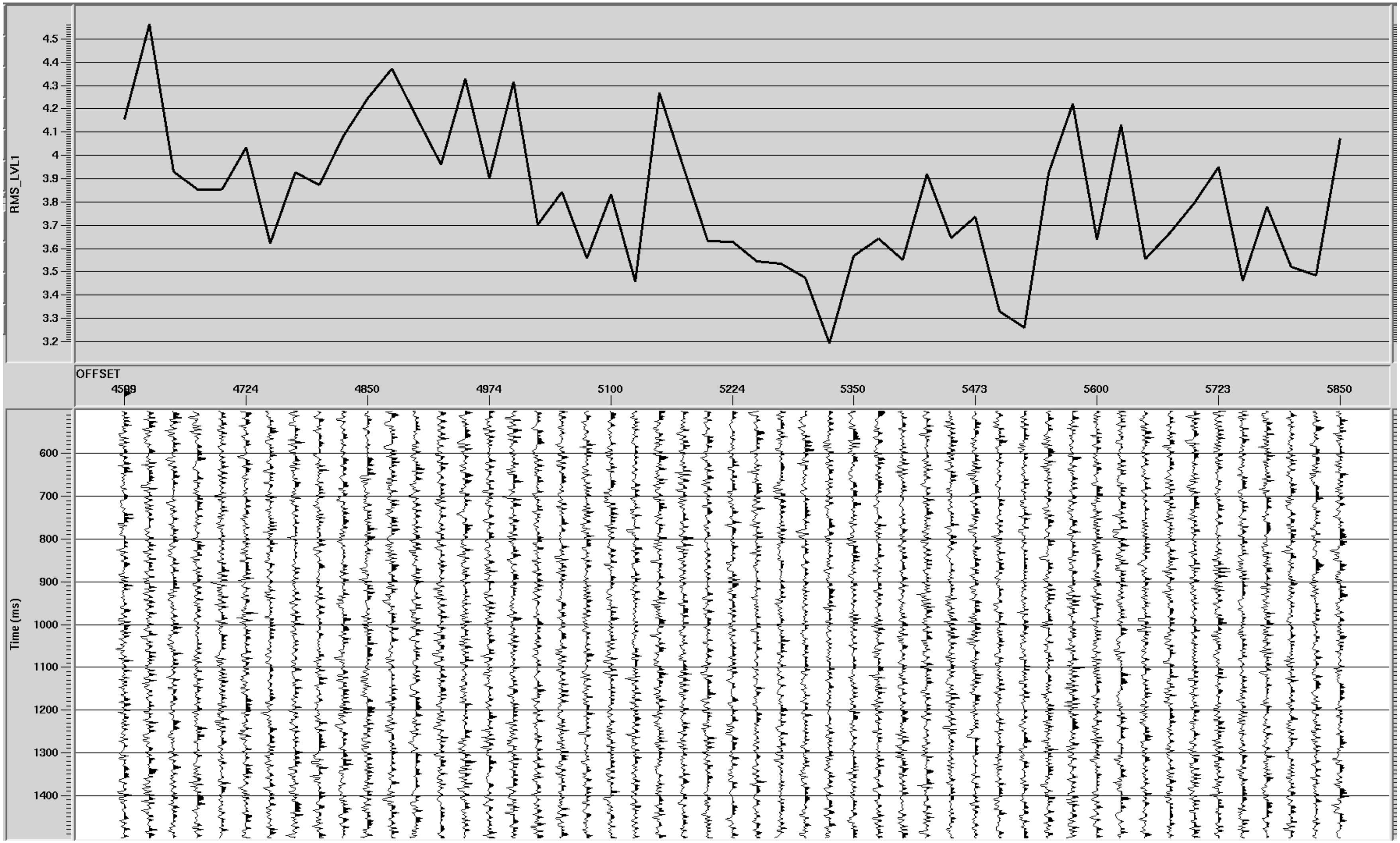


Elboth et al., 2012



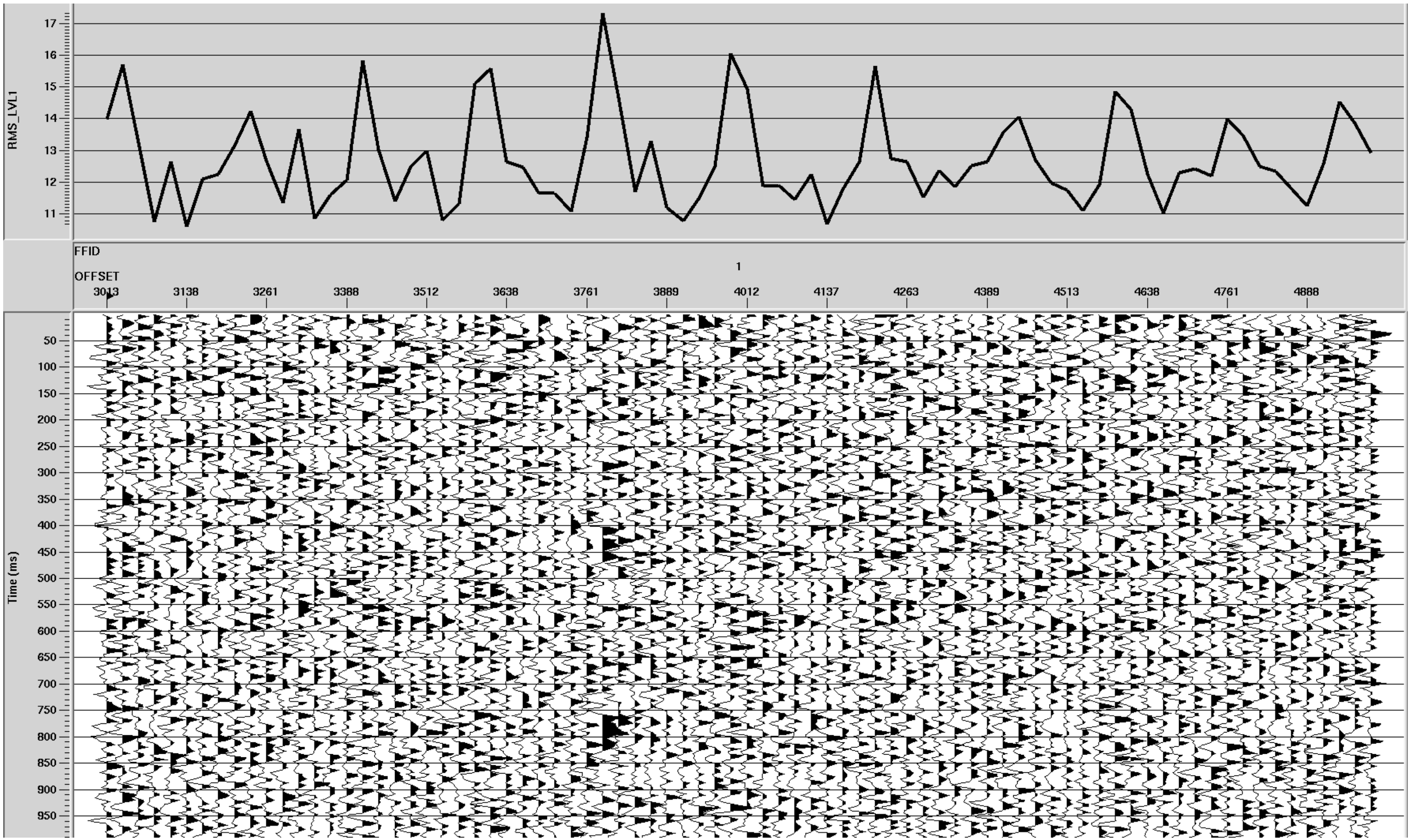
Landrø et al., 1989

Background noise (RMS-microbar) at shallow (less than 100 m) waterdepth (seabed hydrophone)



