Presentation prepared for:

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Overview of Human-Made Sound Sources in the Marine Environment

John Hildebrand
Marine Mammal Commission
and
Scripps Institution of Oceanography
University of California San Diego

Joint MMC and JNCC
London
September 28, 2004

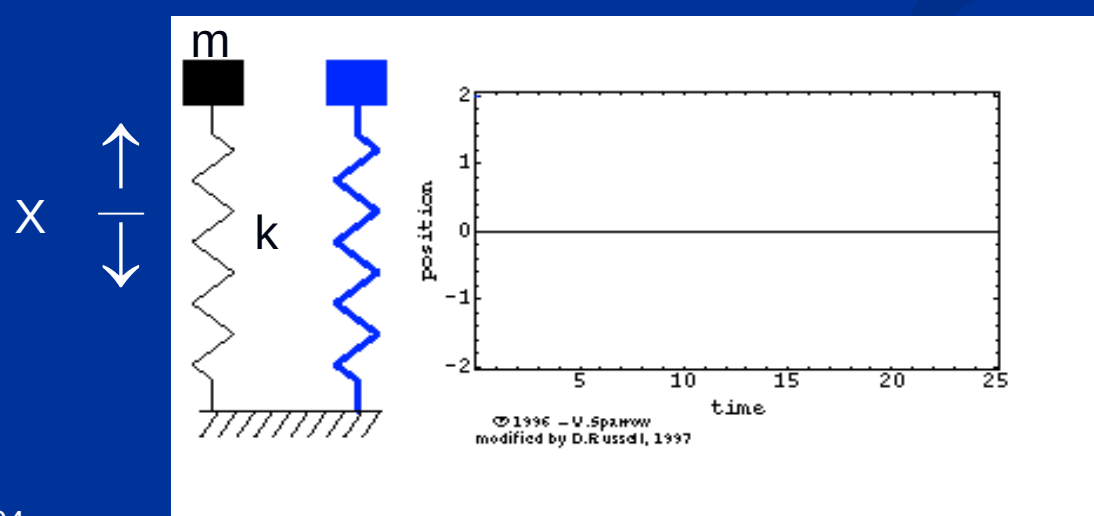
INTRODUCTION to ACOUSTICS: Simple Harmonic Oscillator

Parameters:

$$m = \text{mass}; \quad k = \text{spring constant}; \quad R = \text{damping}$$

Two Kinds of Energy:

$$\text{Kinetic} = \frac{1}{2} m V^2 \qquad \text{Potential} = \frac{1}{2} k X^2 \qquad \text{Total} = \text{Kinetic} + \text{Potential}$$



ACOUSTIC UNITS and TERMS

Acoustic Intensity (AI) – Energy flow per unit area per unit time

$$AI = P\,V$$

Underwater Acoustics Measure Pressure (P) – a scalar value
Land Seismology Measure Velocity (V) – a vector value

How to determine Acoustic Intensity when only measure P or V?
Acoustic Impedance (Z) – a complex scalar

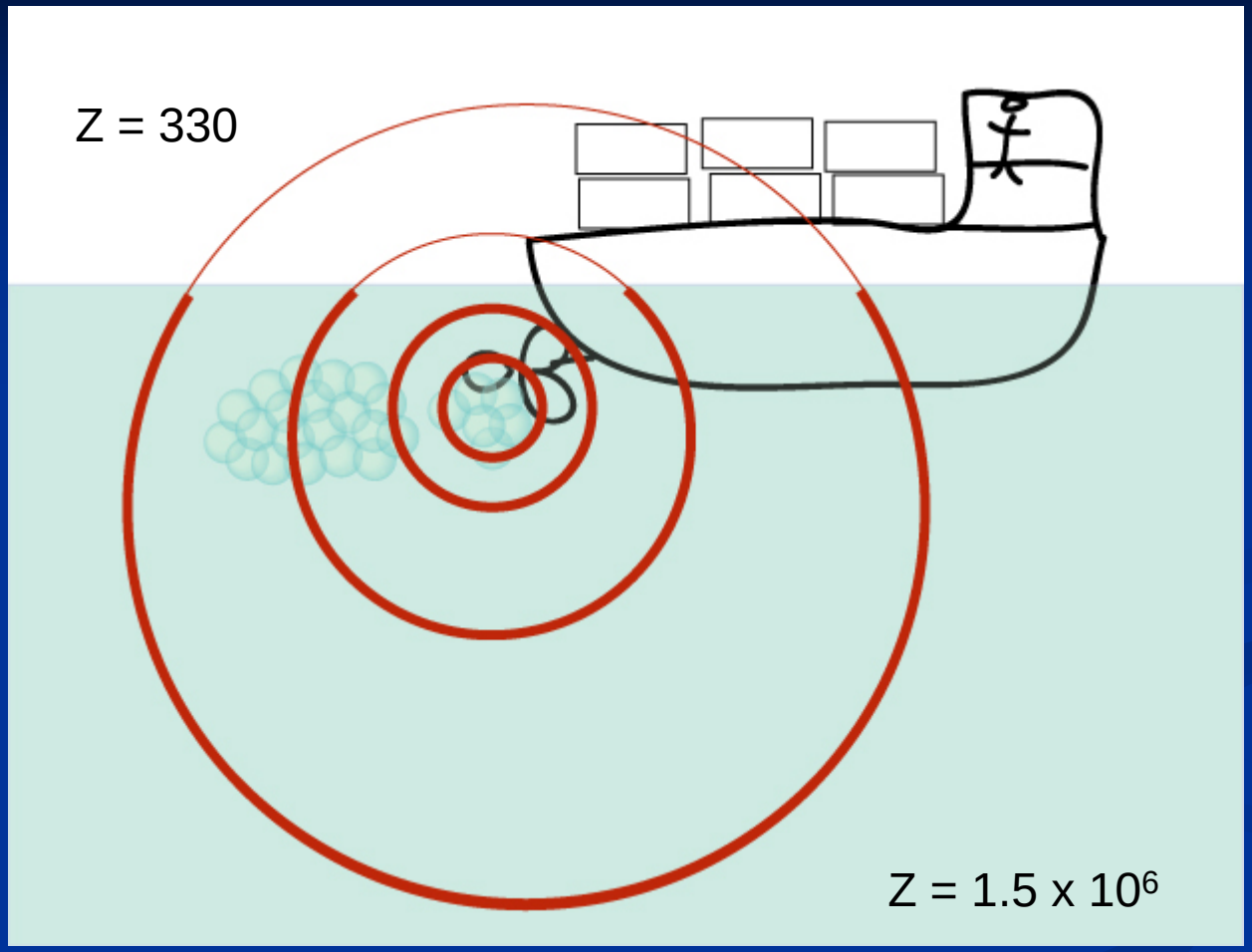
$$|V| = P / Z$$

Within a single media Sound Pressure Level (SPL)

$$\text{SPL dB (re: } \mu\text{Pa)} = 10 \log_{10} (P / P_o)^2$$

$$\text{SPL dB (re: } \mu\text{Pa)} = 20 \log_{10} (P / P_o)$$

Why Ocean Noise does not Deafen Sailors?

