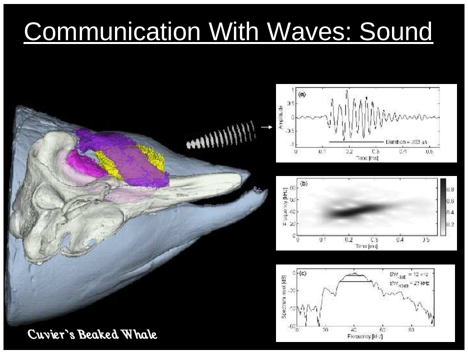
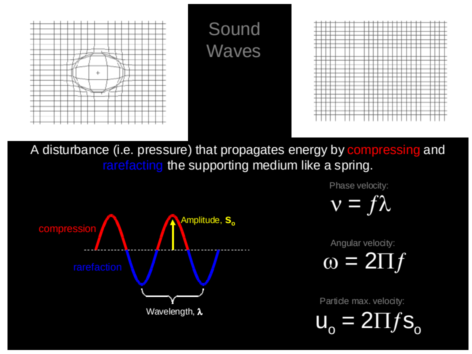
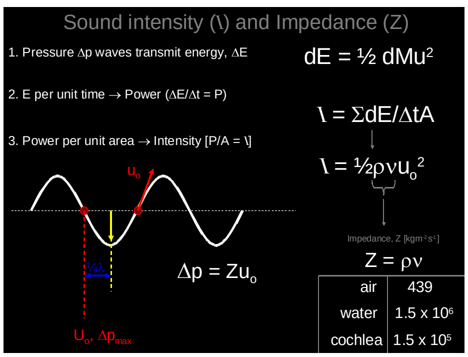
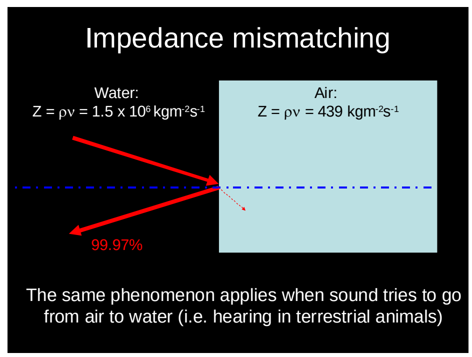
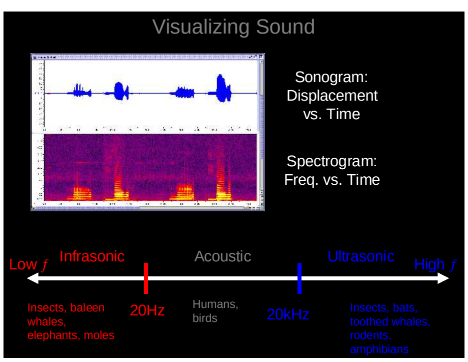
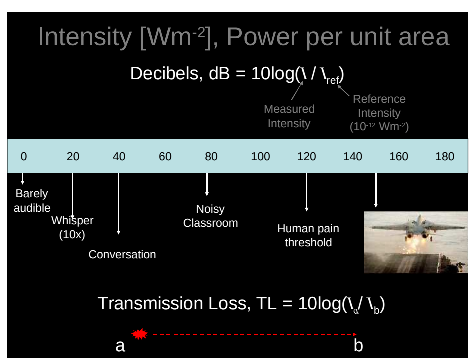

Communication With Waves: Sound
Cuvier's Beaked Whale


Sound Waves
A disturbance (i.e. pressure) that propagates energy by compressing and rarefacting the supporting medium like a spring.
compression
rarefaction
Amplitude, s_o
Wavelength, λ
Phase velocity:
$\nu = f\lambda$
Angular velocity:
$\omega = 2\Pi f$
Particle max. velocity:
$u_o = 2\Pi f s_o$

