Introduction to Sound Speed and its Application to Multi-Beam Data

January 19, 2012
Newport, Oregon
LT Caryn Zacharias,
NOAA Ship *Fairweather*

Sound Speed Profile

- Why do we need to measure the water column sound profile?
- What data problems occur if we don't?
- How do we measure the profile?
- How do we apply the profile data to our Multi-Beam Echo Sounder data?

How sonar measures depth

Water surface

Ping

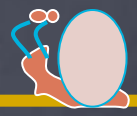
Ping return

t_1

t_2

$$\frac{(t_1 + t_2)}{2} \cdot S = d$$

t_1 = ping time down
t_2 = ping time up
S = speed of sound in water
d = water depth



Sea bottom

Example

Our ping takes 4/100th of a second for the echo to return to the ship

$t_1 + t_2 = 0.04$ seconds

S = 1500 meters/second (assumed)

t_1 = ping time down
t_2 = ping time up
S = speed of sound in salt water (~1500 m/s)
d = water depth

$$\frac{(t_1 + t_2)}{2} \cdot S = d$$

$$\frac{(0.04 \text{ seconds})}{2} \cdot \frac{1500 \text{ meters}}{\text{second}} = 30 \text{ meters}$$

Factors which affect sound speed in Sea Water

- Temperature:

speed increases by about 4.6 m/s per degree C.

http://www.nodc.noaa.gov/dsdt/cwtg/all.html

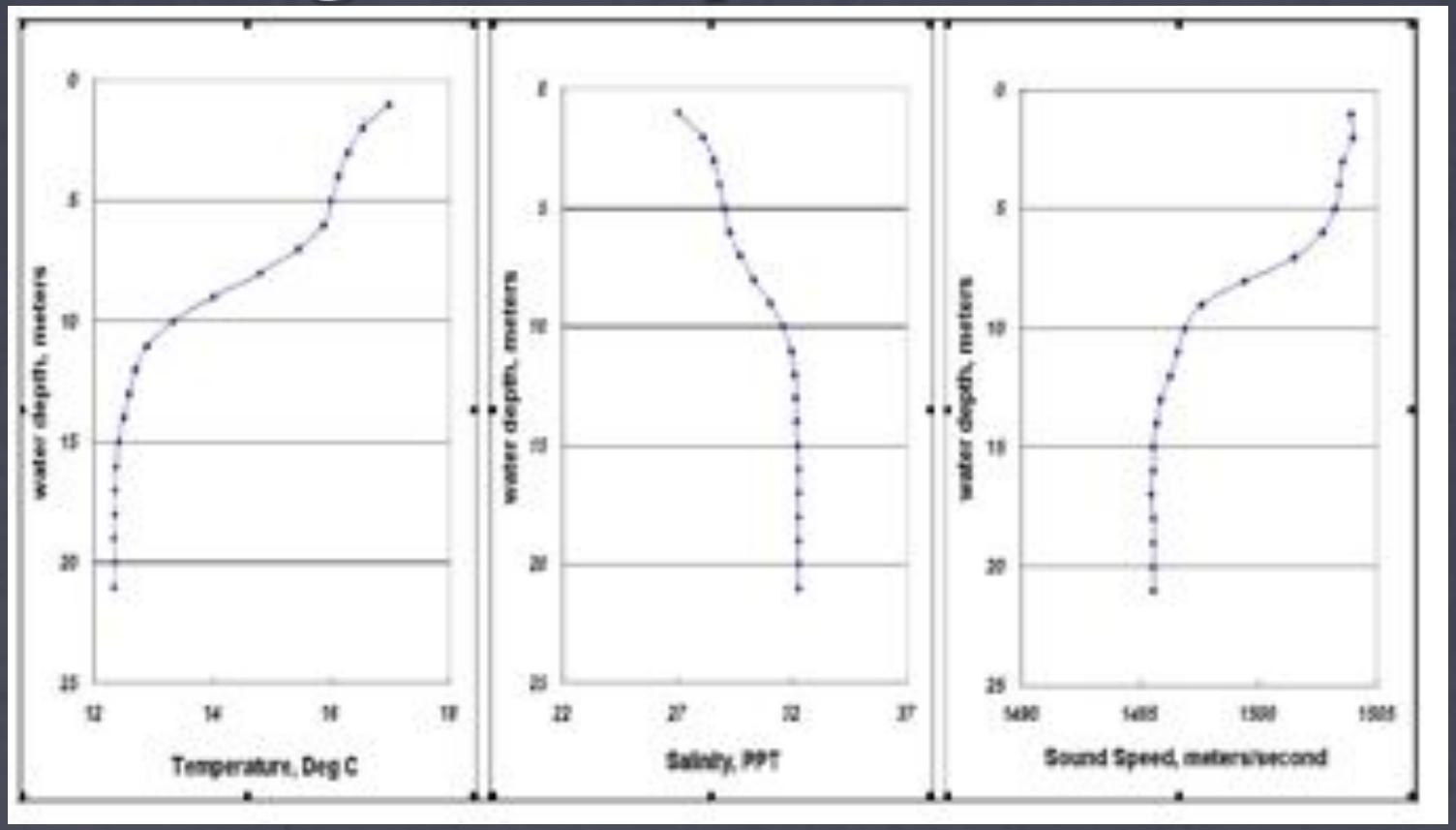
- Salinity:

speed increases by 1.3 m/s for each PSU increase.

- Pressure:

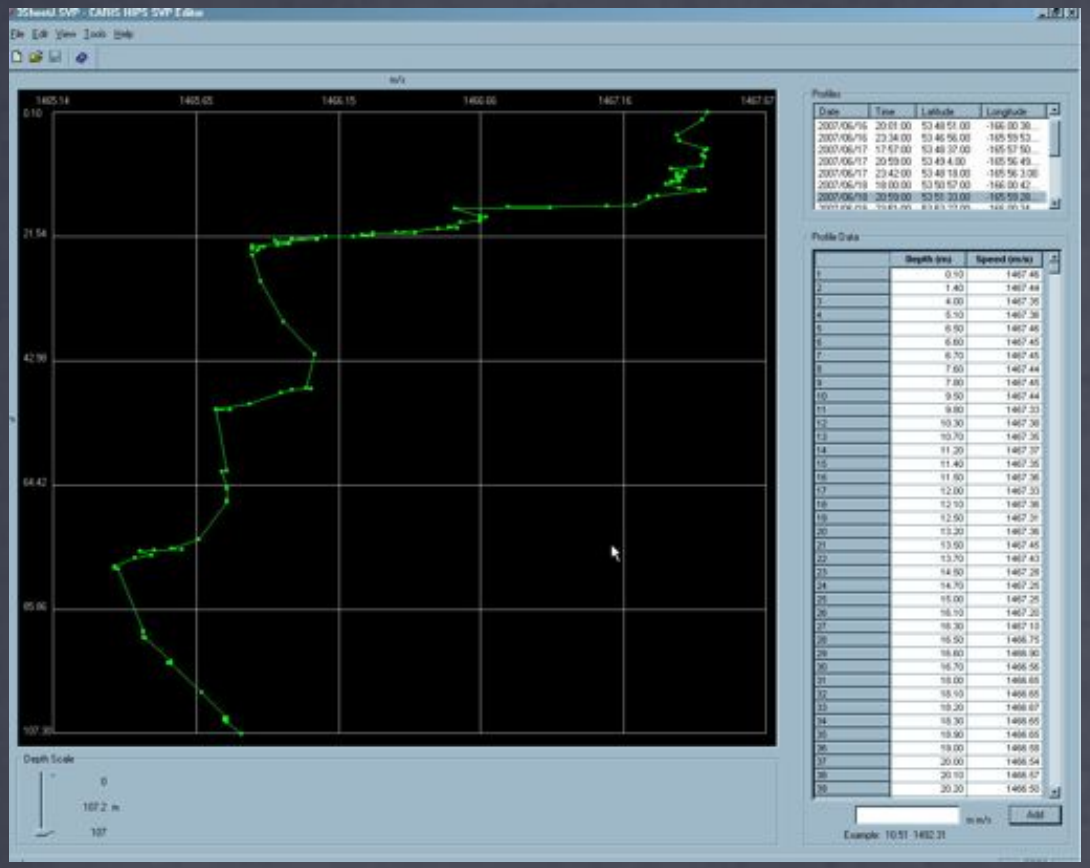
less than 0.2 m/s per atmosphere increase (each 30 meters depth)*

Measuring sound speed



Summer CTD cast showing measured temperature and salinity relative to depth, the sound speed profile (right) may be calculated from these using Velocwin program.