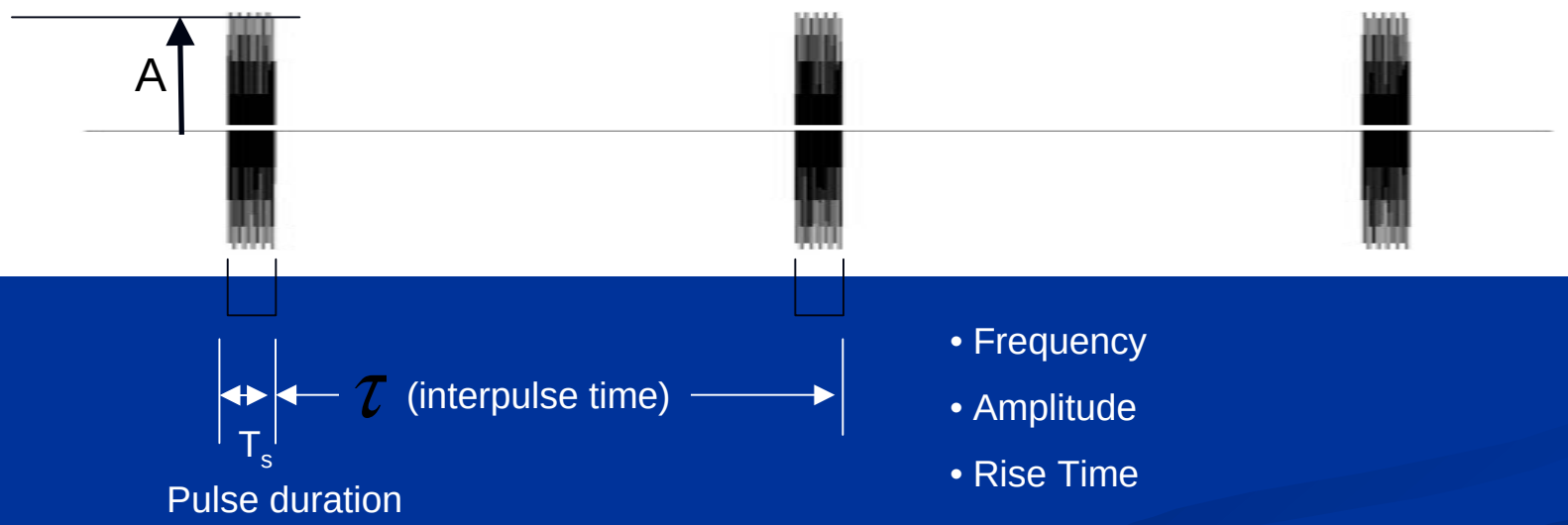


Loss in acoustic intensity crossing the air-sea boundary

For a given particle velocity $p_{OCEAN} >> p_{AIR}$

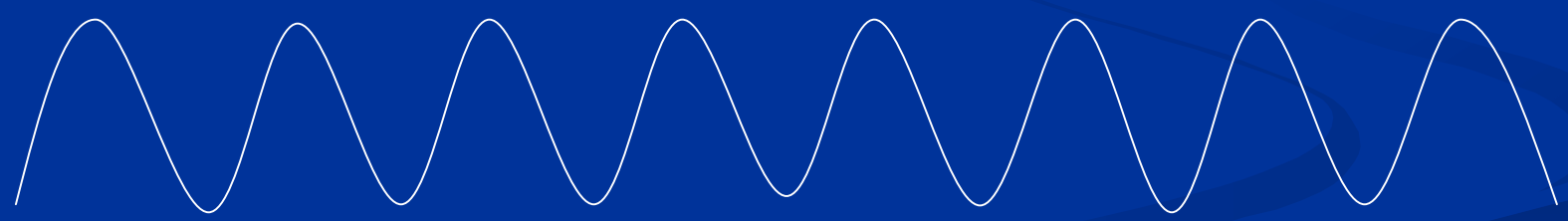
Source Signature – Acoustic Time Series

Periodic sequence of transient pulses



- Frequency
- Amplitude
- Rise Time

Continuous Wave



* Frequency
* Amplitude

Comparing Acoustic Sources

Fourier Transform –

Analyze a Time Series into Frequency Components:

Power Spectral Density – μPa^2 / Hz

Standard for NOISE to use 1 Hz wide frequency bins

Alternatively use OCTAVE or 1/3 OCTAVE bins

Δ dB = 10 $\log_{10}$ (Bandwidth)

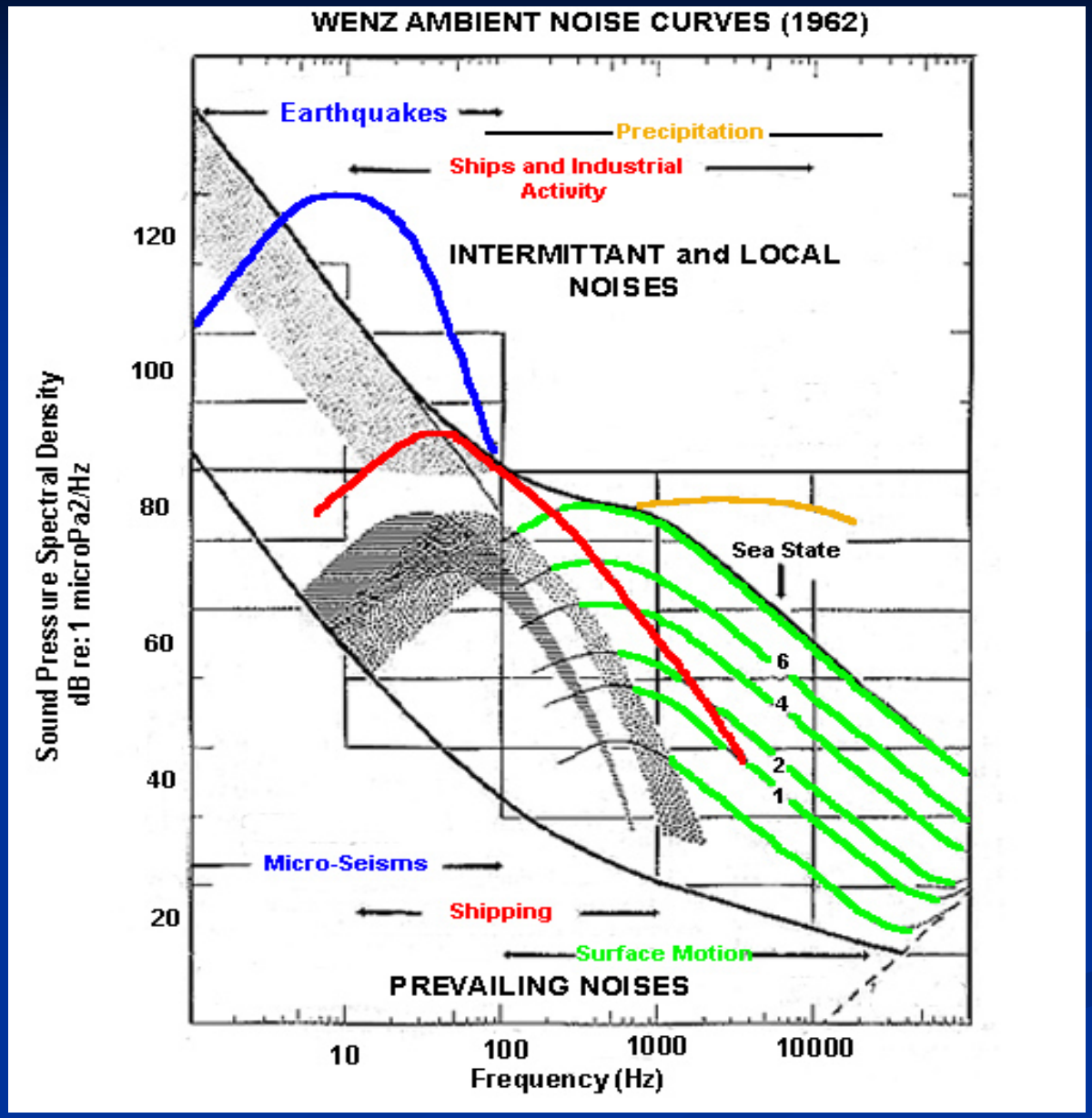
Ping "Energy" – Accounts for Signal Duration

Δ dB = 10 $\log_{10}$ (Duration)

Array "Energy" – Accounts for Multiple Sources

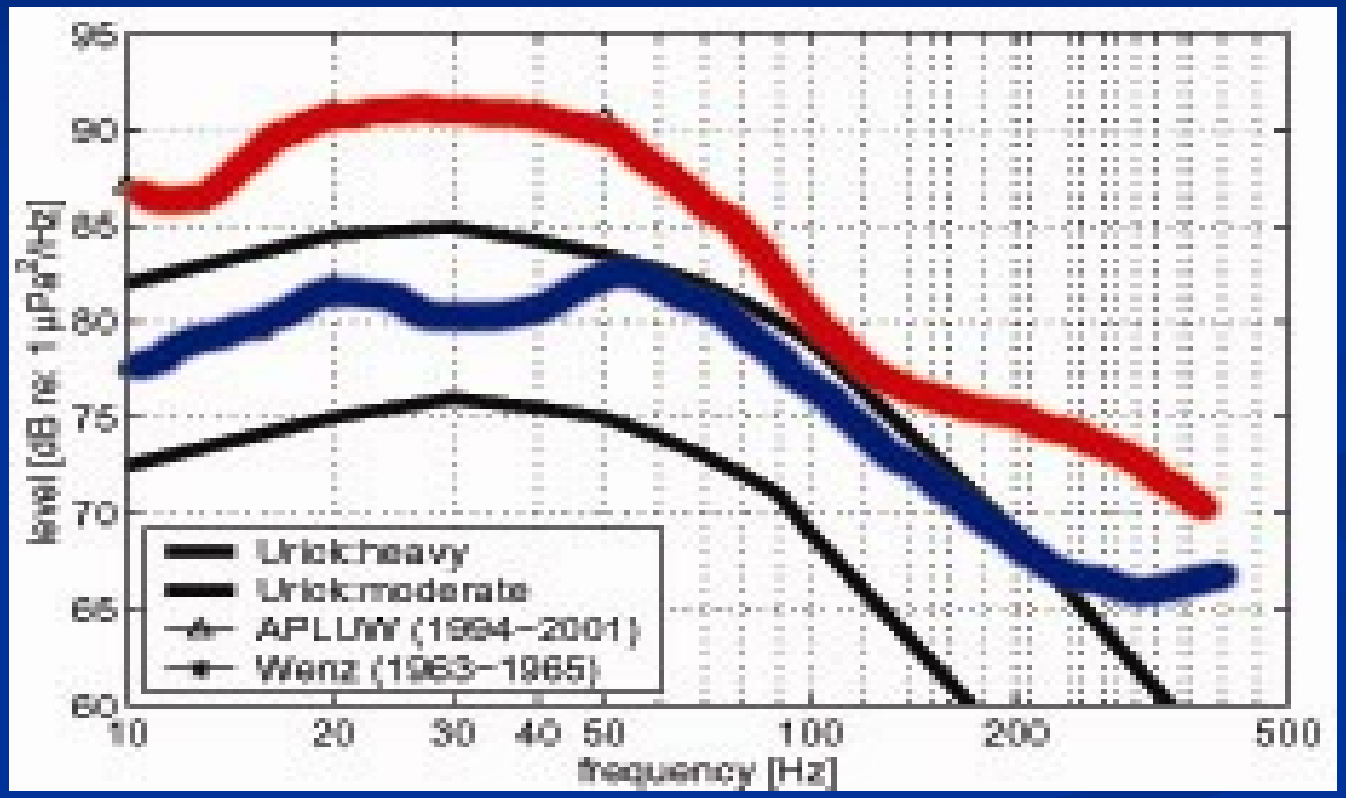
Δ dB = 10 $\log_{10}$ (Number)