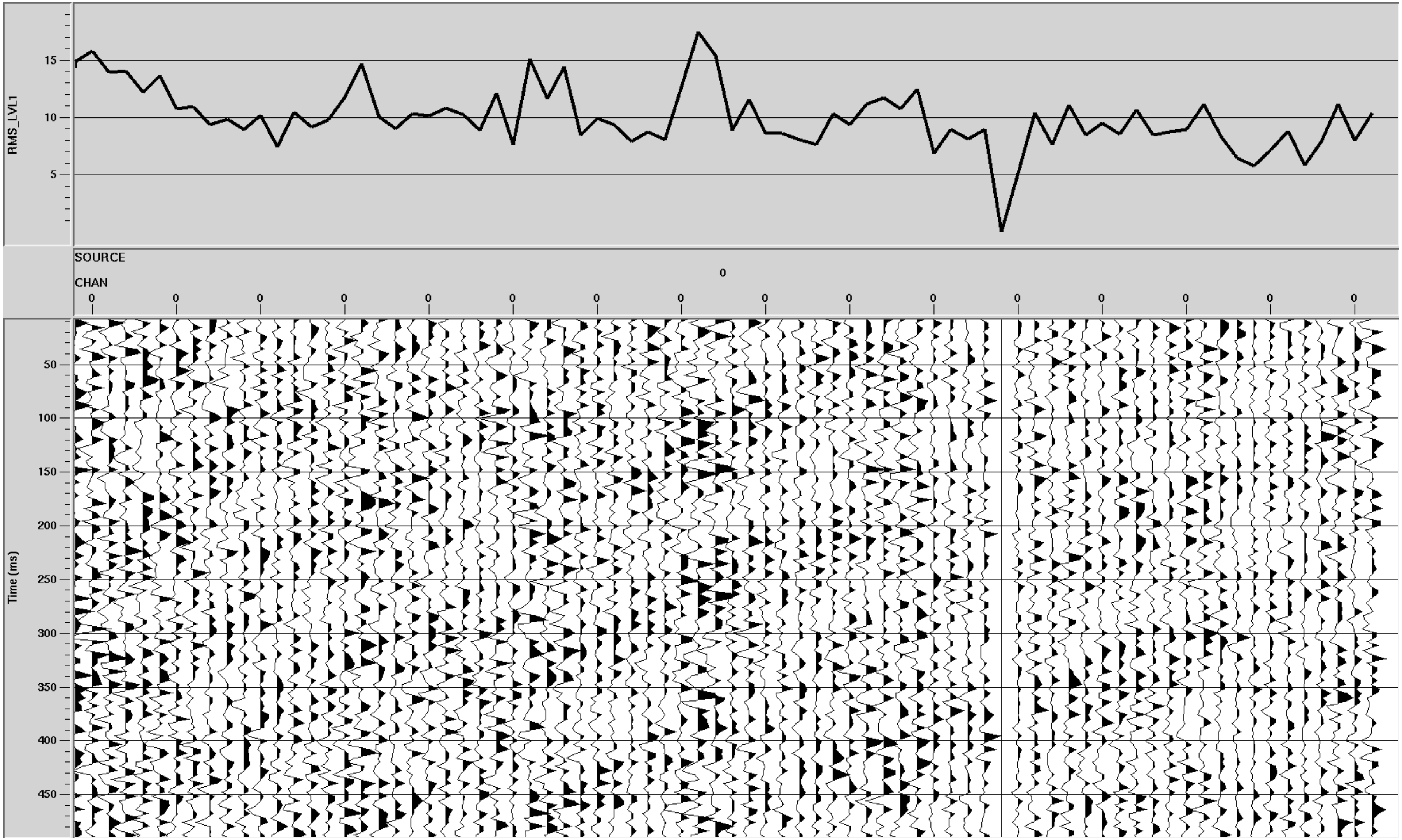
3.7 microbar on average

Estimated noise (seabed hydrophone) – water depth larger than 100 m

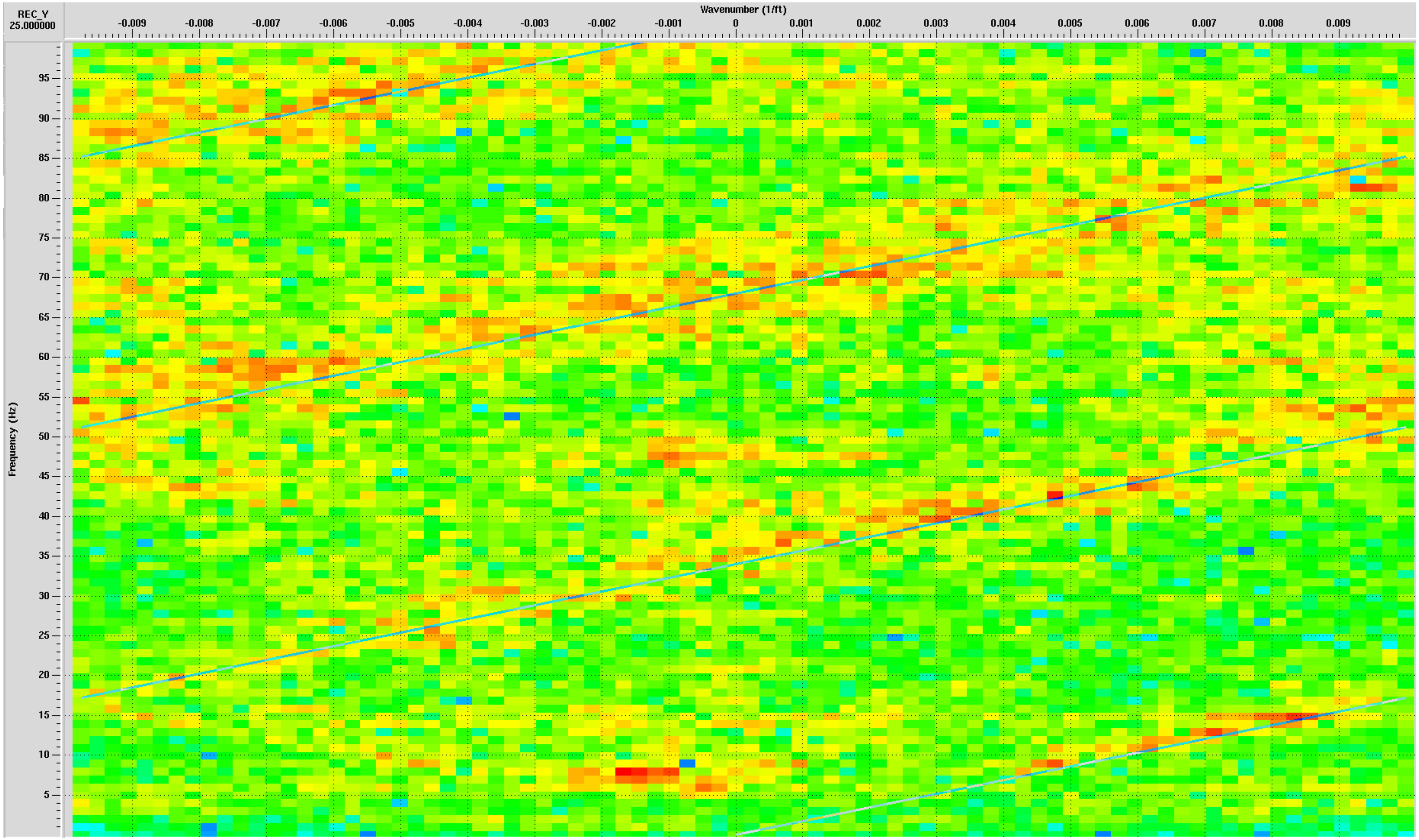


13 microbar average

Water depth < 100 m; 10 microbar on average – some directional noise



Fk-plot

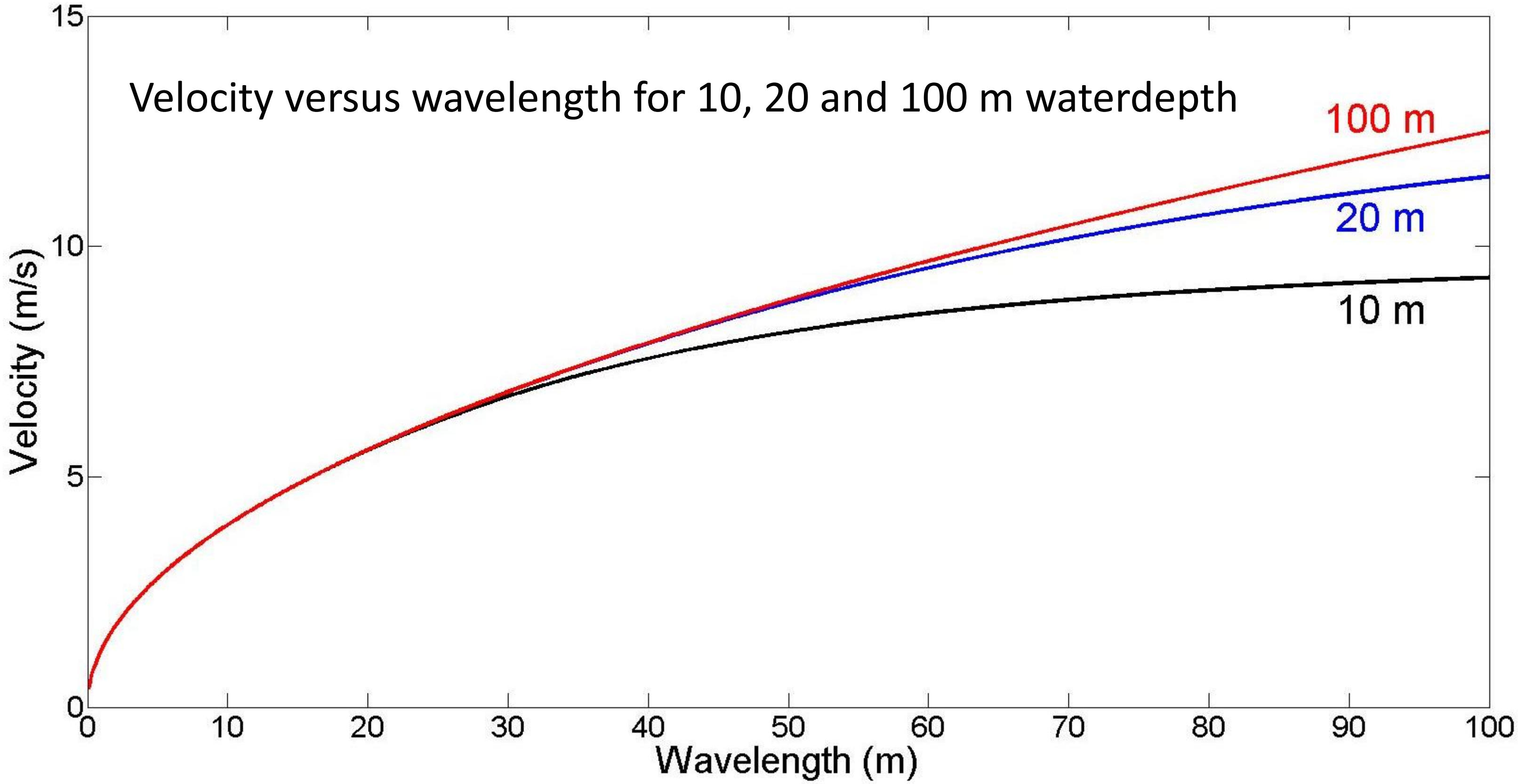


Apparent velocity: 1750 m/s => 59 degrees relative to the cable

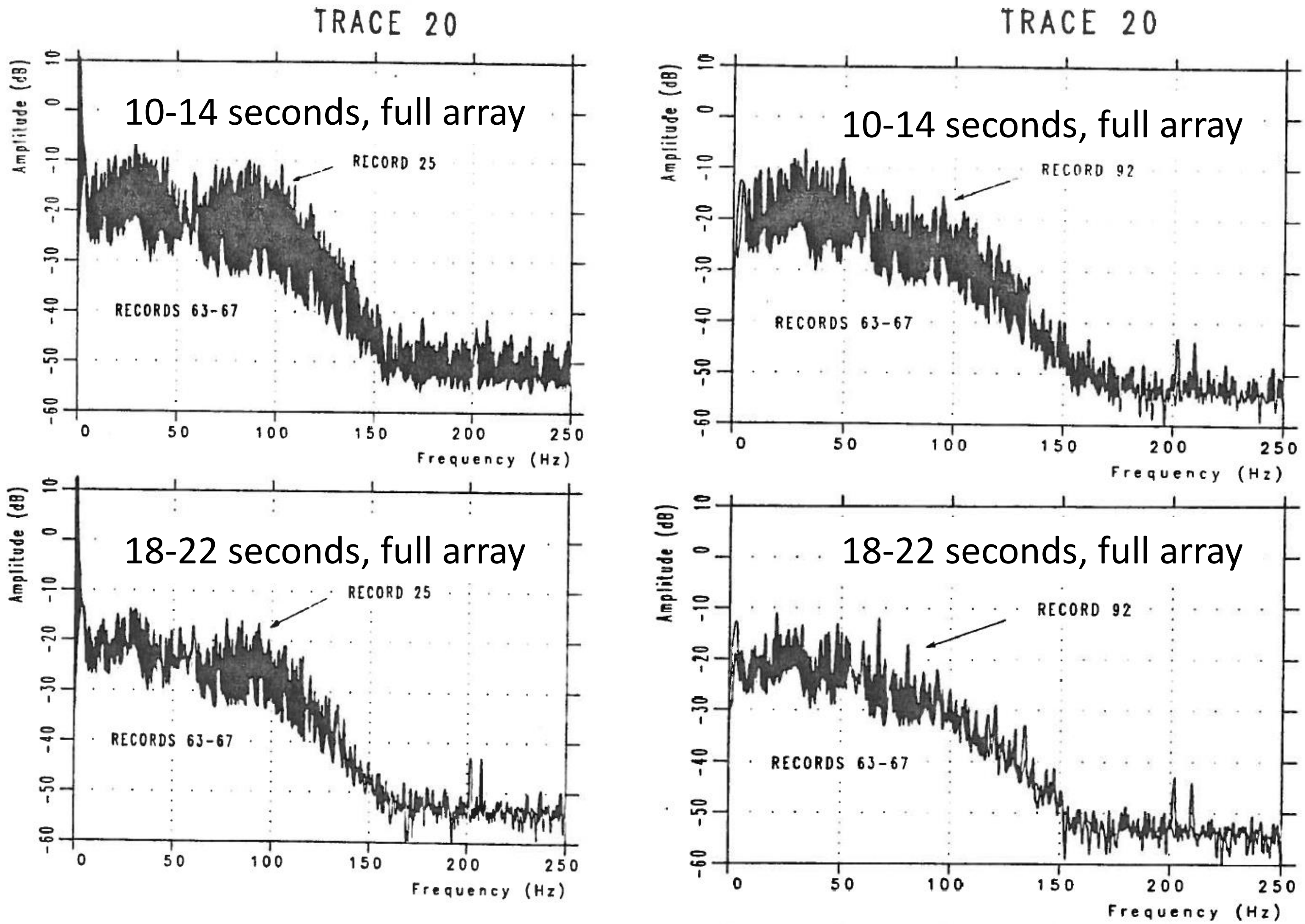
The velocity of a sinusoidal ocean wave

$$v = \sqrt{\frac{g\lambda}{2\pi}\tanh\left(\frac{2\pi d}{\lambda}\right)}$$

λ = wave length
g = acceleration gravity
d = water depth

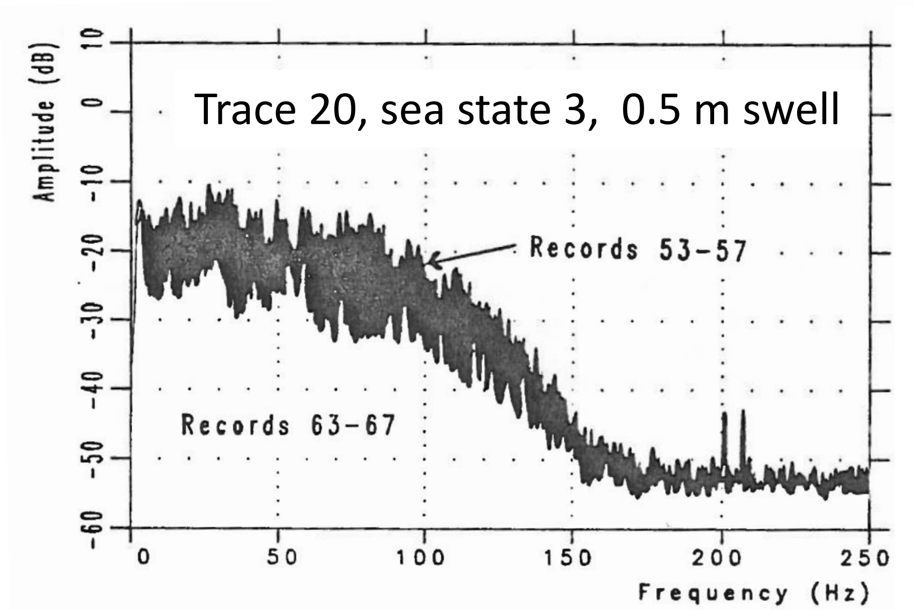


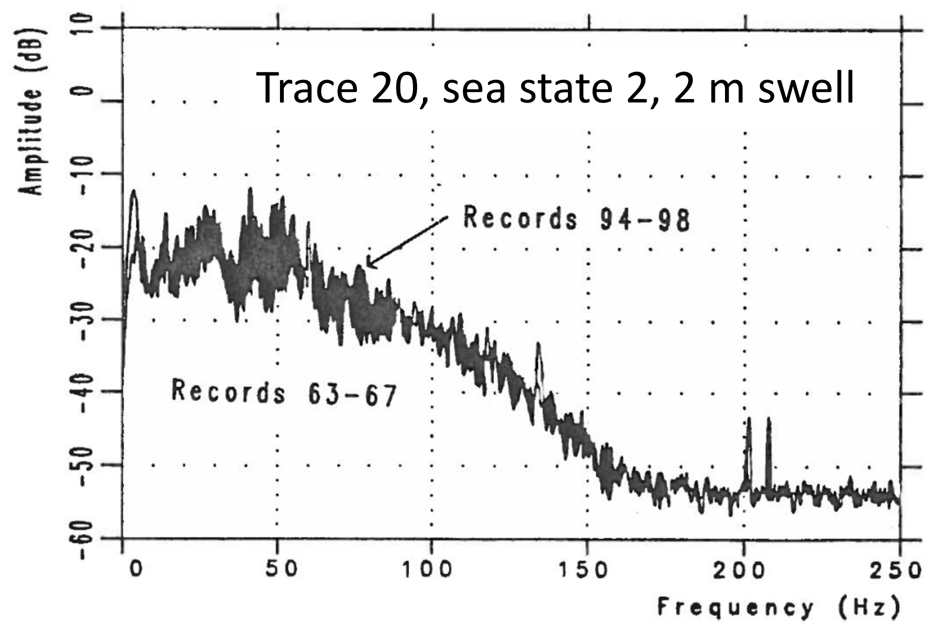
Do we observe receiver ghosts for shot noise?

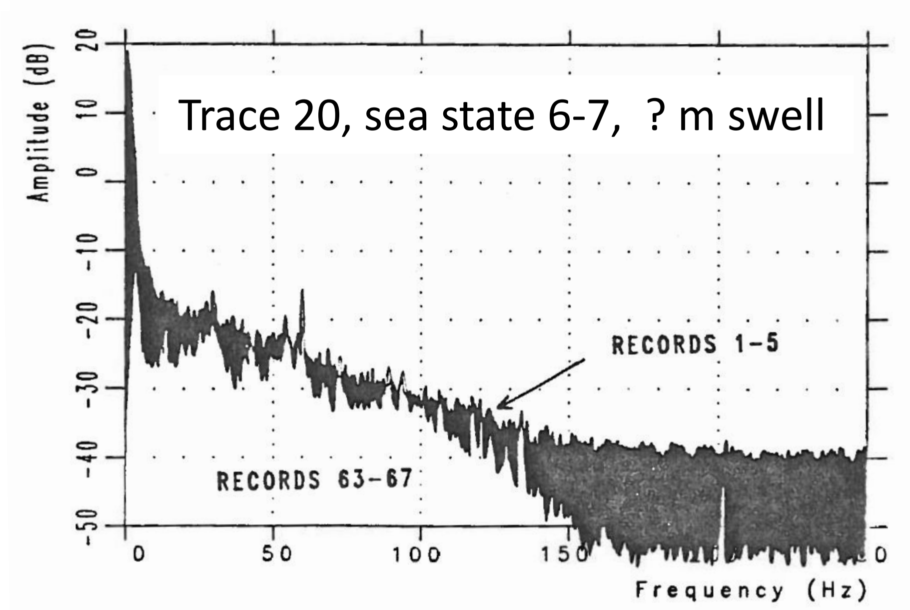