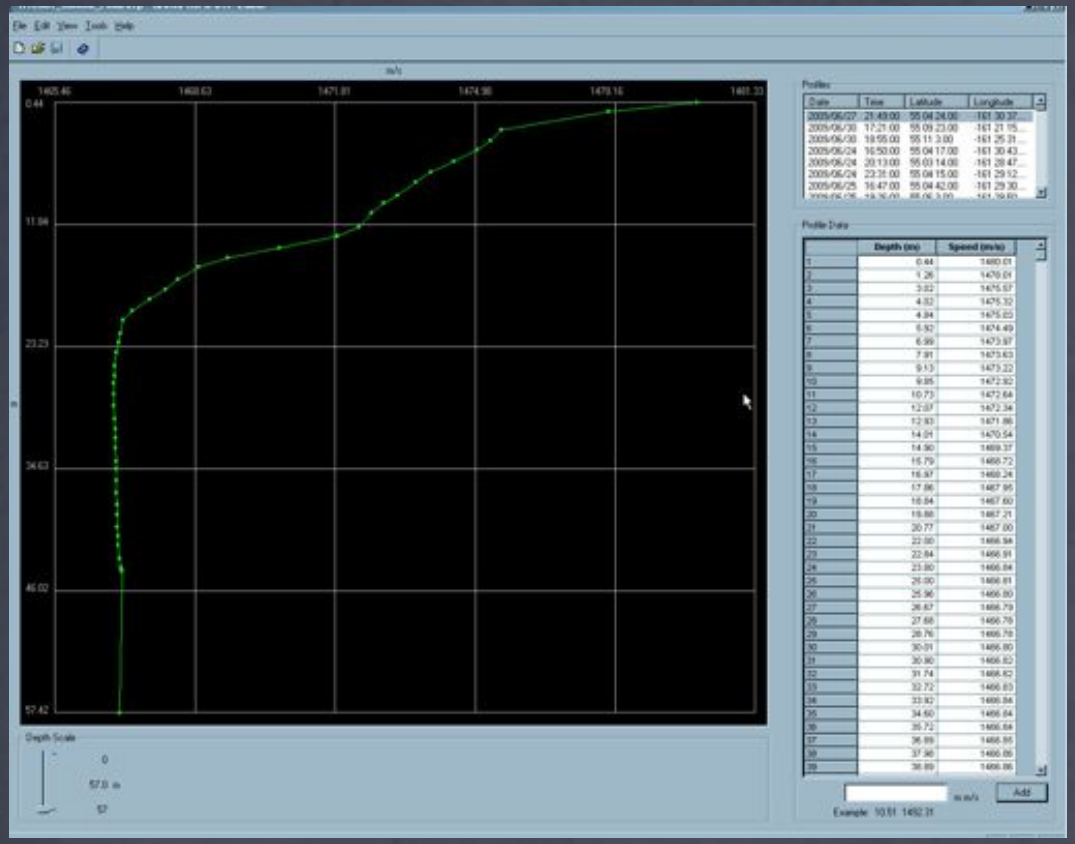
Sound Speed Profile



CARIS HIPS SVP Editor

June - Alaska

Sound Speed Profile



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