AMBIENT NOISE IN THE OCEAN



Ambient Noise – Long Term Trends

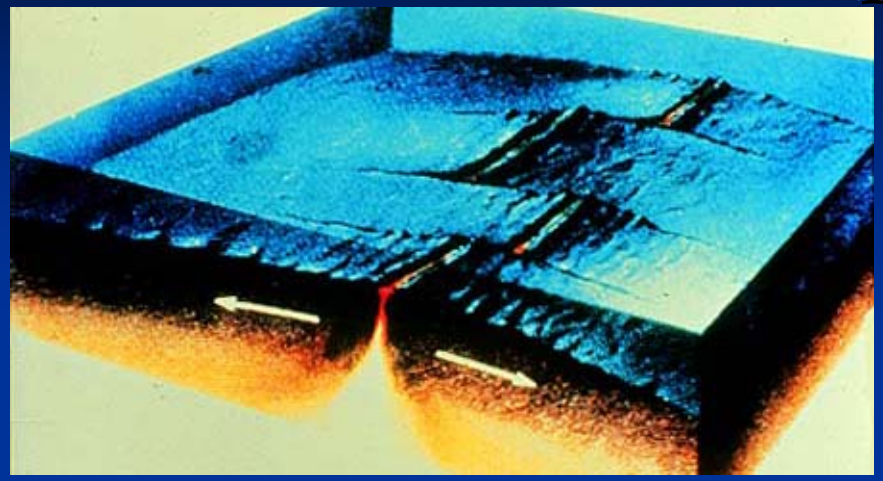
Point Sur SOSUS Array – 1964 (Blue), 2001 (Red)

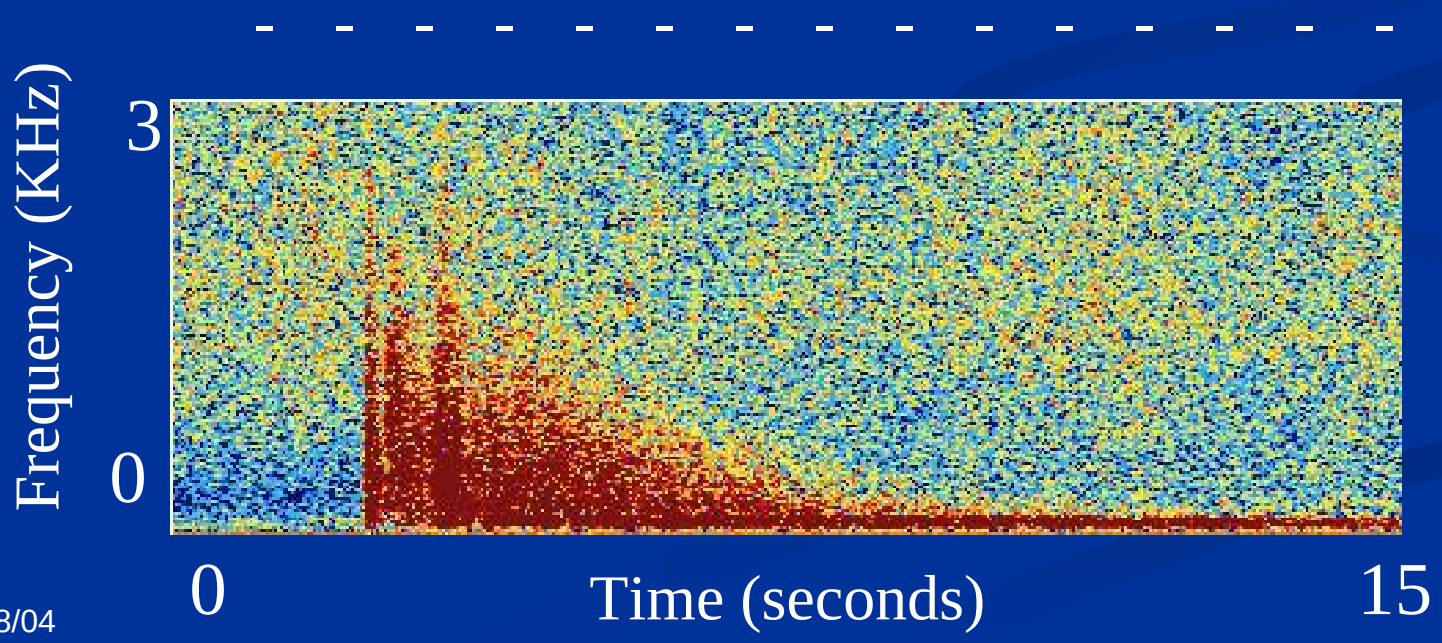


Shipping noise in N. Hemisphere has increased ~3 dB/decade

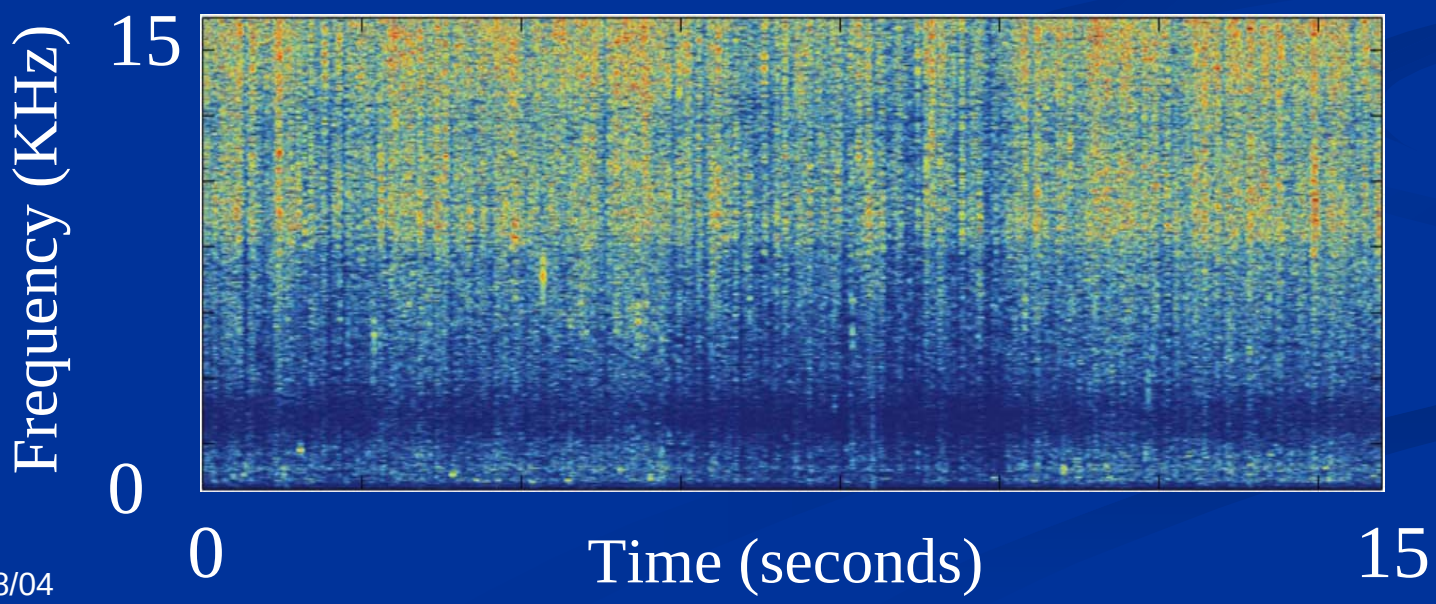
From Andrew et al. Acoustic Research Letters Online (2002)