Observe notches around 60 Hz for all examples => 12 m streamer depth
Noise wavefield has a strong vertical component

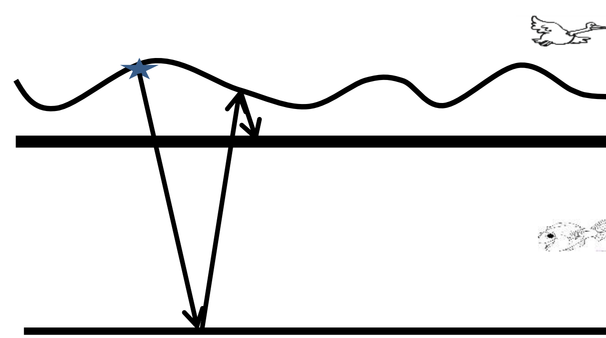
Do we observe receiver ghost notches for weather noise?





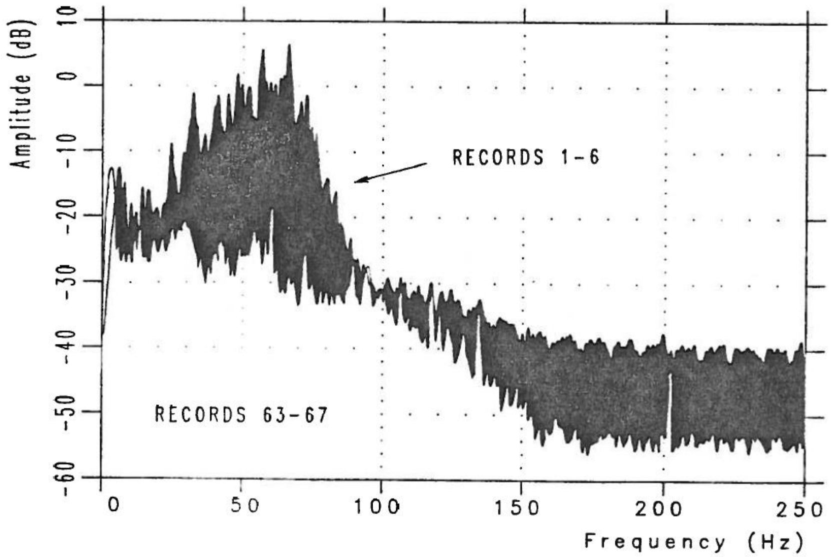


Observe weak notches around 60 Hz for all examples => 12 m streamer depth. Noise wavefield has a vertical component

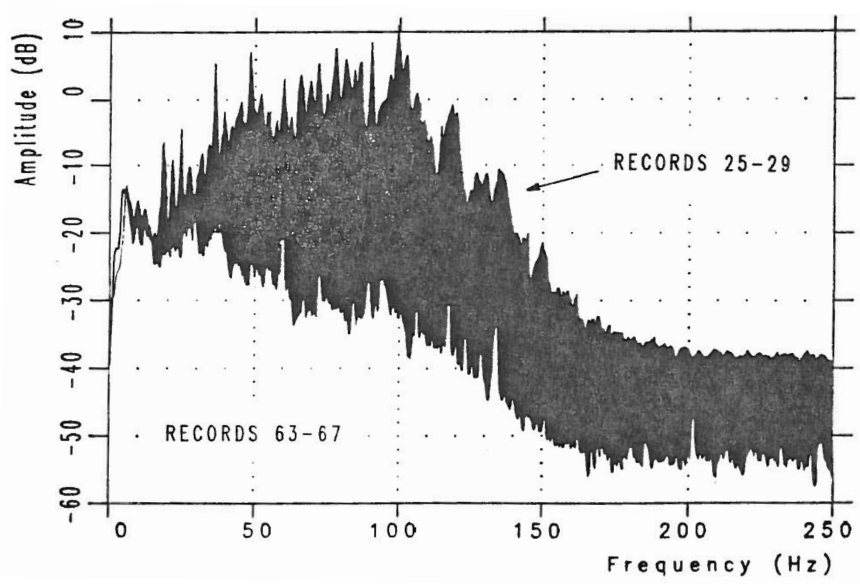


Do we observe receiver ghosts for ship noise?

Russian tanker, Admiral Chekov,
9 km away

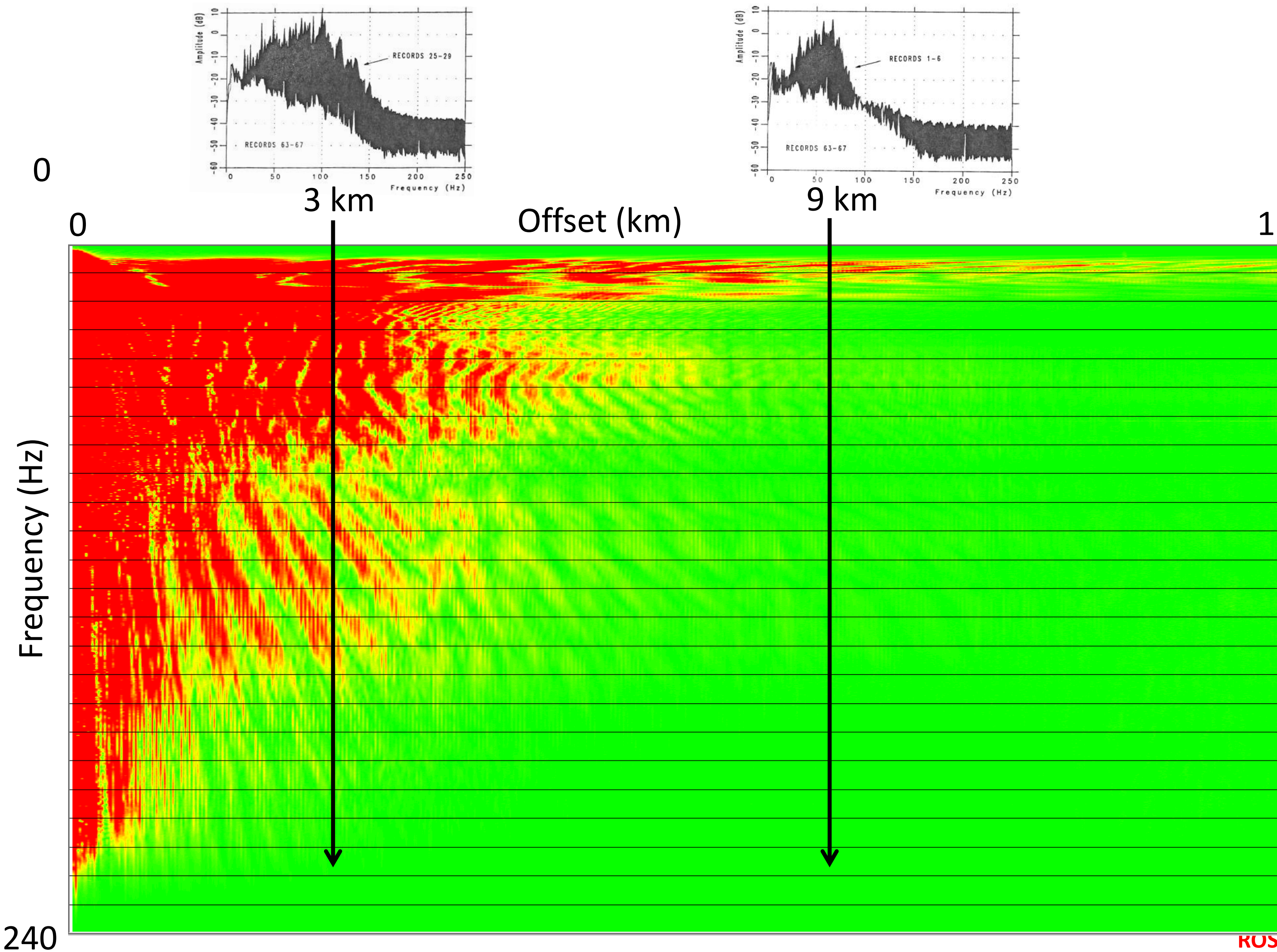


Small coastal ship, 3 km away



No notches around 60 Hz – noise signal is predominantly horizontal – normal modes? Huge difference between the two – caused by distance or different engines?

