Sound Movement and Sound Measurement

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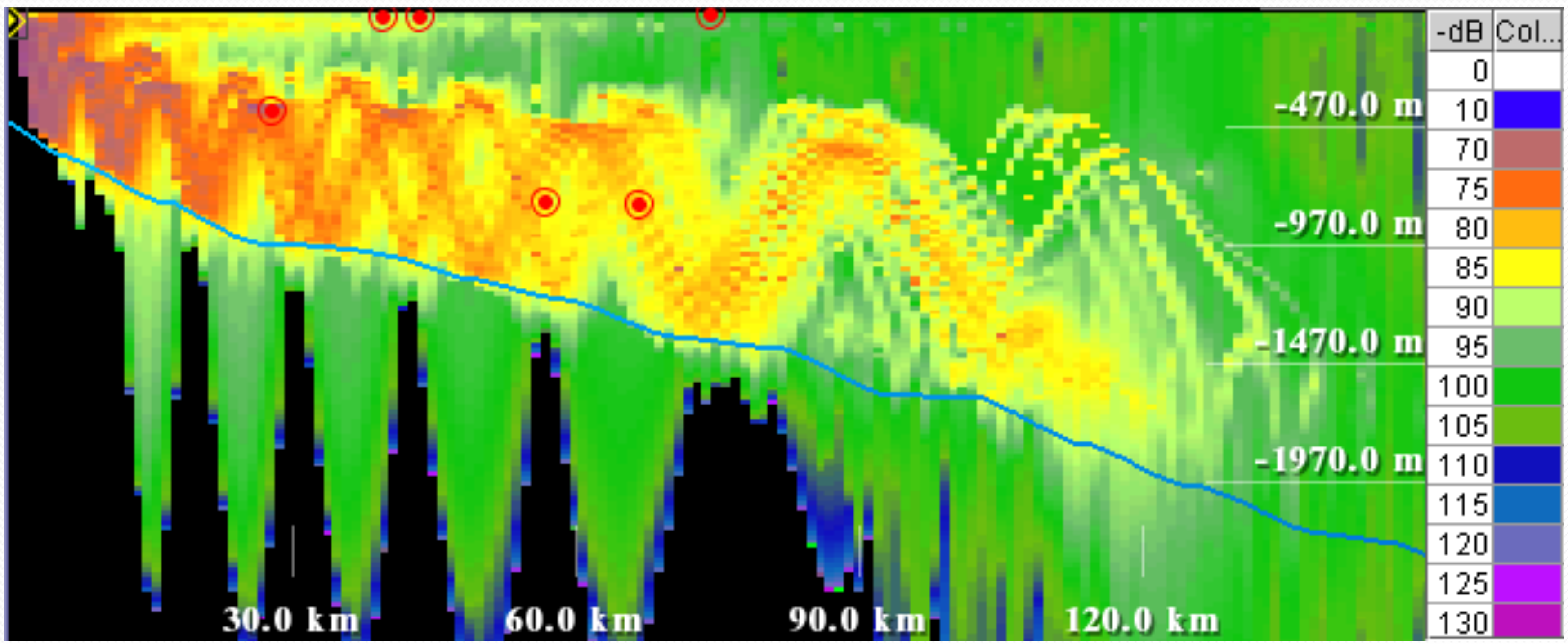
Outline of Presentation

- First step in determining if a sound might affect a marine animal is to calculate the level of sound at different distances and depths from the source
- Complex propagation modeling output
- Basic, stepwise approximations
  - Propagation: spherical, cylindrical
  - Movement: reflection, refraction
- Interactions among sounds: phase differences
- Sound levels: different types of decibels