Ambient Noise - Earthquake

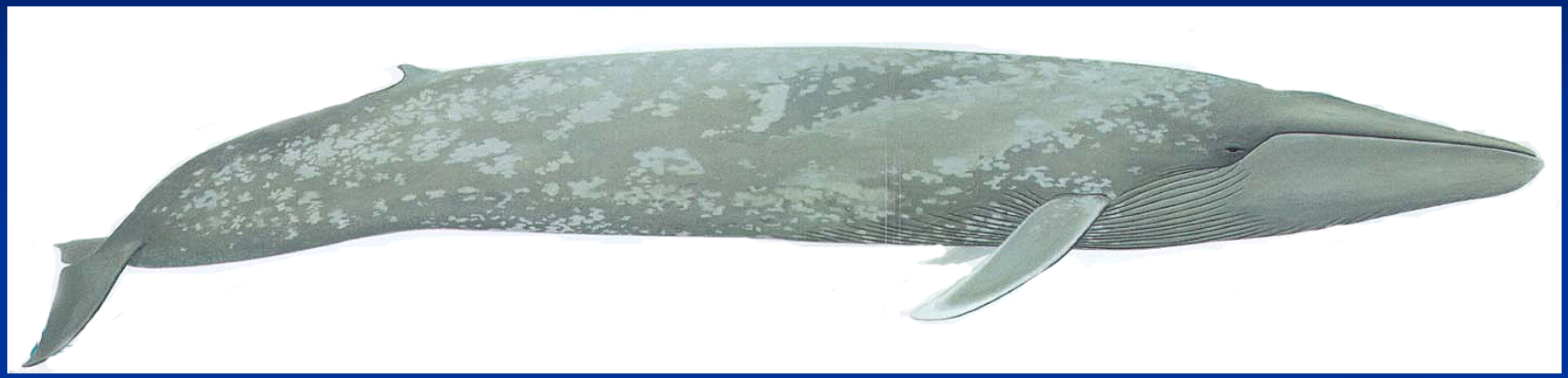


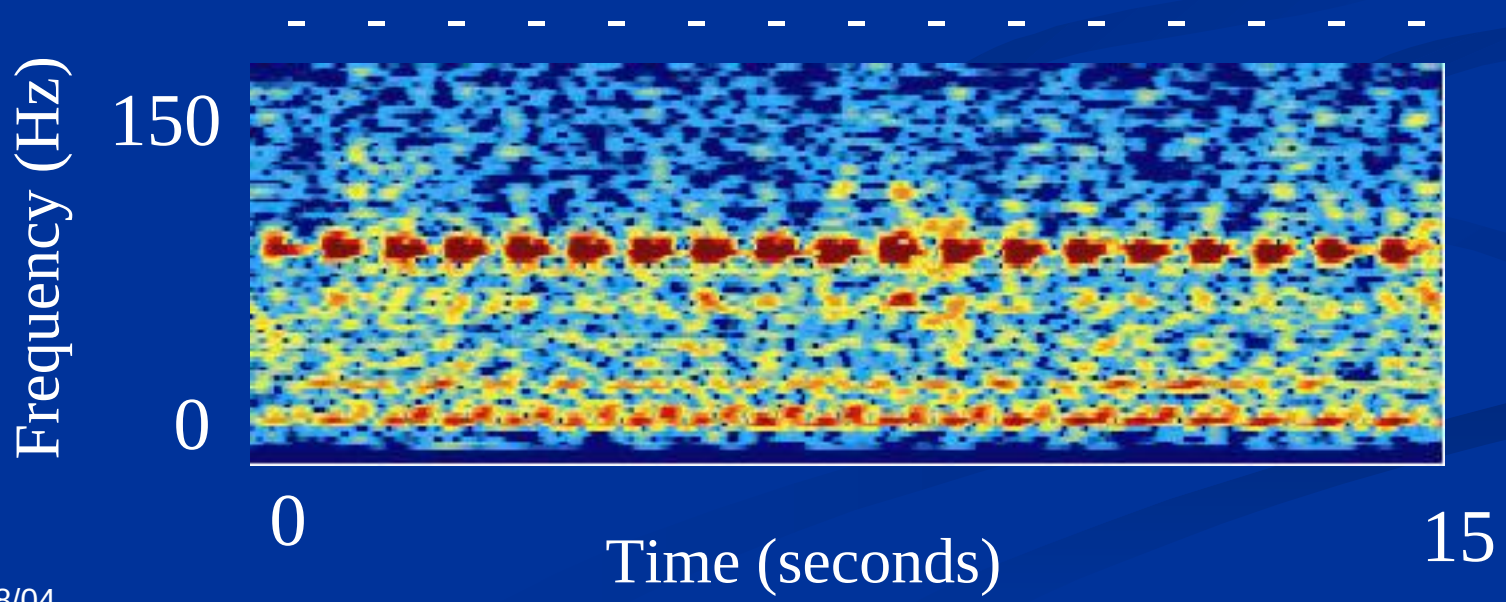


Ambient Noise - Rainfall

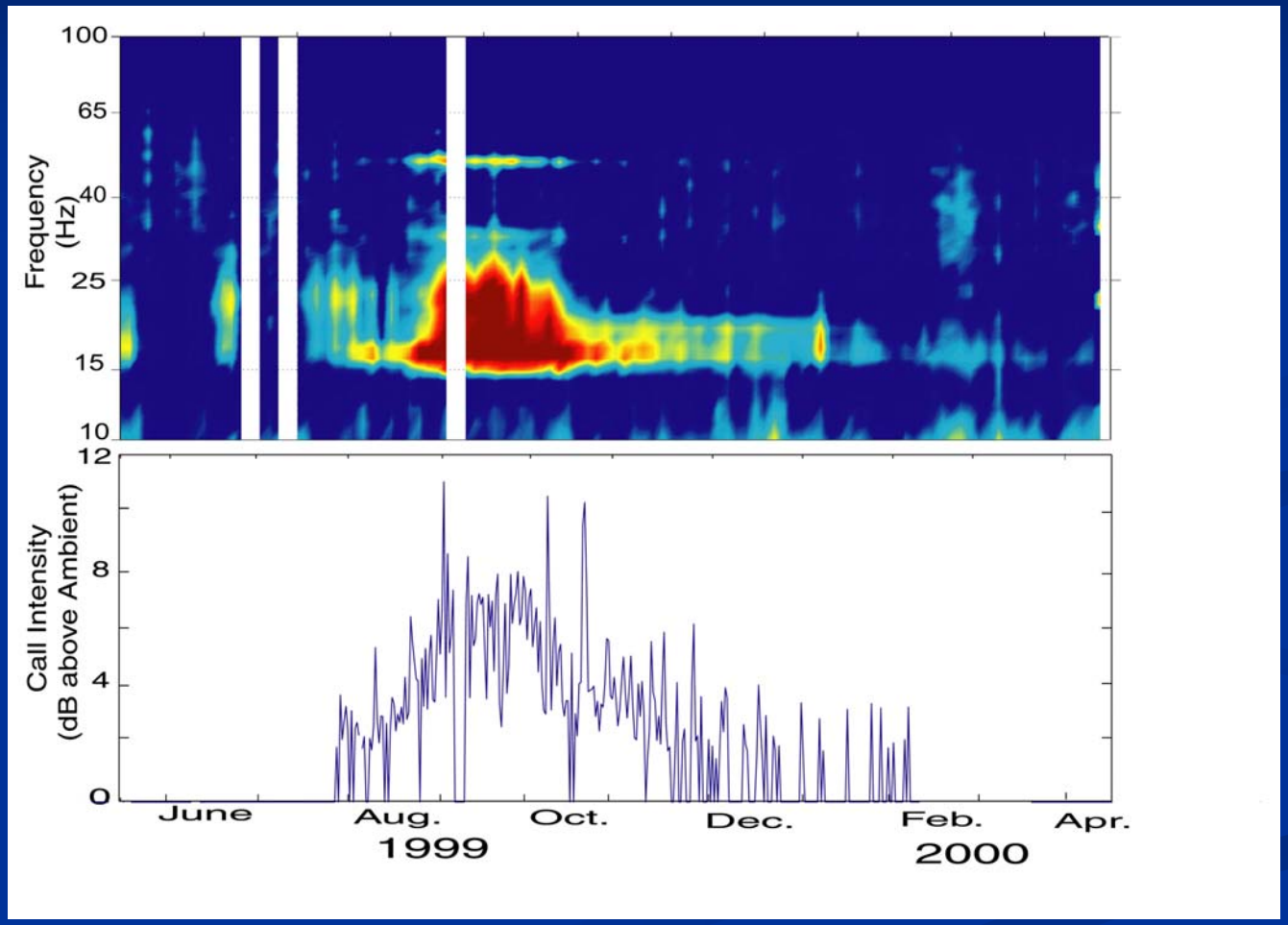


Ambient Noise - Blue Whale

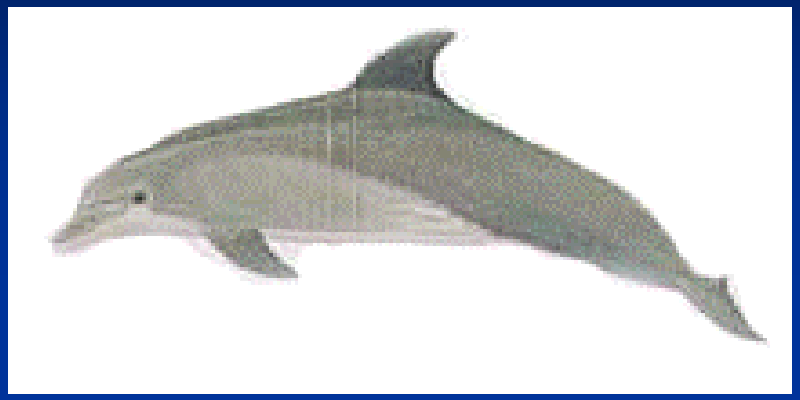




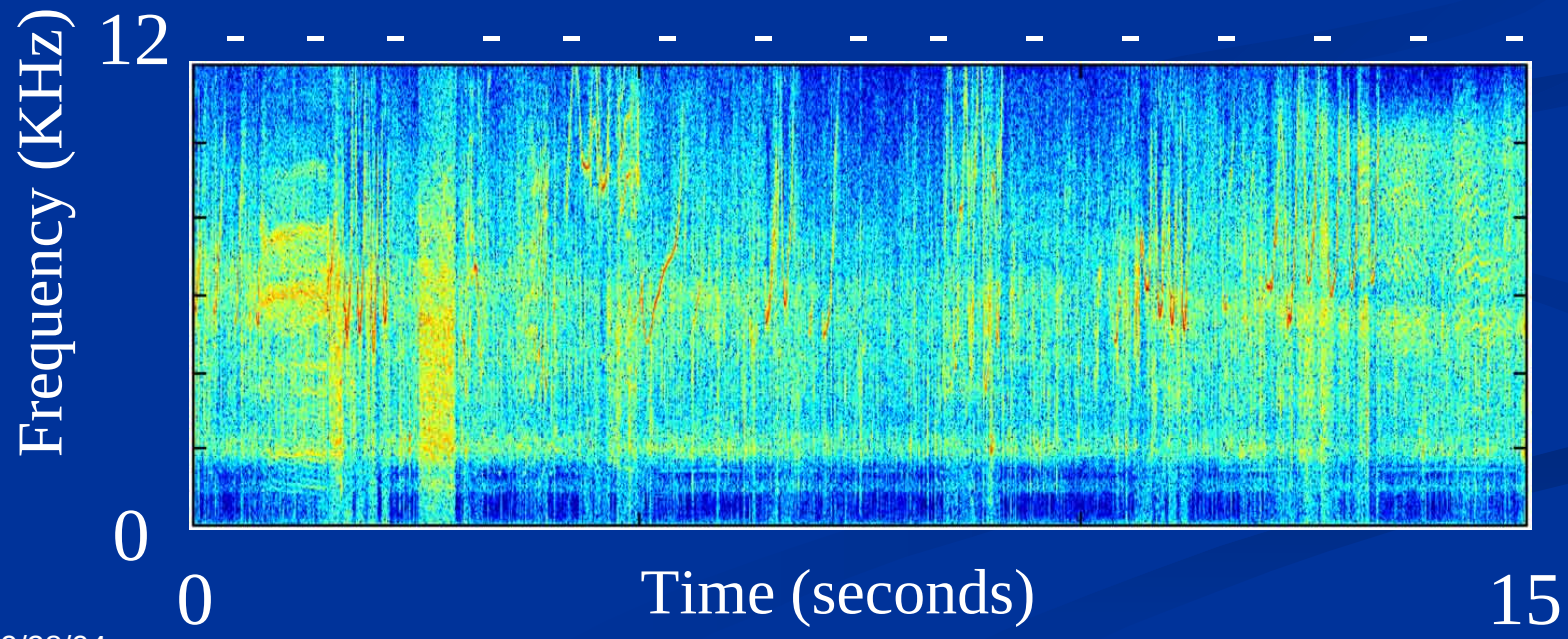
Ambient Noise – Blue and Fin Whale



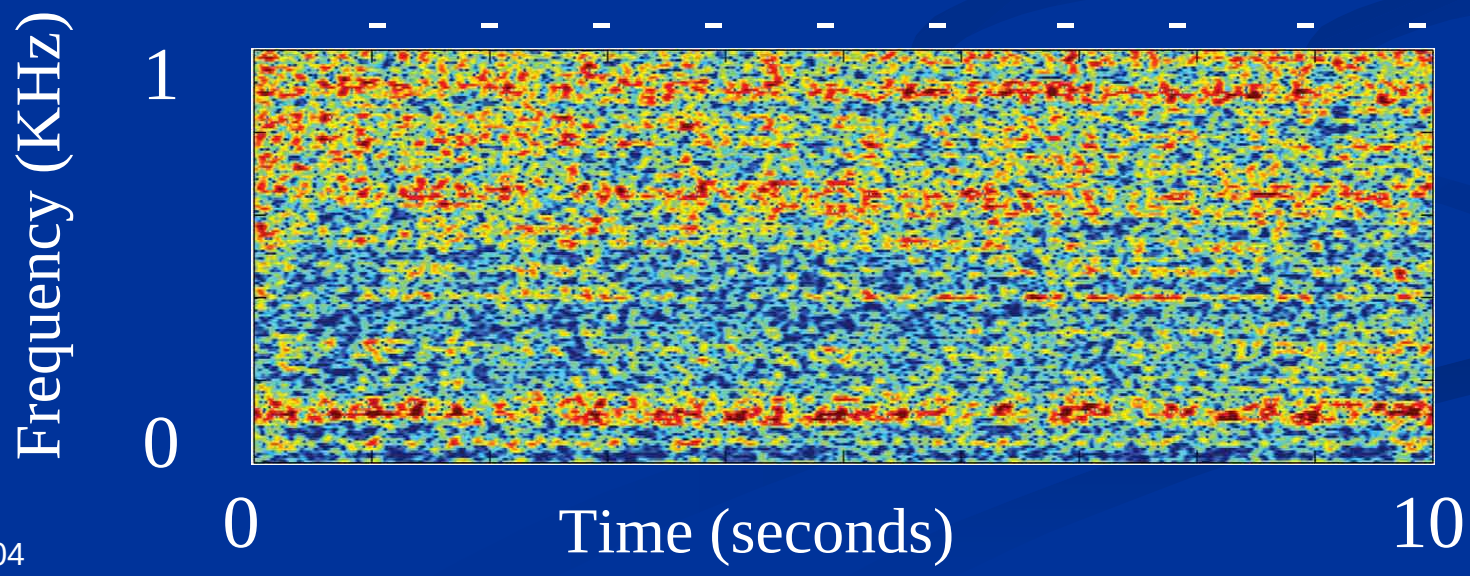
