Introduction to Acoustical Oceanography
SMS-598, Fall 2005.

Instructors: Mick Peterson and Emmanuel Boss

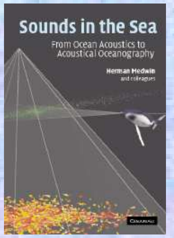
Introductions: why are we here?

Expectations: participation, homework, term-paper.

Emphasis: learning through participation and collaboration, hands-on and demonstrations.

Syllabus: basis for change depending on demand.

Textbook: Medwin and Clay, Fundamental of Acoustical Oceanography, Academic Press, 1997. **Out of print**.



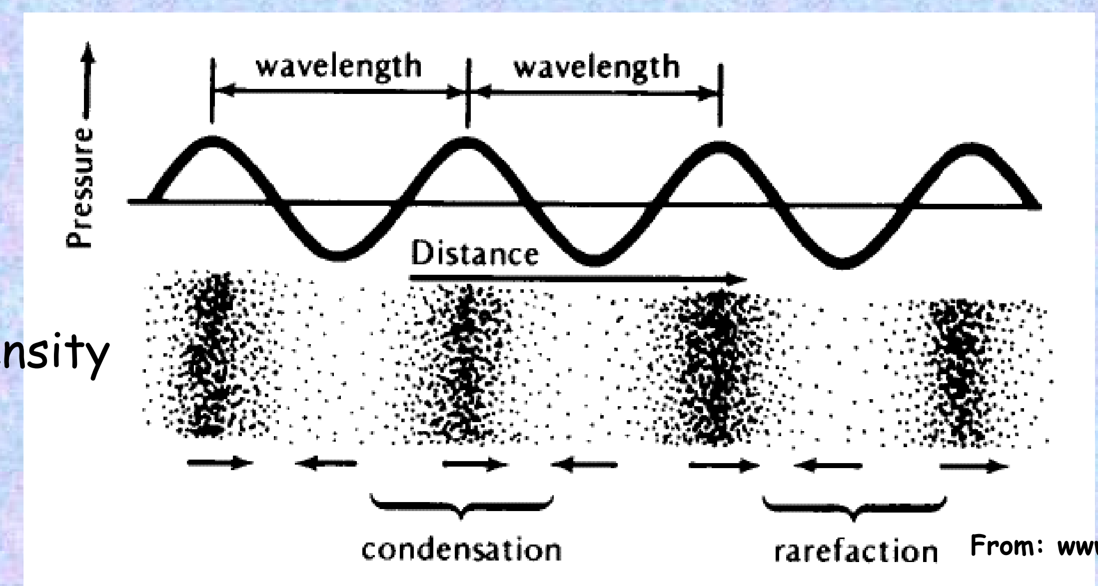
New textbook: Medwin, Sounds in the Sea, University of Cambridge Press 2005. I have ordered 10 at $60 each (cost $100 otherwise).

What is sound?

From Wikipedia: Sound is vibration, as perceived by the sense of hearing. In more technical language, sound "is an alternation in pressure, particle displacement, or particle velocity propagated in an elastic material" (Olson 1957) or series of mechanical compressions and rarefactions or *longitudinal waves* that successively propagate through media that are at least a little compressible (solid, liquid or gas but not vacuum).

In sound waves parts of matter (molecules or groups of molecules) move in a direction of the spreading of the disturbance (as opposite to transversal waves). The cause of sound waves is called the **source of waves**, e.g. a violin string vibrating upon being bowed or plucked.

density



Direction of propagation

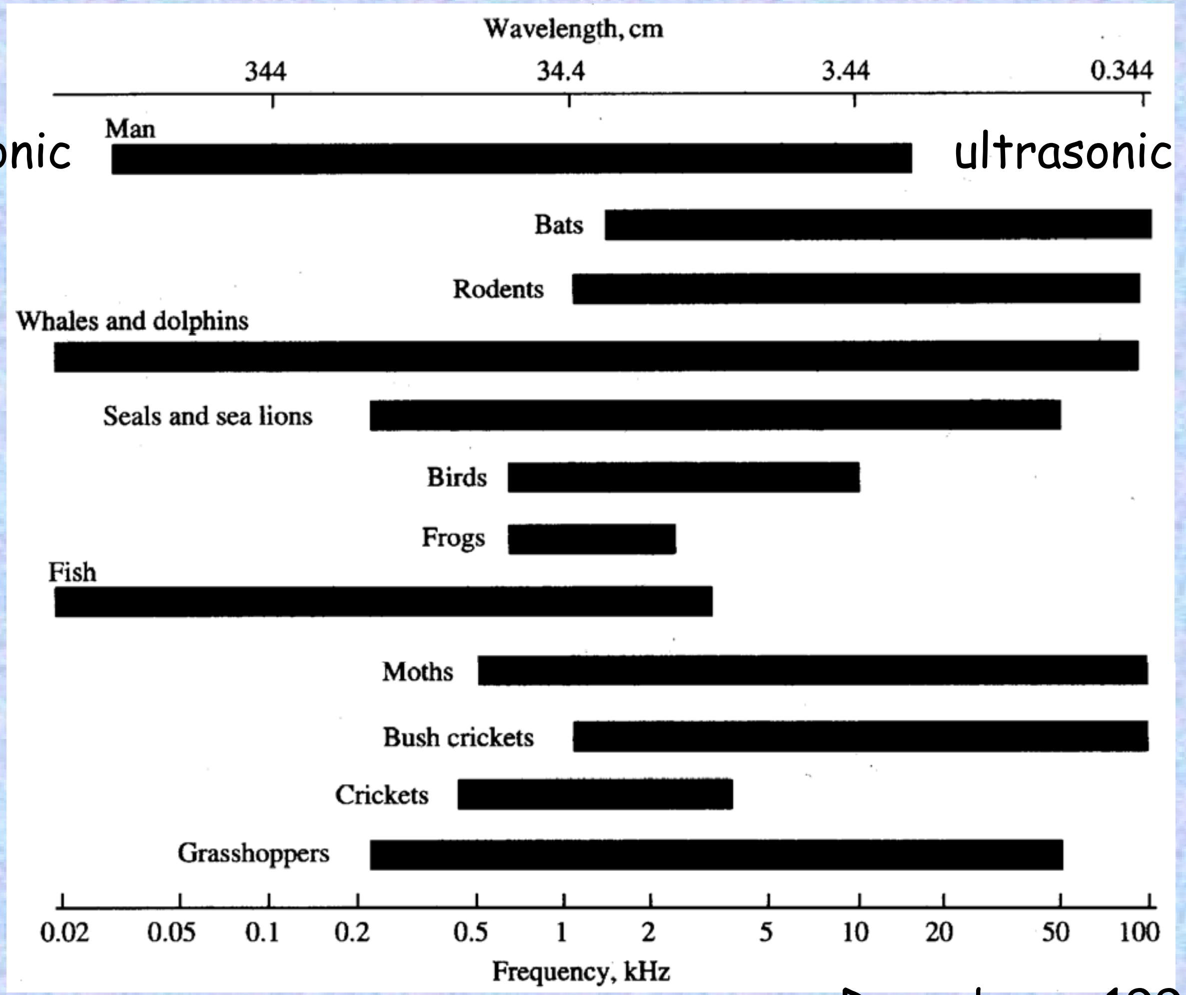
From: www.neurophys.wisc.edu/ ~ychen/textbase/s1-p5.html

Attributes of sound:
Frequency and wavelength

The **frequency** is the number of air pressure (density or velocity) oscillations per second at a fixed point. One single oscillatory cycle per second corresponds to 1 Hz. Sound speed does not vary much with frequency but attenuation and wavelegth do.

Wavelength: The wavelength of a sound wave of frequency *f* and travelling at speed *c* is given by *c*/*f*.