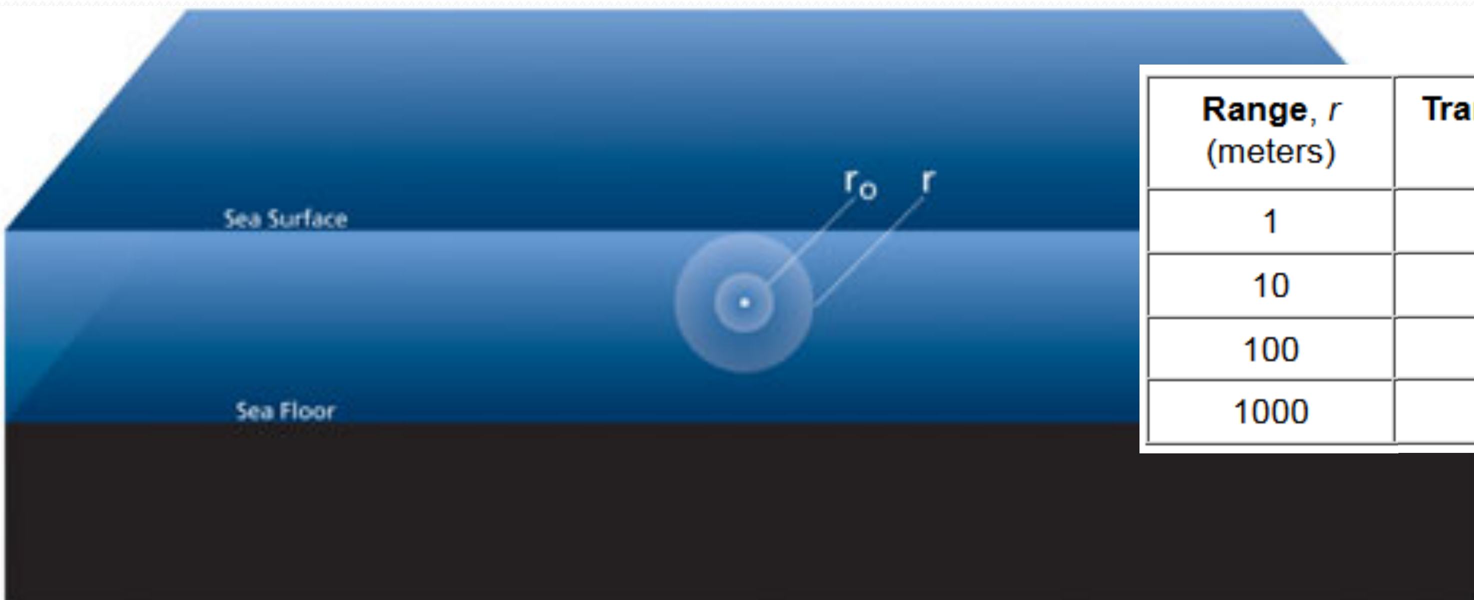
Complex Propagation Outputs

- Range and depth dependent acoustic field
- Complex inputs
  - Sound source, sound velocity profile, sea floor acoustics, bathymetry, etc.
- Models available at Ocean Acoustics Library (http://oalib.hlsresearch.com/)
  - Not for the novice user, but nice background documents and good starting point for advanced practitioners



Propagation: Spherical

- Most simple approximation of sound movement
- Sound source is at mid-depth in the water column
- Sound wave propagates from the source uniformly in all directions
- Sound level decreases rapidly: TL = 20 $\log_{10}$ r (where r=range)
- For example, SL= 240 dB rms re 1 μPa at 1 m, RL at 1 km = 180 dB rms