Frequency variation with offset - field data

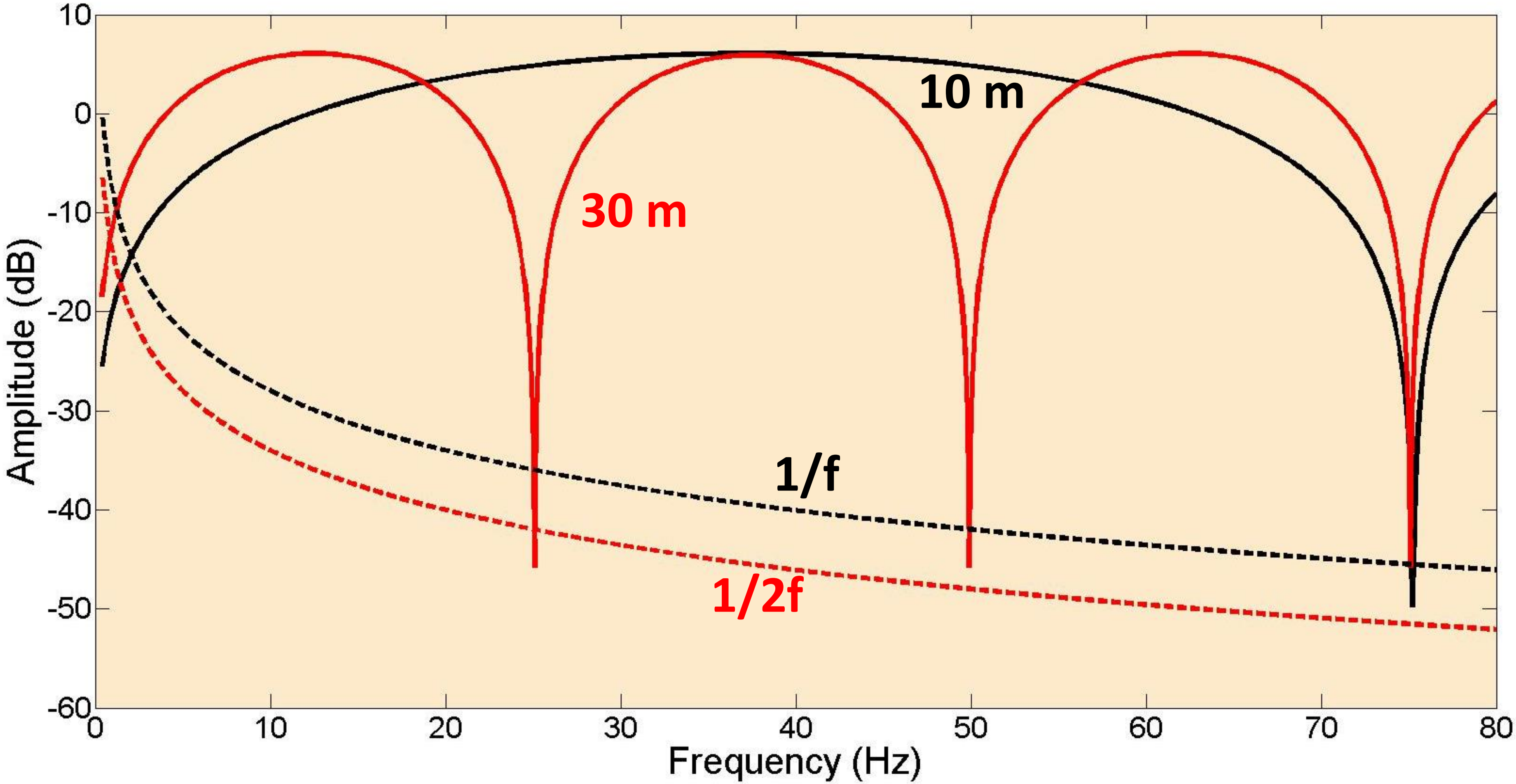


	STATE OF SEA		SWELL	
Code	Descriptive terms	Height in metres	Descriptive terms	Height in metres
0	Calm (glassy)	0	No swell	
1	Calm (rippled)	0 - 0.1	Low swell, short or average length	0- 2
2	Smooth (wavelets)	0.1 - 0.5	Low swell, long	
3	Slight	0.5 - 1.25	Moderate swell, short	
4	Moderate	1.25- 2.5	Moderate swell, average length	2- 4
5	Rough	2.5 - 4	Moderate swell, long	
6	Very rough	4 - 6	Heavy swell, short	
7	High	6 - 9	Heavy swell, average length	≥ 4
8	Very high	9 -14	Heavy swell, long	
9	Phenomenal	≥14	Confused swell	

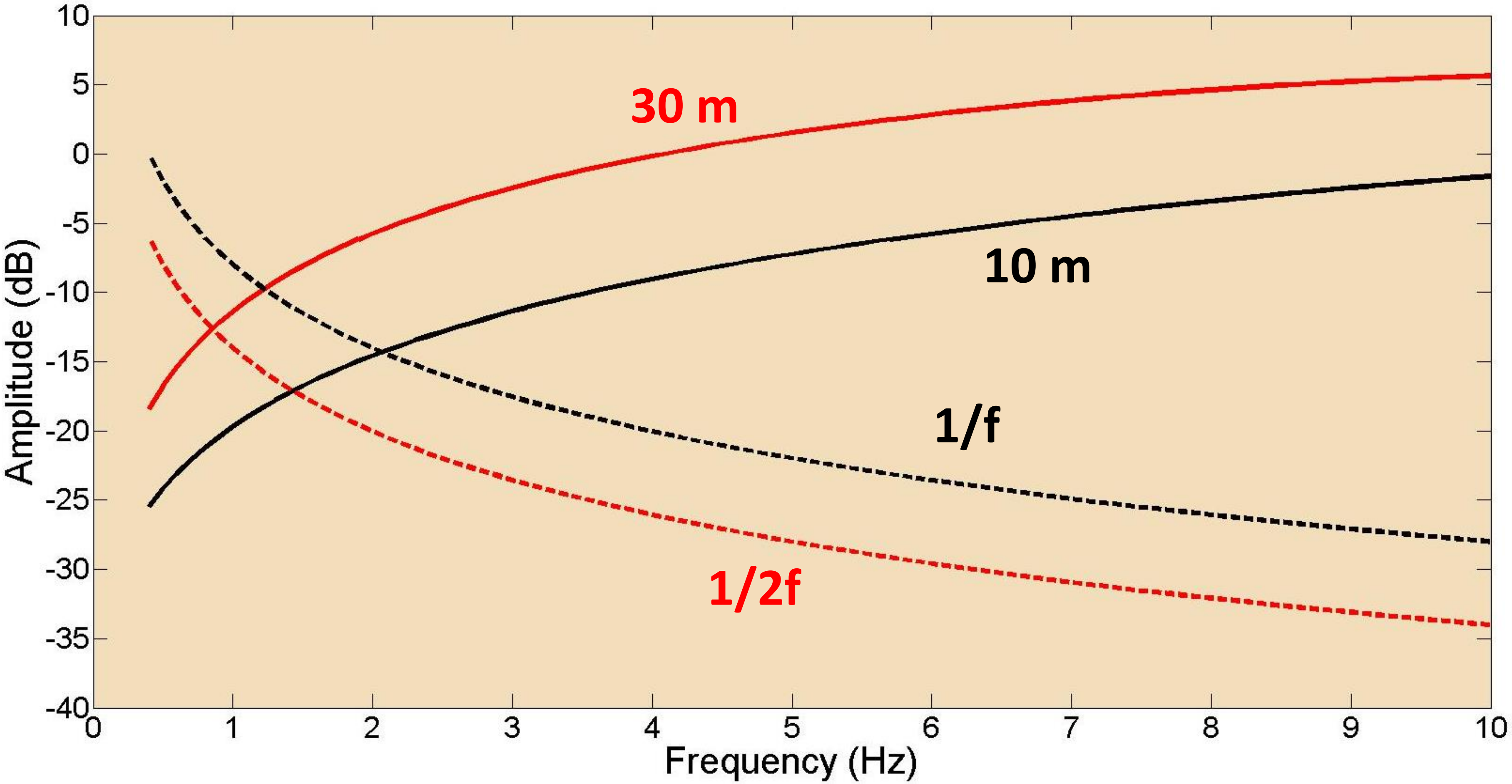
Beaufort scale

Beaufort numbers	Descriptive term	Wind speed equivalent (knots)	Specifications for observations on board ship (open sea)
0	Calm	0-1	Sea like a mirror.
1	Light Air	1-3	Ripples with appearance of scales, no foam crests.
2	Light Breeze	4-6	Small wavelets still short. Crests glassy and do not break.
3	Gentle breeze	7-10	Large wavelets; crests begin to break. Foam glassy. Perhaps scattered white horses.
4	Moderate breeze	11-16	Small waves becoming longer. Fairly frequent white horses.
5	Fresh breeze	17-21	Moderate waves with pronounced long form. Many white horses. Perhaps spray.
6	Strong breeze	22-27	Large waves beginning. Extensive white foam crest. Probably spray.
7	Near gale	28-33	Sea heaps up and foam from breaking waves blown in streaks with wind.
8	Gale	34-40	Moderately high waves of greater length. Spindrift and well-marked streaks of foam.
9	Strong gale	41-47	High waves. Dense foam streaks. Wave crests begin to topple. Spray may effect visibility.
10	Storm	48-55	Very high waves with long overhanging crests. Surface of sea white. Tumbling of sea heavy and shock-like. Visibility affected.
11	Violent Storm	56-63	Exceptionally high waves, (small and medium-size ships lost to view at times). Sea completely covered in foam. Visibility affected.
12	Hurricane	≥64	Air filled with foam and spray. Sea completely white with driving spray. Visibility very seriously affected.

