Sounds in the ocean
SMS-491, Fall 2012

Instructors: Emmanuel Boss and Jim Loftin

Introductions: why are we here?

Expectations: participation, blog, 5 assignments, term-paper.

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

Syllabus: basis for change depending on demand.

No textbook (list of books available to you on my self is on the web site.

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.
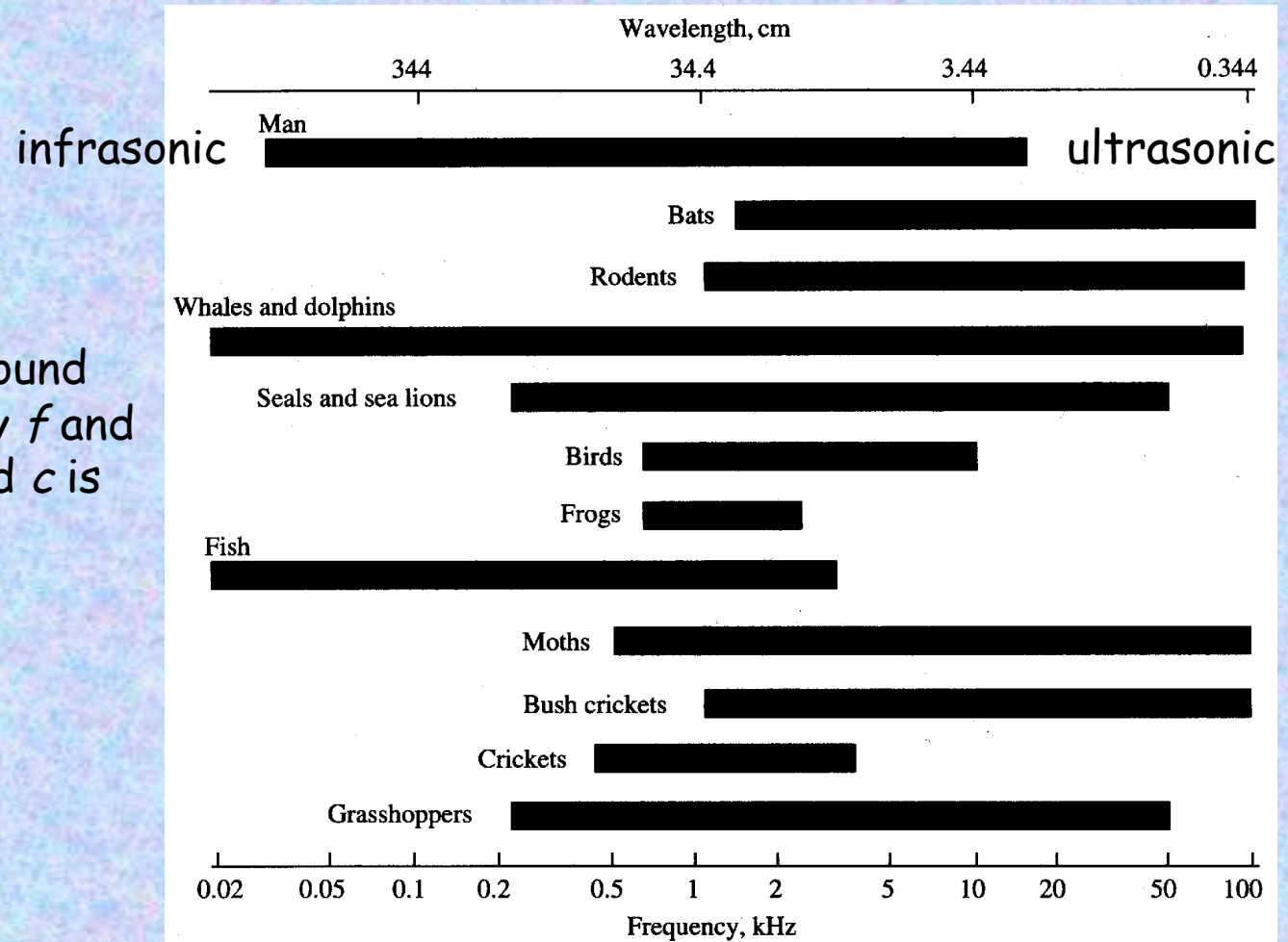

density

Direction of propagation

From: www.neurophys.wisc.edu/ ~ychen/textbase/s1-p5.html
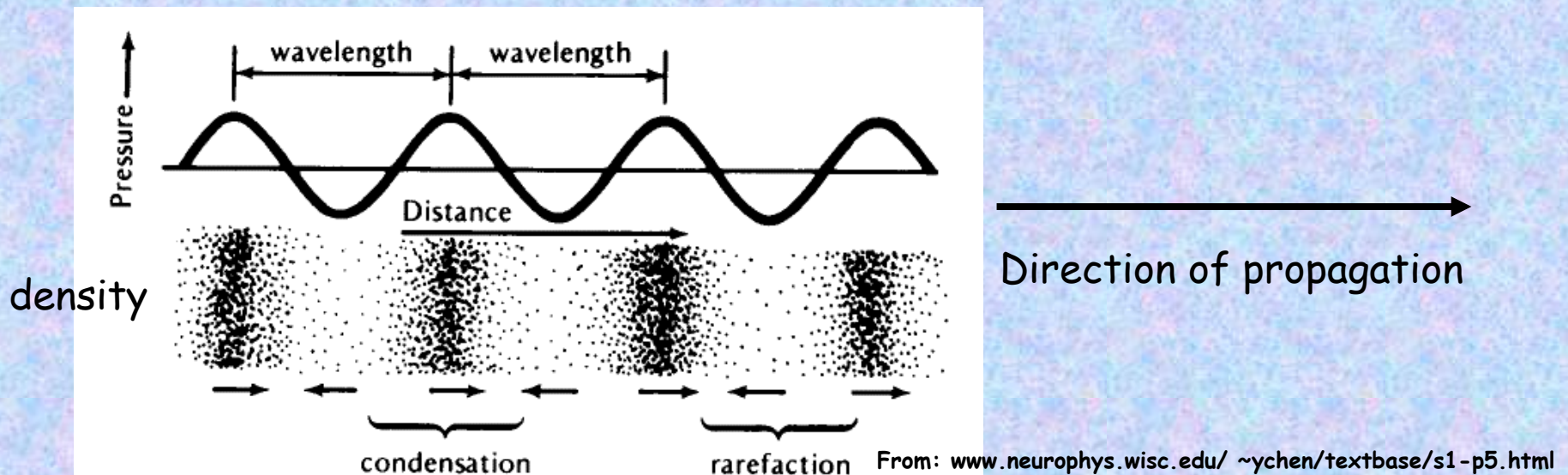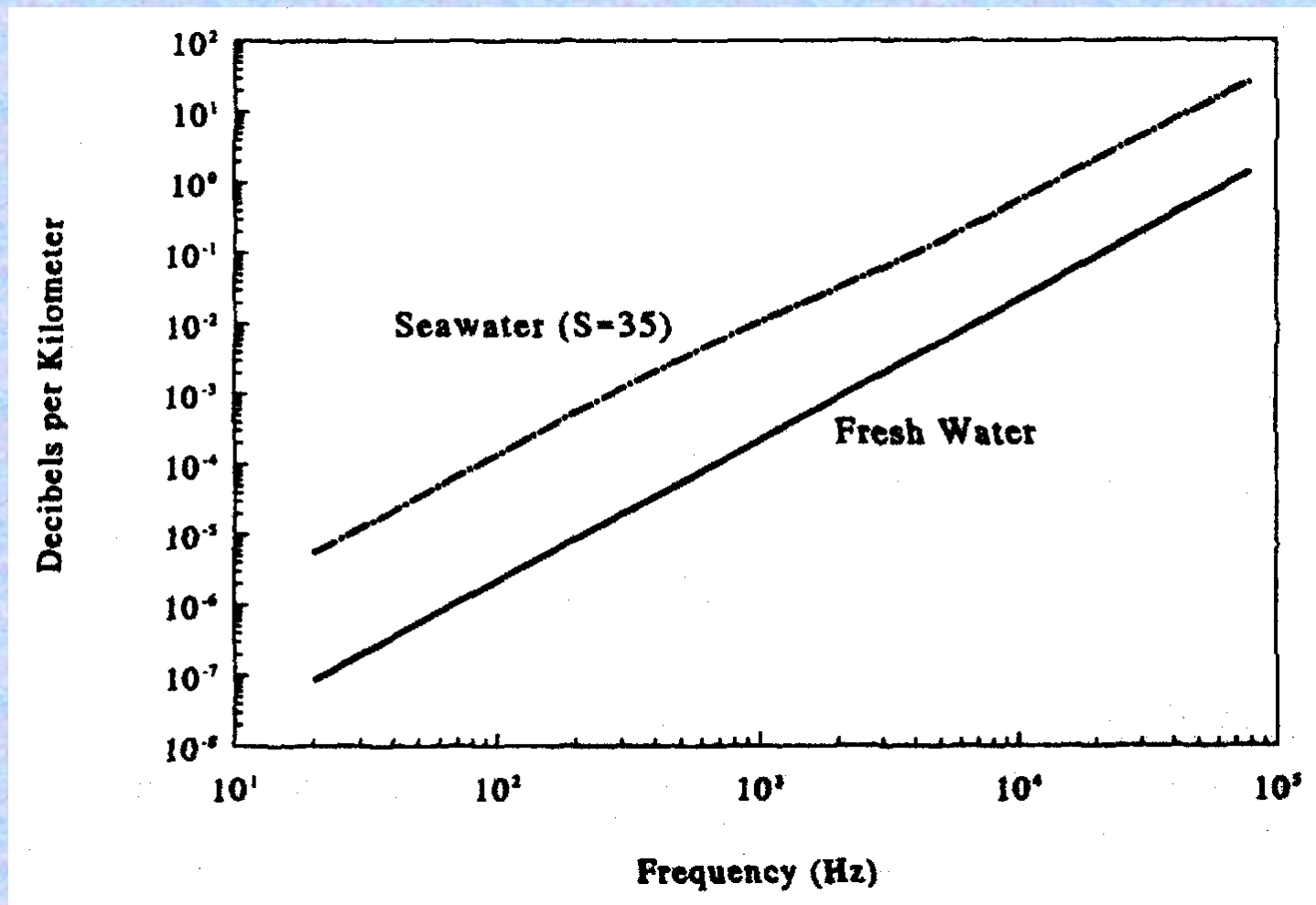
Attributes of sound:
Frequency and wavelength
The **frequency** is the number of air pressure (density or velocity) oscillations per second at a fixed point. One single oscillatory cycle per second corresponds to 1 Hz. Sound speed does not vary much with frequency but attenuation and wavelegth do.