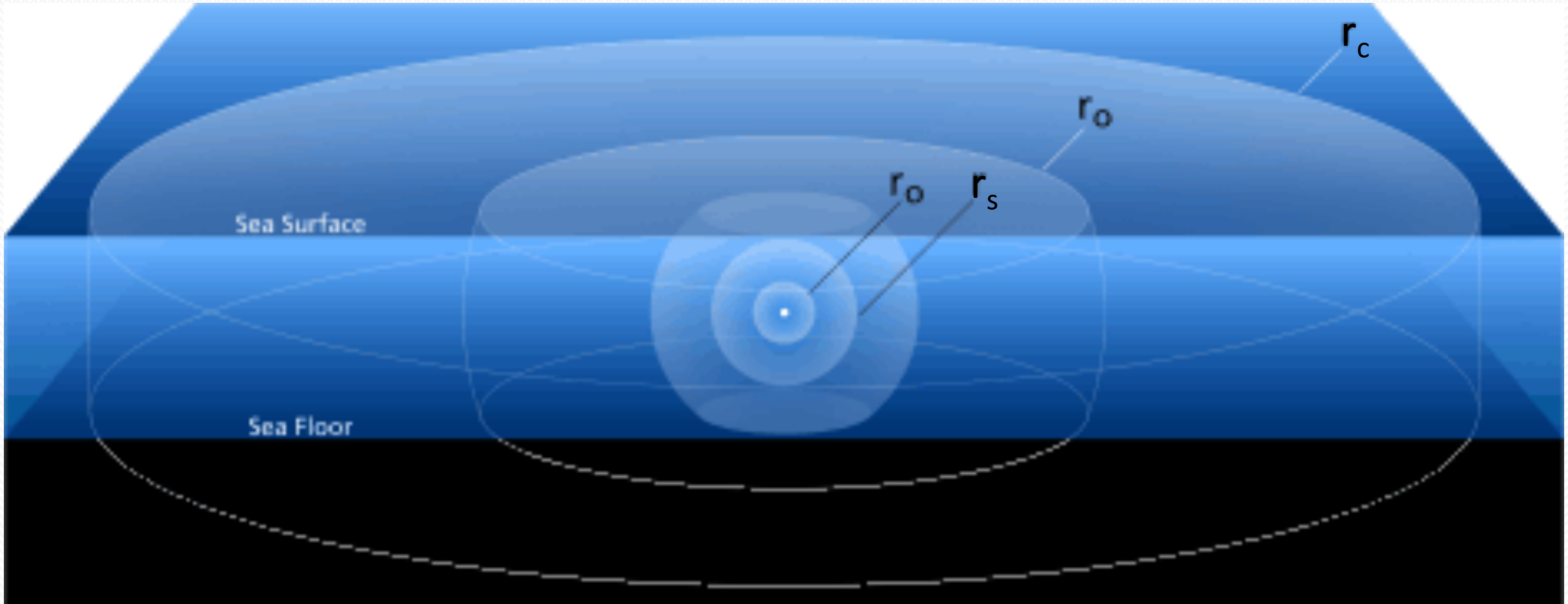


Range, *r* (meters)	**Transmission Loss**, *TL* (dB)
1	0
10	20
100	40
1000	60

http://www.dosits.org/science/advancedtopics/spreading/

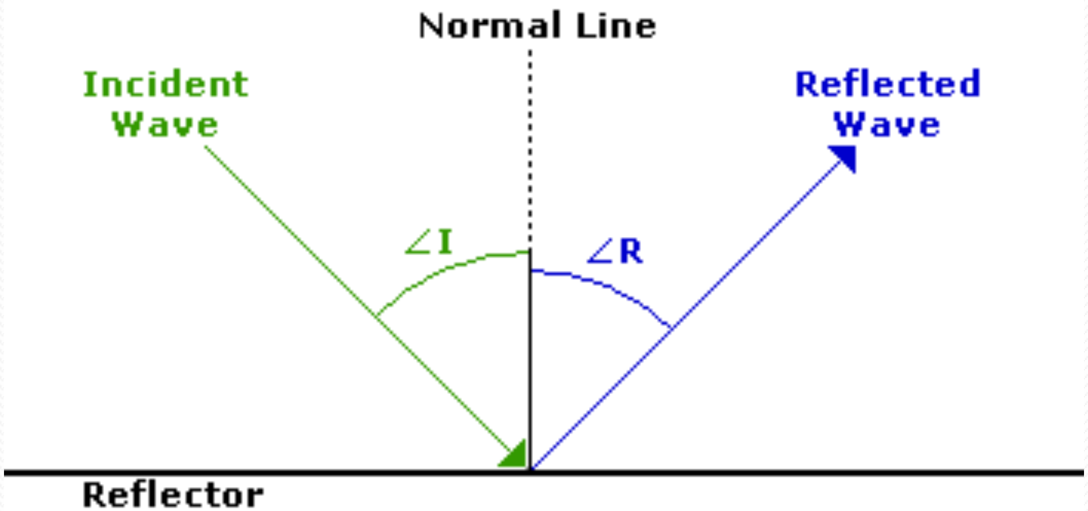
Propagation: Spherical + Cylindrical

- Beyond some range, sound will hit the sea surface or sea floor.
- Propagation changes from spherical to cylindrical.
- Sound wave propagates horizontally from the source.
- Sound levels decrease less rapidly, at a rate of $10 \log_{10} r$ (where r=range)
- $TL = 20 \log r_s + 10 \log r_c/r_s$
  - r_s= range of spherical spreading; r_c = range of cylindrical spreading
  - For example, 5,000 m ocean, source at 2,500 m = r_s : $20 \log 2500 + 10 \log r_c /2500$



