Sound speed and ray tracing

Today we will:

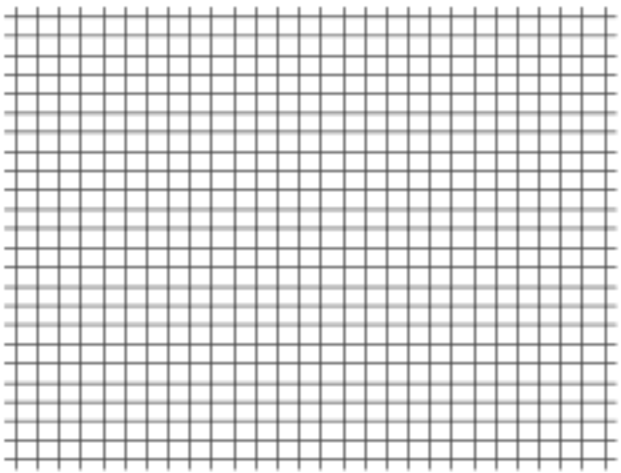
1. Learn about sound speed (why?).

2. Use Matlab to compute sound speeds in the ocean as function of pressure, temperature and salinity.

3. Extract sound speeds from climatology.

4. If time permits: begin to compute paths of sound rays in the ocean.

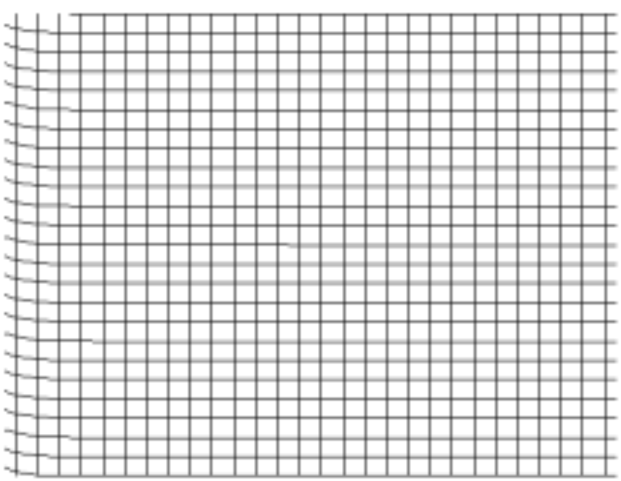
Sound speed: distance traveled per unit time relative to medium



Compression (longitudinal) wave

Sound wave in fluids & solids

Motion || direction of propagation



Transverse (shear, elastic) wave

2^{nd} type of sound wave in solids (e.g. earthquakes). Slower than compression waves

Motion $\perp$ direction of propagation

From Wikipedia (speed of sound)

Sound speed

In most application can be assumed to be independent of frequency (non-dispersive), and energy travels at the *phase speed*.

Speed of compression wave depends on: compressibility and density.

Speed of S-wave depends on: compressibility, density and shear modulus (related to sideways deformations).

Sound speed relates to material properties by the Newton-Laplace equation:

$$c = \sqrt{\frac{E}{\rho}}$$

Where E is the bulk modulus (inverse of compressibility) and ρ the material's density.

Sound speed

Let us develop some intuition into the sound speed of the oceans.

Using the routing ‘sndspd.m’ compute the sound speed for:

1. Constant pressure and temperature with salinity ={0:1:34}psu
2. Constant pressure and salinity with temperature ={0:1:30}°C
3. Constant salinity and temperature with pressure={0:100:3000} dB

Note: you will have to choose a formulae (default is Mackenzie)

Sound speed

Obtaining a sound speed profile for a specific location:

Use ‘Extract_sndspd.m’ and ocean climatology files to:

1. Obtain sound speed along a transect.

2. Plot sound speed along a depth level.

3. Save a median profile.

From: http://staff.washington.edu/dushaw/atoc.html

NB: program interpolates.

Sound propagation

In order to know how sound will propagate (or by reciprocity, where it comes from, we need to know:

1. How it propagates.

2. How it attenuates.

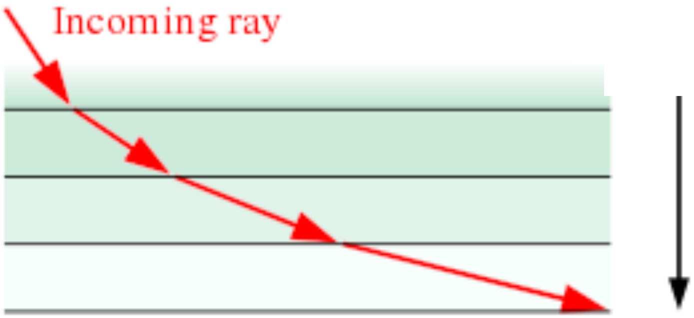
There exist different approaches:

a. Model sound as wave (more exact).

b. Model sound as rays (less complicated).