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

infrasonic

ultrasonic

Wavelength, cm

| 344 | 34.4 | 3.44 | 0.344 |

Man

Bats

Rodents

Whales and dolphins

Seals and sea lions

Birds

Frogs

Fish

Moths

Bush crickets

Crickets

Grasshoppers

0.02 0.05 0.1 0.2 0.5 1 2 5 10 20 50 100
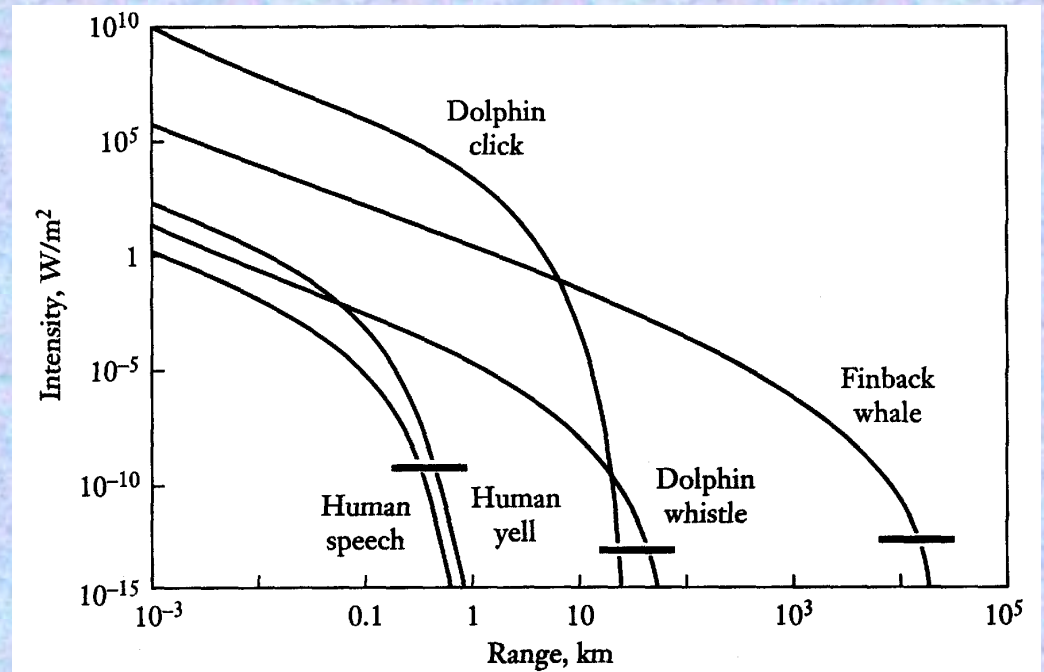
Frequency, kHz

Dusenbery, 1992

Attenuation in sea water is frequency and salinity dependent:

Dusenbery, 1992

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

$$I(r)=I(r=0)exp(-\alpha_e r)/4\pi r^2$$

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 (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

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

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 /m^2; N = newton) .

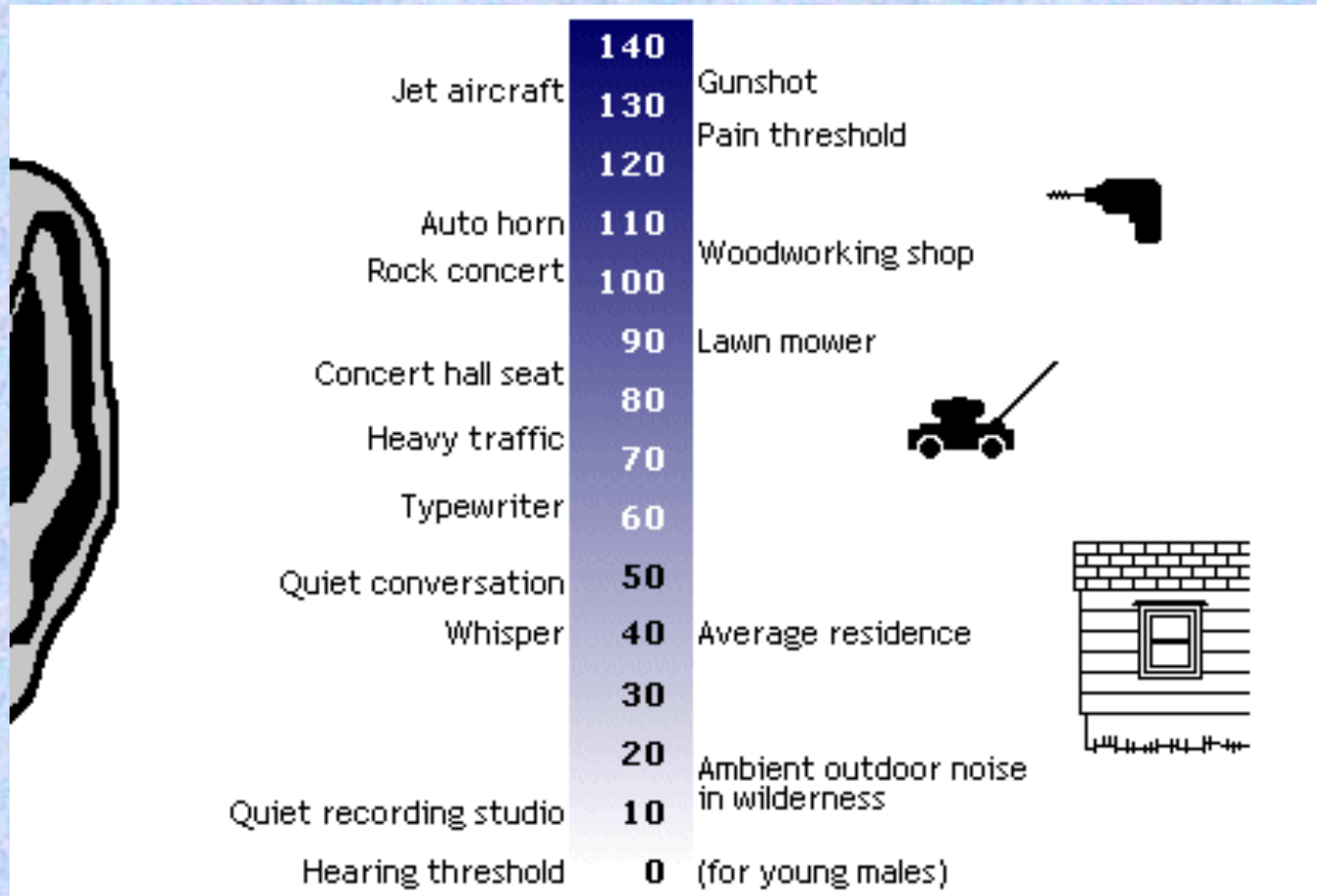Only decibel values using the same reference can be compared.

dB	I/I_0 dB SIL	P_s/P_0 dB SPL	Plane wave intensity w/m²	Plane wave intensity in water (same P_s)
			$I_0 = 10^{-12}$ w/m², Air	
-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/m².

Decibel scale:

dB		
140		
Jet aircraft	130	Gunshot
		Pain threshold
	120	
Auto horn	110	
Rock concert		Woodworking shop
	100	
	90	Lawn mower
Concert hall seat		
	80	
Heavy traffic	70	
Typewriter	60	
Quiet conversation	50	
Whisper	40	Average residence
	30	
	20	
Quiet recording studio	10	Ambient outdoor noise in wilderness
Hearing threshold	0	(for young males)

$C_{air}=350ms^{-1}$

$C_{water}=1500ms^{-1}$

$\rho_{air}=1.225Kgm^{-3}$

$\rho_{water}=1025Kgm^{-3}$

$$I=I_0 \times 10^{dB/10} \qquad I=<P^2>/(\rho c)$$

Each decade in the dB scale is an increase in sound intensity by a factor of 10!