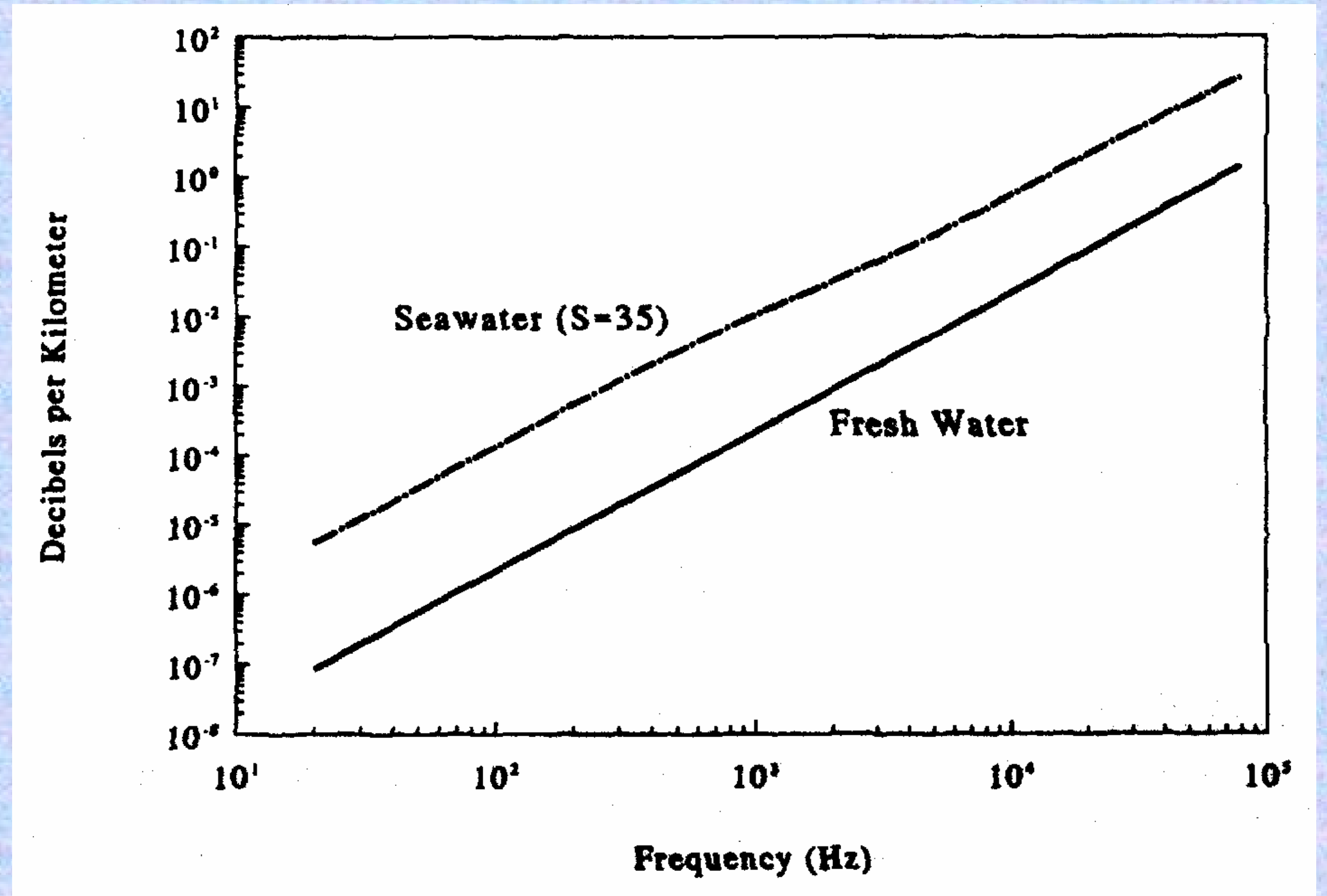
infrasonic



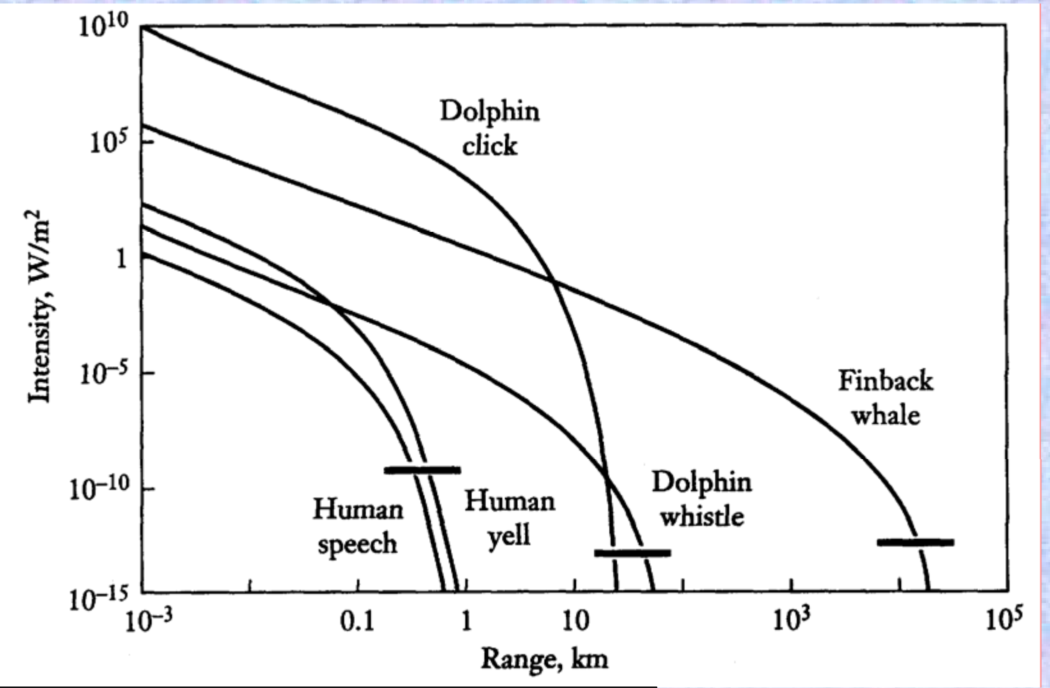
ultrasonic

Dusenbery, 1992

Attenuation in sea water is frequency and salinity dependent:



- Differences in frequencies and source intensities result in differences in range of propagation of sound:



$$I(r)=P\exp(-\alpha_e r)/4\pi r^2$$

Source	Frequency (Hz)	Power (W)	Attenuation (km^{-1})	Range (km)
Human speech	1000	10^{-5}	30	0.4
Human yell	1000	10^{-3}	30	30.6
Dolphin click	25000	10^{5}	1.3	30
Dolphin whistle	10000	10^{-4}	0.25	70
Finback whale	20	10	0.0007	10.000

Dusenbery, 1992

Amplitude: The amplitude is the magnitude of sound pressure change within the wave. It is the maximal displacement of particles of matter that is obtained in compressions, where the particles of matter move towards each other and pressure increases the most and in rarefactions, where the pressure lessens the most.

Sound pressure level (SPL)

The amplitude of a sound wave is most commonly characterized by its sound pressure. In the environment, a very wide range of pressures can occur and it is therefore a convention that sound pressure is measured on a logarithmic scale using the decibel. If *p* is the **rms** sound pressure amplitude then the sound pressure level (SPL) is defined as 20 times the logarithm of the ratio of the pressure to some reference pressure.

Sound pressure level (SPL) is calculated in decibels as

$$L_p = 20 \log_{10}\left(\frac{p_1}{p_0}\right) = 10 \log_{10}\left(\frac{p_1^2}{p_0^2}\right) \text{ dB}SPL$$

The reference sound pressure in air is by convention the threshold of hearing at 1KHz, P_0 = 20 μPa in air, while it is 1 μPa in water. (Pa = pascal = N /m²; N = newton) .

Only decibel values using the same reference can be compared.

dB	I/I_0	P_s/P_0	Plane wave intensity	w/m^2
			(P_0=20μPa Air)	(P_0=1μPa Water)
-20	0.01	0.1	1×10^{-14}	7×10^{-21}
0	1	1	1×10^{-12}	7×10^{-19}
10	10	3.16	1×10^{-11}	7×10^{-18}
20	100	10	1×10^{-10}	7×10^{-17}
40	10^4	100	1×10^{-8}	7×10^{-15}

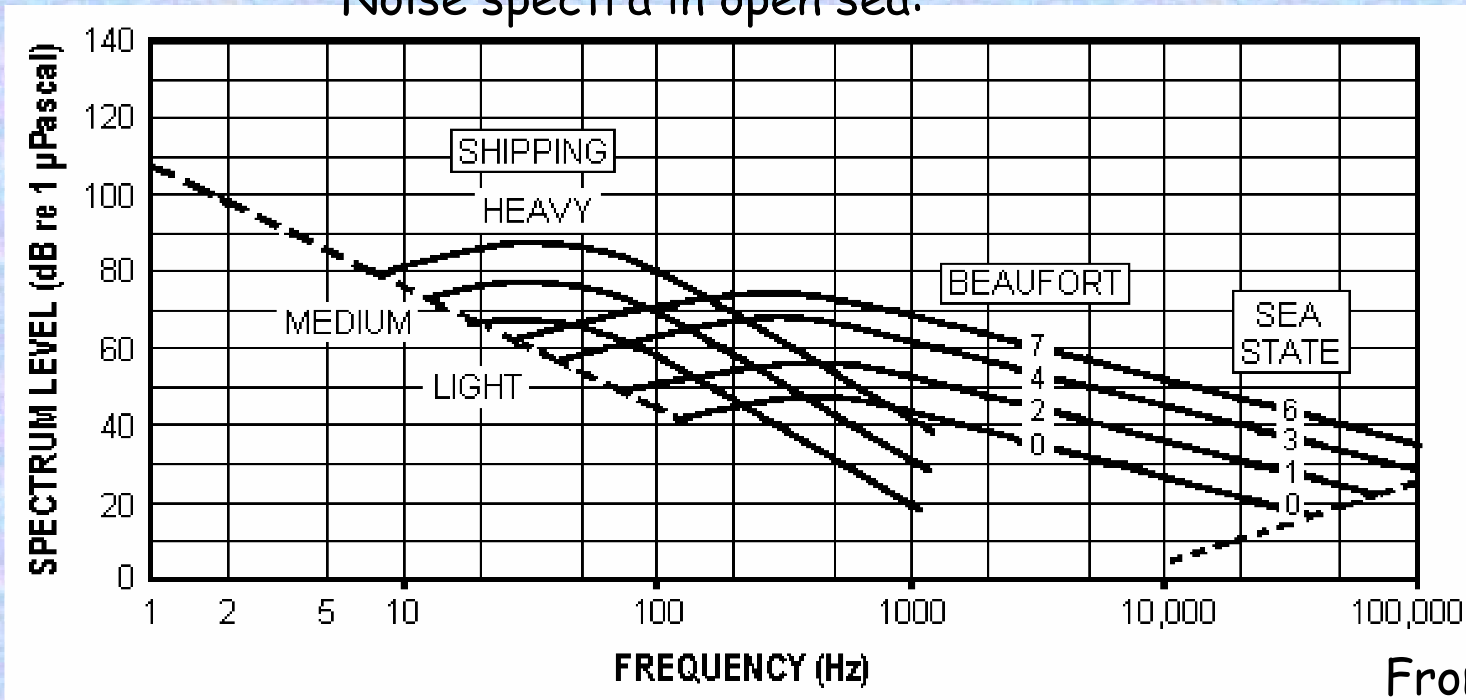
From Dusenbery, 1992

Range of human hearing: 0->100dB For comparison: solar constant=1.37Kw/m^2.