Ambient Noise - Bottlenose Dolphin



1m



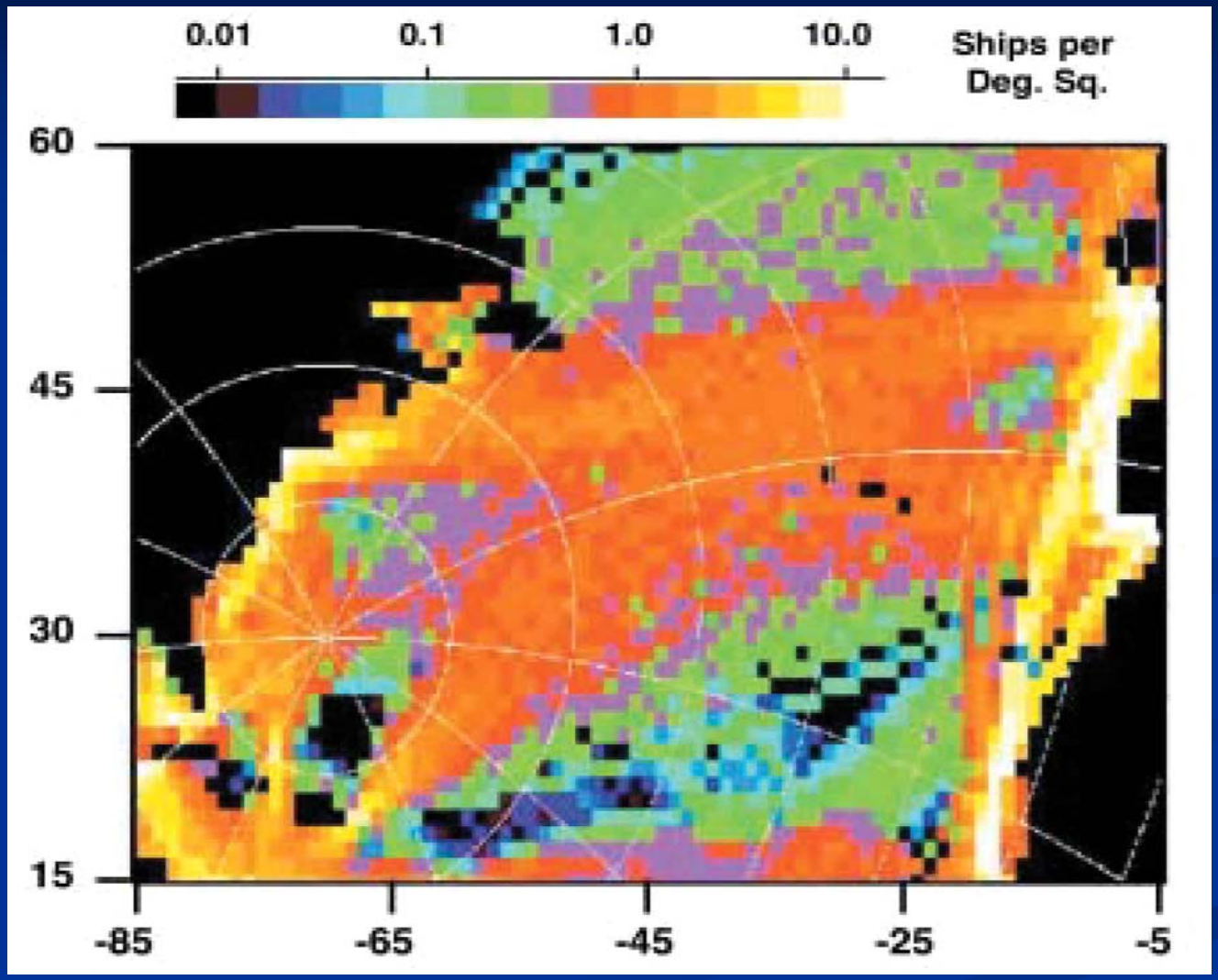
Ambient Noise - Shipping



Container Trades into the US

Source: Mark Womersley – British Maritime Technology

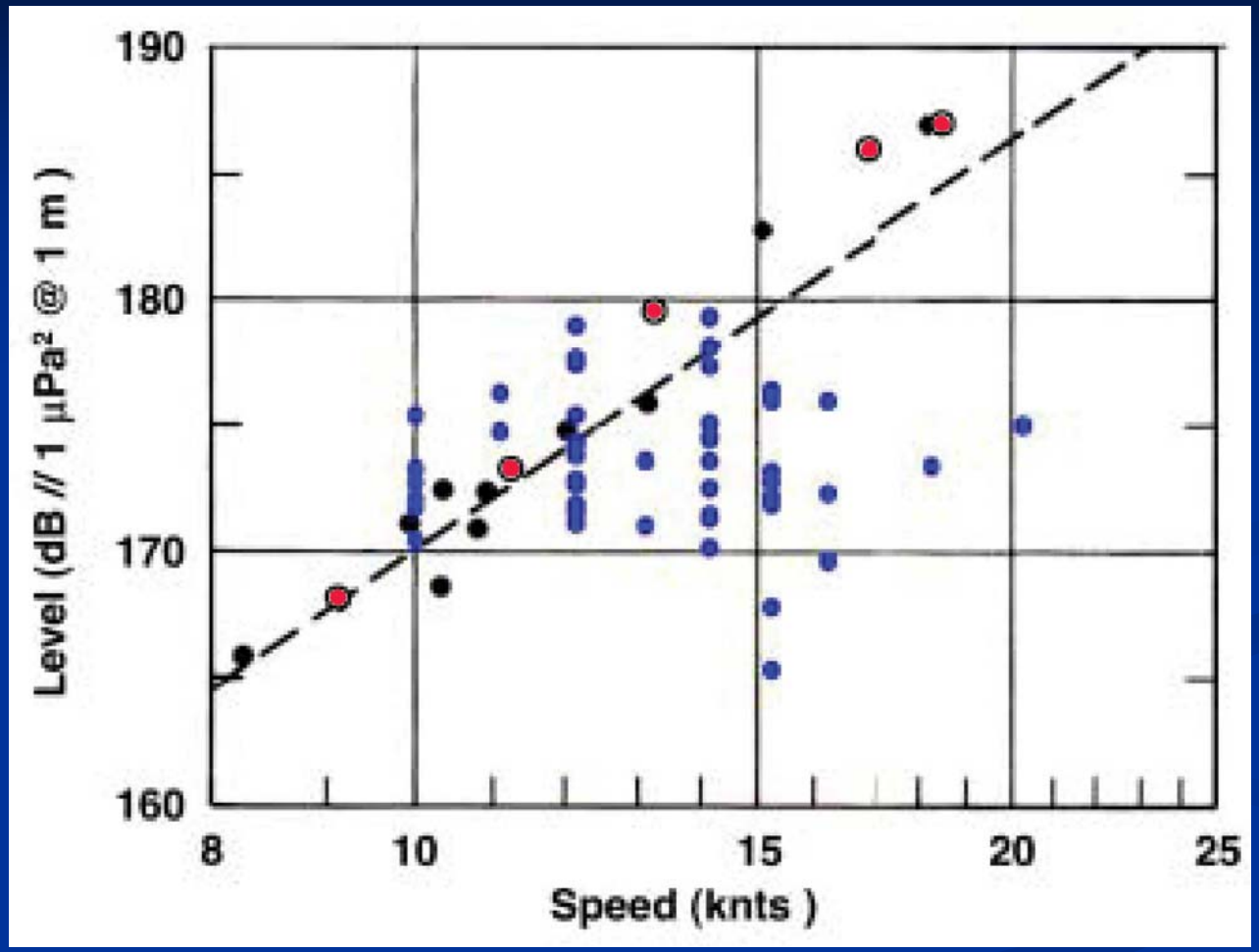
Shipping Distribution



North Atlantic Shipping Lanes

from Heitmeyer et al. 2004

Dependence of Shipping Noise on Vessel Speed ?