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:
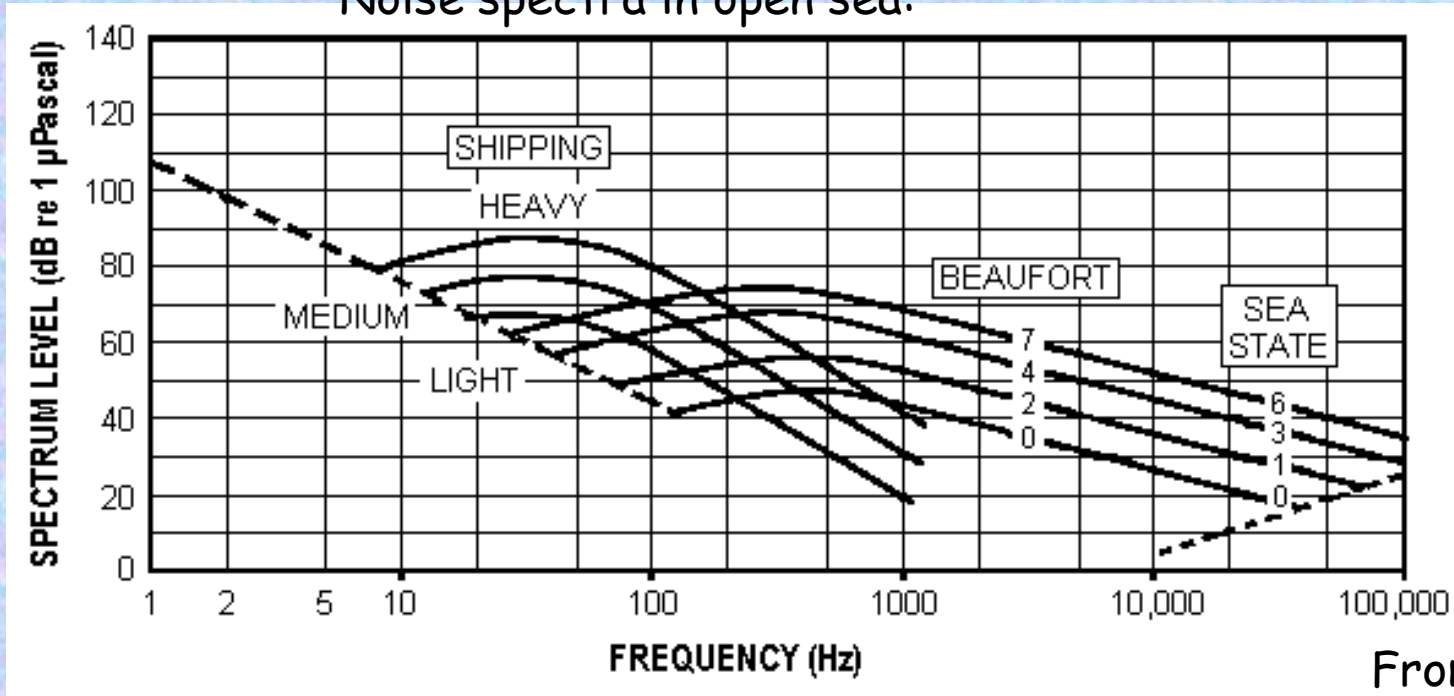
From Urick, 1983.

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:
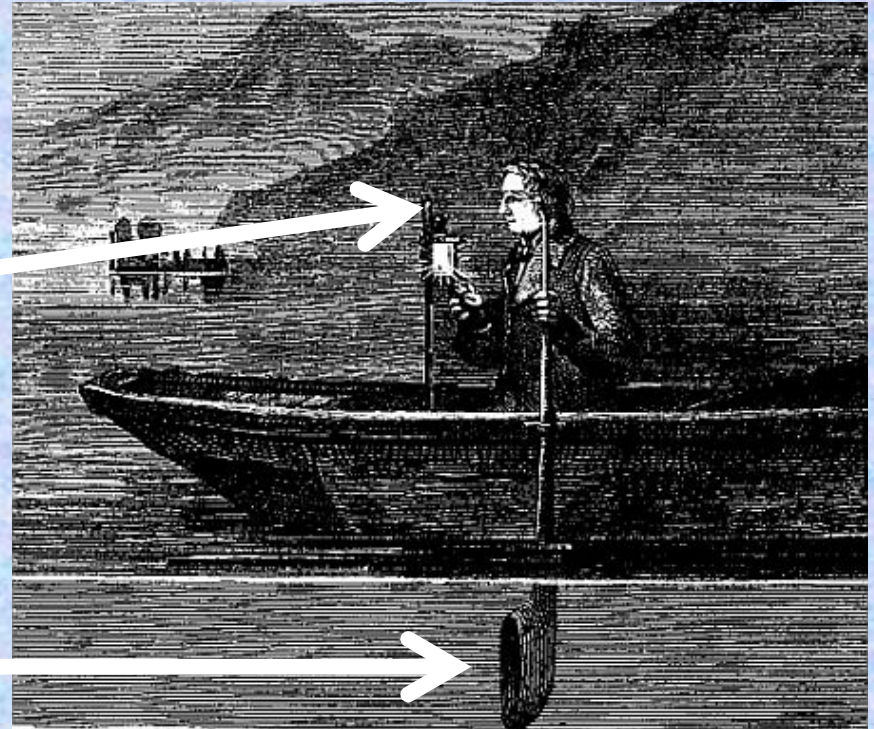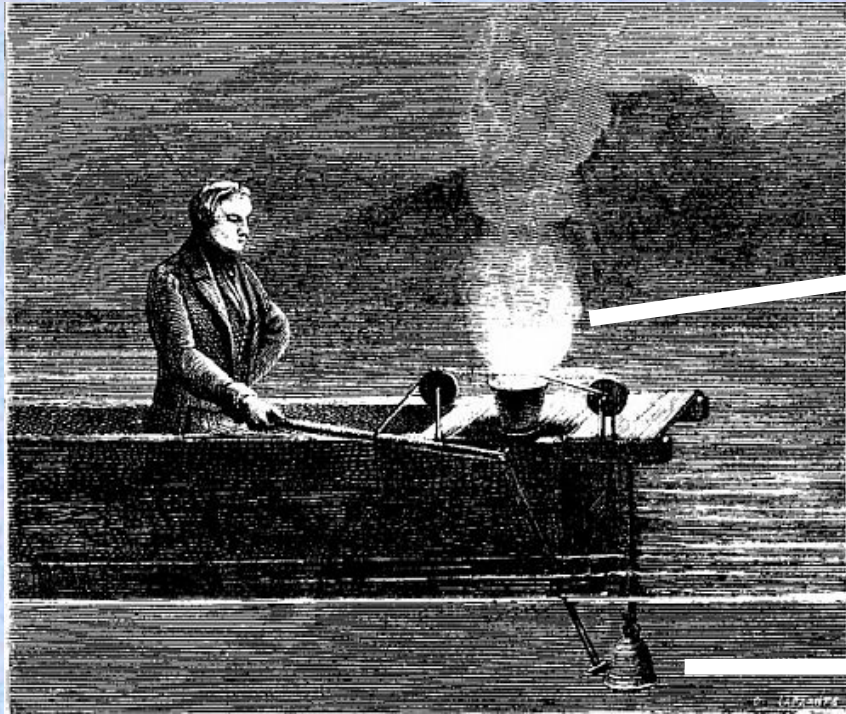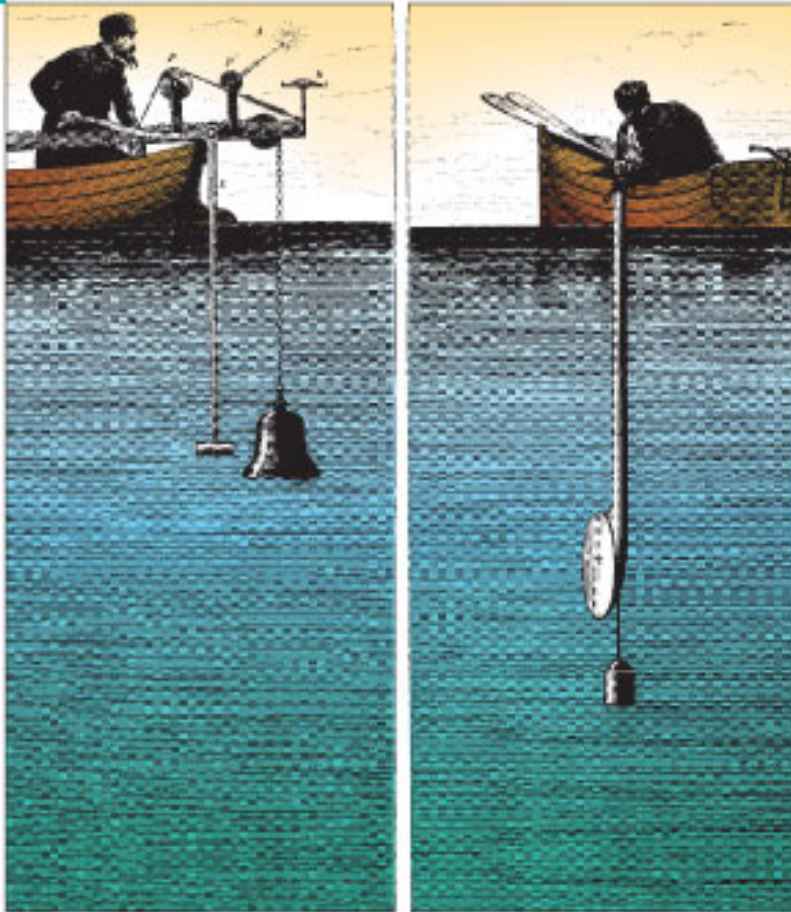
Sounding out shallow waters