Types of sounds

Noises are irregular and disordered vibrations including all possible frequencies. Their picture does not repeat in time. The noise is an aperiodic series of waves.

Noise spectra in open sea:



From Urick, 1983.

Sounds that are sine waves with fixed frequency and amplitude are perceived as **pure tones**. While sound waves are usually visualised as sine waves, sound waves can have arbitrary shapes and frequency content. In fact, most sound waves consist of multiple overtones (harmonics) and any sound can be thought of as being composed of sine waves (Fourier's theorem).

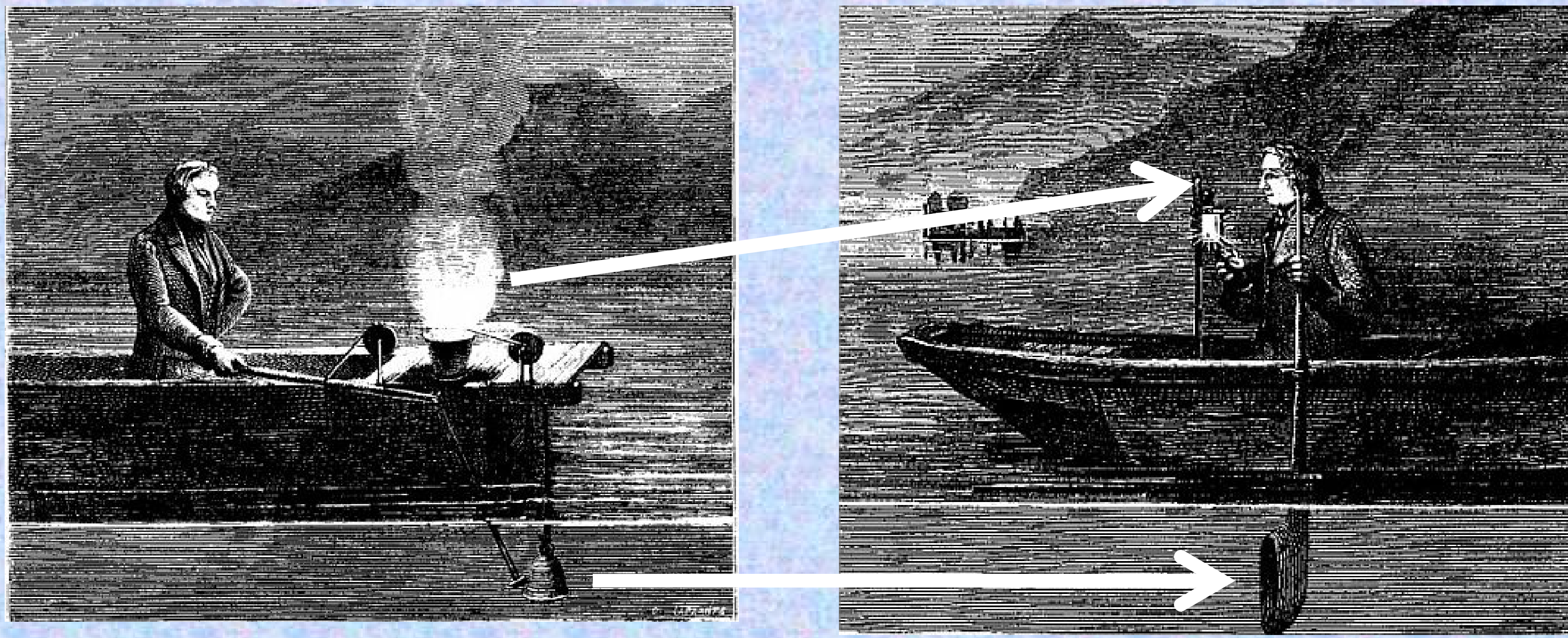
Perception of sound

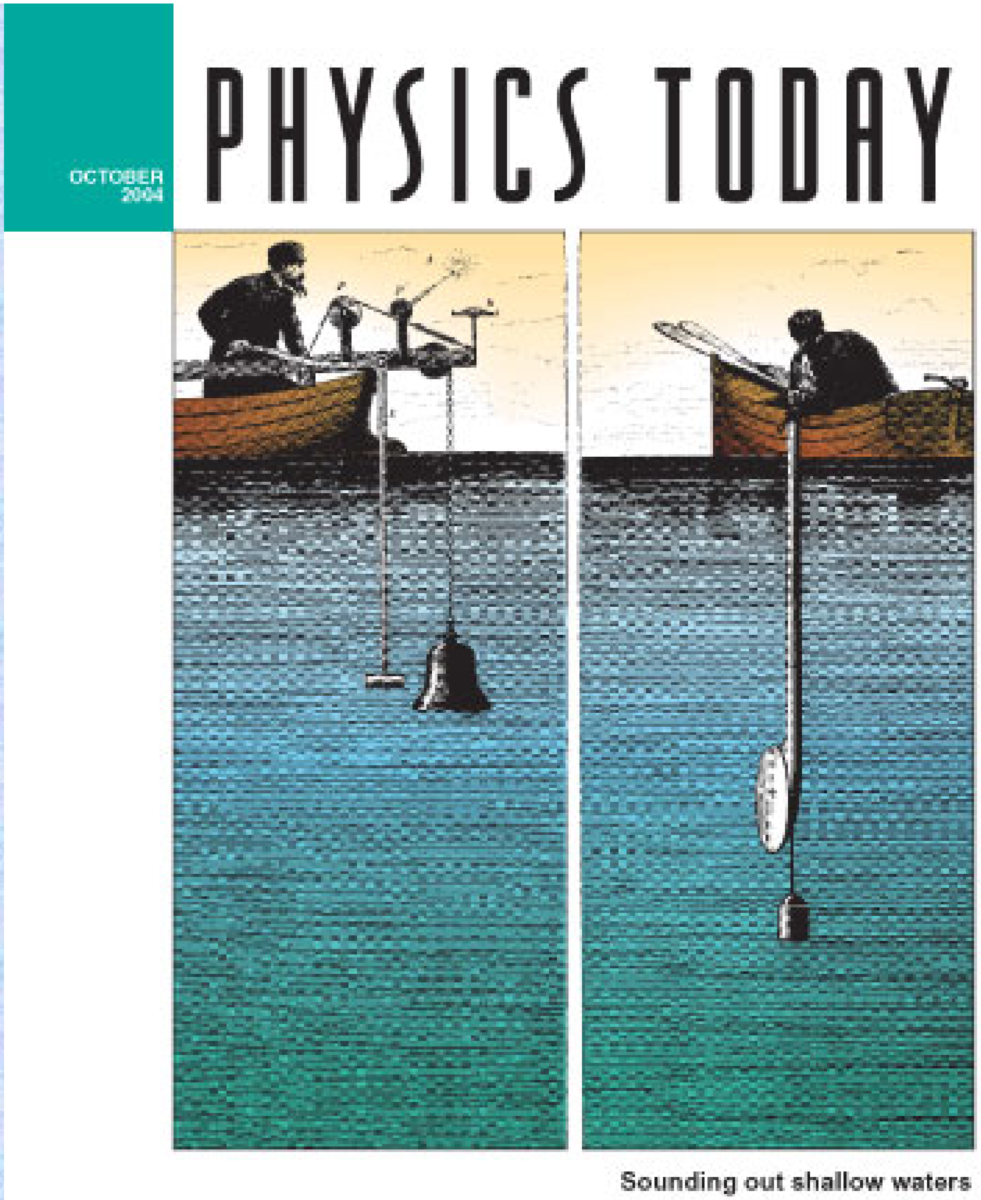
The perception of sound is the sense of hearing. In humans and many animals this is accomplished by the ears, but loud sounds and low frequency sounds can be perceived by other parts of the body.

Sound and animals:
- Communication.
- Obtain information about the surrounding environment.

Human vision-3 primary color. Human hearing-24 distinguishable frequency bands → higher informational content.

A little bit of history:





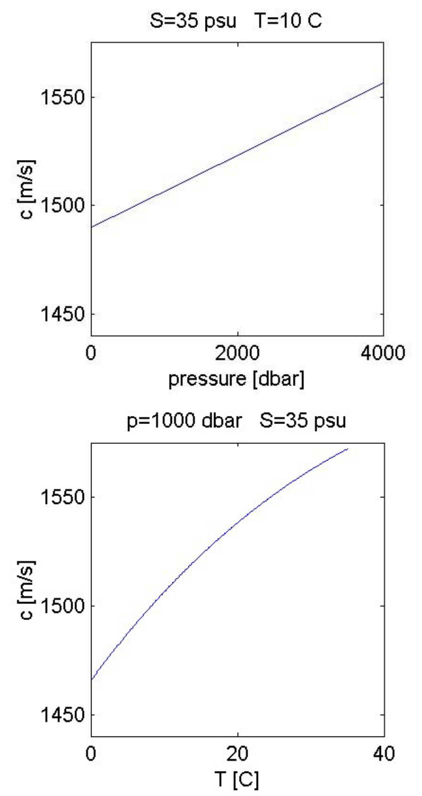
In 1826, an experiment measured the speed of sound in the waters of Lake Geneva, Switzerland, as memorialized in this sketch. One rower simultanously struck a bell and lit a spark while the other, ten miles away, measured the time difference between detecting the two events. (Image adapted from J. D. Colladon, *Souvenirs et Mémoires,* Albert-Schuchardt, Geneva, 1893.)