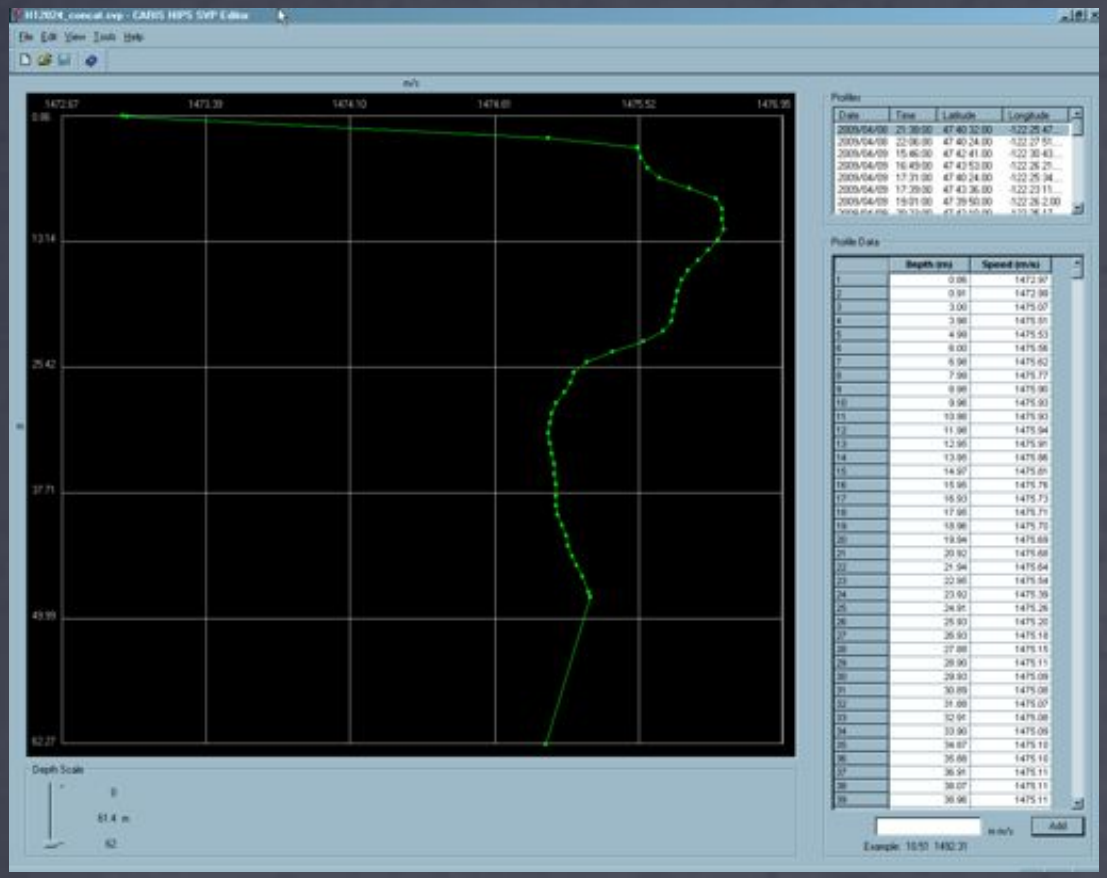
June - Alaska

Sound Speed Profile



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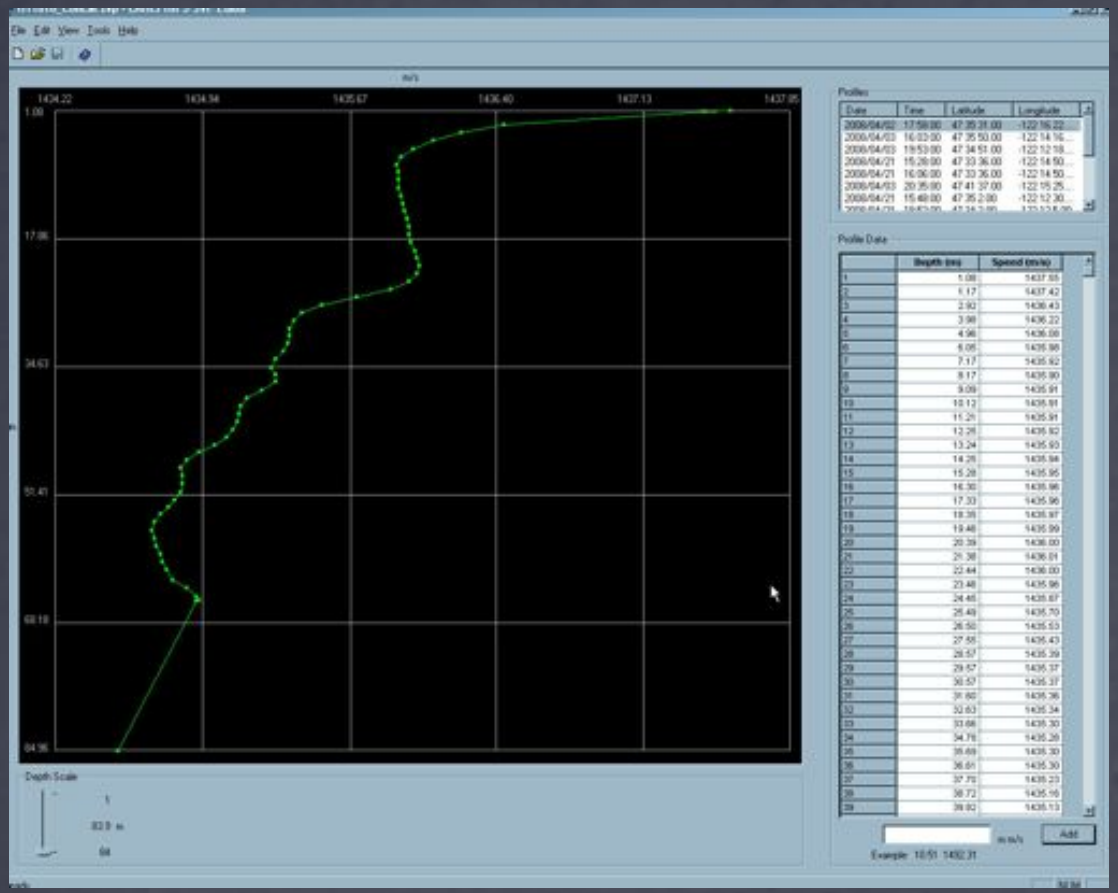
April -
Puget Sound