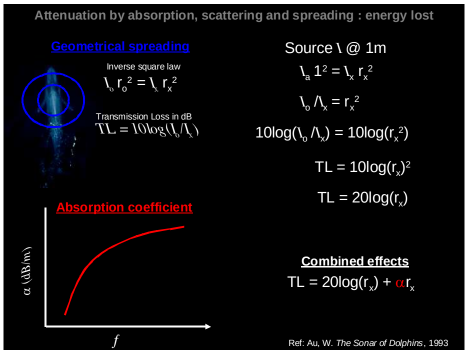

Sound intensity (\) and Impedance (Z)
1. Pressure Δp waves transmit energy, ΔE
$dE = ½ dMu^2$
2. E per unit time → Power (ΔE/Δt = P)
$\ = \Sigma dE/\Delta tA$
3. Power per unit area → Intensity [P/A = \]
$\ = ½\rho\nu u_o^2$
u_o
¼λ
$U_o, \Delta p_{max}$
$\Delta p = Zu_o$
Impedance, Z [kgm⁻²s⁻¹]
$Z = \rho\nu$
air 439
water 1.5×10^6
cochlea 1.5×10^5


Impedance mismatching
Water:
$Z = \rho\nu = 1.5 \times 10^6$ $kgm^{-2}s^{-1}$
Air:
$Z = \rho\nu = 439$ $kgm^{-2}s^{-1}$
99.97%
The same phenomenon applies when sound tries to go from air to water (i.e. hearing in terrestrial animals)

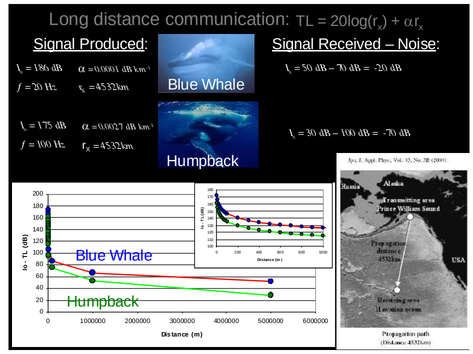

Visualizing Sound
Sonogram: Displacement vs. Time
Spectrogram: Freq. vs. Time
Low f
Infrasonic
Acoustic
Ultrasonic
High f
Insects, baleen whales, elephants, moles
20Hz
Humans, birds
20kHz
Insects, bats, toothed whales, rodents, amphibians


Intensity [Wm^{-2}], Power per unit area
Decibels, dB = 10log(\ / $\_{ref}$)
Measured Intensity
Reference Intensity (10^{-12} Wm^{-2})
0 20 40 60 80 100 120 140 160 180
Barely audible
Whisper (10x)
Conversation
Noisy Classroom
Human pain threshold
Transmission Loss, TL = 10log($\_a$/ $\_b$)
a
b

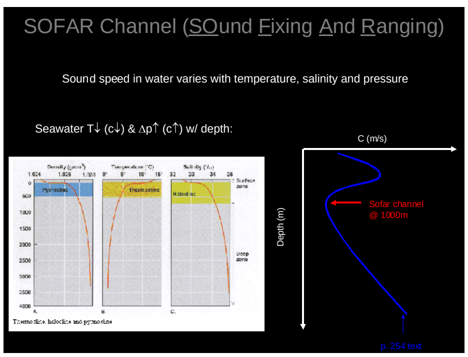
15/03/2007



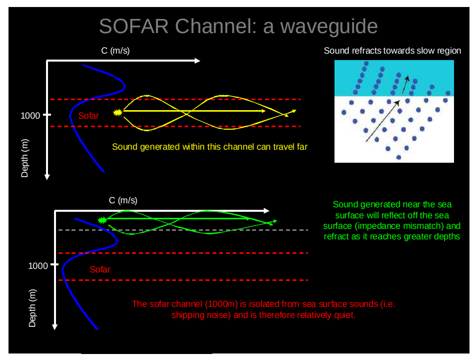
Attenuation by absorption, scattering and spreading : energy lost
Geometrical spreading
Inverse square law
\o ro2 = \x rx2
Transmission Loss in dB
TL = 10log(\o/\x)
Source \ @ 1m
\a 12 = \x rx2
\o /\x = rx2
10log(\o /\x) = 10log(rx2)
TL = 10log(rx)2
TL = 20log(rx)
Absorption coefficient
α (dB/m)
f
Combined effects
TL = 20log(rx) + αrx
Ref: Au, W. The Sonar of Dolphins, 1993