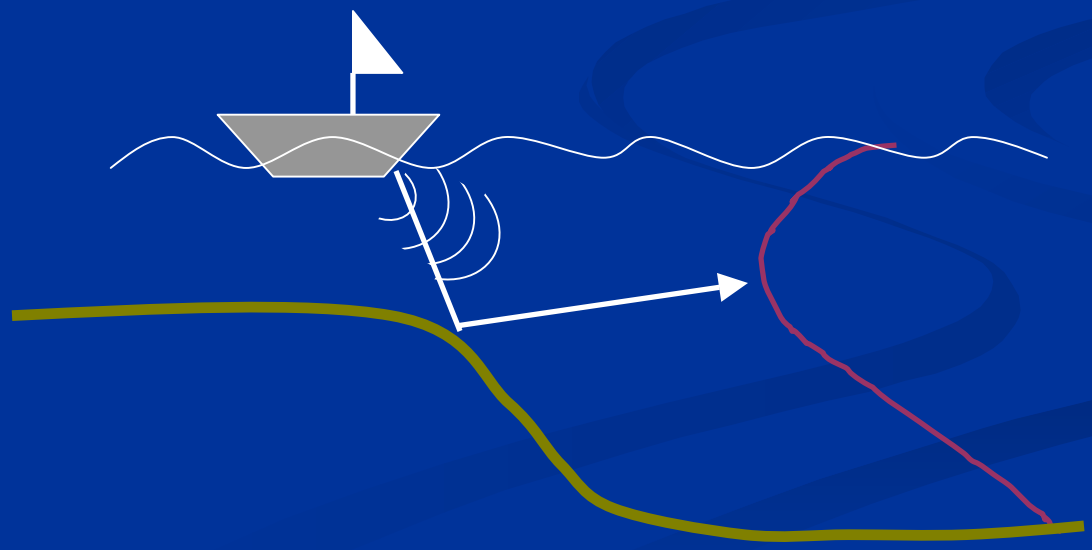
Blue Dots = Ensemble of Many Ships
Red Dots = Single Ship (Astrid Passenger)

from **Heitmeyer et al. 2004**

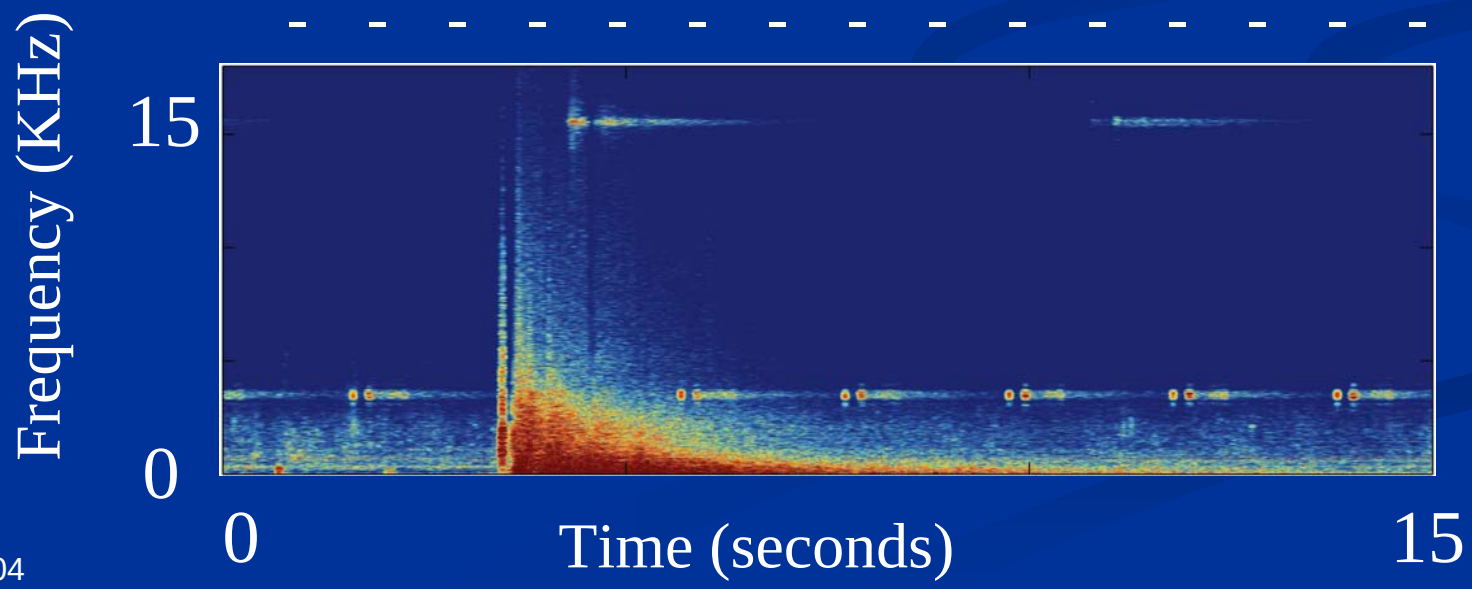
Propagation of Shipping Noise

Shallow Water Continental Shelf

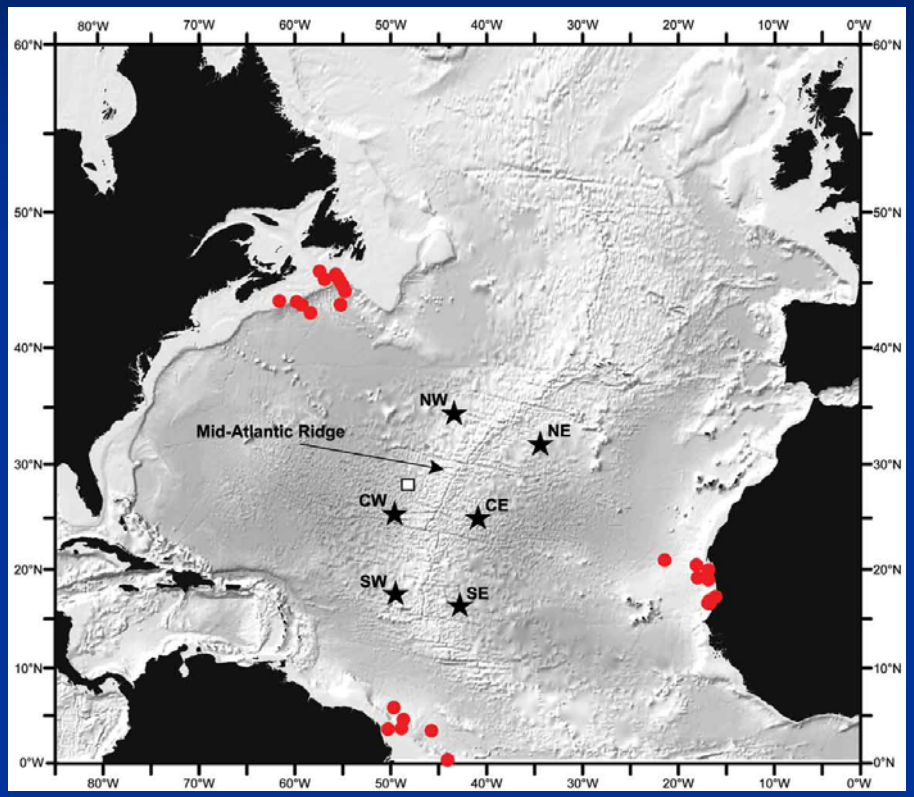
Down-slope Conversion of Sound to Deep Water