Sound Speed Profile



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April - Lake Washington

Chen - Millero Equation

$$c(S,T,P) = Cw(T,P) + A(T,P)S + B(T,P)S^{3/2} + D(T,P)S^2$$

$$\begin{aligned} Cw(T,P) = {} & (C_{00} + C_{01}T + C_{02}T^2 + C_{03}T^3 + C_{04}T^4 + C_{05}T^5) + \\ & (C_{10} + C_{11}T + C_{12}T^2 + C_{13}T^3 + C_{14}T^4)P + \\ & (C_{20} + C_{21}T + C_{22}T^2 + C_{23}T^3 + C_{24}T^4)P^2 + \\ & (C_{30} + C_{31}T + C_{32}T^2)P^3 \end{aligned}$$

$$\begin{aligned} A(T,P) = {} & (A_{00} + A_{01}T + A_{02}T^2 + A_{03}T^3 + A_{04}T^4) + \\ & (A_{10} + A_{11}T + A_{12}T^2 + A_{13}T^3 + A_{14}T^4)P + \\ & (A_{30} + A_{31}T + A_{32}T^2)P^3 \end{aligned}$$

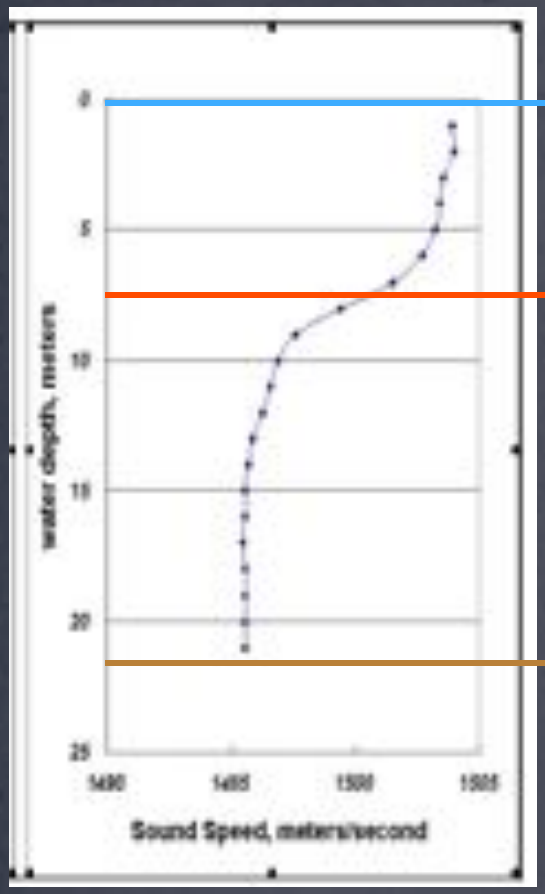
$$B(T,P) = B_{00} + B_{01}T + (B_{10} + B_{11}T)P$$

$$D(T,P) = D_{00} + D_{10}P$$

T = temperature in degrees Celsius
S = salinity in PSU or ppt
P = pressure in bar
Everybody else is a coefficient

http://www.tsuchiya2.org/soundspeed/unesco.htm (Jan 2010)