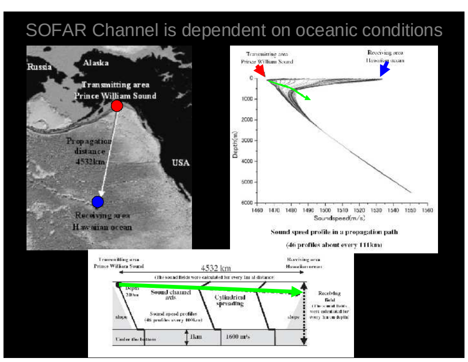
Long distance communication: TL = 20log(rx) + αrx
Signal Produced:
\o = 186 dB α = 0.0001 dB km-1
f = 20 Hz rx = 4532km
Blue Whale
\o = 175 dB α = 0.0027 dB km-1
f = 100 Hz rx = 4532km
Humpback
Signal Received – Noise:
\x = 50 dB – 70 dB = -20 dB
\x = 30 dB – 100 dB = -70 dB
Io - TL (dB)
Distance (m)
Blue Whale
Humpback
Jpn. J. Appl. Phys. Vol. 43, No. 5B (2004)
Russia
Alaska
Transmitting area Prince William Sound
Propagation distance 4532km
USA
Receiving area Hawaiian ocean
Propagation path (Distance 4532km)



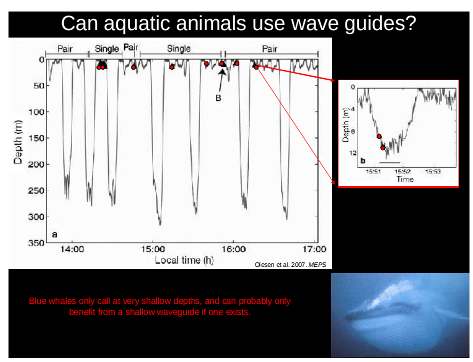
SOFAR Channel (SOund Fixing And Ranging)
Sound speed in water varies with temperature, salinity and pressure
Seawater T↓ (c↓) & Δp↑ (c↑) w/ depth:
Density
Temperature (°C)
Salinity
Pycnocline
Thermocline
Halocline
Surface zone
Deep zone
Thermocline, halocline and pycnocline
C (m/s)
Depth (m)
Sofar channel @ 1000m
p. 254 text



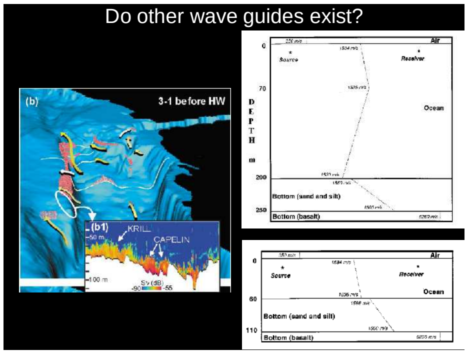
SOFAR Channel: a waveguide
C (m/s)
1000
Sofar
Depth (m)
Sound generated within this channel can travel far
Sound refracts towards slow region
C (m/s)
1000
Sofar
Depth (m)
Sound generated near the sea surface will reflect off the sea surface (impedance mismatch) and refract as it reaches greater depths
The sofar channel (1000m) is isolated from sea surface sounds (i.e. shipping noise) and is therefore relatively quiet.

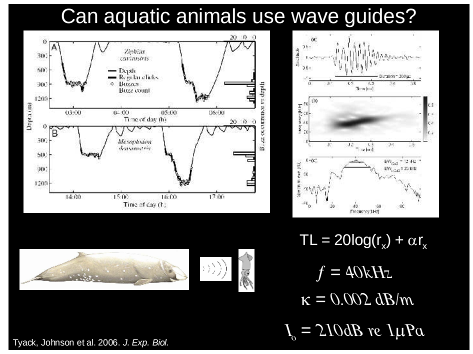


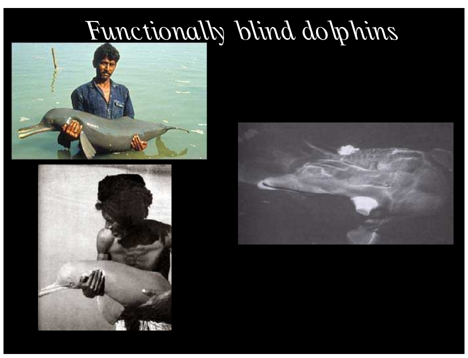
SOFAR Channel is dependent on oceanic conditions
Russia
Alaska
Transmitting area Prince William Sound
Propagation distance 4532km
USA
Receiving area Hawaiian ocean
Sound speed profile in a propagation path
4532 km