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.
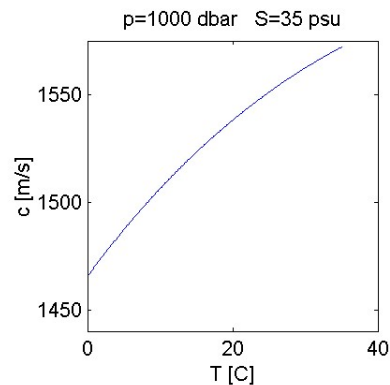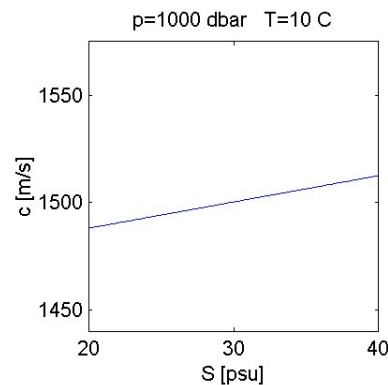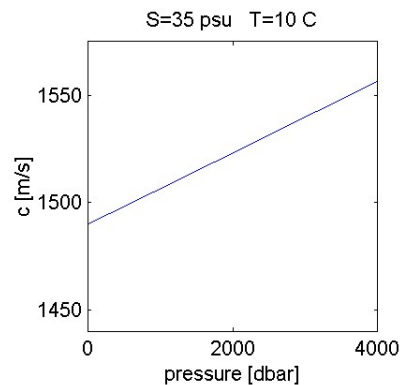
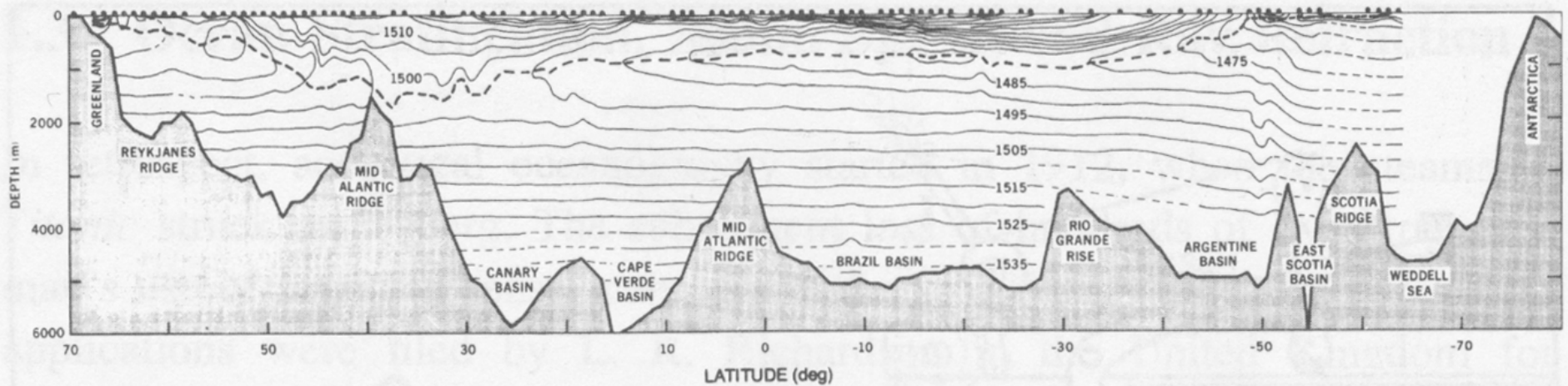➔Invert sound speed to obtain temperature and/or salinity

Moum, 2003
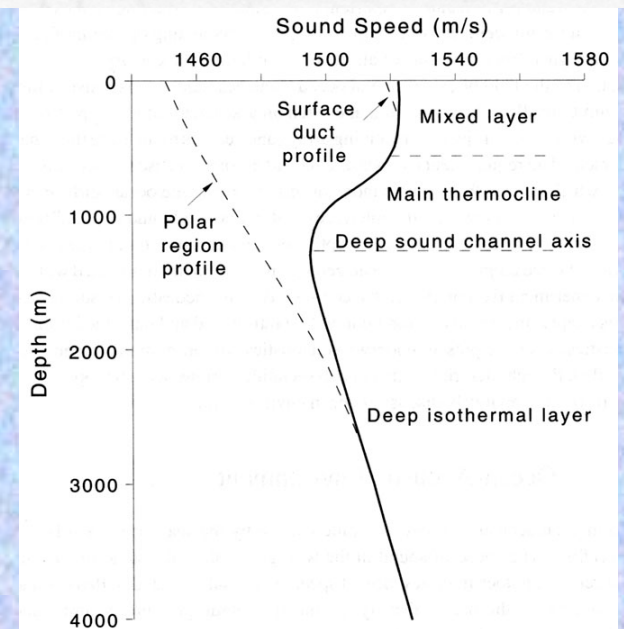available as Matlab seawater routines
(http://sea-mat.whoi.edu/)
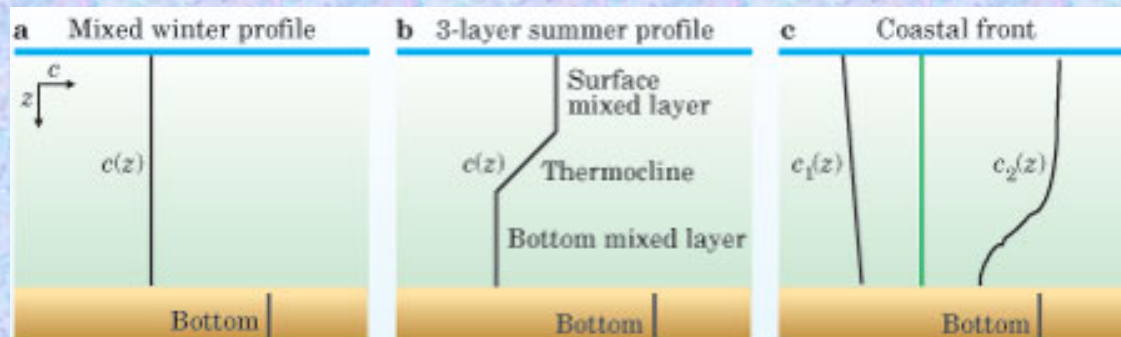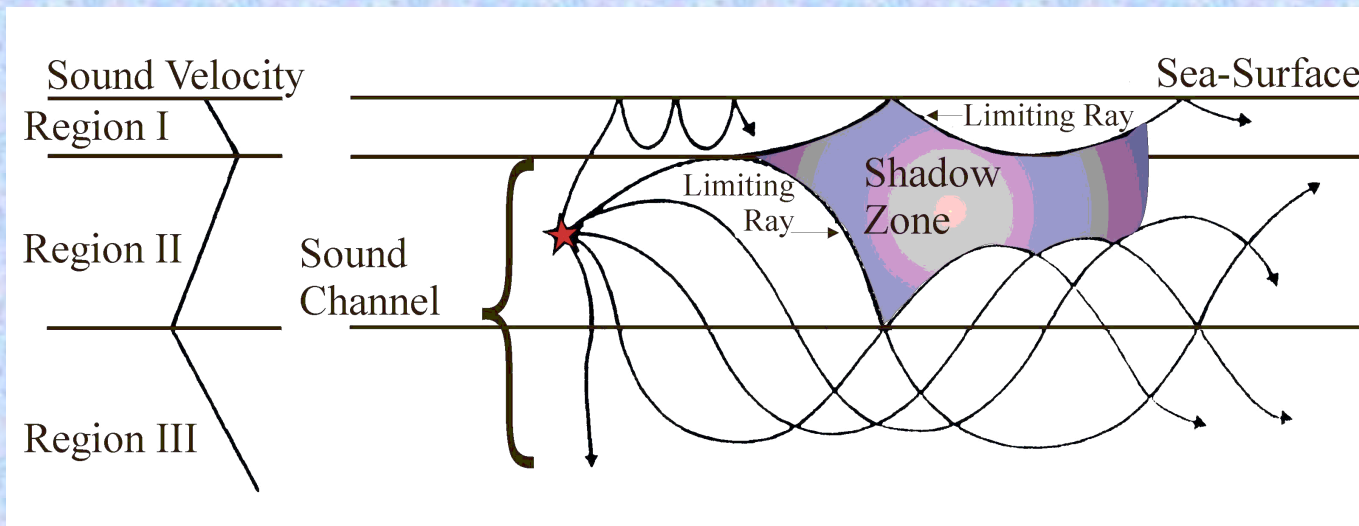
Distribution of sound speed:
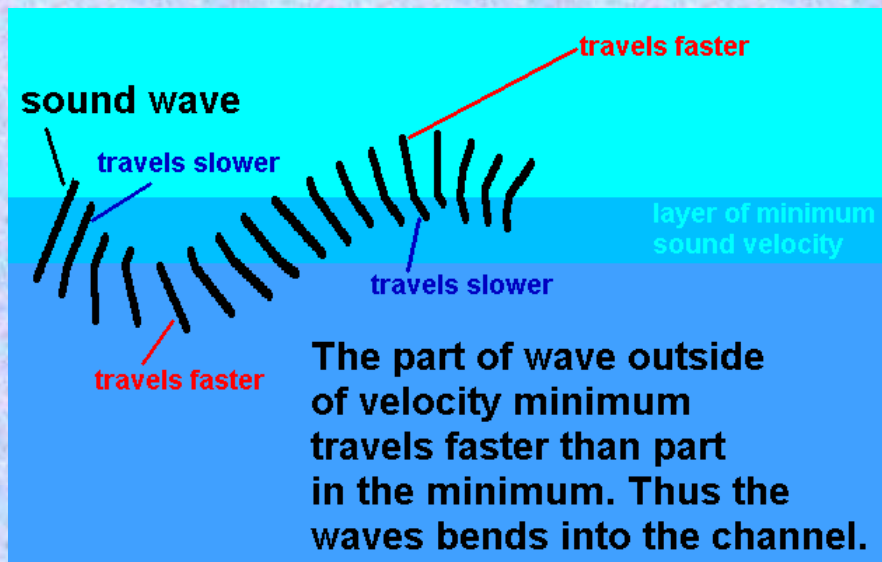
Deep ocean:

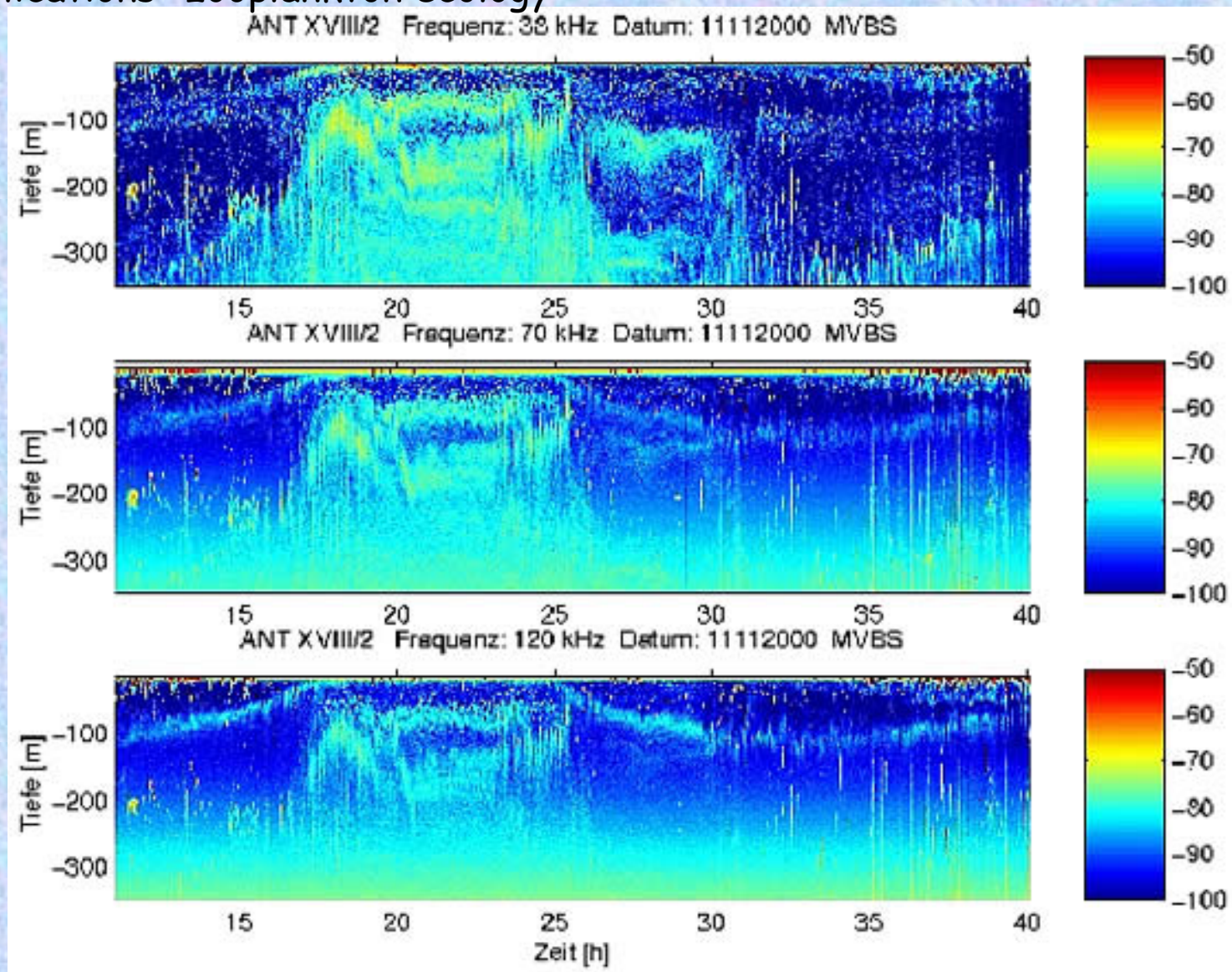Northrup and Colborn, 1974

Coastal ocean:

Kuperman and Lynch, 2004

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

http://freespace.virgin.net/mark.davidson3/propagation/propagation.html
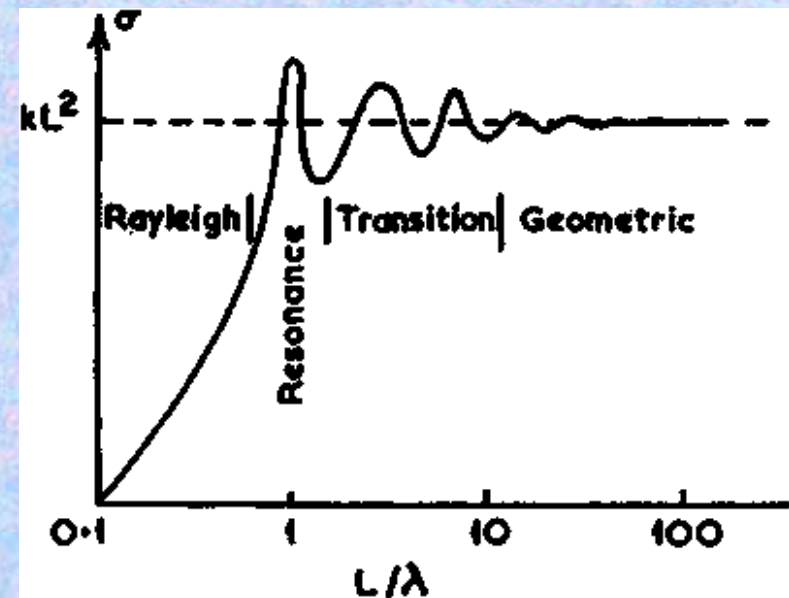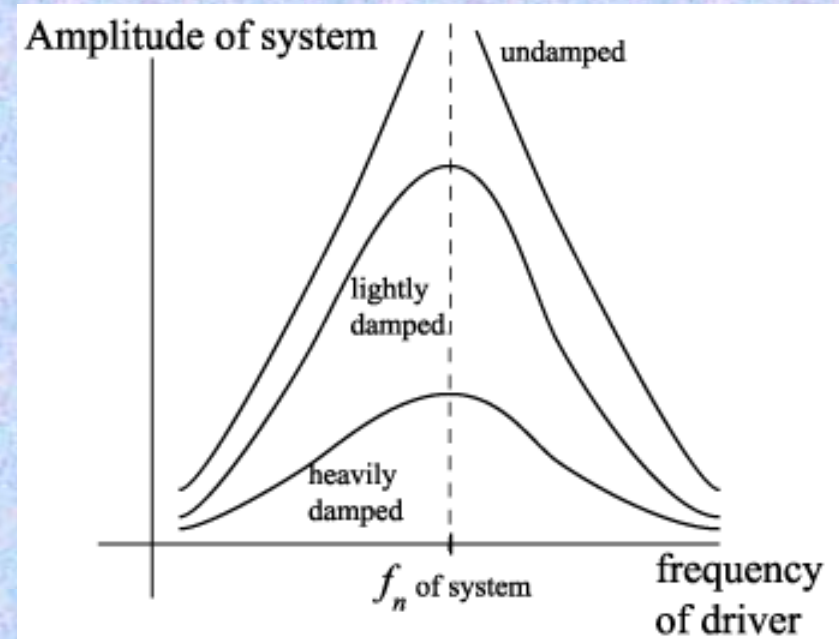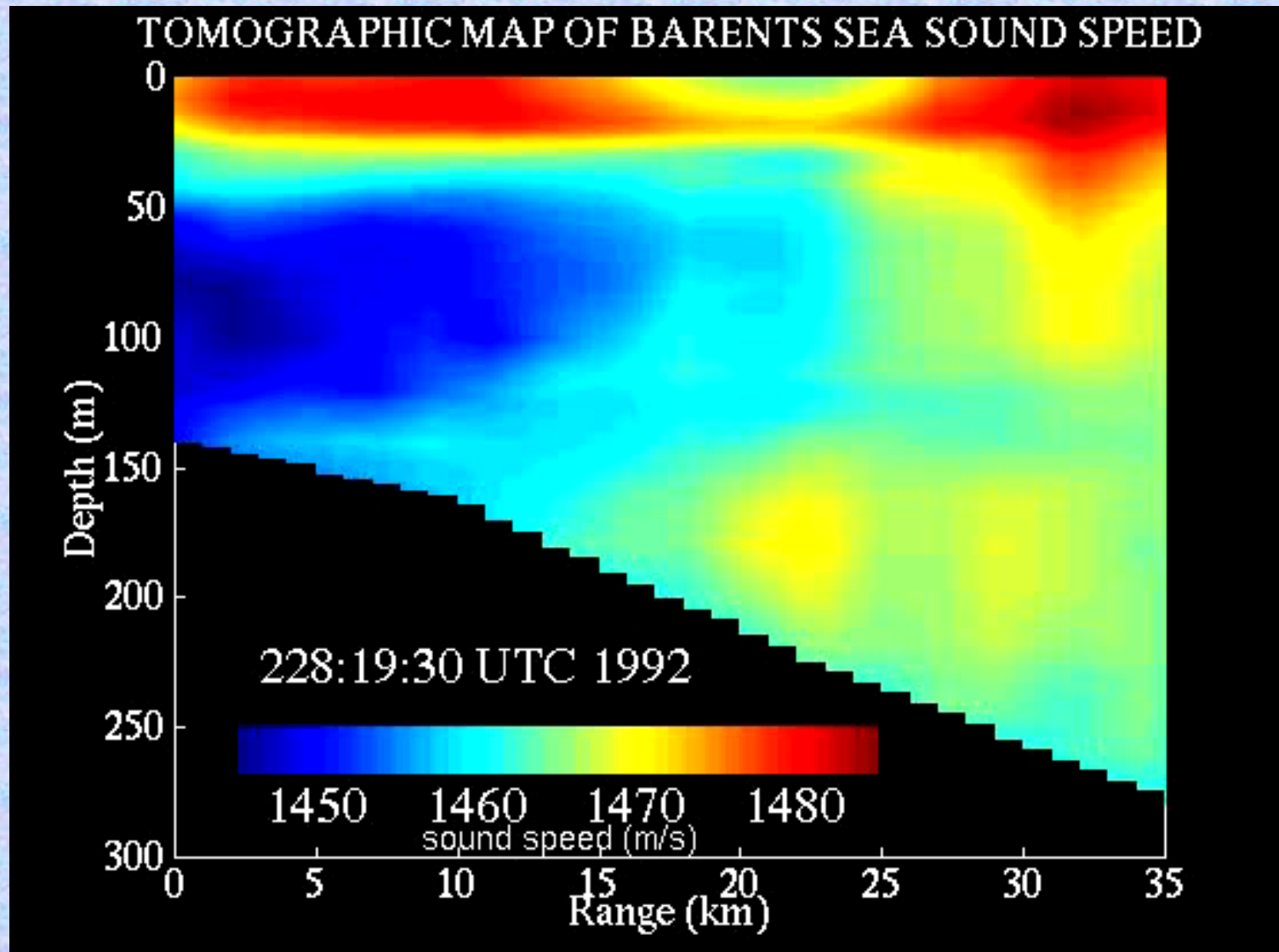
Applications- zooplankton ecology:

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:

TOMOGRAPHIC MAP OF BARENTS SEA SOUND SPEED

228:19:30 UTC 1992

sound speed (m/s)

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

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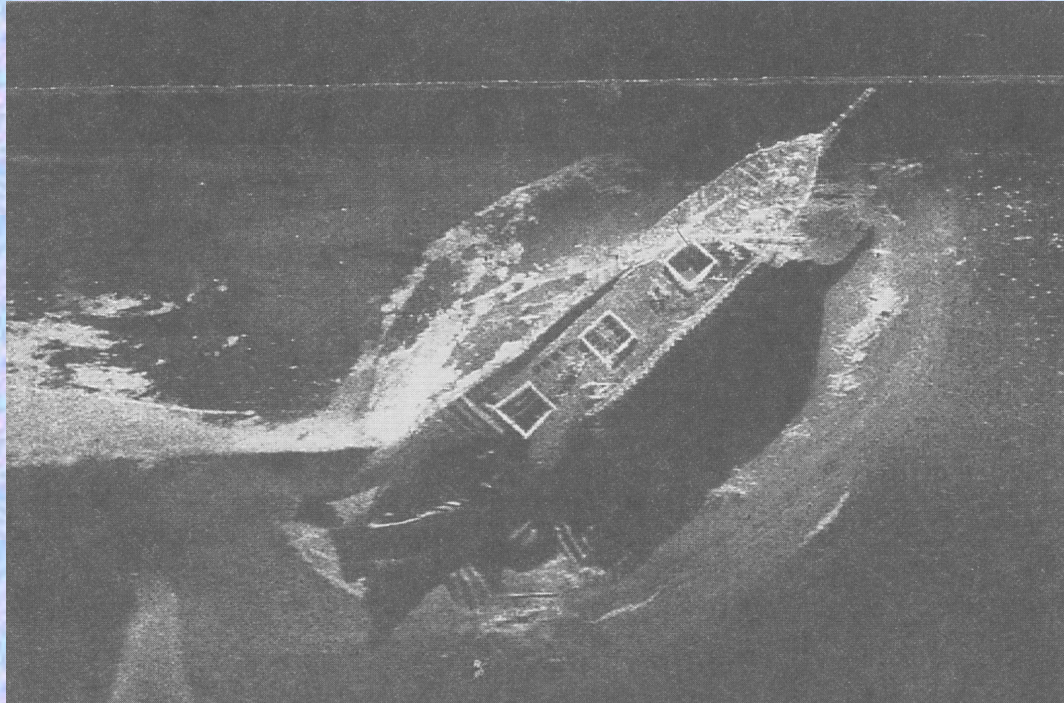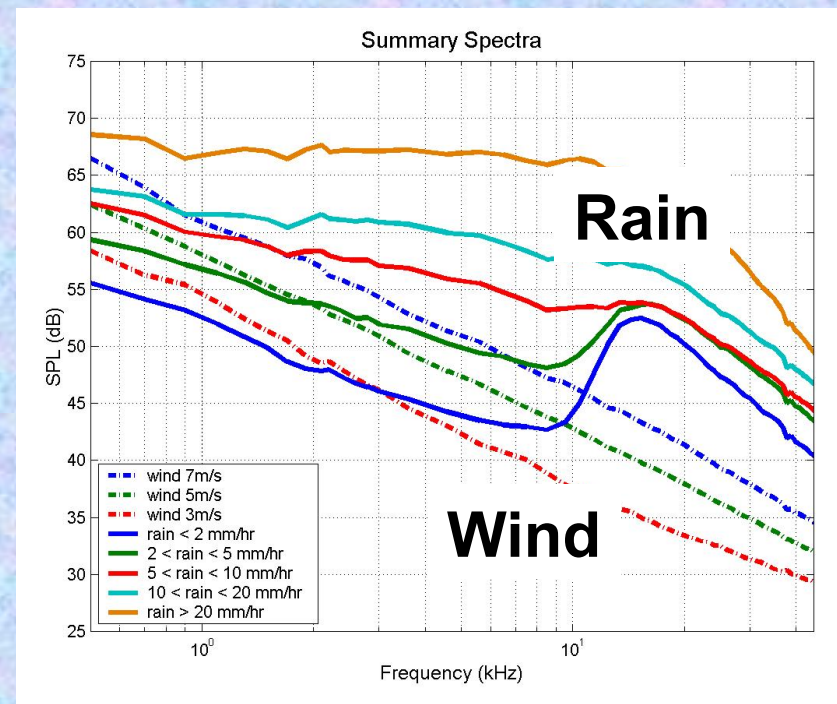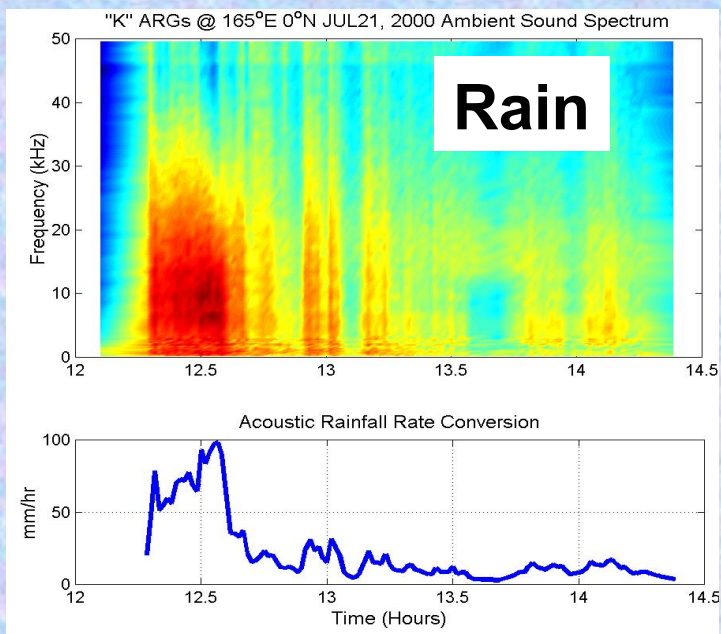