Simplifying this Cast



Sea Surface

0 meters

~ 1503 m/s

Thermocline (approx)

7 meters

~ 1496 m/s

22 meters

Sea Bottom

The average sound speed for this profile is: 1498 meters/second

How a Vertical Beam is Affected

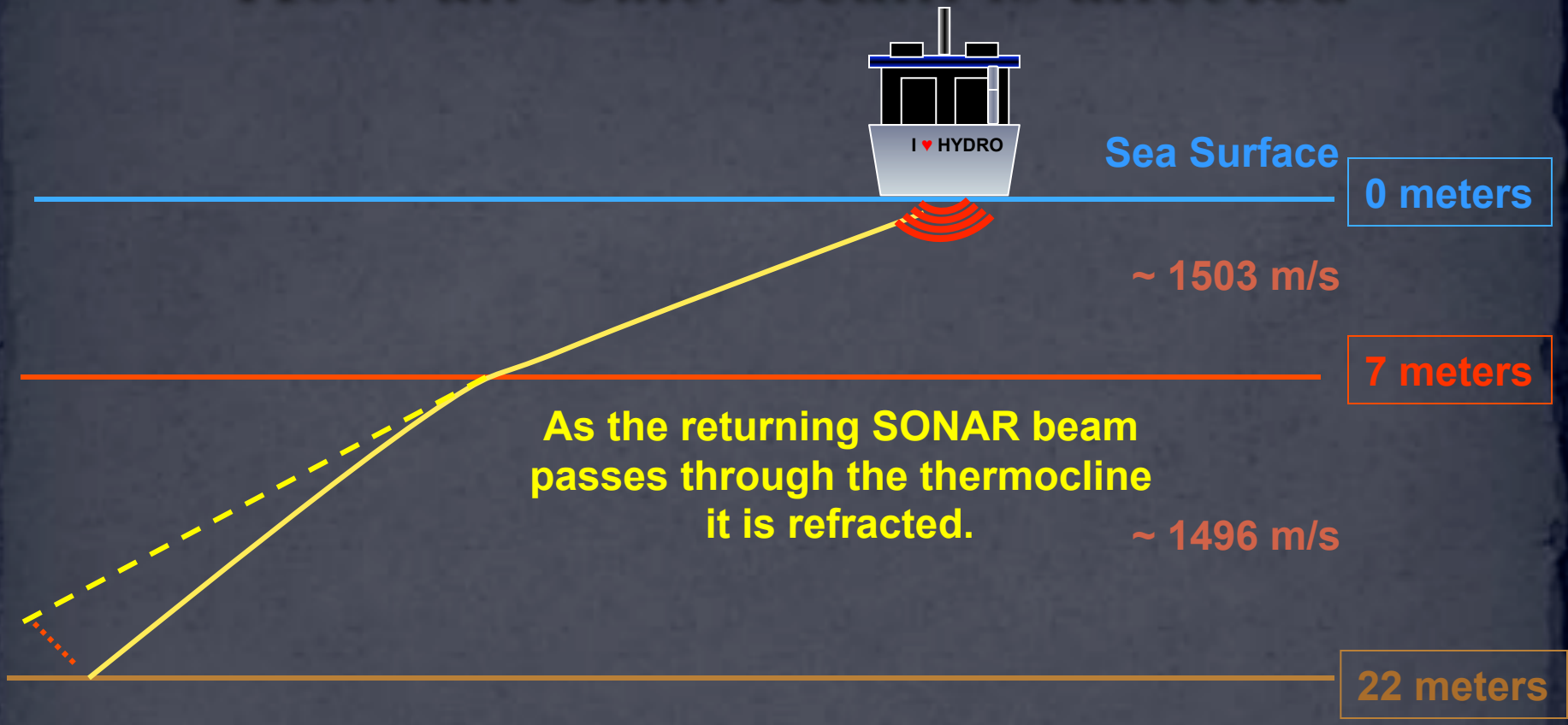
Round trip time: = $\frac{44\text{ m}}{1498\text{ m/s}}$ = 0.0294 seconds