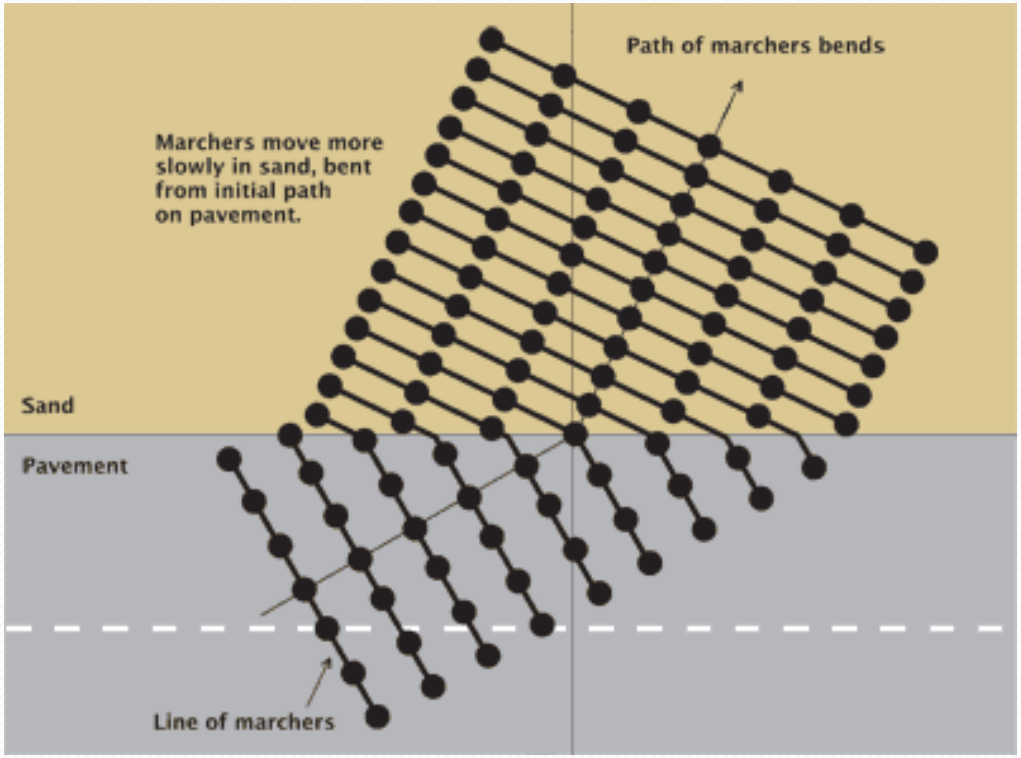
Movement: Reflection

- When sound hits a boundary (or reflector, such as the sea surface), the reflector can change the direction of the incoming wave.
- The boundary between the ocean and the air (i.e., the sea surface) is a nearly perfect reflector under calm conditions.
  - Amount of energy in the reflected wave = incident wave.
- As the two media become more similar (e.g., ocean and watery sand seafloor), there is less energy in the reflected wave and more energy is transmitted into the 2nd medium