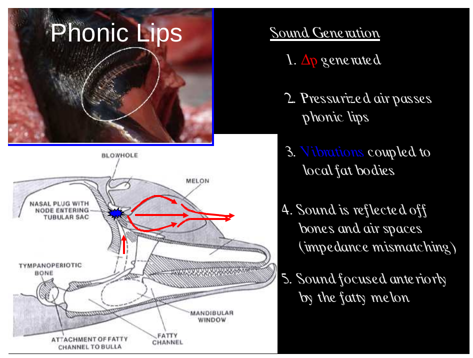


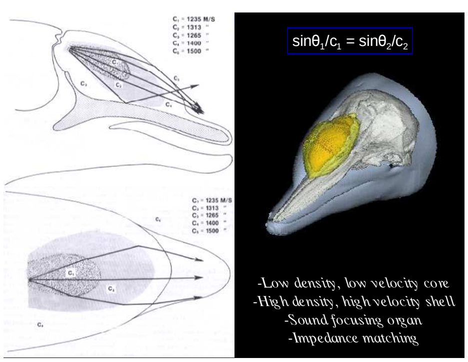
Can aquatic animals use wave guides?
Pair
Single
Pair
Single
Pair
Depth (m)
Local time (h)
14:00
15:00
16:00
17:00
B
Time
Olesen et al. 2007. MEPS
Blue whales only call at very shallow depths, and can probably only benefit from a shallow waveguide if one exists.

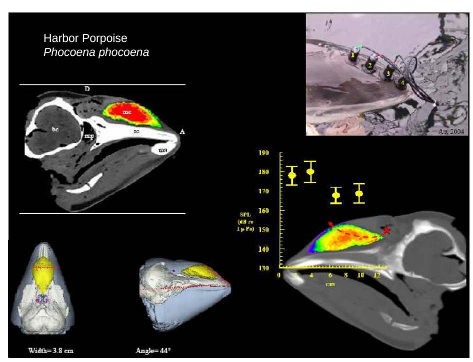

Do other wave guides exist?
3-1 before HW
(b)
(b1)
KRILL
CAPELIN
Source
Receiver
Air
Ocean
DEPTH m
Bottom (sand and silt)
Bottom (basalt)


Can aquatic animals use wave guides?
TL = 20log(rx) + αrx
f = 40kHz
κ = 0.002 dB/m
I0 = 210dB re 1μPa
Tyack, Johnson et al. 2006. J. Exp. Biol.


Functionally blind dolphins


Phonic Lips
Sound Generation
1. Δp generated
2. Pressurized air passes phonic lips
3. Vibrations coupled to local fat bodies
4. Sound is reflected off bones and air spaces (impedance mismatching)
5. Sound focused anteriorly by the fatty melon
BLOWHOLE
MELON
NASAL PLUG WITH NODE ENTERING TUBULAR SAC
TYMPANOPERIOTIC BONE
MANDIBULAR WINDOW
FATTY CHANNEL
ATTACHMENT OF FATTY CHANNEL TO BULLA


sinθ1/c1 = sinθ2/c2
-Low density, low velocity core
-High density, high velocity shell
-Sound focusing organ
-Impedance matching


Harbor Porpoise
Phocoena phocoena
Width= 3.8 cm
Angle= 44°

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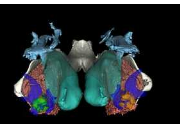
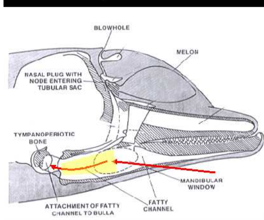
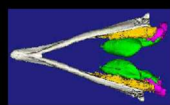
Sound Reception

2. Sound hits window
2. Sound channeled by fat posteriorly
3. Sound encounters bulla
4. Air sinuses provide reflection sites



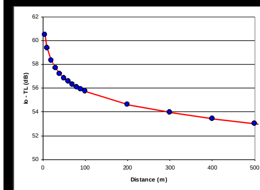
Back View





Bottom View

Echolocating beaked whale



$TL = 20\log(r_x) + \alpha r_x$

f = 40kHz

κ = 0.002 dB/m

I_o = 210dB re 1μPa

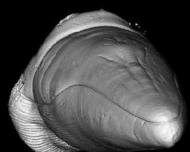
Lose .701 upon reflection

Hearing threshold may be: ~50 db (p.333 in text)

Beaked whale may only be able to detect prey several 100 m away

Probably no help from sofar b/c sound is attenuated so rapidly and signal is directional (concentrated)

Can baleen whales echolocate on prey?