Ghost notches versus 1/f- noise



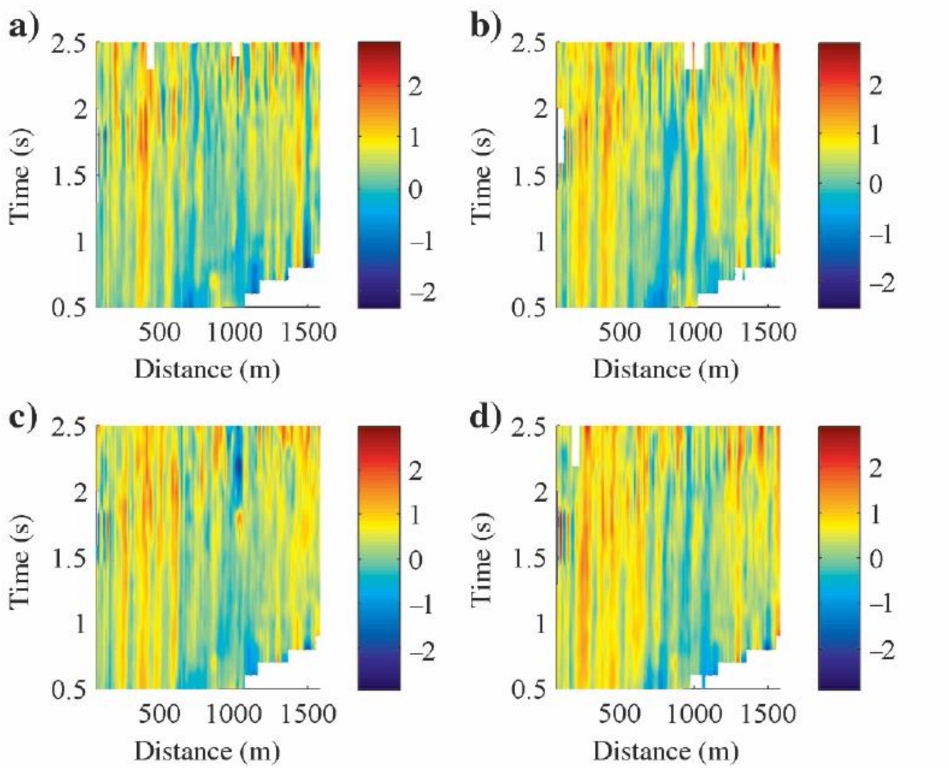
Zoomed version of previous plot



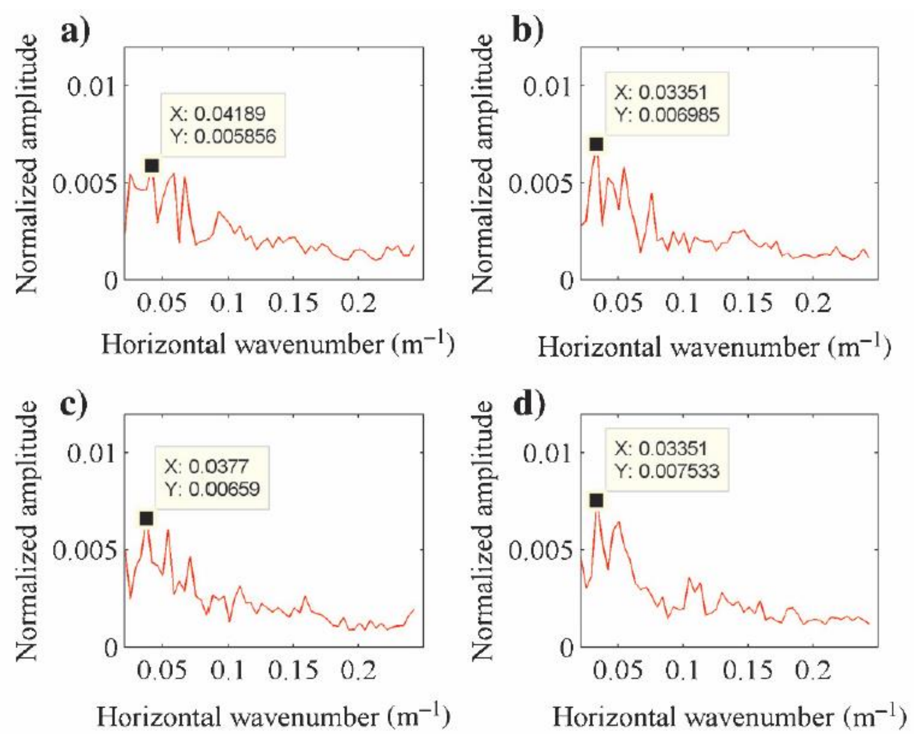
Constant fight between noise and ghosts!!

Effects of time-varying sea surface in marine seismic data

Okwudili C. Orji[1], Walter Söllner[2], and Leiv-J. Gelius[3] *Geophysics, 2012*



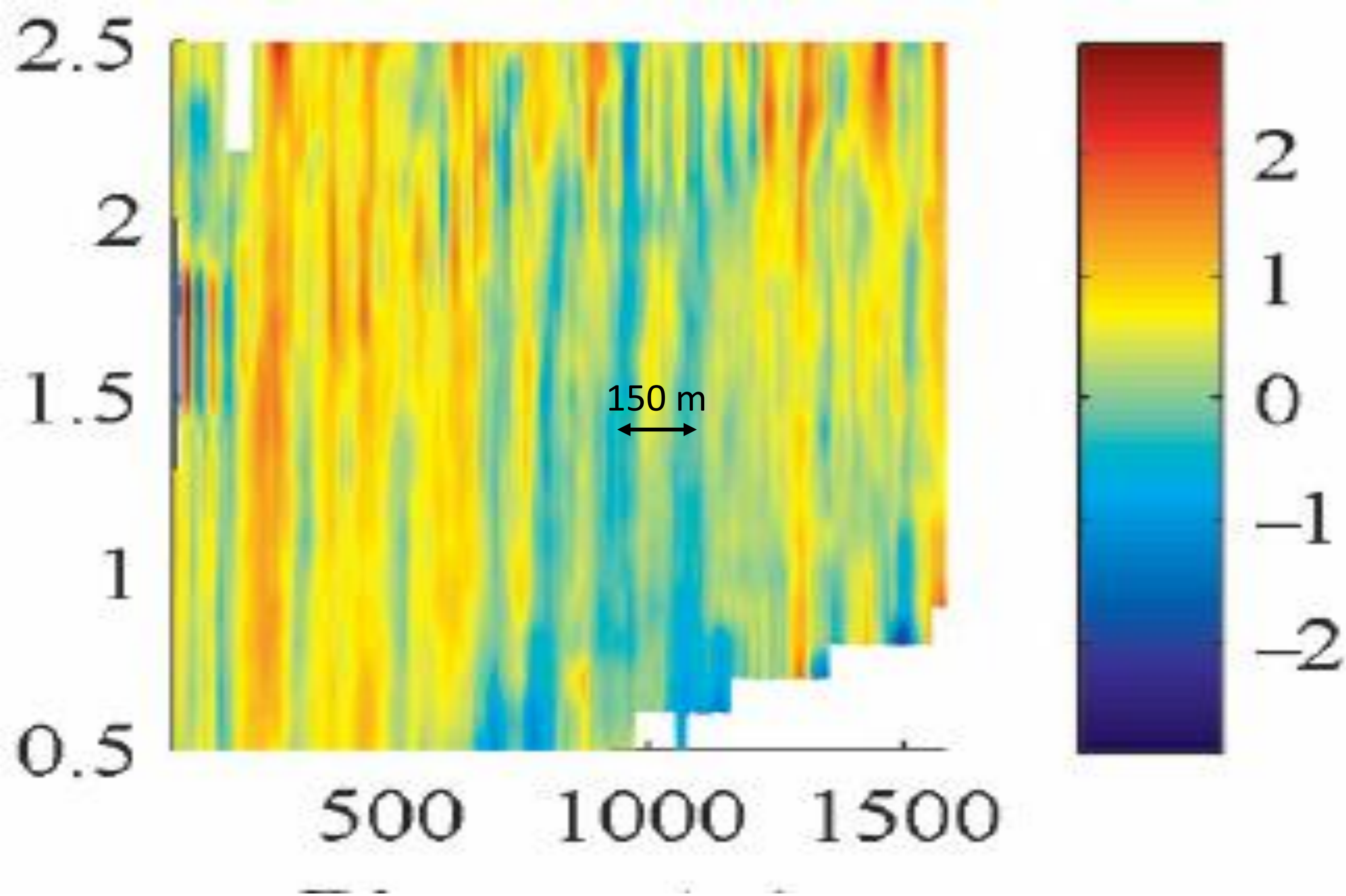
Estimated image of sea surface



Wavenumber spectra => dominant wavelength ~170 m

Wavelength/waveheight ratio = 170/4 = 43 (s=1/43)

Zoom of Okwuduli et al.'s sea surface image



Wave steepness (s)

Steepness : s = H/L

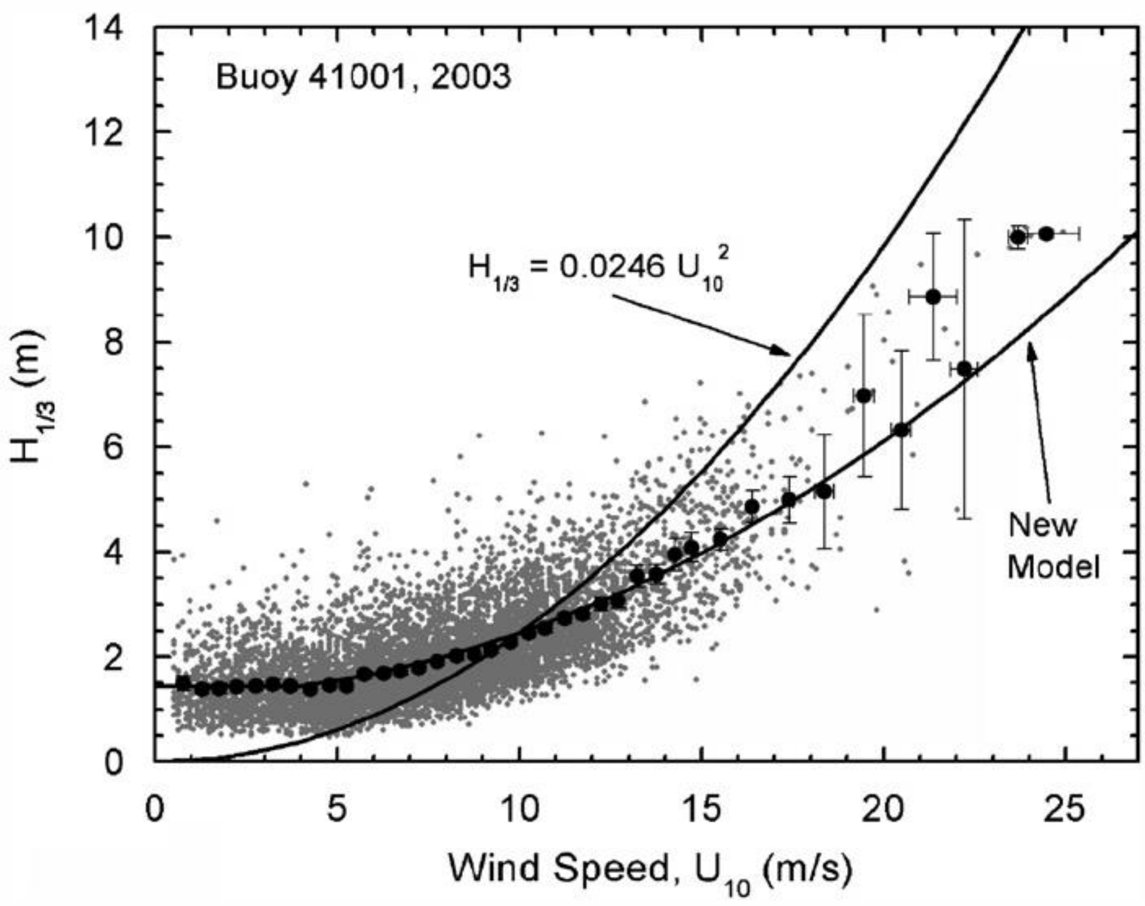
Significant waveheight: Average of 1/3 of waves present

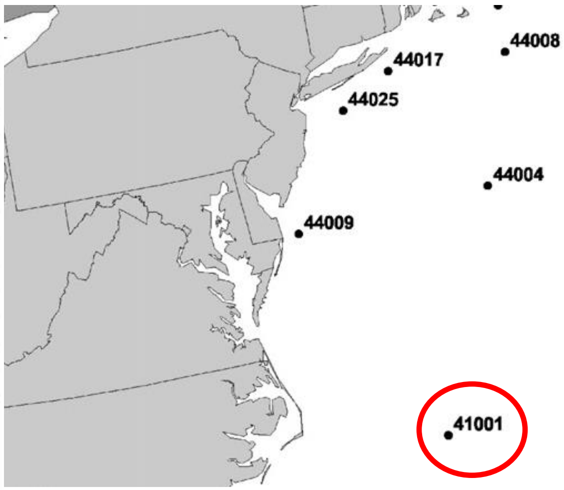
Typical steepness values might ragne between s = 1/15 to s=1/150