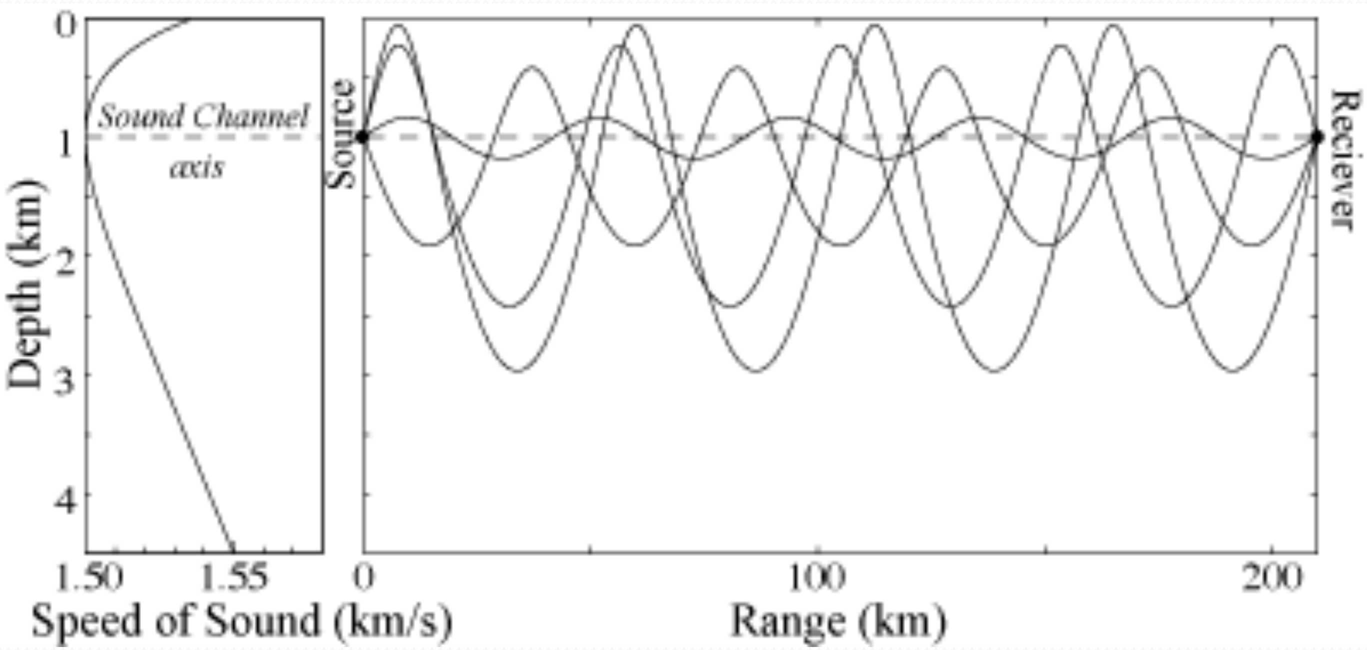
Movement: Refraction

- If sound moves into a new medium, or the sound speed within the given medium changes with changes in temperature, salinity, and pressure, sound can refract.
- Refraction is the bending of sound waves towards the slowest speed.
- Example of marching band moving from pavement (fast sound speed) to sand (slow sound speed)



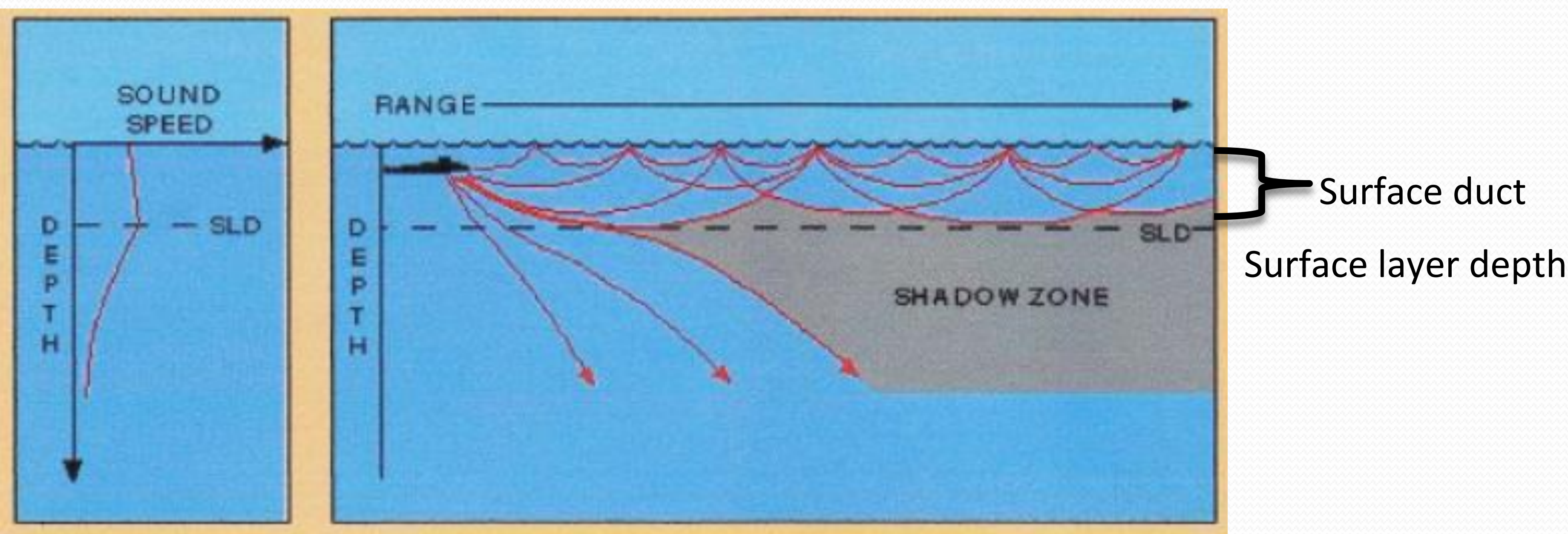
Movement: Refraction

- Refraction is the bending of sound waves towards the slowest speed.
- A sound channel exists in the ocean because sounds waves are bent, or refracted, towards the sound speed minimum.
- Sound waves leaving the source at specific angles will remain in the sound channel and not lose energy to interactions with the sea surface or sea floor.