$\Delta x = \lambda$

Δx = 40mm

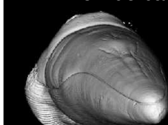
$\lambda = v/f$

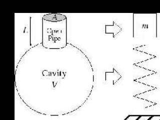
$\lambda = (1500ms^{-1})/(40Hz)$

λ = 38m

Echolocation not possible for prey, only large land masses may be detected

How do baleen whales make sound?





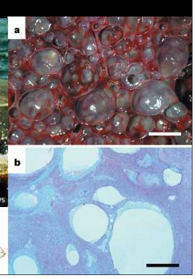
$f = (v/2\Pi)\sqrt{(A/LV)}$

$f = (1500/2\Pi)\sqrt{(0.13m^2/0.5m*1m^3)}$

f = 46 Hz

Beaked whales and navy sonar

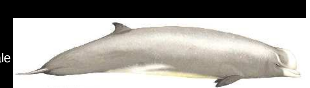
- Gas-bubble lesions in stranded cetaceans. Jepson et al., 2003 *Nature.*



Family: ziphiidae (beaked whales)

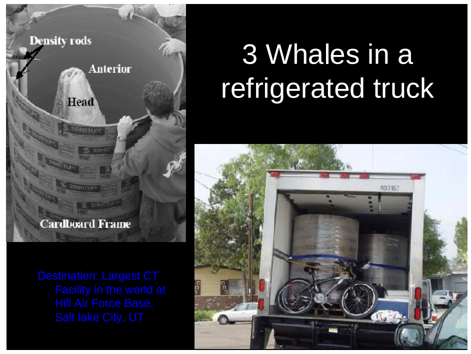
Cuvier's Beaked Whale

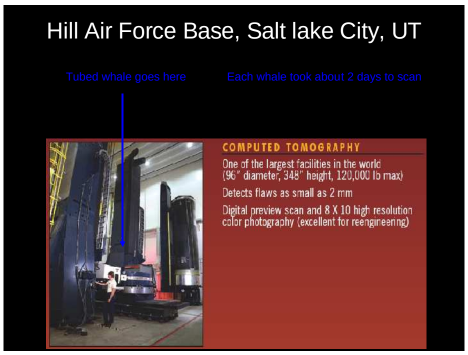
Northern Bottlenose Whale

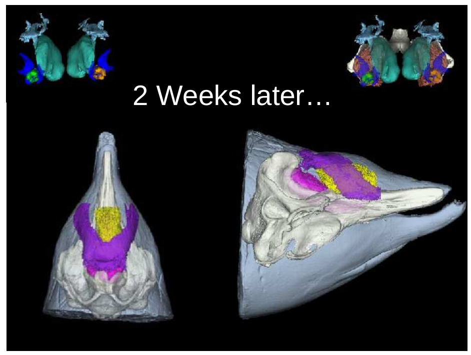


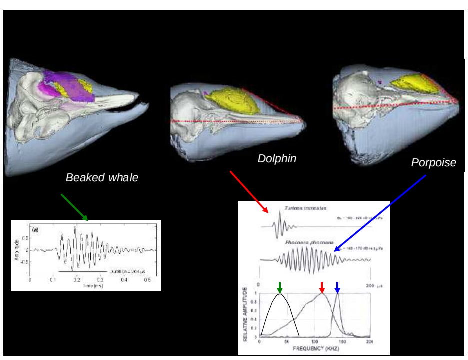
Sowerby's Beaked Whale


Data on internal morphology needed


3 Whales in a refrigerated truck
Density rods
Anterior
Head
Cardboard Frame
Destination: Largest CT Facility in the world at Hill Air Force Base, Salt lake City, UT


Hill Air Force Base, Salt lake City, UT
Tubed whale goes here
Each whale took about 2 days to scan
COMPUTED TOMOGRAPHY
One of the largest facilities in the world (96" diameter, 348" height, 120,000 lb max)
Detects flaws as small as 2 mm
Digital preview scan and 8 X 10 high resolution color photography (excellent for reengineering)


2 Weeks later…


Beaked whale
Dolphin
Porpoise


The Namib Desert golden mole
(*Eremitalpa granti namibensis)*
-Functionally blind
-Nocturnal Insectivore
-Massive malleus, confers low-frequency sensitivity, *via* the cochlea, to substrate vibrations.

15/03/2007