If s > 1/7 the wave breakes

Waveheight versus wind speed

Andreas and Wang, 2007

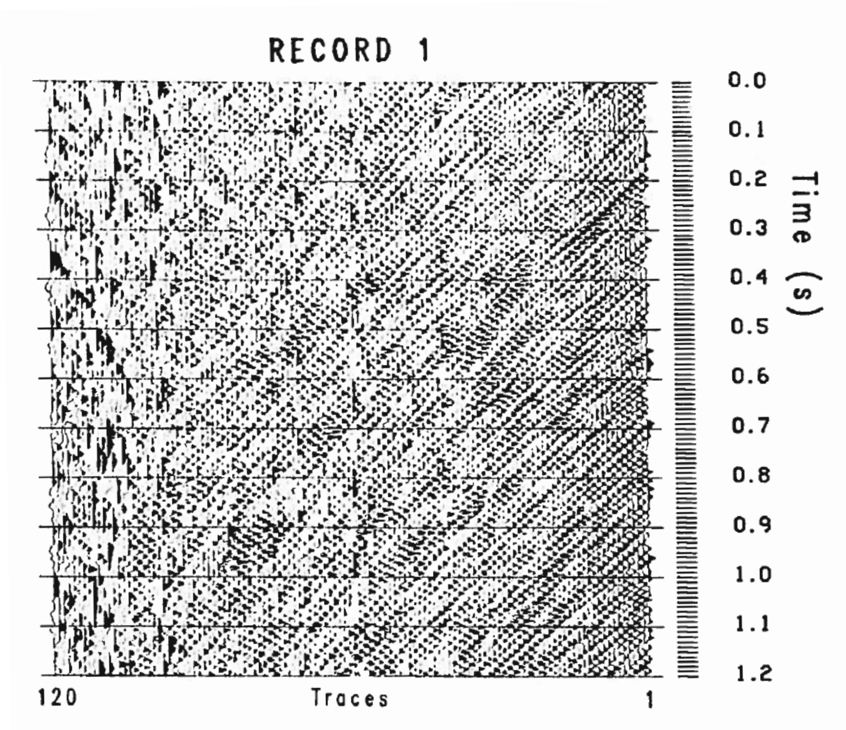




Data from 2003 150 nautical miles east of Cape Hatteras; water depth: 4400 m

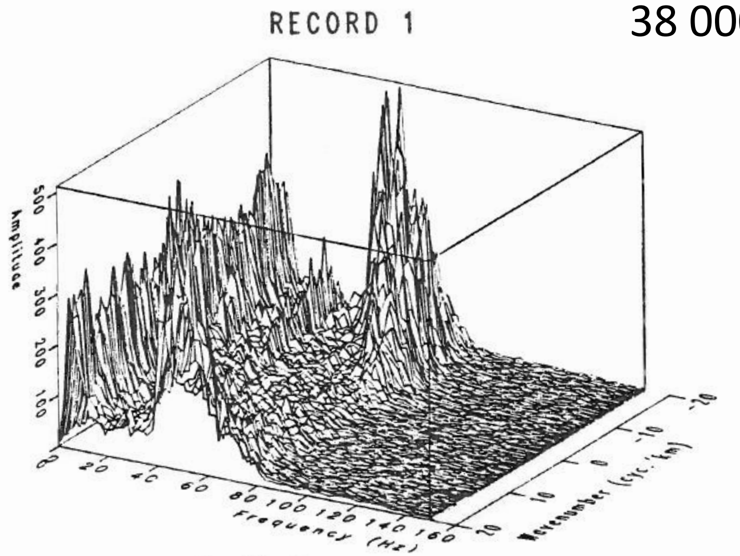
Recorded noise from ship traffic

Ship	Record	Speed	Distance	Low cut Filter
"Admiral Chekov"	1-6	15 kts	5.5 miles	in
"	7-20	"	"	out
Small coastal ship	21-50	13 kts	2 miles off	in



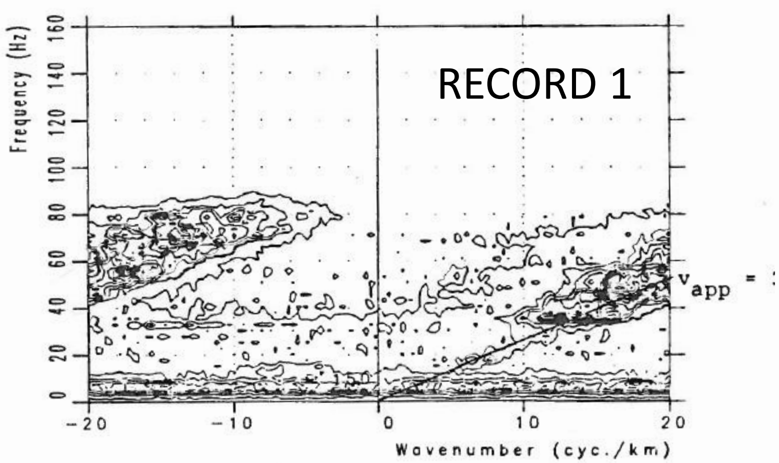
fk plot of «Admiral Chekov»

38 000 ton Russian tanker with one single screw (5 blades)

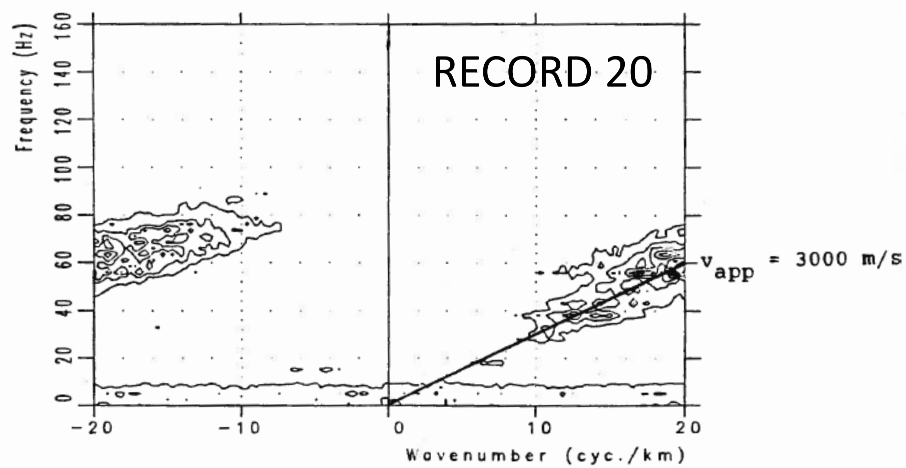


NOISE F–K PERSPECTIVE VIEW

- Apparent velocity increases with increasing record number => angle between Chekov and the streamer