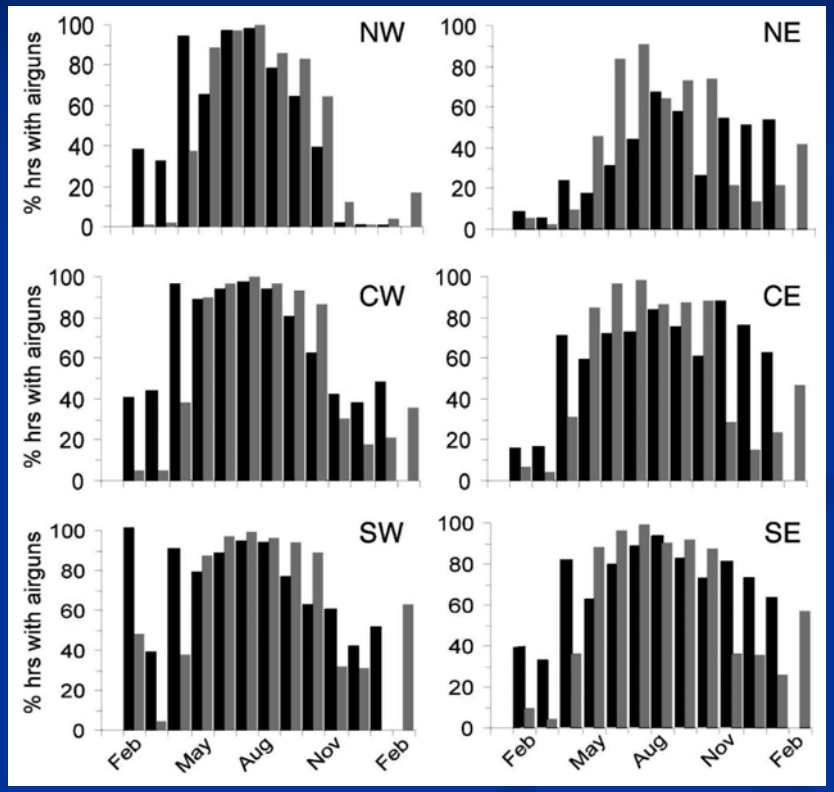


Ambient Noise – Airguns and Echosounders



Airguns in North Atlantic

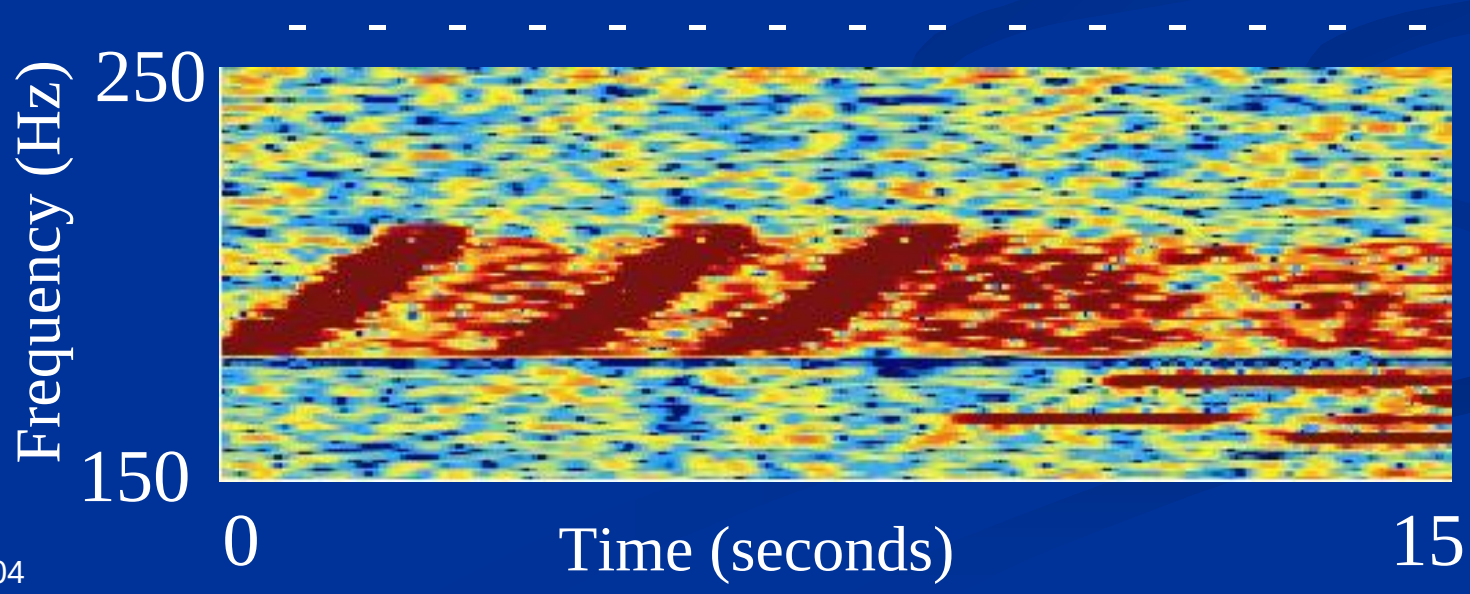




Hydrophones (stars) in the central North Atlantic record airguns (red dots) nearly continuously in the summer months.

From Nieukerk et al. 2004

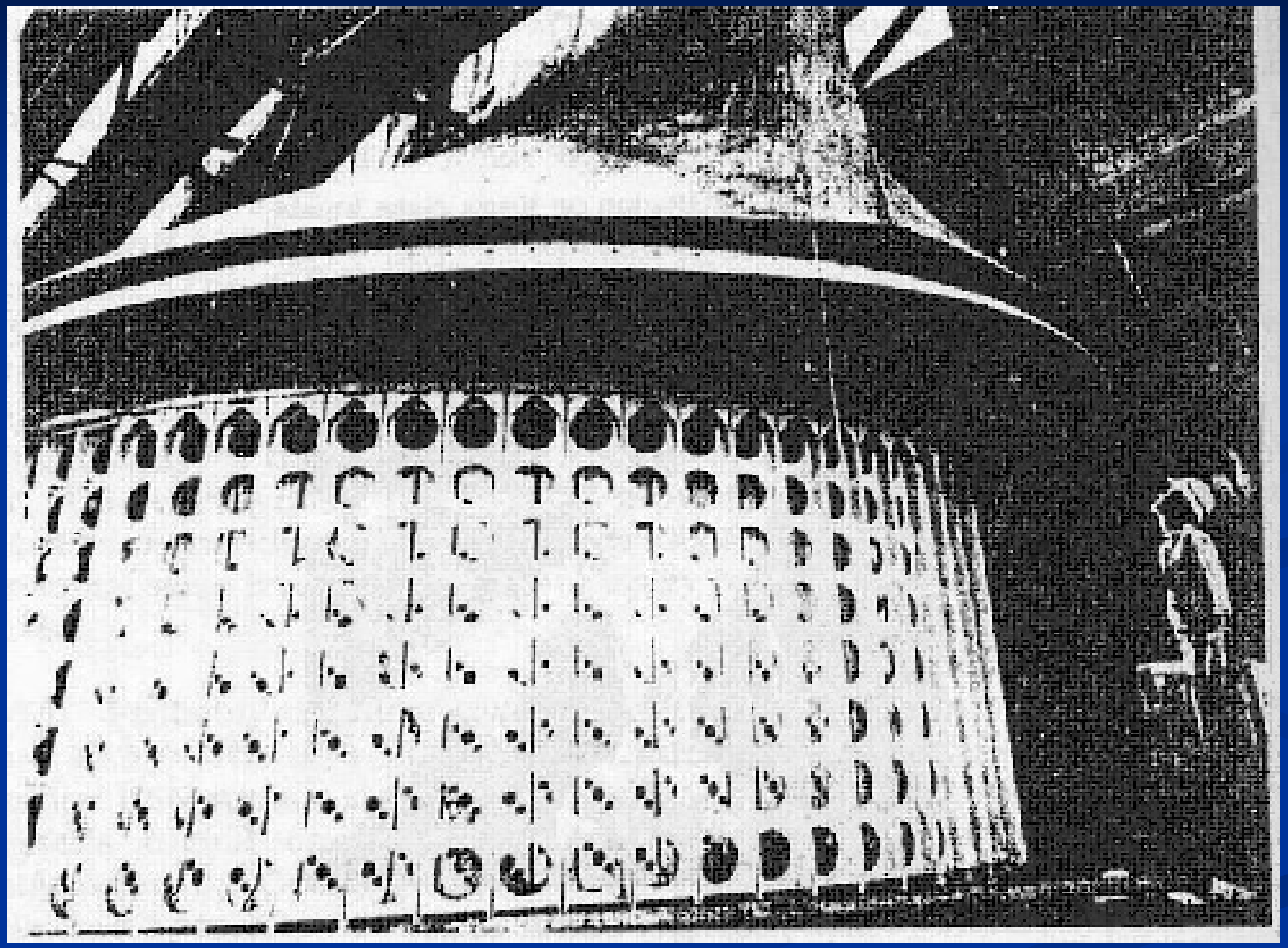
Ambient Noise – LFA Sonar



US Navy ASW Sonars

Type of Ship	Class	Type of Sonar	Number in use
Cruiser	Ticonderoa	SQS-53	27
Destroyer	Spruance	SQS-53	11
Destroyer	Arleigh Burke	SQS-53	49
Frigate	Oliver Hazard Perry	SQS-56	30
Total			117