500 kHz sidescan sonar image towed 14 m above bottom

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
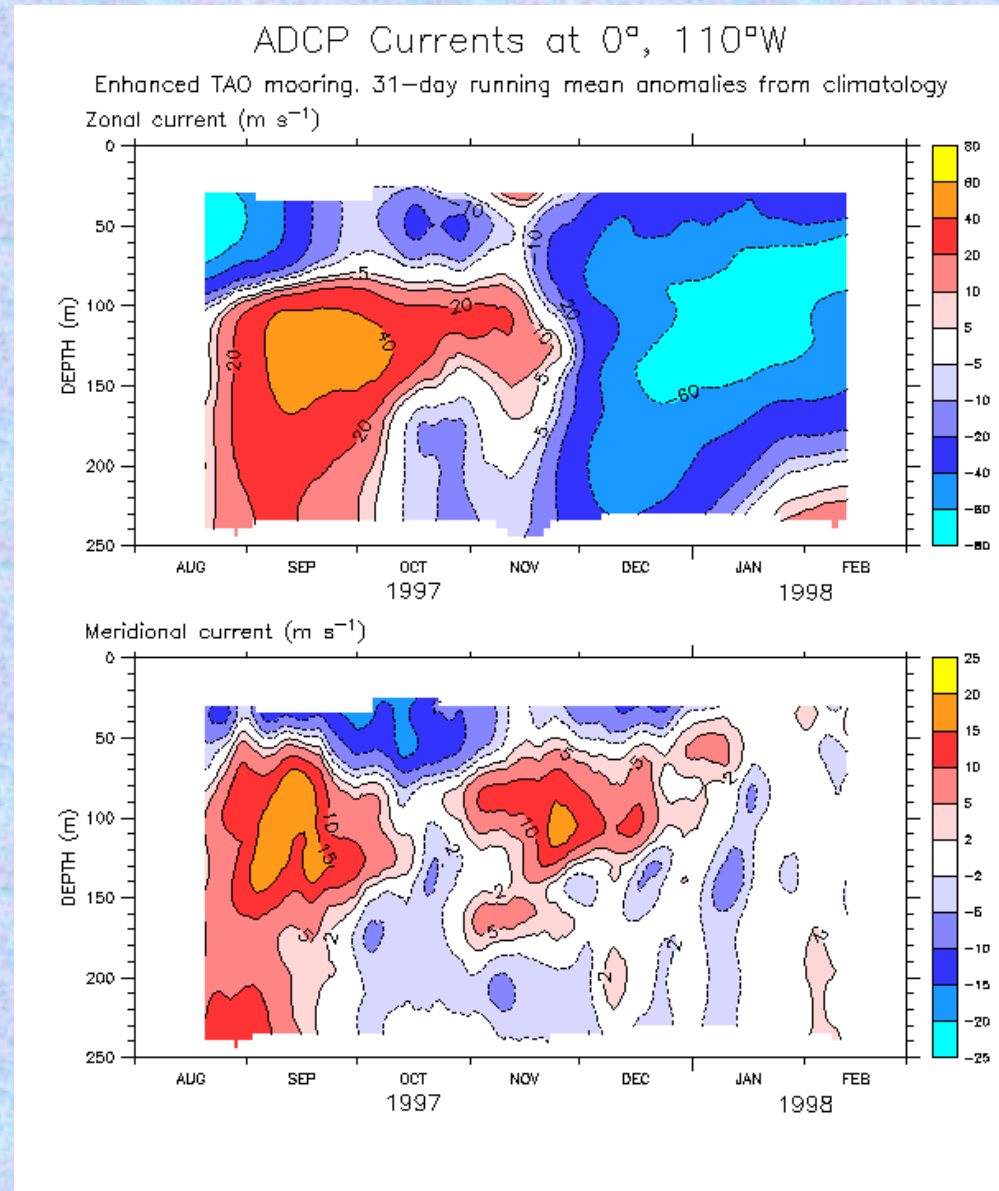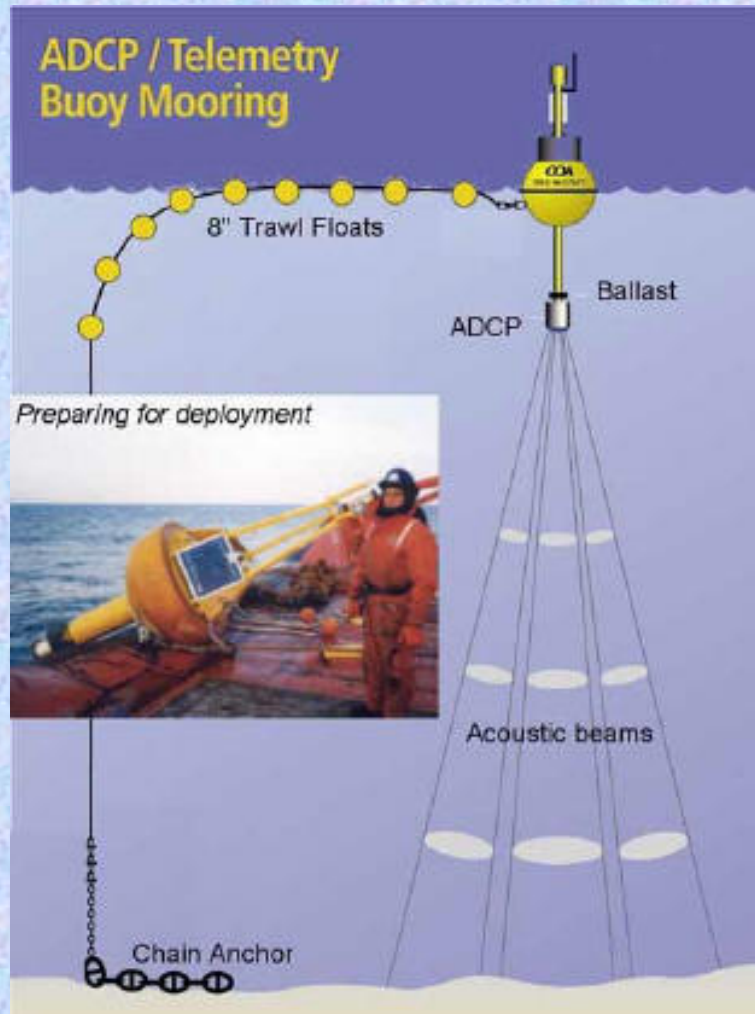
Doppler shift

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

Stationary source:

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

Stationary receiver:

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

Both moving:

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

Long Wavelength Low Frequency   Small Wavelength High Frequency

The Doppler Effect for a moving sound source
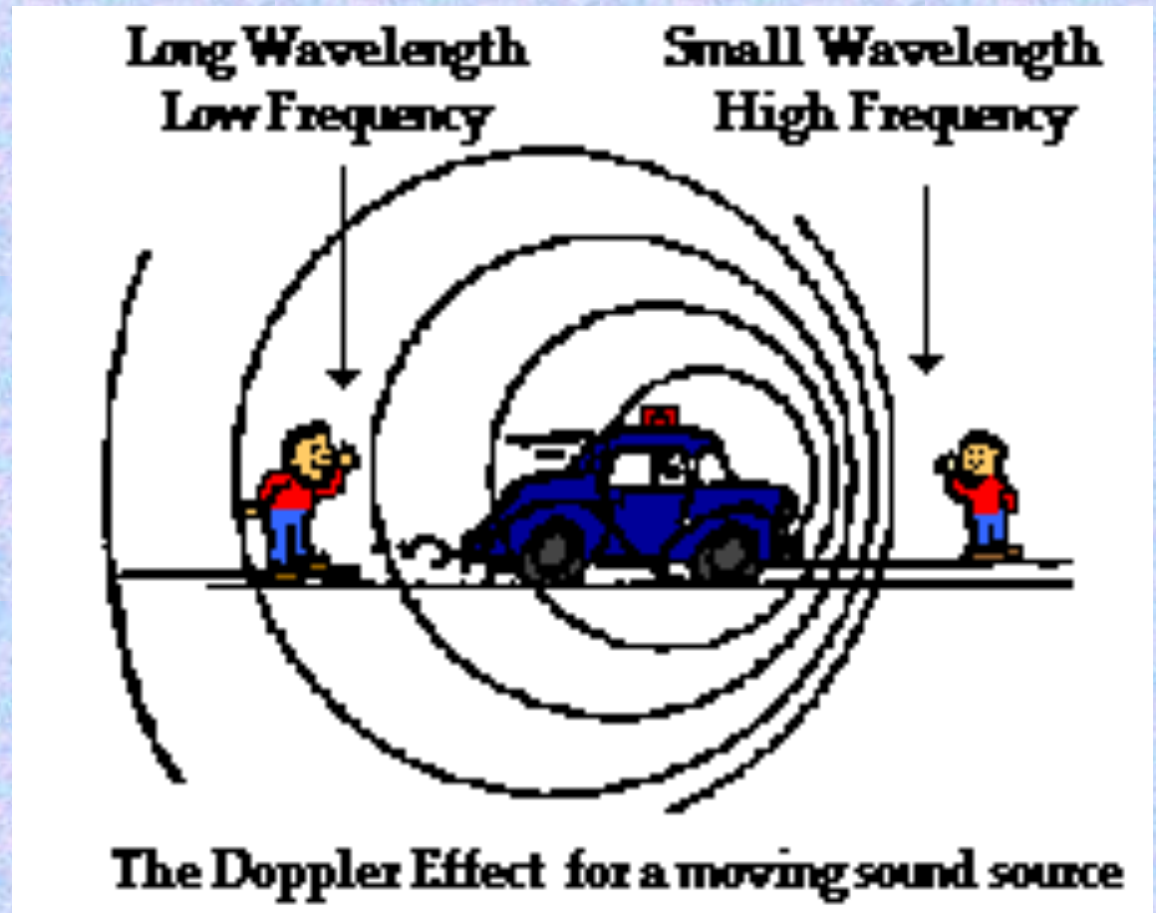
How is acoustics used and why (Howe, 2004)?