Velocity of sound in the ocean:

$$c = \sqrt{\frac{\partial p}{\partial \rho}}_{const.entropy} = \sqrt{\frac{\text{Bulk modulus}}{\rho}}$$

$C=1449.2+4.6T-0.055T^2+2.9\times10^{-4}T^3+(1.34-0.01T)(S-35)+1.6\times10^{-2}z$

[T]=C, [S]=ppt, [z]=m,   Urick, 1983.

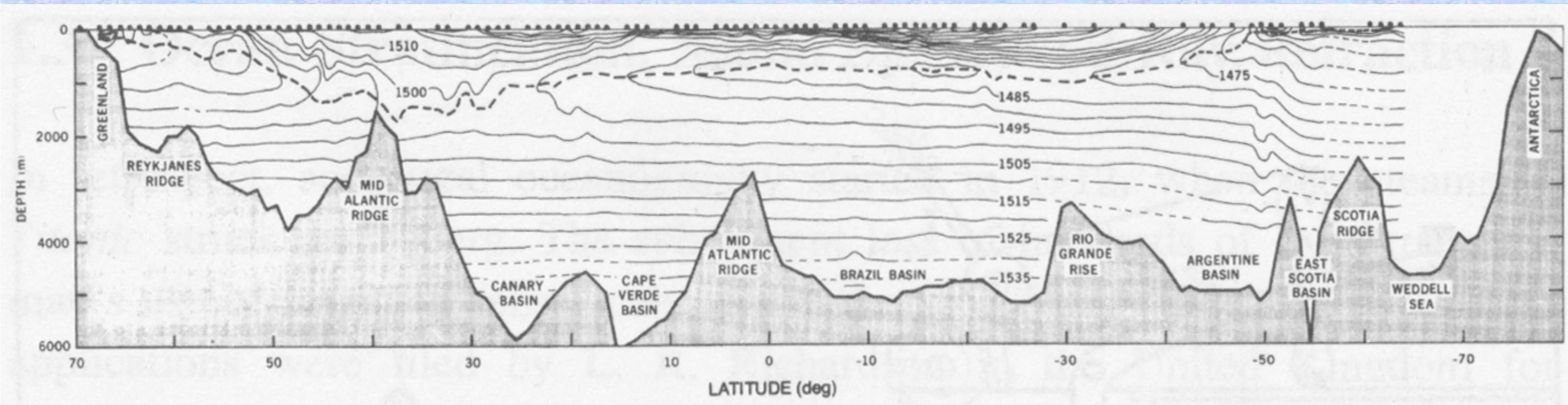


➔Invert sound speed to obtain temperature and/or salinity

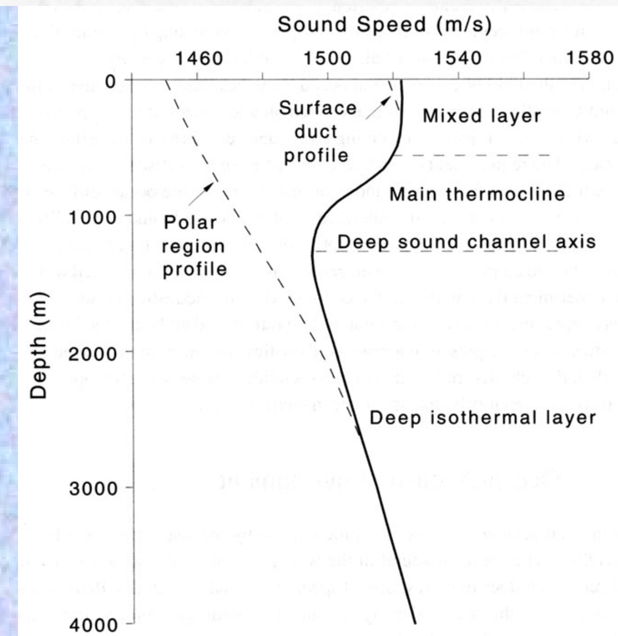
Moum, 2003
available as Matlab seawater routines
(http://sea-mat.whoi.edu/)

Distribution of sound speed:

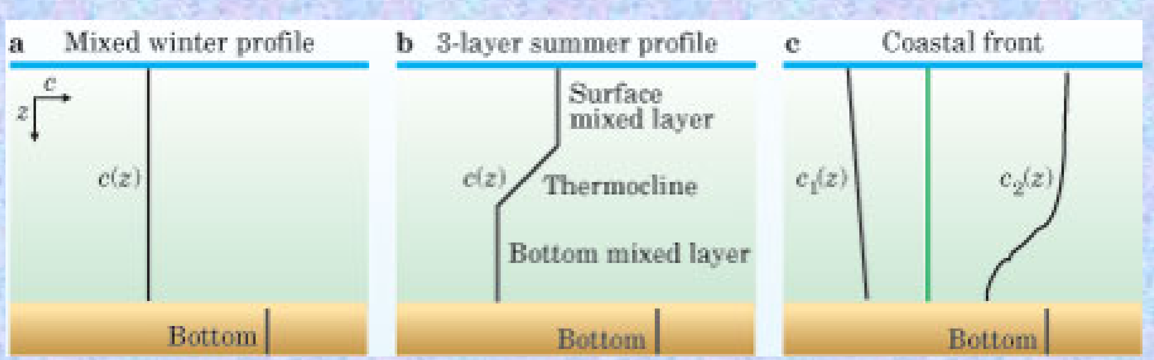
Deep ocean:



Northrup and Colborn, 1974

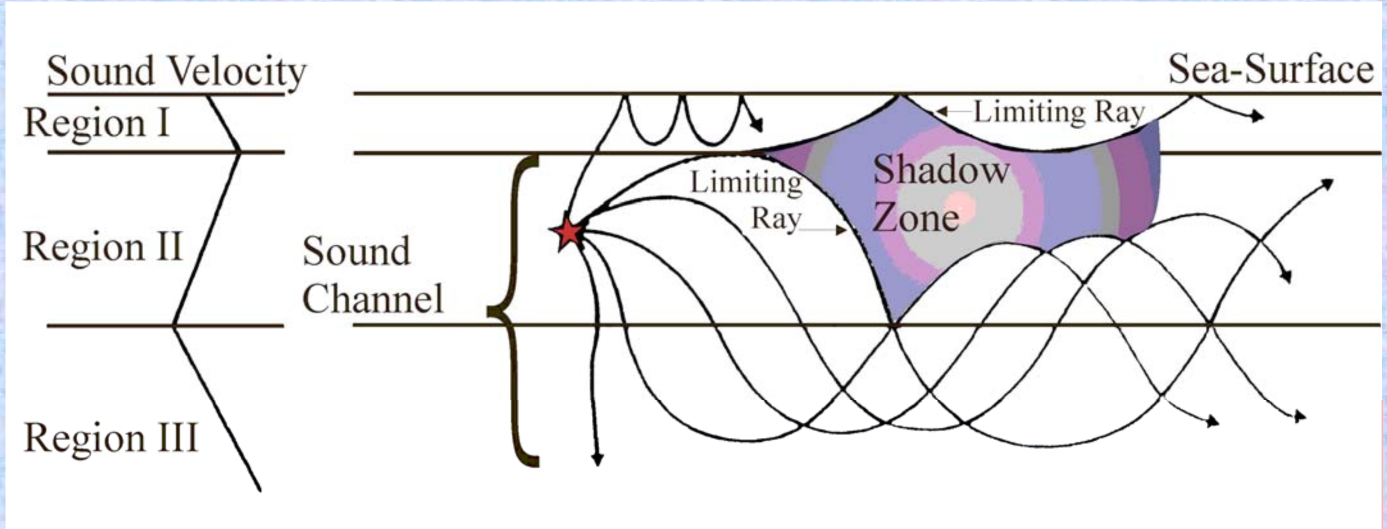


Coastal ocean:

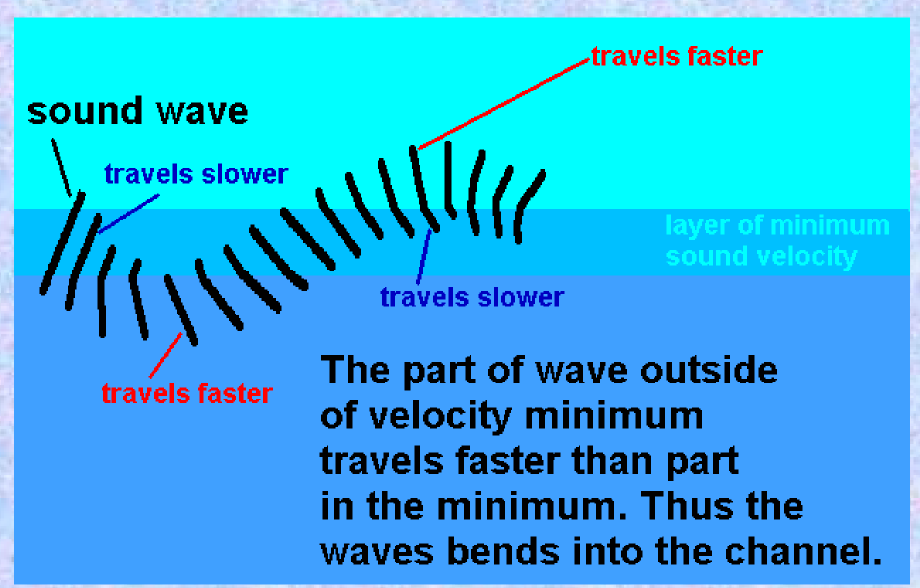


Kuperman and Lynch, 2004

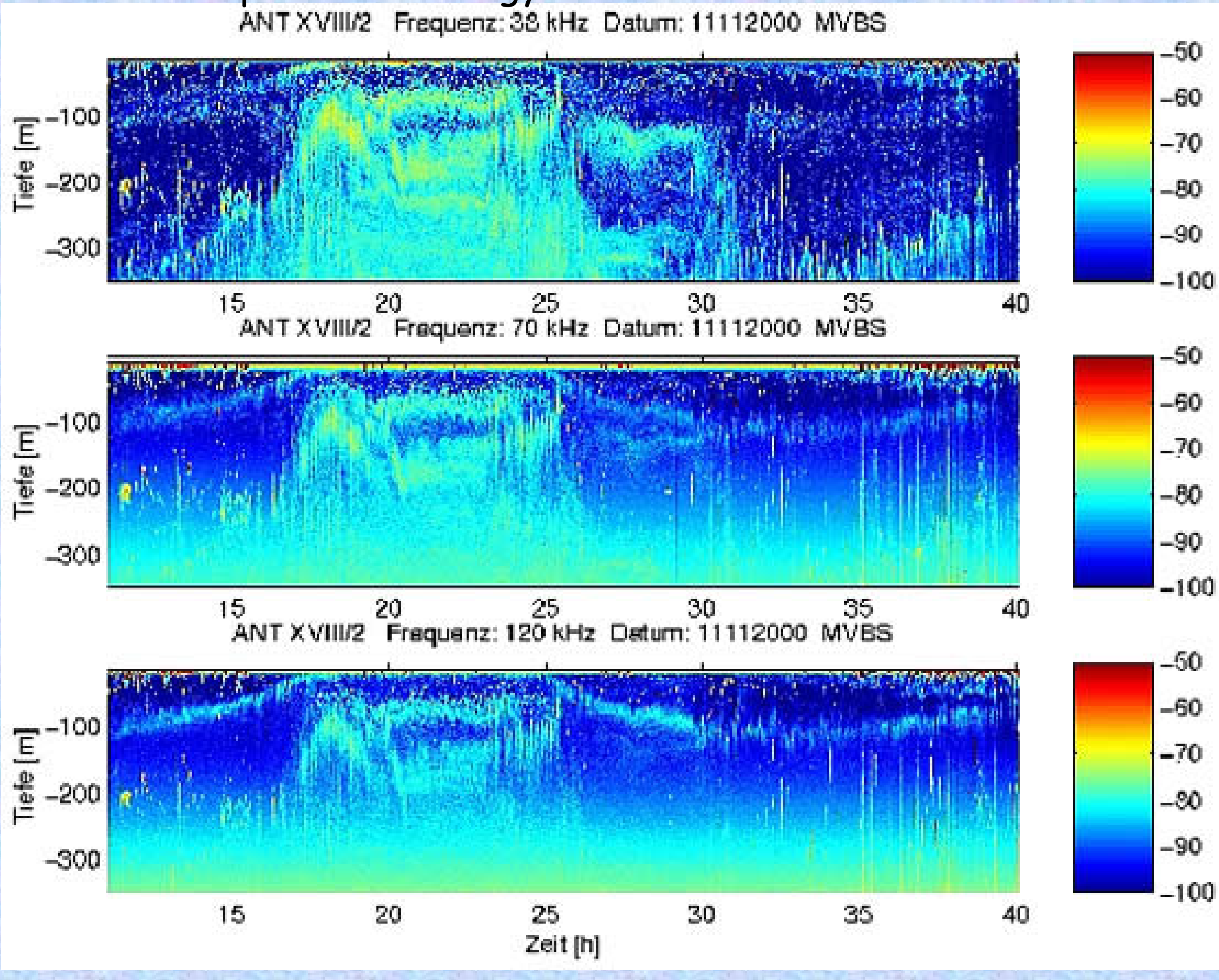
Sound diffraction, the SOFAR (SOund Fixing And Ranging) channel:



http://freespace.virgin.net/mark.davidson3/propagation/propagation.html



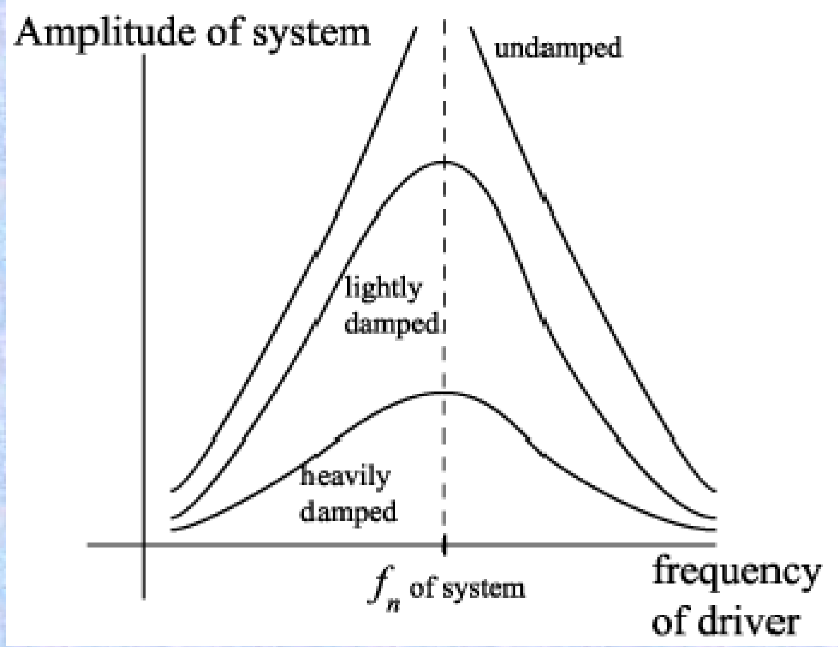
Applications- zooplankton ecology:



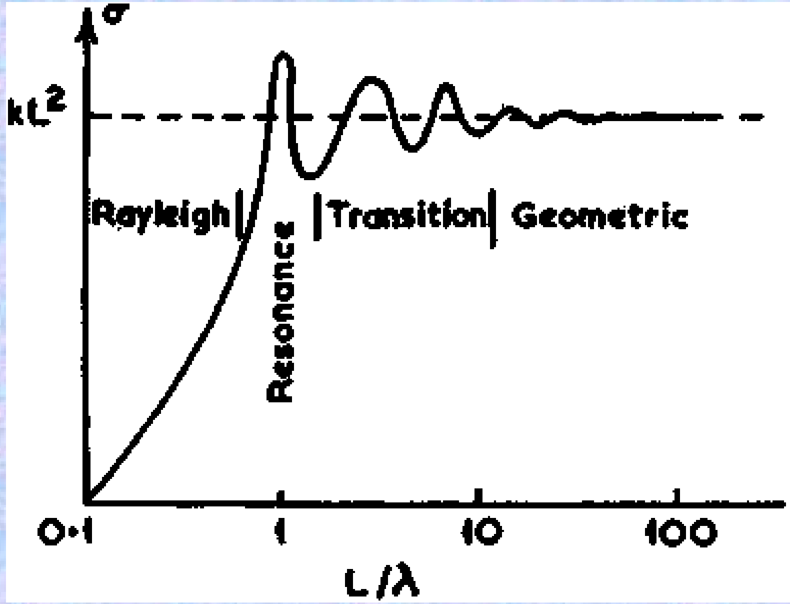
http://www.awi-bremerhaven.de/Biomeer/zooplankton-top03-e.html