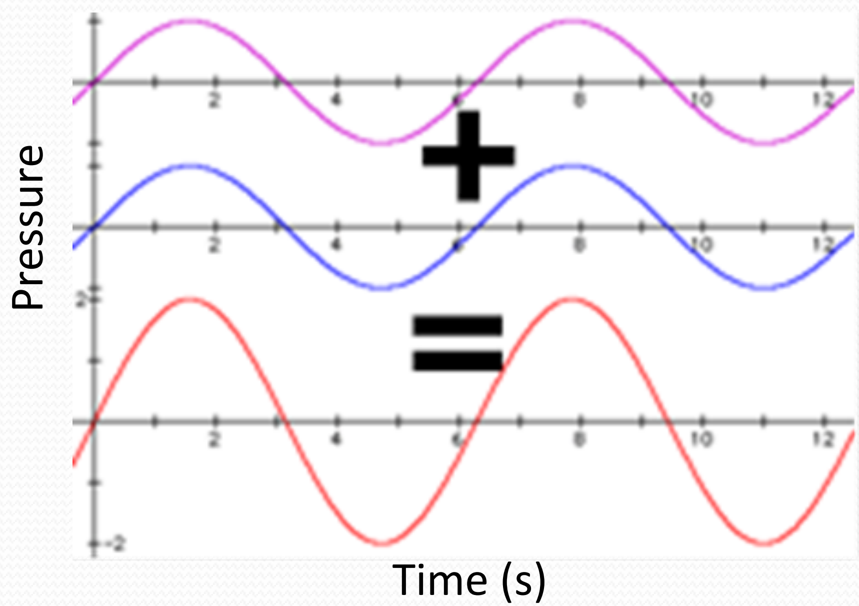
Movement: Reflection and Refraction

- The surface mixed layer can cause sound to propagate as a surface duct.
- Sound refracts towards the surface, then reflects off the sea surface to be refracted back to the surface.
- Some sound energy leaves the surface duct and is refracted towards the sea floor, creating a shadow zone between the surface duct and the deep layer.



Interactions among Sounds: Phase Differences

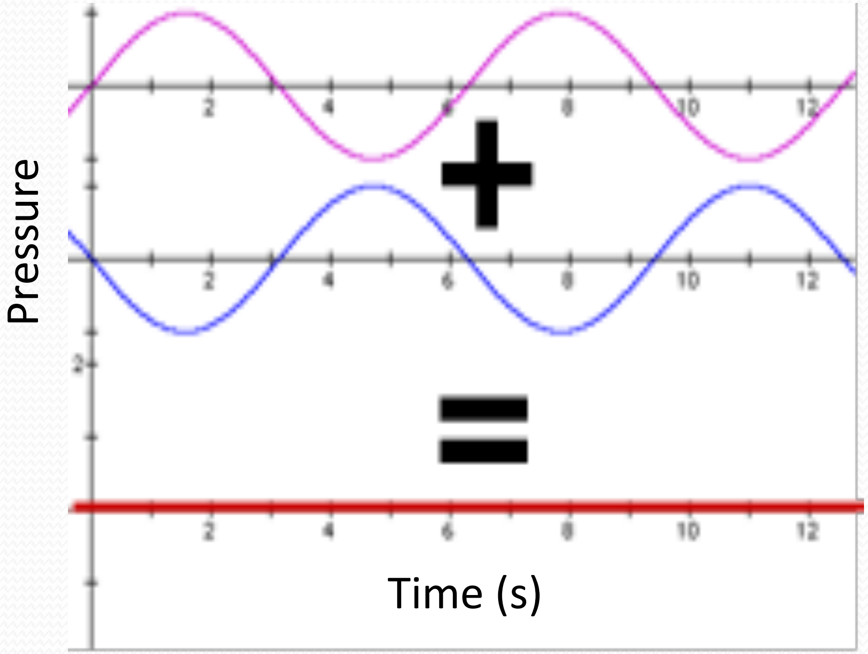
- When two (or more) sounds combine, their phase difference determines whether the amplitudes of the sounds will add or cancel each other out.
- Waveform = graph of pressure (relative amplitude) vs time
- Phase = the location of a point within a wave cycle of a repetitive waveform
- For example, two sounds of the same frequency that are perfectly aligned are “in phase” and their amplitudes add.