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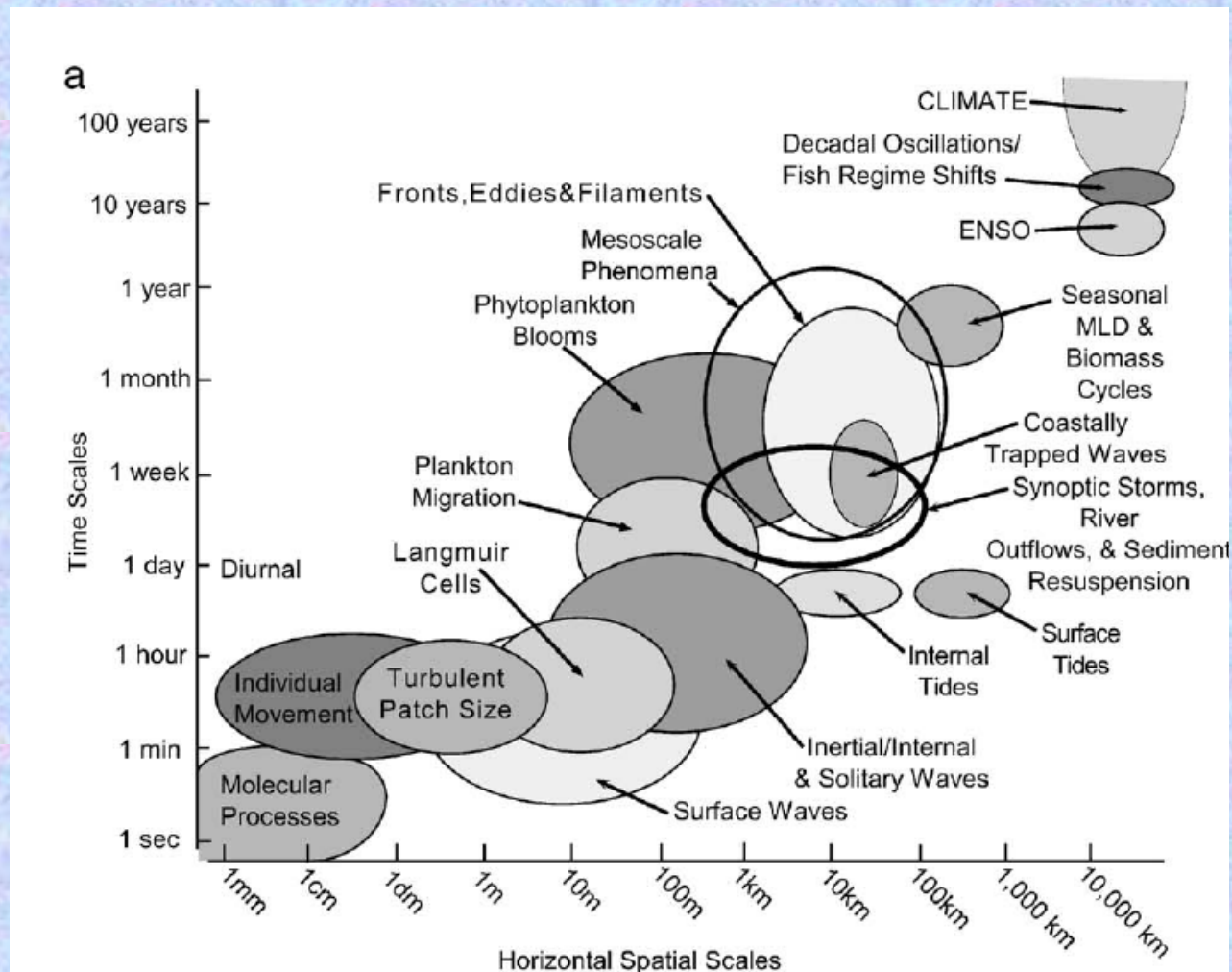
Dickey, T., 2003, Emerging ocean observations for interdisciplinary data assimilation systems, J. Mar. Syst., 40-41, 5-48. (RB)

Ocean
Observations
Howe, 2004

ice

Science Enabled by Ocean Observatory Acoustics

Bruce M. Howe[1], James H. Miller[2], and the IASOO Committee[3]
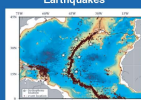
[1] Applied Physics Laboratory, University of Washington, Seattle, WA 98105-6698 | howe@apl.washington.edu
[2] Department of Ocean Engineering, University of Rhode Island, Narragansett, RI 02882 | miller@egr.uri.edu
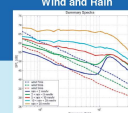[3] Acoustical Oceanography Subcommittee on Integrated Acoustics Systems for Ocean Observatories, Acoustical Society of America | www.oce.uri.edu/aol/AOWEBPAGE
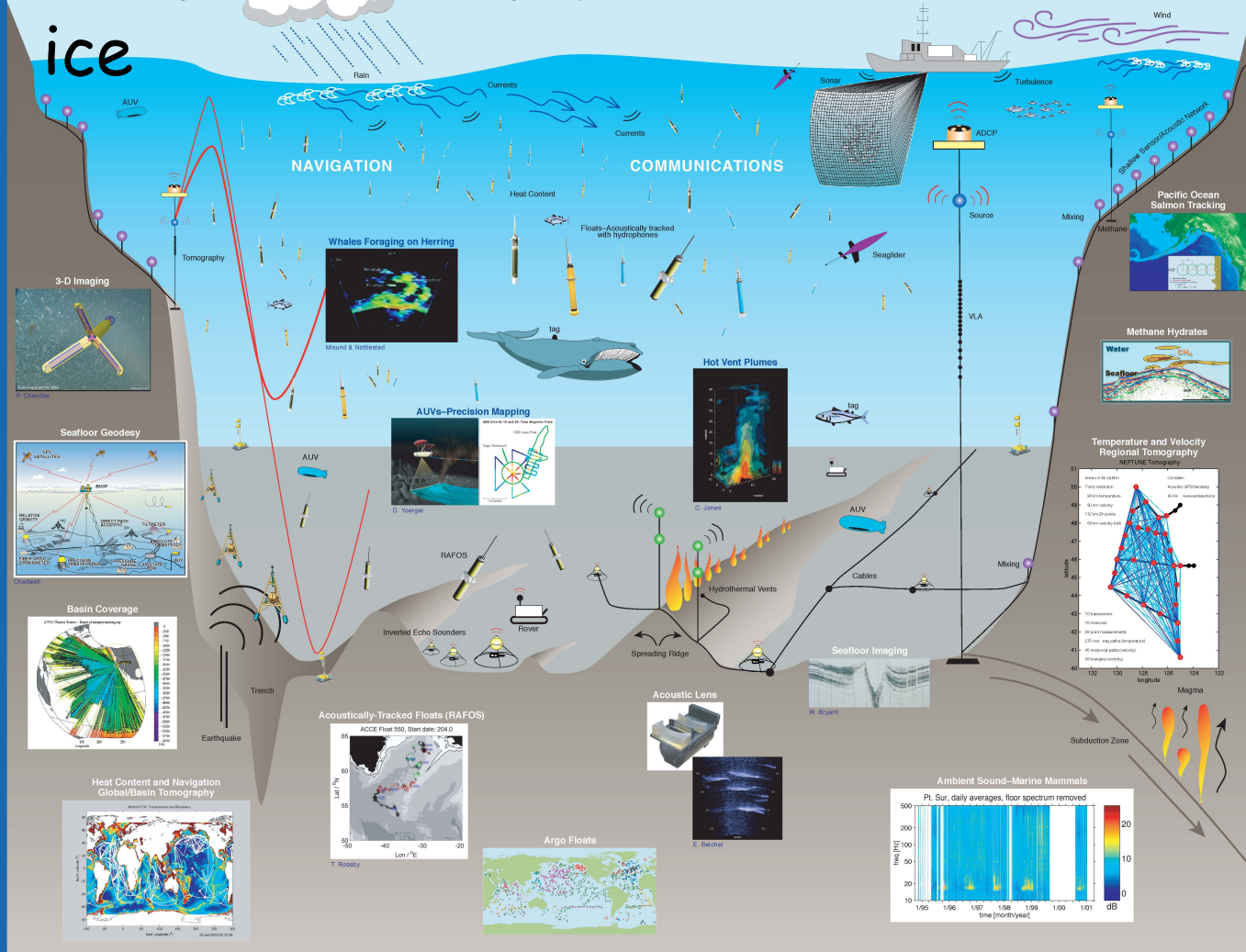
Ocean observatories have the potential to examine the physical, chemical, biological and geological parameters and processes of the ocean at time and space scales previously unexplored. *Acoustics* provides an efficient and cost-effective means by which these parameters and processes can be measured and information can be communicated. *Integrated acoustics systems* providing navigation and *communications* and conducting acoustic measurements in support of *science applications* are, in concept, analogous to the Global Positioning System, but rely on acoustics because the ocean is opaque to electromagnetic waves and transparent to sound. A series of nested systems is envisioned, from small- to regional- to basin-scale. A small number of acoustic sources sending coded, low power signals can service unlimited numbers of inexpensive receivers. Drifting and fixed receivers can be tracked accurately while collecting ocean circulation and heat content data (both point and integral data), as well as ambient sound data about wind, rain, marine mammals, seismic T-phases, and anthropogenic acitivity. The sources can also transmit control data from users to remote intruments, and if paired with receivers enable two-way acoustic communications links. Instrumentation that shares the acoustic bandwidth completes the concept. The ocean observations presently in the planning and implementation stages will require these integrated acoustics systems.

Ambient Sound–
Earthquakes

D. K. Smith

Ambient Sound–
Wind and Rain

J. Nystuen

NAVIGATION

COMMUNICATIONS

Wind

Rain

Currents

AUV

Currents

Sonar

Turbulence

ADCP

Shallow Sensor/Acoustic Network

Heat Content

Source

Mixing

Methane

Pacific Ocean
Salmon Tracking

Tomography

Whales Foraging on Herring

Misund & Nottestad

Floats–Acoustically tracked
with hydrophones

Seaglider

VLA

3-D Imaging

P. Chandler

tag

Methane Hydrates

Water

Seafloor

Hot Vent Plumes

AUVs–Precision Mapping

tag

D. Yoerger

C. Jones

AUV

Temperature and Velocity
Regional Tomography
NEPTUNE Tomography

Seafloor Geodesy

AUV

Chadwell

RAFOS

Mixing

Hydrothermal Vents

Cables

longitude

Magma

Basin Coverage

Inverted Echo Sounders

Rover

Seafloor Imaging

W. Bryant

Spreading Ridge

Trench

Earthquake

Acoustically-Tracked Floats (RAFOS)
ACCE Float 550, Start date: 204.0

Acoustic Lens

E. Belcher

Subduction Zone

Heat Content and Navigation
Global/Basin Tomography

T. Rossby

Argo Floats

Ambient Sound–Marine Mammals
Pt. Sur, daily averages, floor spectrum removed