Resonance

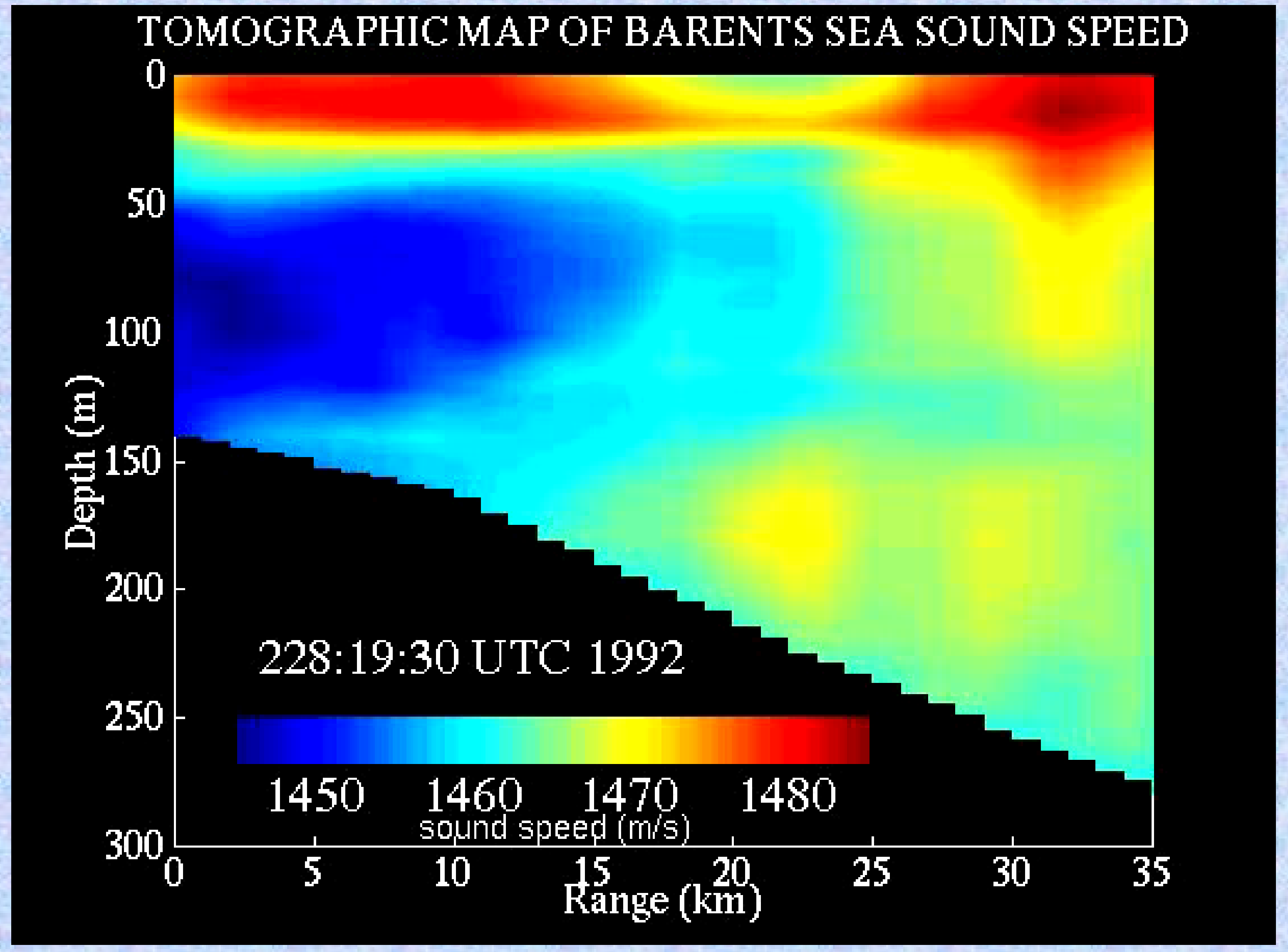
- Physical construct have natural frequencies based on their dimensions.
- Forcing at these frequencies (among others) result in large response at the resonant (s) frequency (ies).



Scattering: Redirction of sound (reflection, refraction, diffraction)

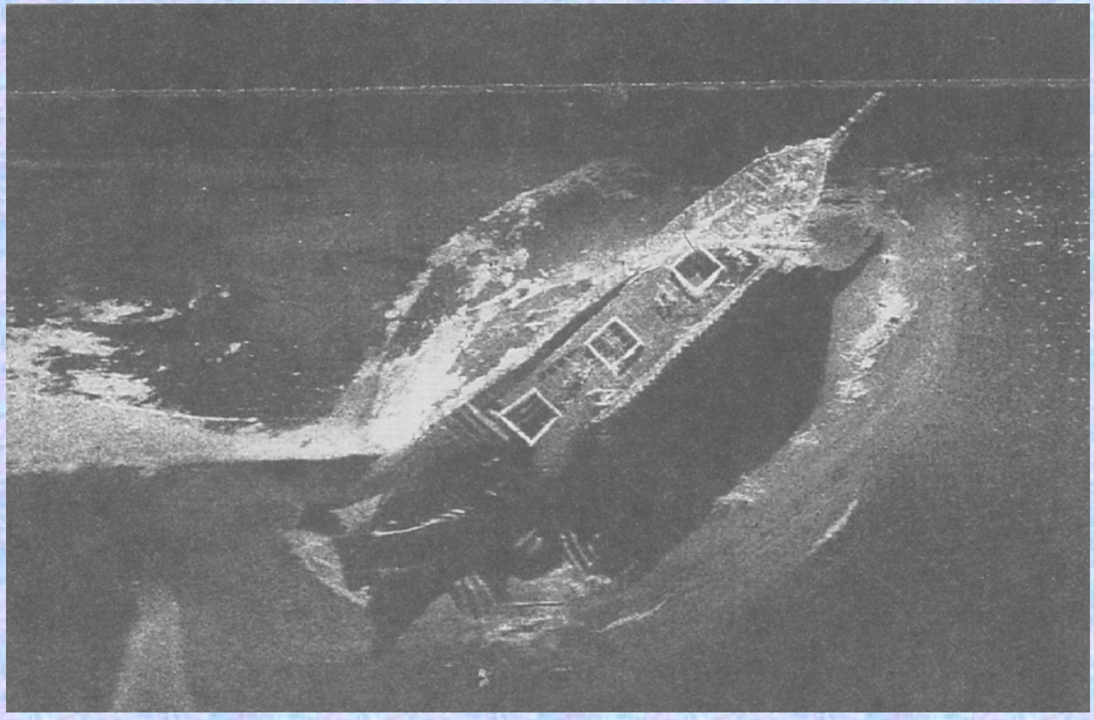


Applications- remote sensing of temperature distribution:



http://www.oal.whoi.edu/tomo2.html

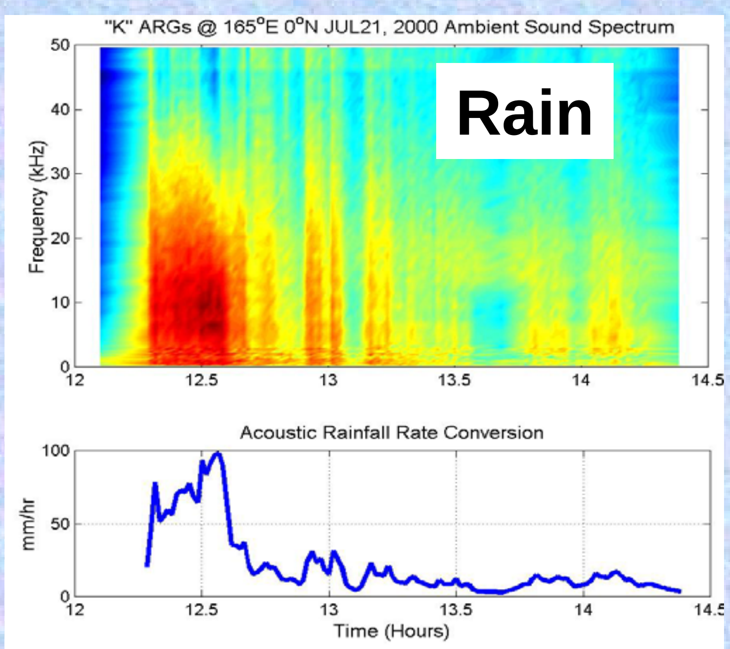
Applications- remote sensing of bottoms and objects above and within it:

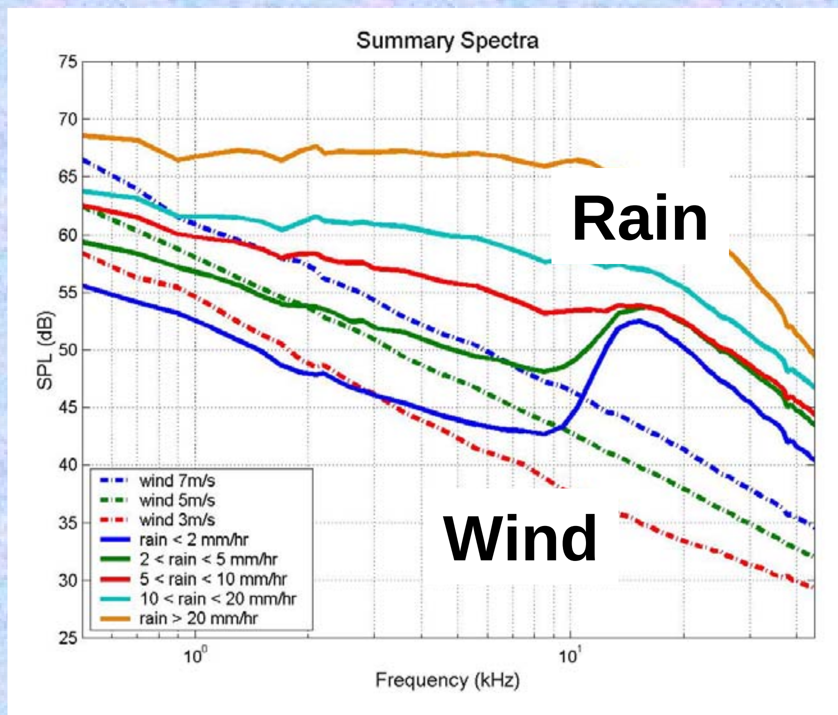


500 kHz sidescan sonar image towed 14 m above bottom

water depth 38 m
ship length 57 m
optical visibility 1 m

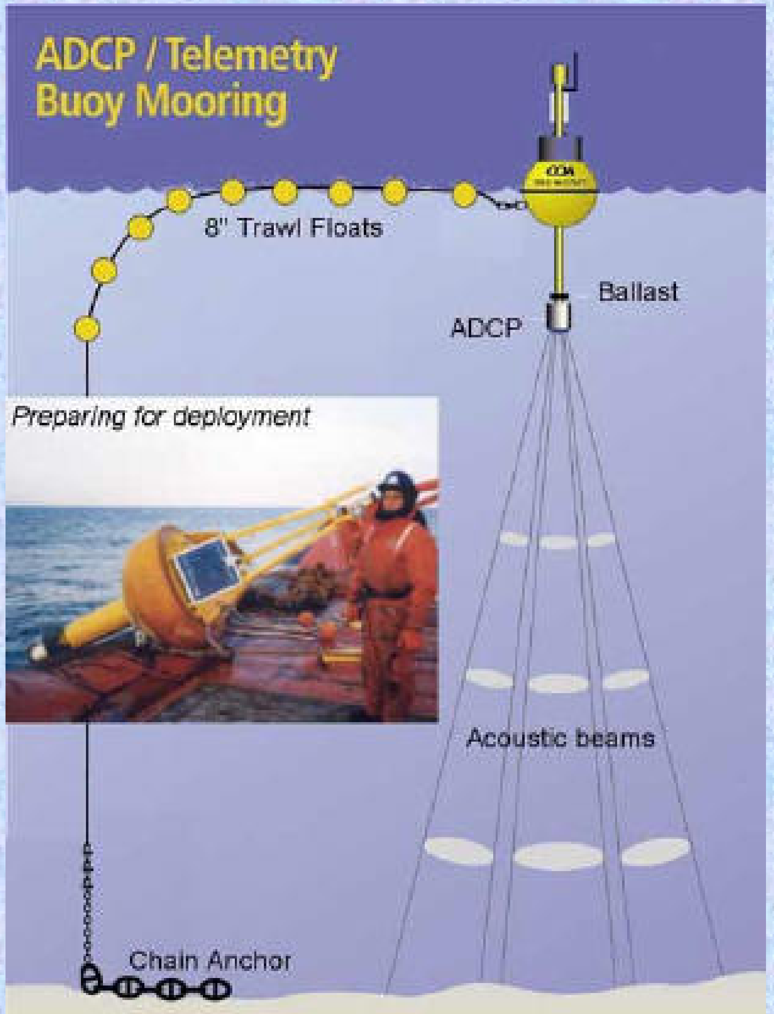
Application: measuring rain on 70% of the earth…

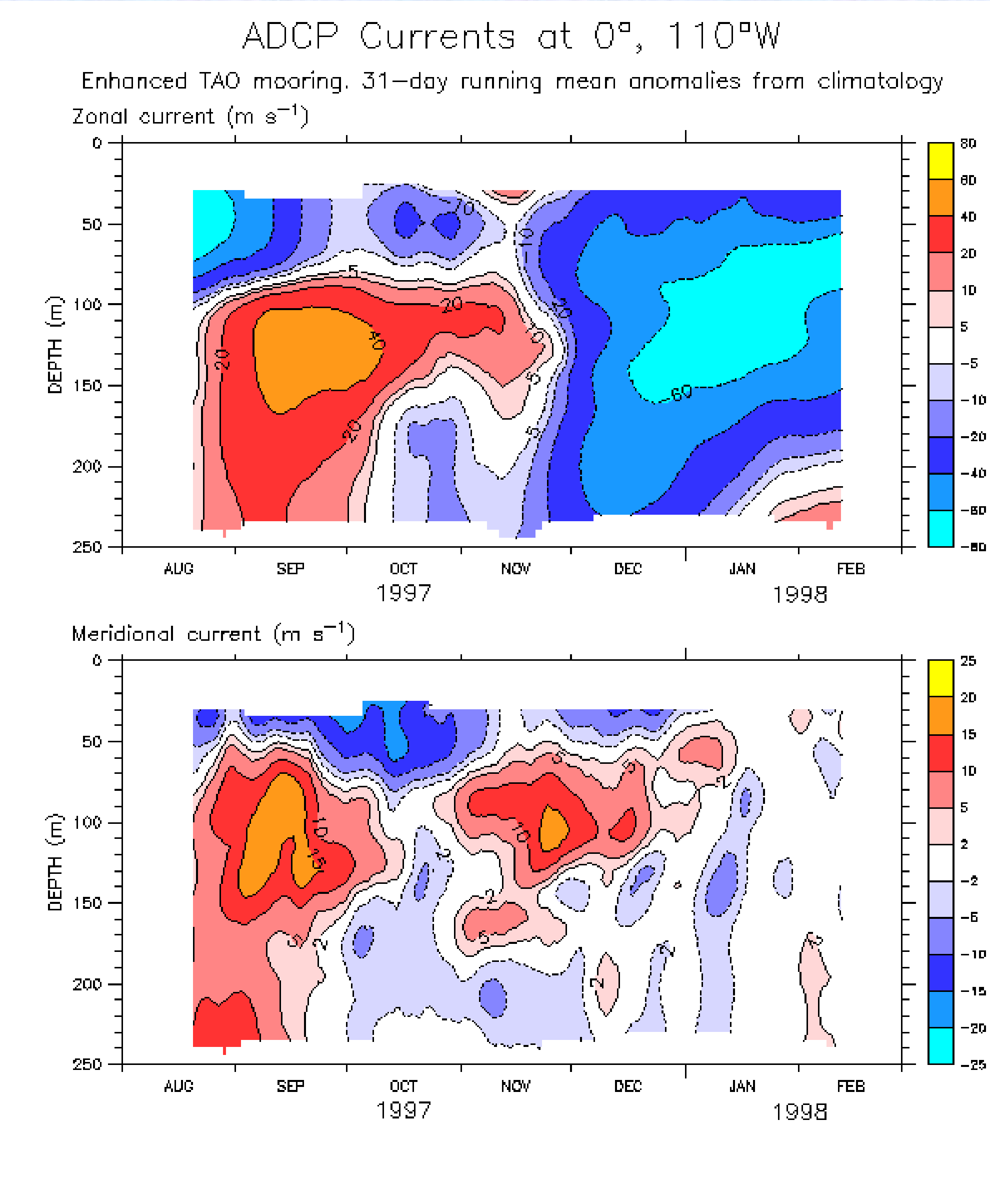




Nystuen

Application: measuring currents through Doppler and Eco Sounding





Doppler shift

- Change in frequency due to the motion of the source and/or the receiver
- Allows for determination of movement of target.

Stationary source:

$f = c/\lambda$

$f' = (c \pm u_r)/\lambda$

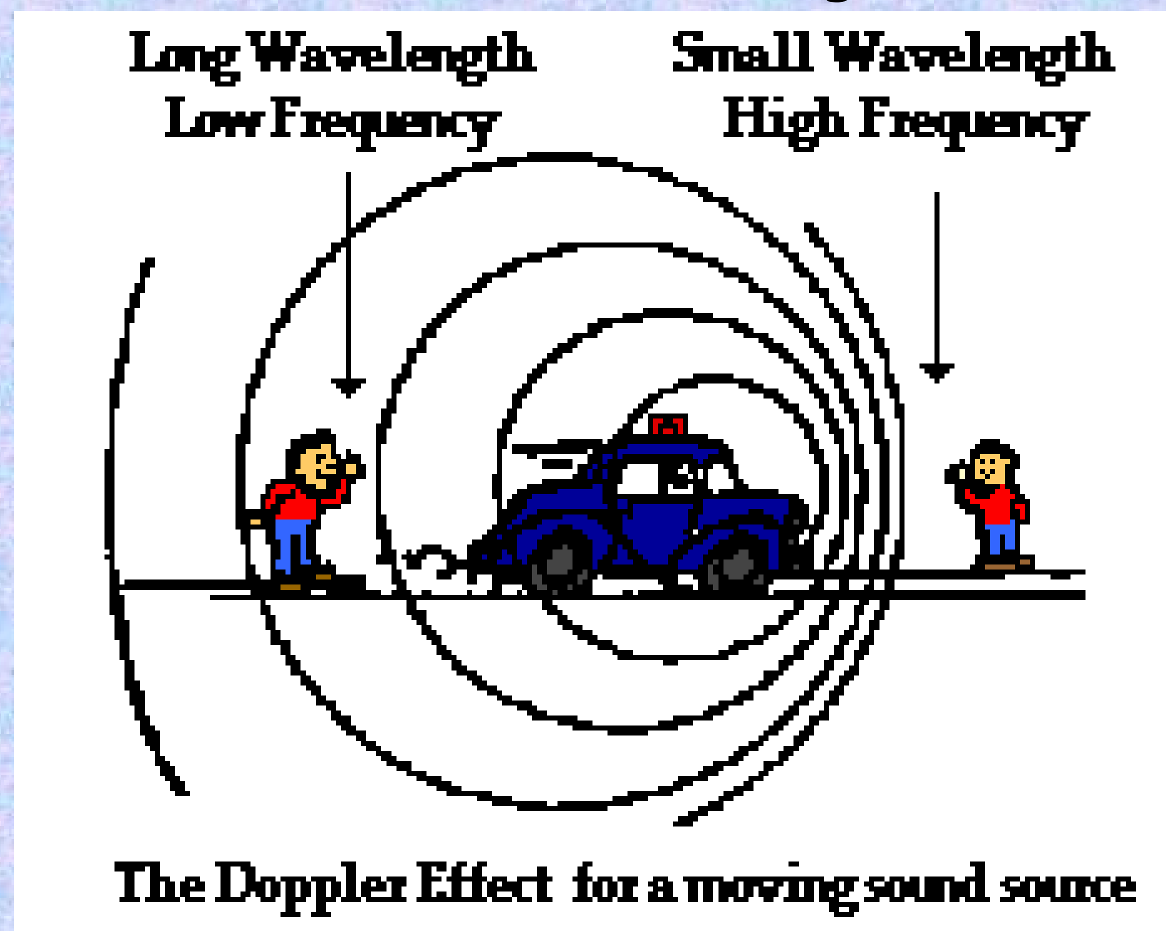
$\rightarrow \Delta f = \pm f u_r / c$

Stationary receiver:

$\Delta f = \pm f u_s/(c \pm u_s) \sim \pm f u_s / c$

Both moving:

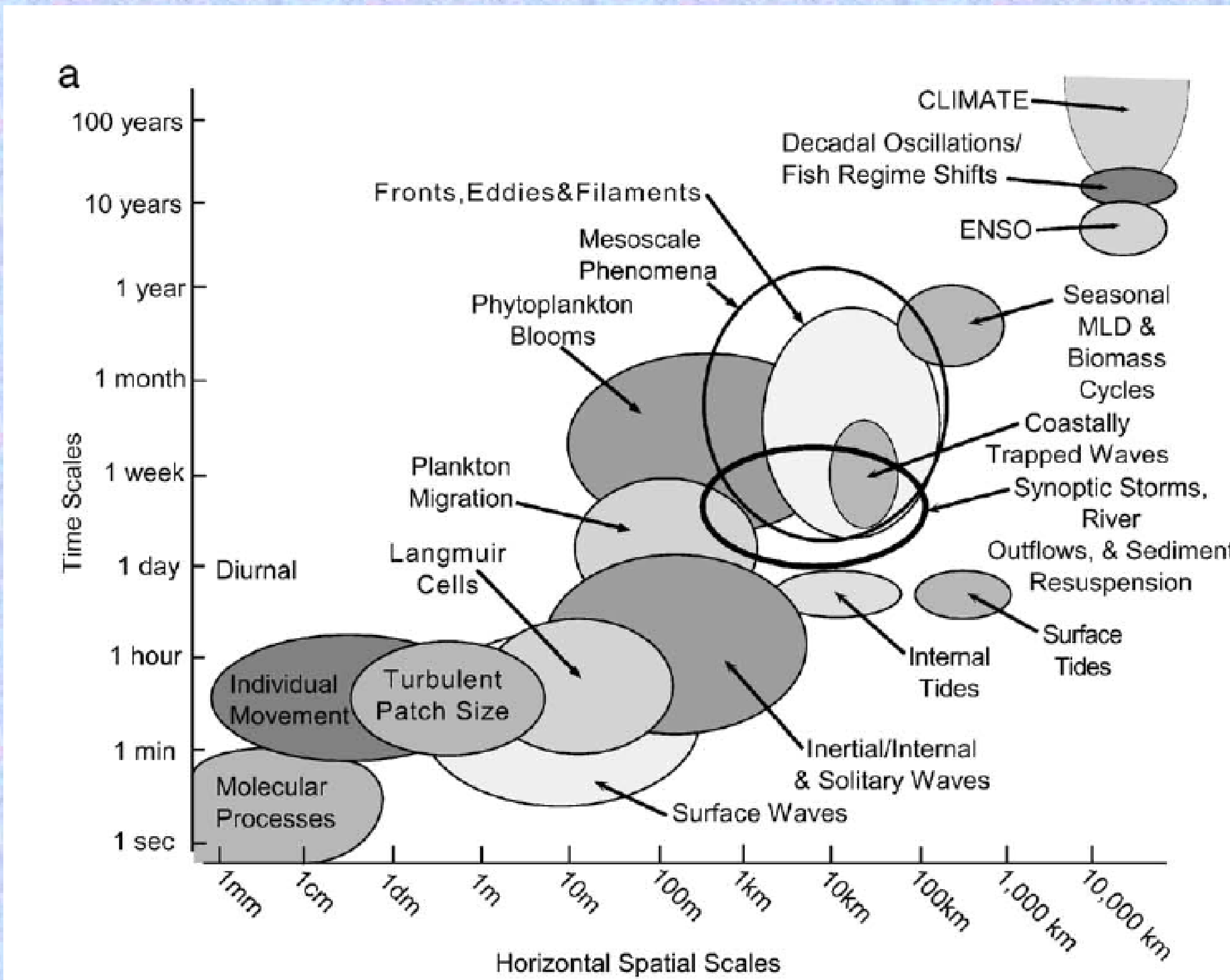
$\Delta f = f(\pm u_s \pm u_r)/c$



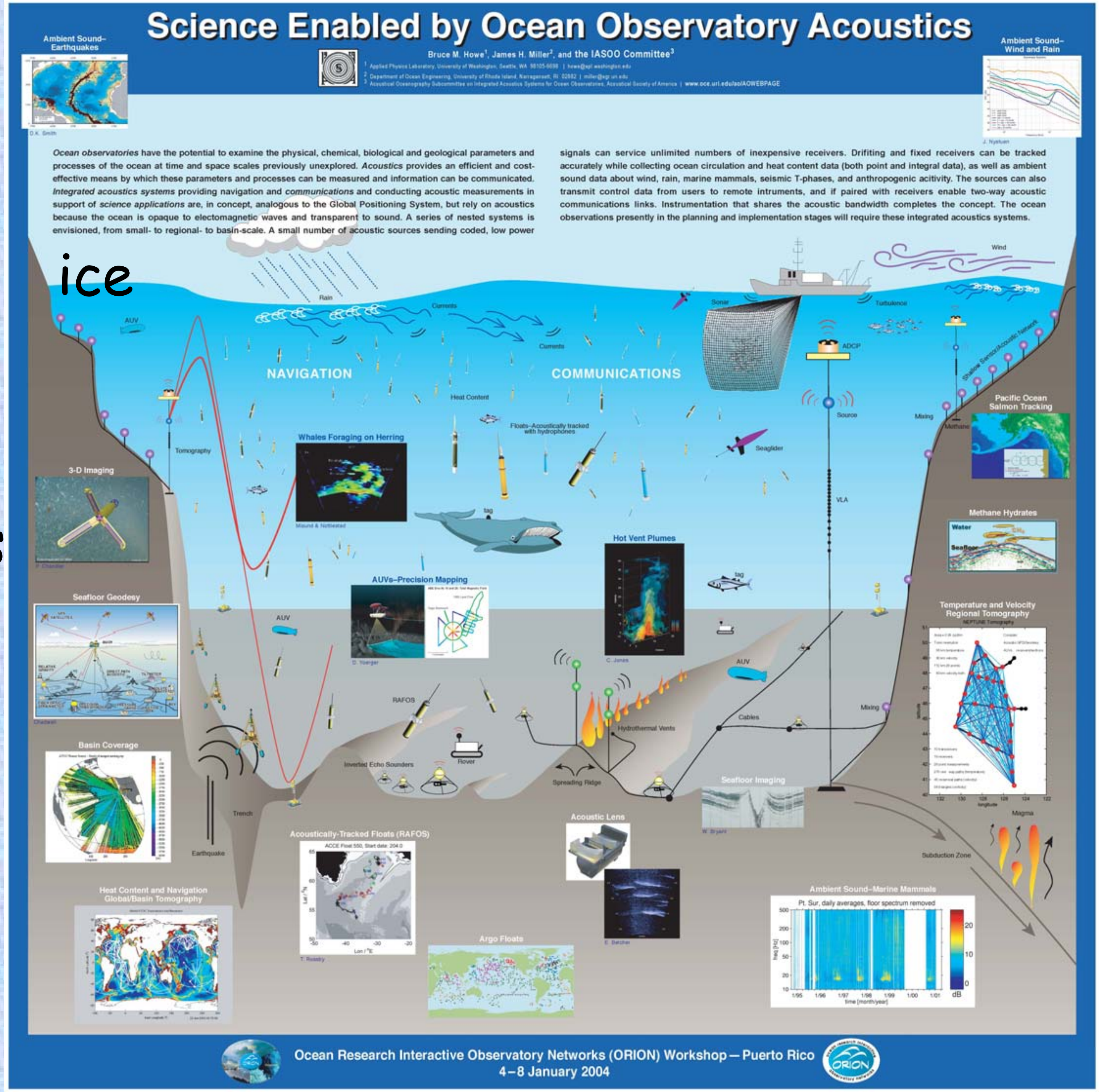
How is acoustics used and why (Howe, 2004)?

- Spatially extend point measurements
- Water borne seismic signals, tectonic events
- Seafloor geodesy
- Synoptic measurement of 3D ocean temperature and velocity fields (e.g. tomography)
- Marine life classification and/or tracking
- Enables real time adaptive sampling
- Robust sensors – long life, insensitive to biofouling, mature technology
- ADCPs, Inverted Echosounders, wind, rain
- Imaging
- Biomass, seabed mapping and characterization, hydrothermal venting, gas hydrate
- Subsea navigation and communications
- Marine animals, AUVs, gliders, floats, remote instruments

Physical (and some biological) processes:



Dickey, T., 2003, Emerging ocean observations for interdisciplinary data assimilation systems, J. Mar. Syst., 40-41, 5-48. (RB)



Ocean Observations
Howe, 2004