Credit: An Acoustics Primer, Chapter 8, URL: www.indiana.edu/~emusic/acoustics/phase.htm

Interactions among Sounds: Phase Differences

- If one of the two sound waves of the same frequency is shifted by one-half cycle relative to the other, they are "out of phase" and cancel each other.
- This is the principle behind noise-cancelling headphones.



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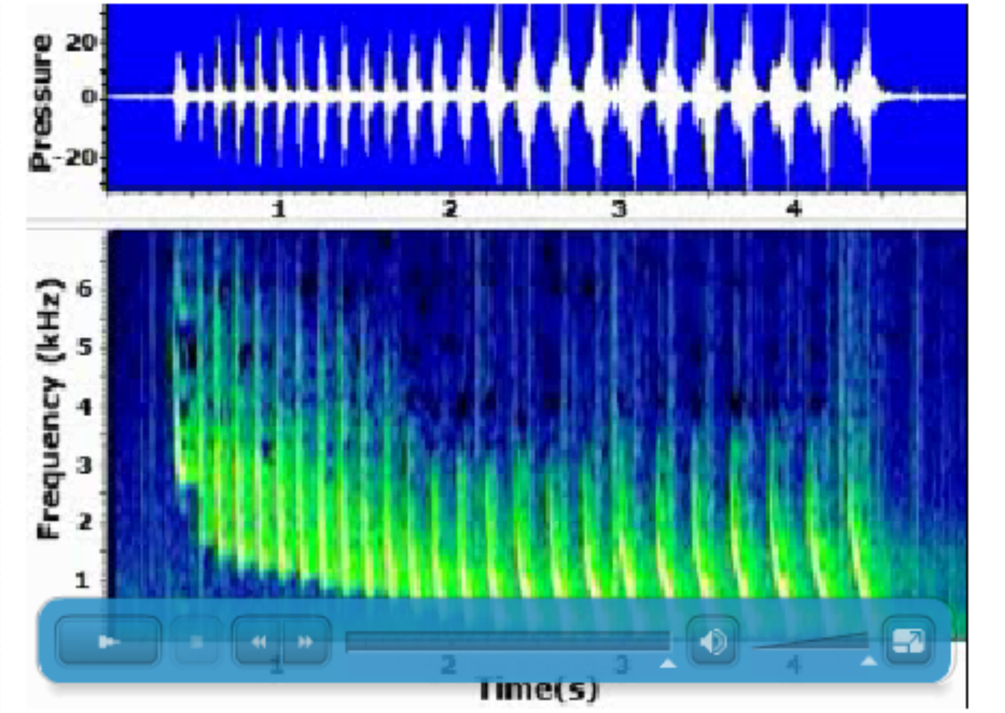
Interactions among Sounds: Phase Differences

- Most sounds consist of many different sine waves at different frequencies.
- Waveforms of all the sine waves are added together at each location along the wave cycle to create the sound
- For example, the call of a Weddell seal
  - Waveform (pressure vs time) on top
  - Spectrogram (frequency vs time) on bottom (*Chris to present animation*)