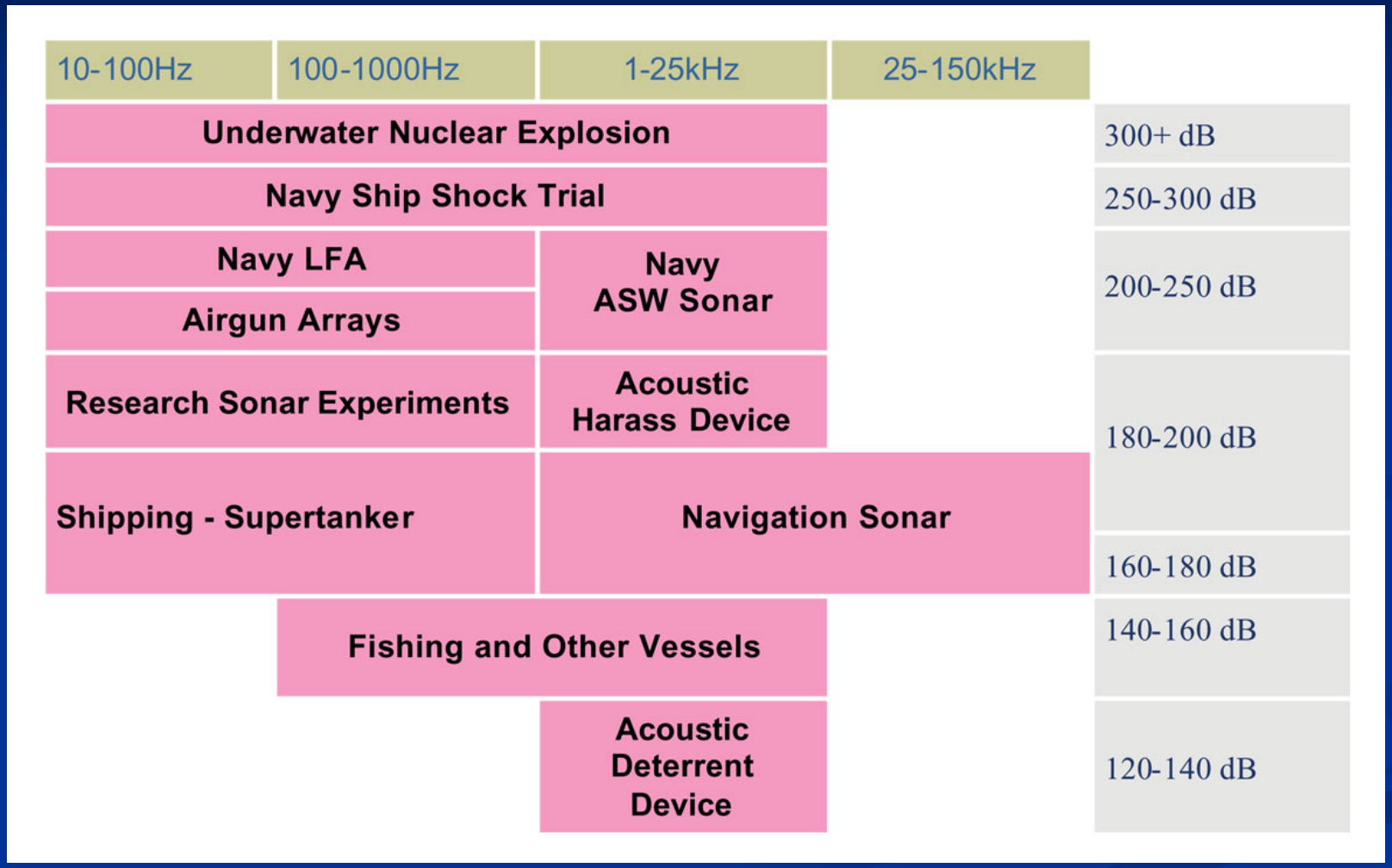
ASW Tactical Sonar SQS-53



Bow of Spruance Class Destoryer

Anthropogenic Sound Source Levels

FREQUENCY



SOURCE LEVEL re:uPa@1m

Developing an Ocean Sound Energy Budget

1) Convert Sound Pressure Level to Acoustic Intensity

$$INTENSITY = \left| p\vec{v} \right| = \frac{\left| p \right|^2}{Z} \qquad \text{Watts/m}^2$$

2) Account for Directionality of Source

$$POWER = 4\pi \left| A_i \right| \qquad \text{Watts} = \text{Joules/sec}$$

3) Account for Duration of Source

$$ENERGY / PING = POWER \times DURATION \qquad \text{Joules}$$

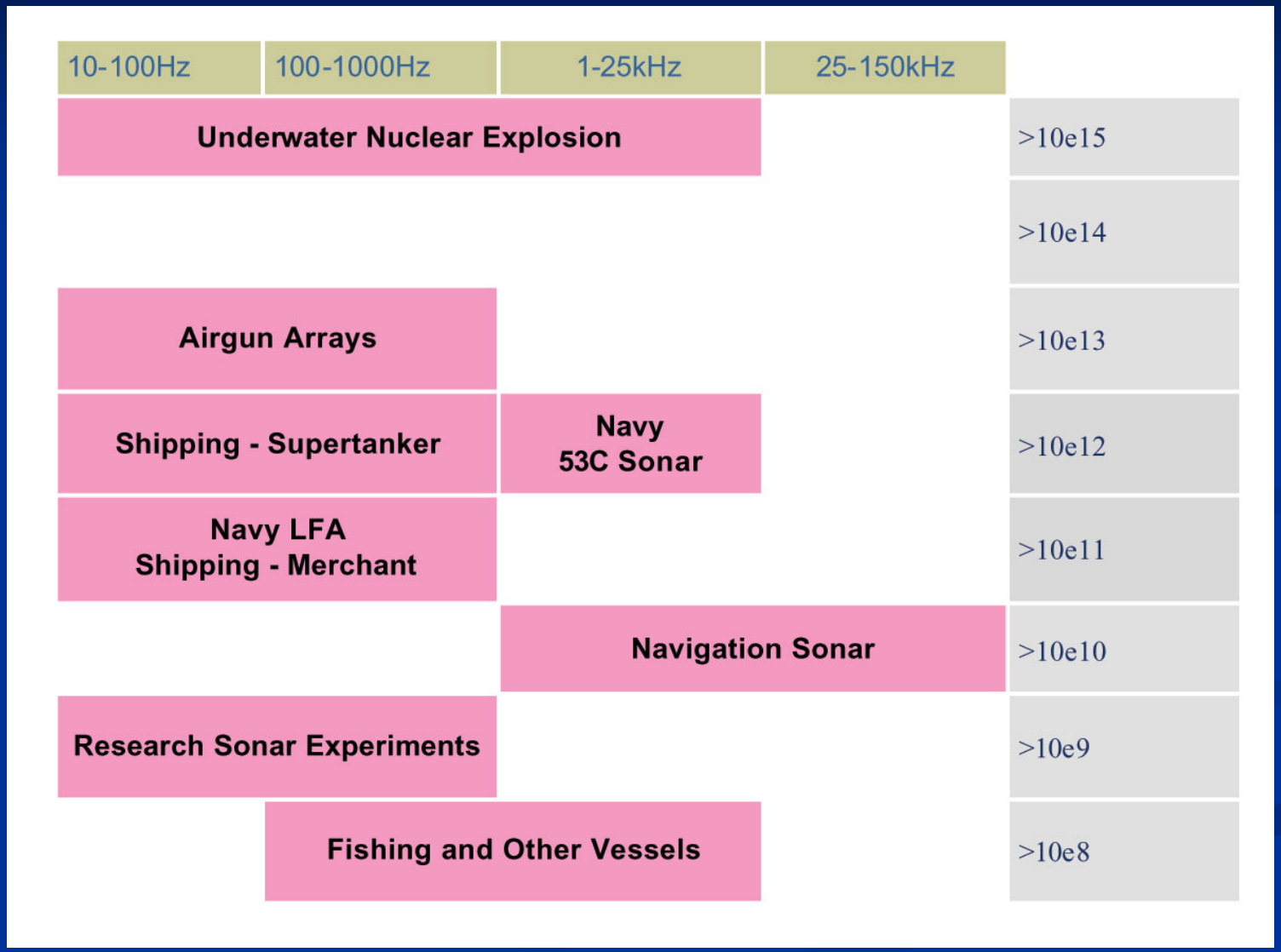
4) Account for Number of Source Pings

$$ENERGY_{total} = ENERGY / PING \times NUMBER \qquad \text{Joules}$$

Anthropogenic Energy Budget per Year

	Inten W/m^2	Power W	Num #	OP Day	Reps Ping/ day	Energy Joules
Nuclear Expl.	146	157	1	.05	1	3xE15
Airgun Arrays	61	66	90	80	4320	4xE13
53C Sonar	53	55	100	30	4320	8xE12
Supertanker	3.2	11	11000	300	CW	4xE12
LFA Sonar	53	58	1	30	175	2xE11
Container Ship	-17	-8.8	40000	300	CW	1xE11
Research Exp.	13	24	10	4	CW	9xE8

Anthropogenic Sound Energy per Year



Priorities for Monitoring Ocean Sound

- Map Ocean Noise in Areas of Anthropogenic Sound: Shipping Lanes, Industrial Sites, Navy Ranges.
- Initiate Long-Term Ocean Noise Monitoring
- Analyze Historic Marine Anthropogenic Noise Data
- Develop Global Models for Ocean Noise
- Signal Characteristics for Anthropogenic Noise Sources
- Determine the Relationship between Anthropogenic Activity Level and Noise Level