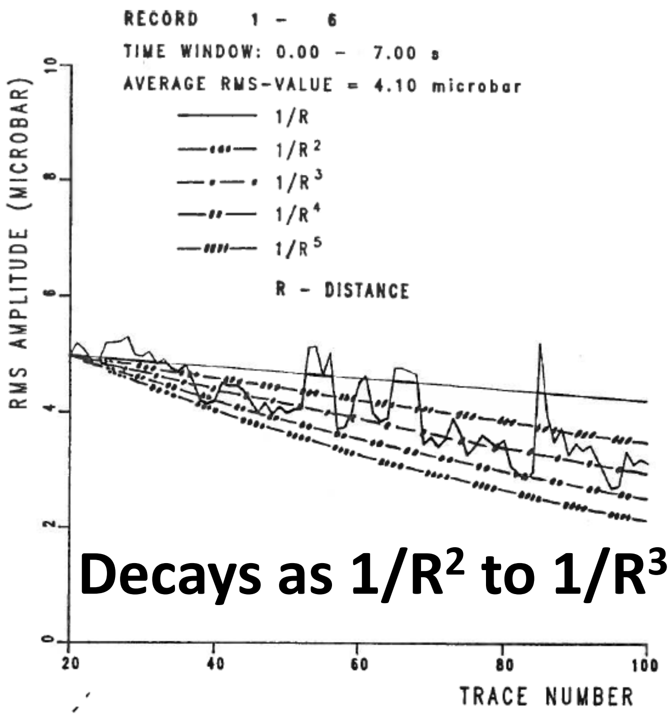


NOISE F–K CONTOUR DISPLAY

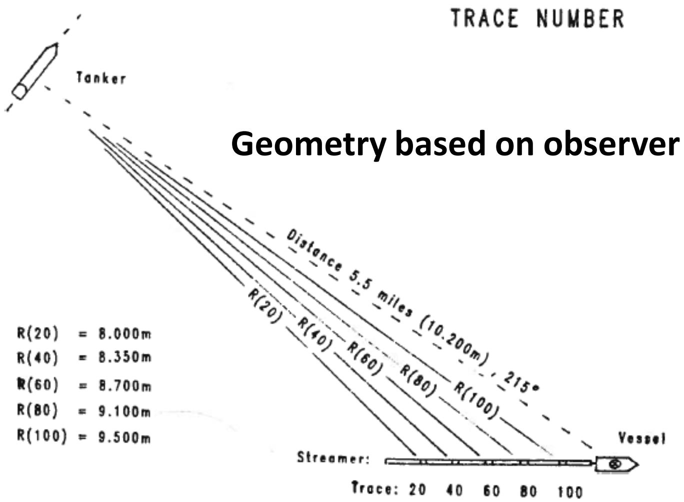


NOISE F–K CONTOUR DISPLAY

Estimating decay curves for noise versus distance

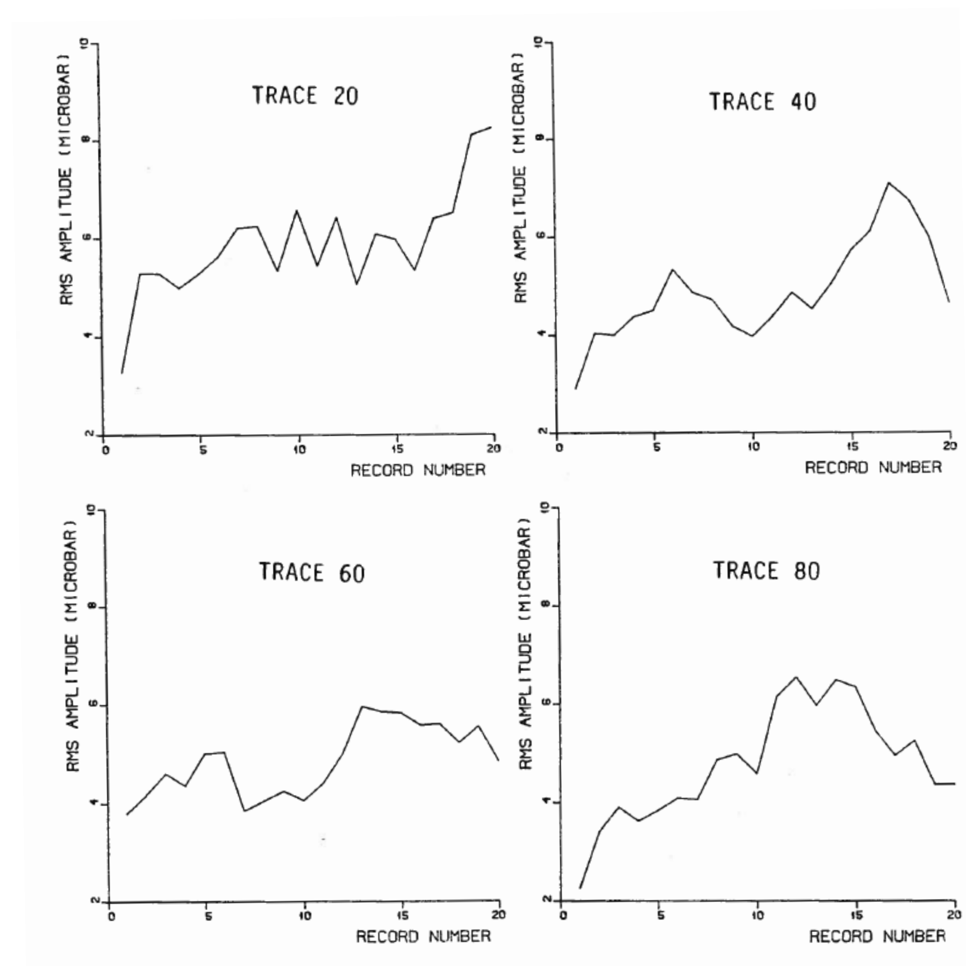


Decays as $1/R^2$ to $1/R^3$



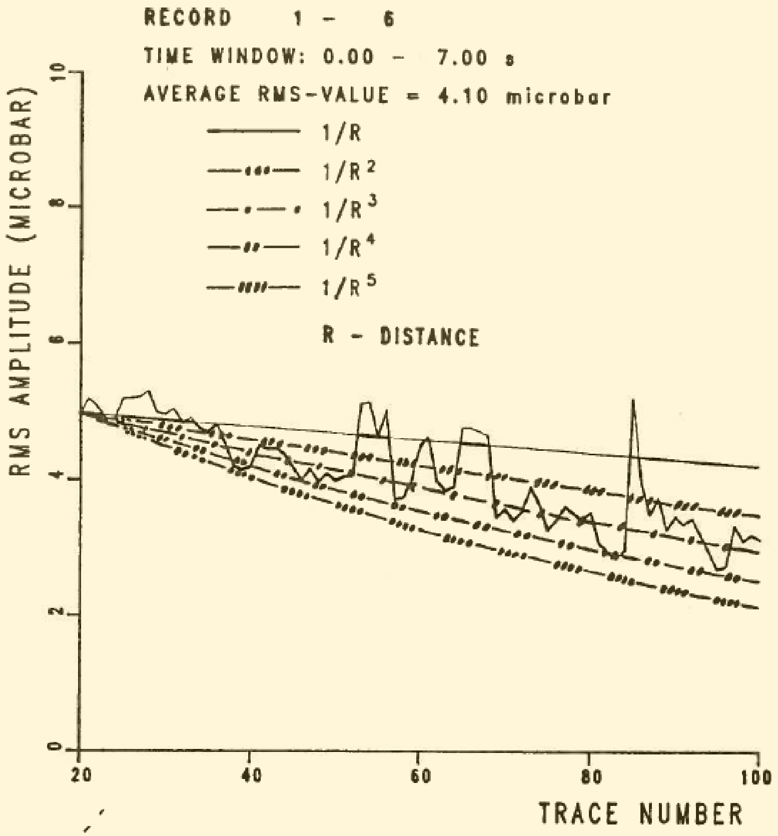
Geometry based on observer log

Admiral Chekov



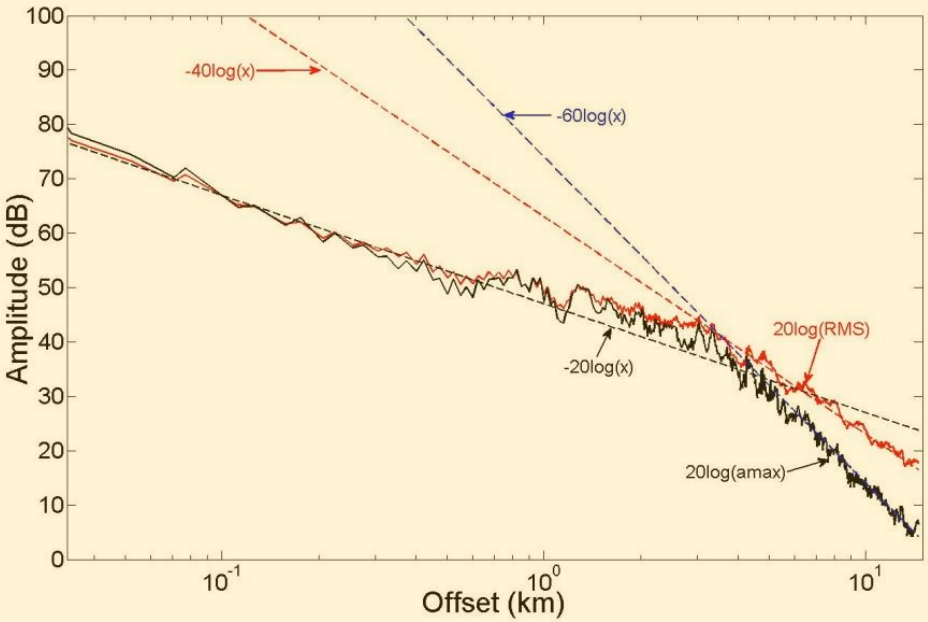
Comparison with a seabed seismic data set