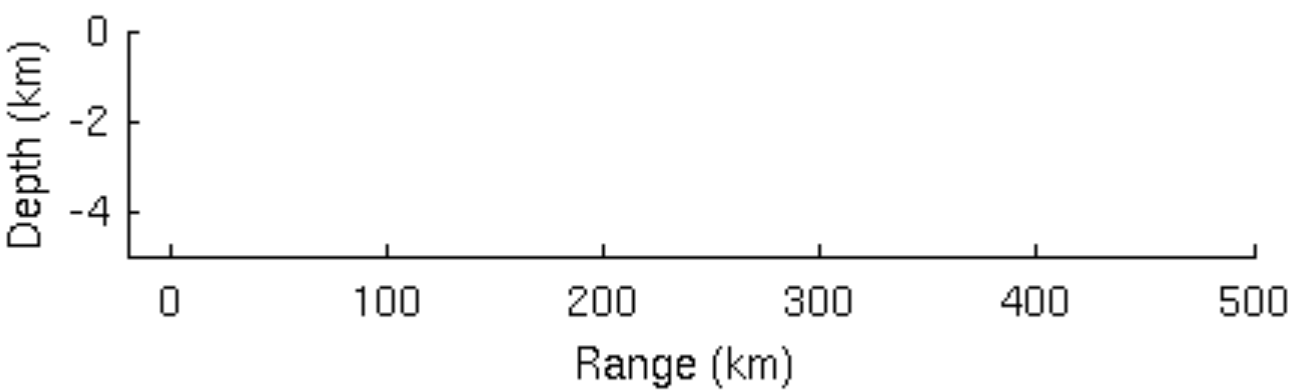
Sound propagation

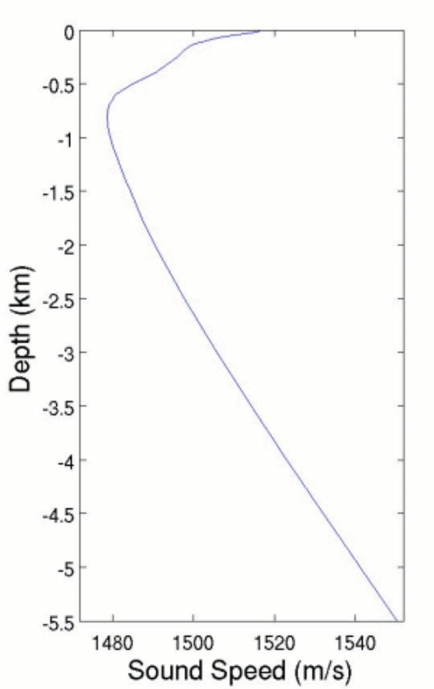
Sound rays bend as sound speed change:



Direction of increasing sound speed

Example: ray tracing through the SOFAR channel:



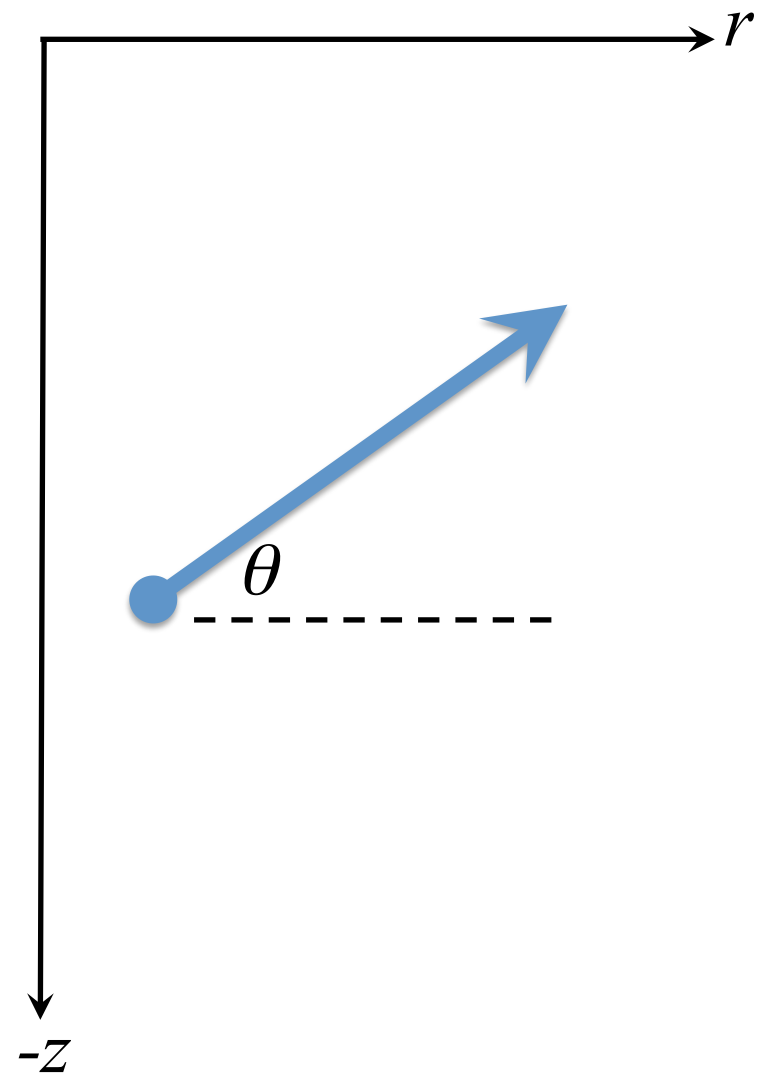


From wikipedia: ray tracing

Ray tracing

Fermat's principle - ray path is that which takes the shortest time :

$$\frac{d\theta}{dr} = \frac{\partial_r c}{c}\tan\theta - \frac{\partial_z c}{c}$$



Definition of θ:

$$\frac{dz}{dr} = \tan\theta$$

Definition of *r*:

$$\frac{dt}{dr} = \frac{sec\theta}{c}$$

Additionally we need:

1. Initial conditions.
2. Boundary conditions.

Ray tracing

Snell's law along a ray: $\frac{\cos\theta}{c} = const.$

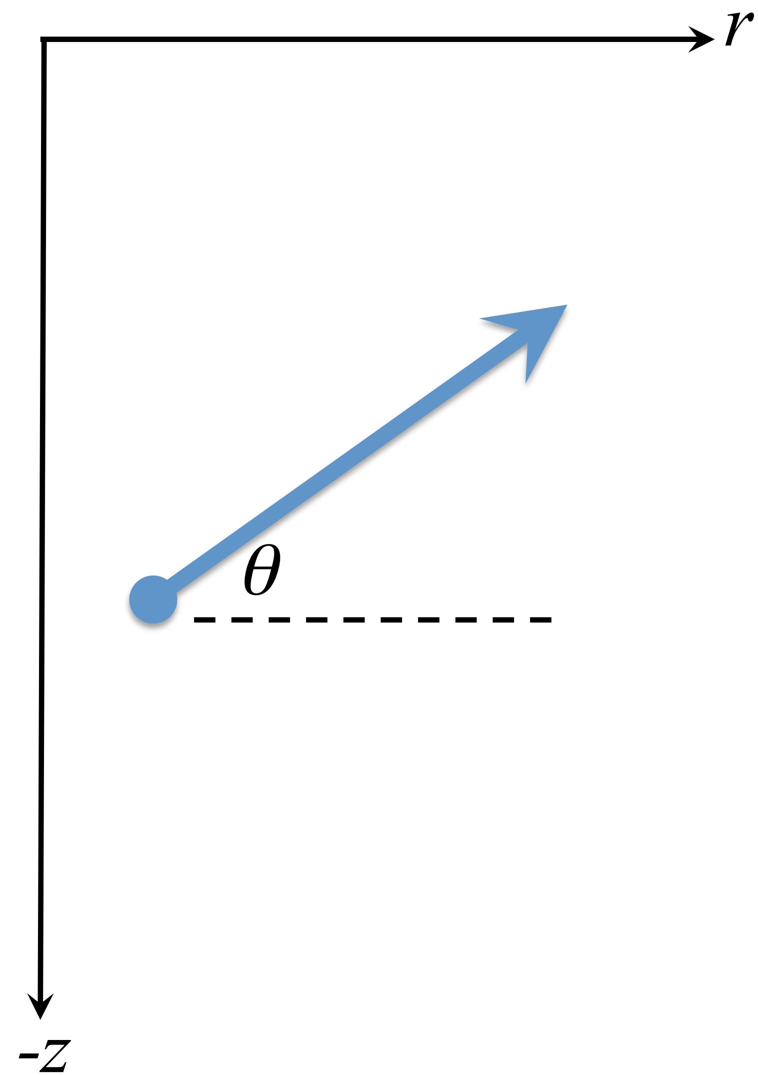
Special cases:

Constant c: no bending

Linearly varying c:

Ray bend as an arc with radius:

$$R = \frac{c_0}{\nabla c} \sim \frac{c_0}{dc / dz}$$



Ray tracing

Using a ray tracing routine such as 'ray_trace.m':

1. Generate several rays to see how their path varies based on initial depth and direction (relative to the horizontal).

2. Repeat with a file of depth and sound speeds (e.g. the one you saved earlier).

3. Evaluate how daily warming can affect sound propagation by using two profiles 100m in depth. Compare ray propagation of an isothermal surface mixed layer and a layer with T increasing from 30m to the surface by 2°C.

Reading for Blog about how acoustics is used now-a-day to study climate effects on ocean basins:

http://en.wikipedia.org/wiki/Ocean_acoustic_tomography