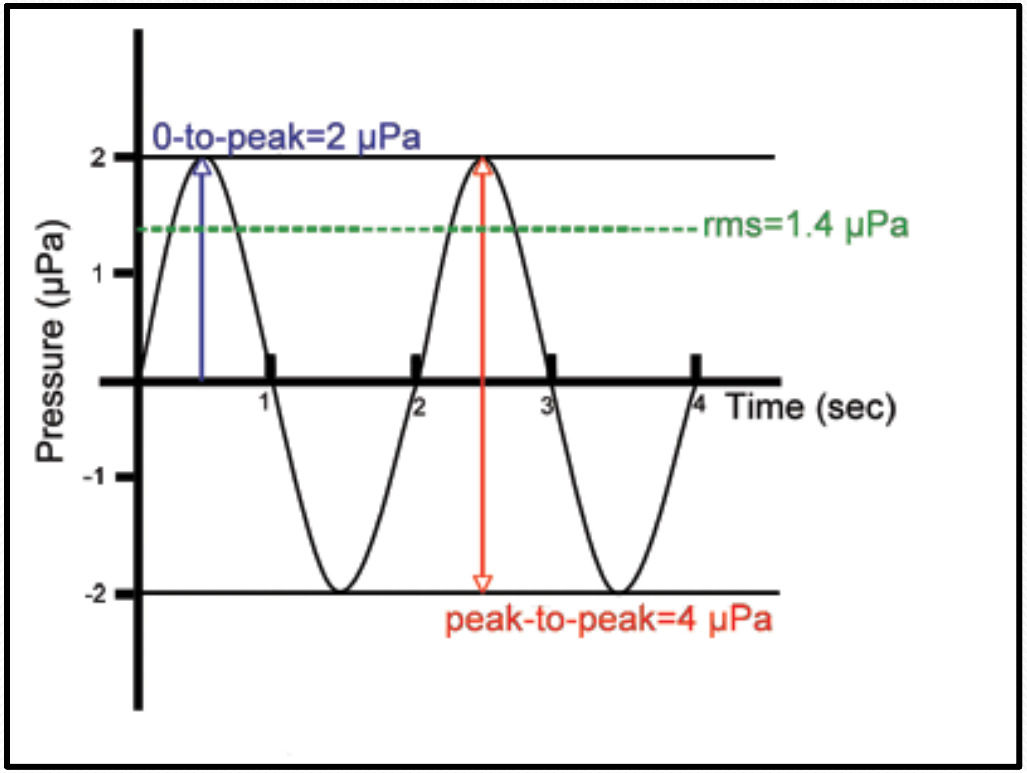


Sound Levels: Decibels

- Relative unit, like temperature (degrees Celsuis vs Fahrenheit)
  - **Must indicate the reference pressure**
  - dB re 1 micropascal (μPa) for water; dB re 20 μPa for air
- Other complex factors but very simple generalization: subtract 61.5 dB from sound levels in water to obtain sound levels in air
- DOSITS page for details: http://www.dosits.org/science/soundsinthesea/airwater/

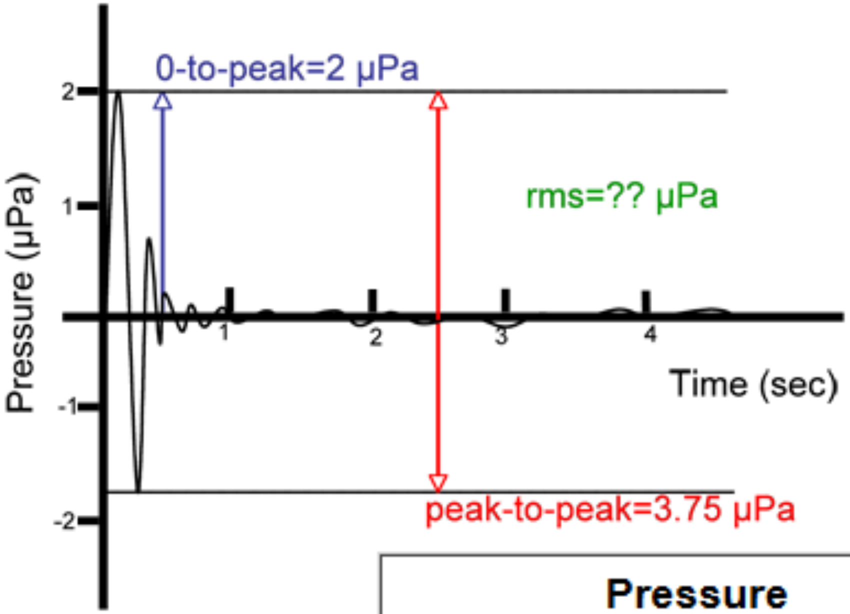
Sound Levels: Decibels

- peak pressure or 0-to-peak pressure
  - range in pressure between zero and the greatest pressure of the signal
- peak-to-peak pressure
  - range in pressure between the most negative pressure and the most positive pressure of the signal
- root-mean-square (rms) pressure
  - the square root of the average of the square of the pressure of the sound signal over a given duration



http://www.dosits.org/science/advancedtopics/signallevels/

Sound Levels: Decibels



Duration over which signal is averaged	rms pressure
0.5 sec	1.4 μPa
1 sec	1.0 μPa
2 sec	0.8 μPa

Pressure	Decibels
rms (0.5 sec): 1.4 μPa	2.9 dB re 1 μPa
rms (1 sec): 1.0 μPa	0 dB re 1 μPa
rms (2 sec): 0.8 μPa	-1.9 dB re 1 μPa
0-to-peak: 2 μPa	6 dB re 1 μPa
peak-to-peak: 3.75 μPa	11.4 dB re 1 μPa

Need to indicate if dB rms, dB peak or dB peak-peak