Admiral Chekov



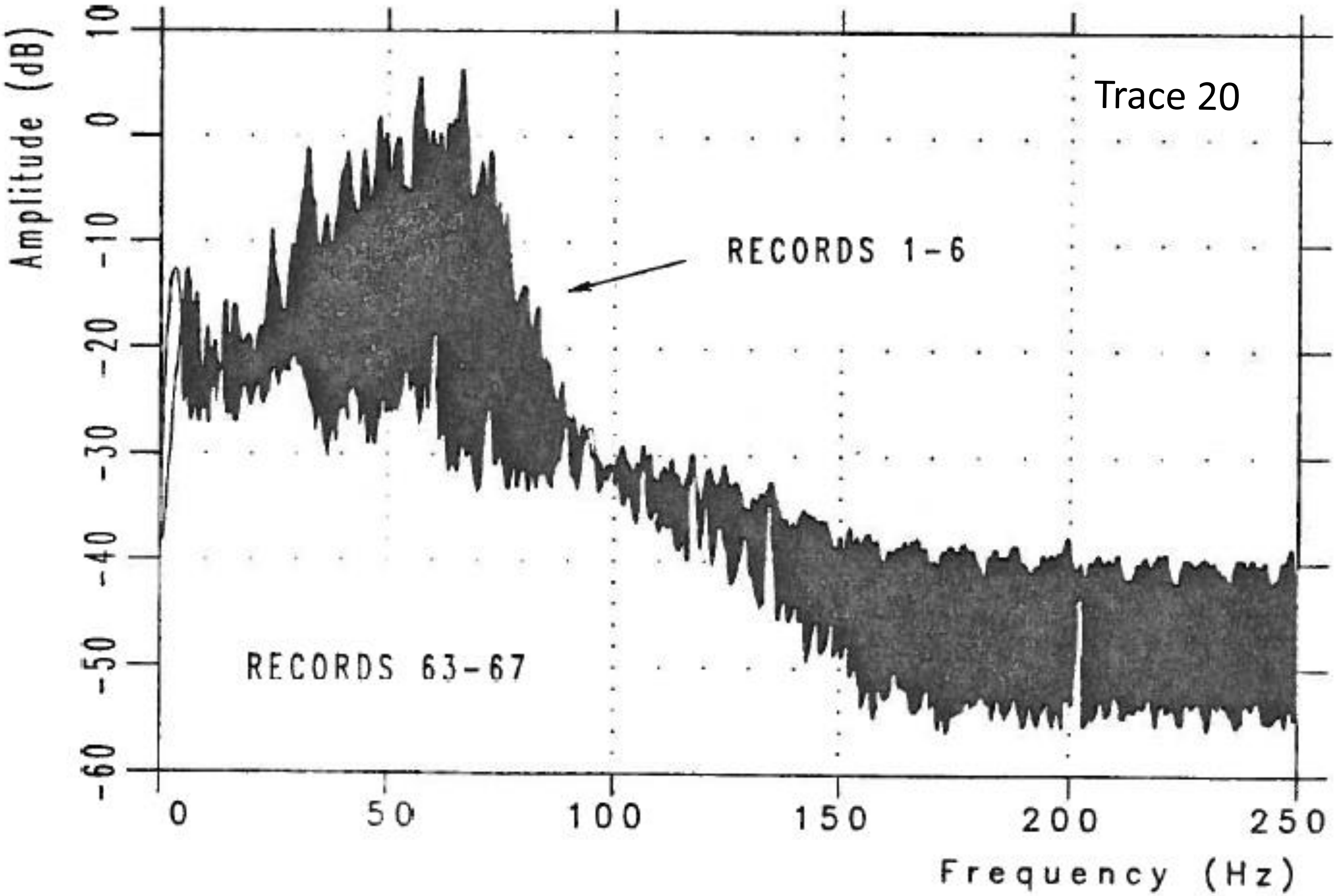
Decays as $1/R^2$ to $1/R^3$

Seabed hydrophone data

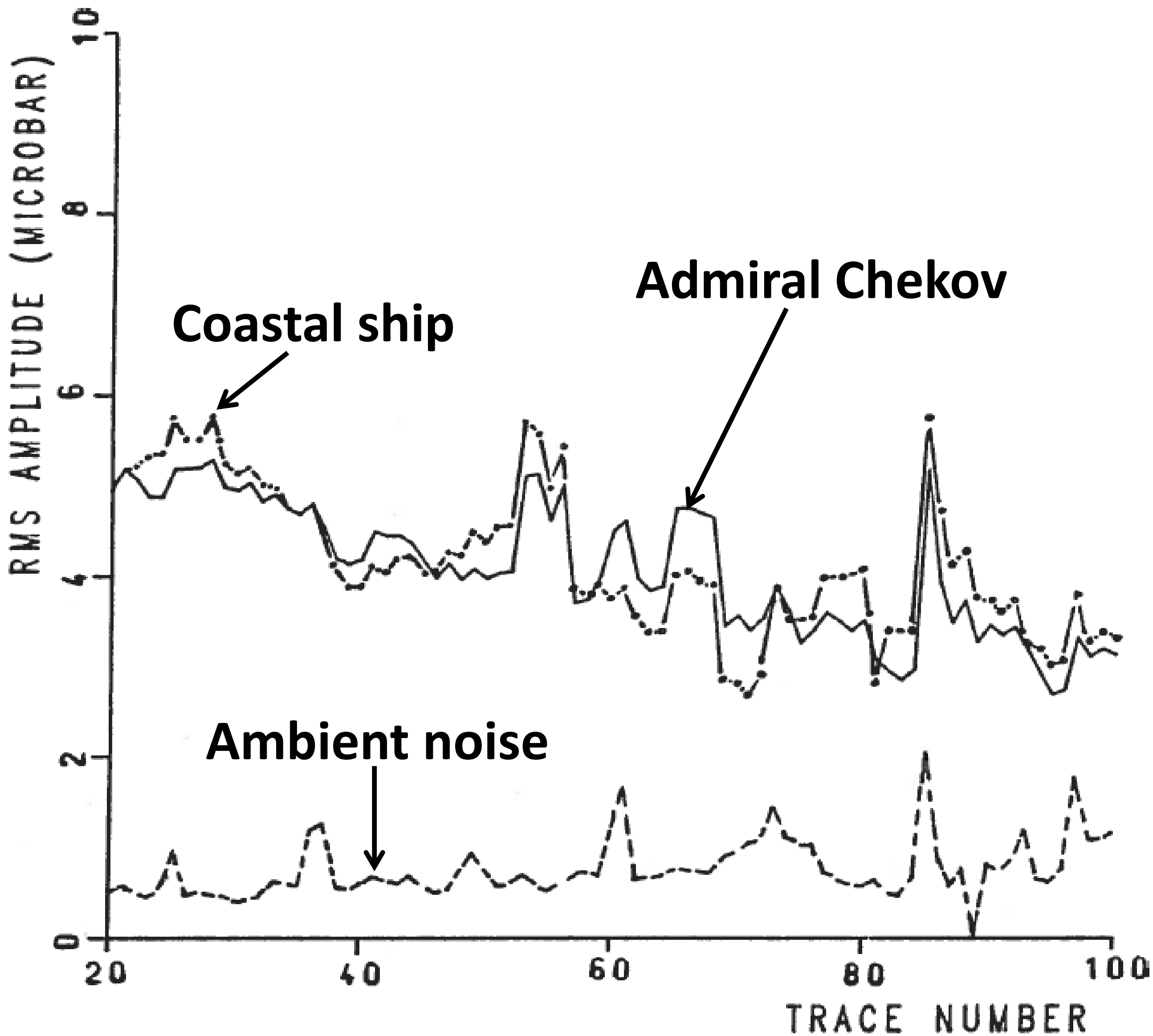


Decays as $1/R^2$ for offsets larger than 4 km

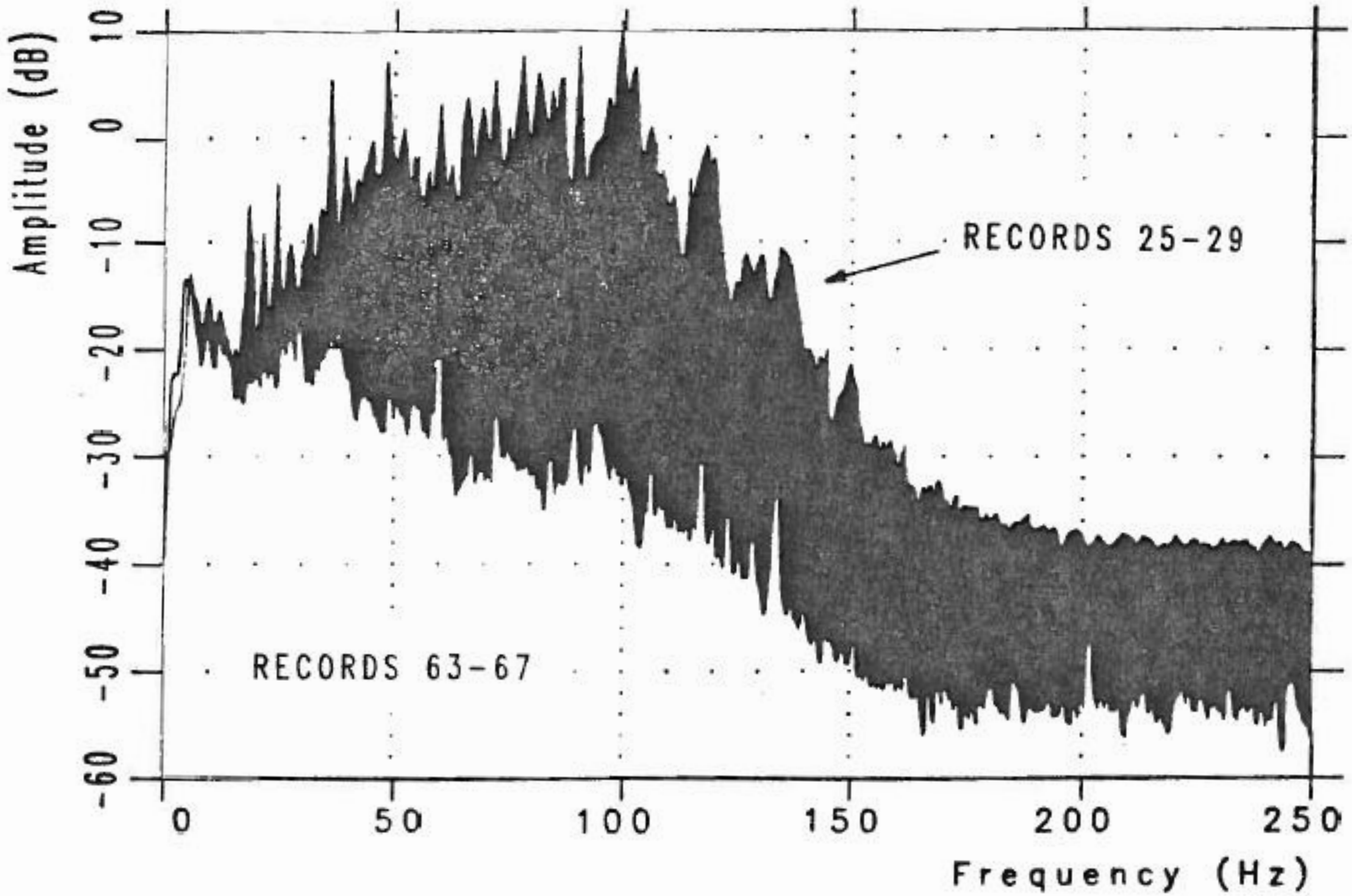
Frequency spectrum – Admiral Chekov (9 km)



Comparison of RMS-levels for «Admiral Chekov (Russian tanker)» and a small Norwegian coastal ship

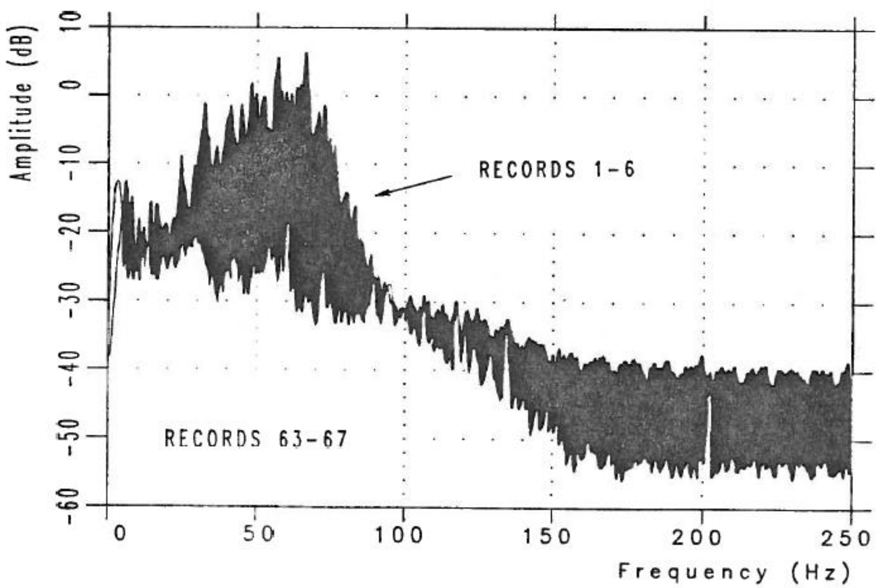


Frequency spectrum – coastal ship (3 km away)

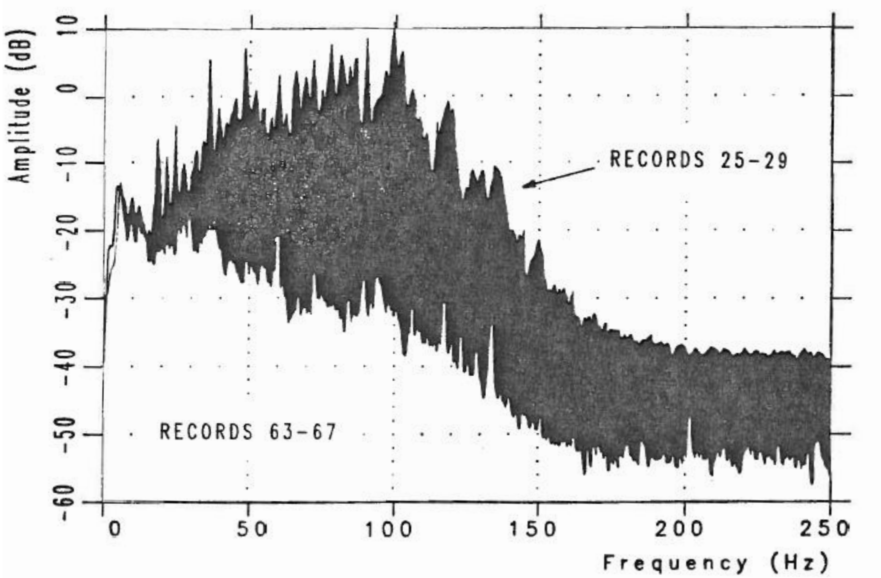


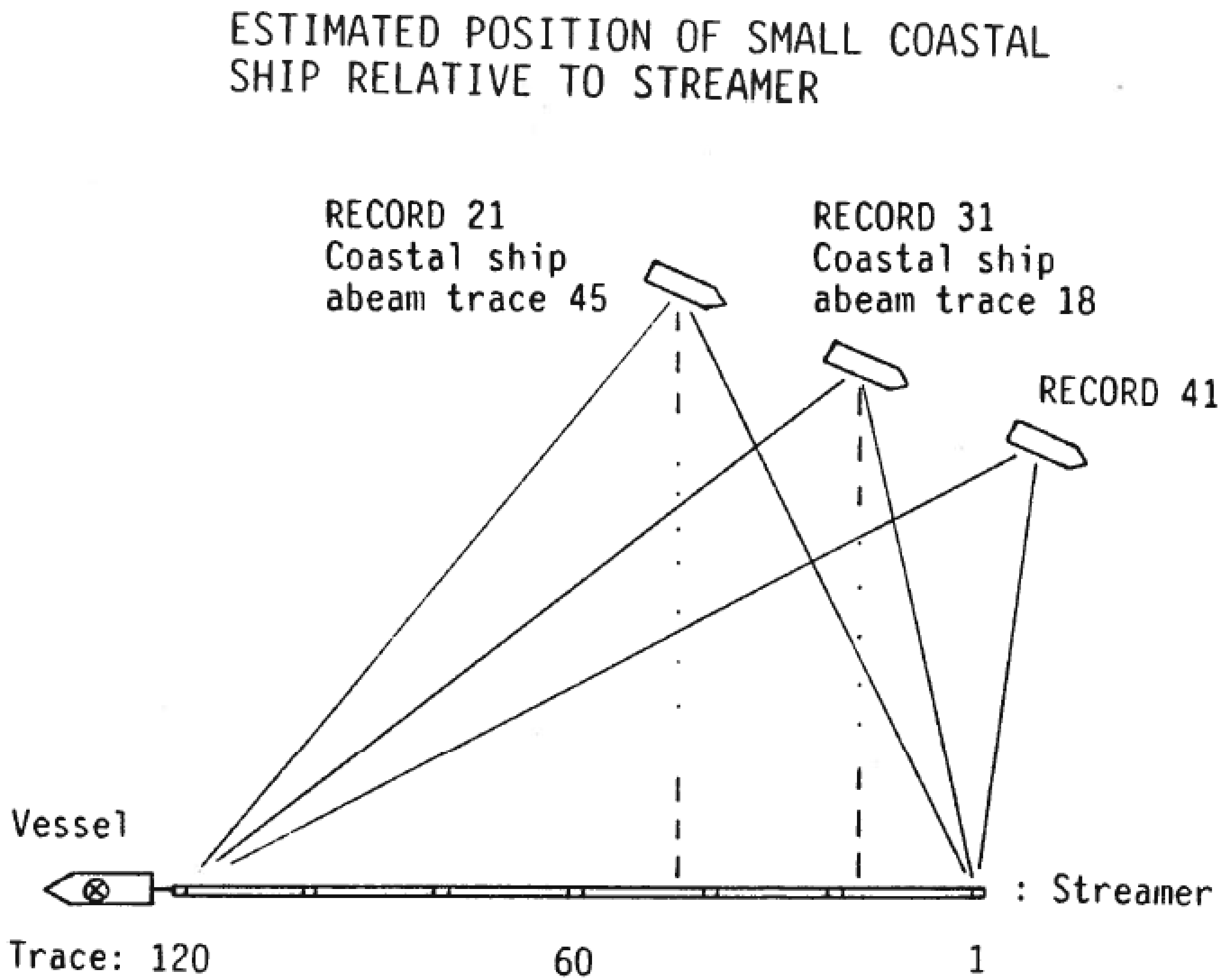
Frequency spectra - comparison

Tanker, 9 km away



Coastal ship, 3 km away




ESTIMATED POSITION OF SMALL COASTAL SHIP RELATIVE TO STREAMER
RECORD 21
Coastal ship
abeam trace 45
RECORD 31
Coastal ship
abeam trace 18
RECORD 41
Vessel
: Streamer
Trace: 120
60
1

4C seismic

- Ocean bottom cables
- Ocean bottom nodes
- Trenched cables for permanent systems
  - Fiber optic systems
  - Electrical systems
- OBS