If we use the sound speed at the surface we will measure the depth to be:

$\frac{0.0294\text{ sec}}{2} * 1503\text{ m/s} = 22.07\text{ meters}$

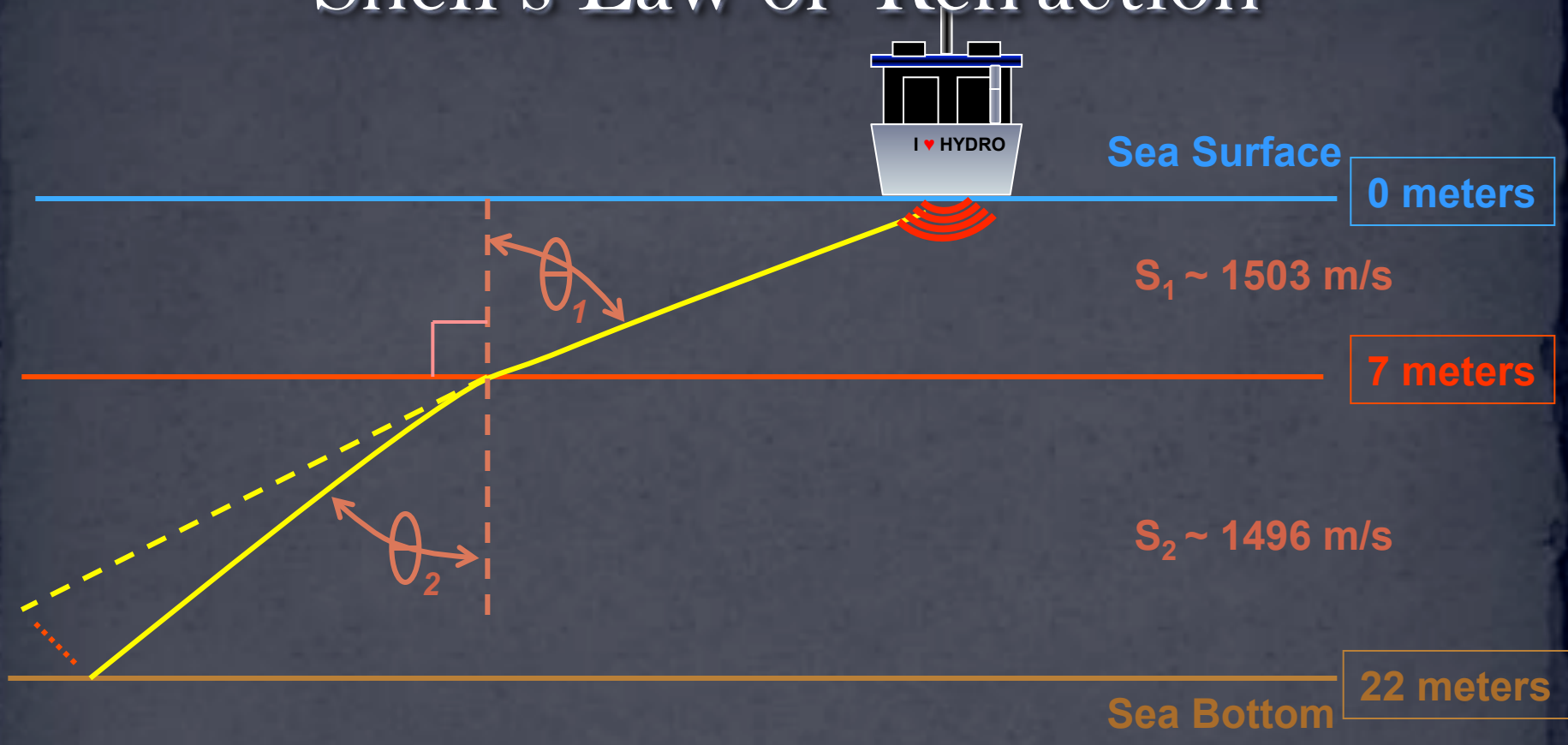
Only 0.3 % error in this example !

How an *Outer* beam is affected



The larger the sound speed variation is above and below the thermocline, the more the beam is bent.

Snell's Law of Refraction

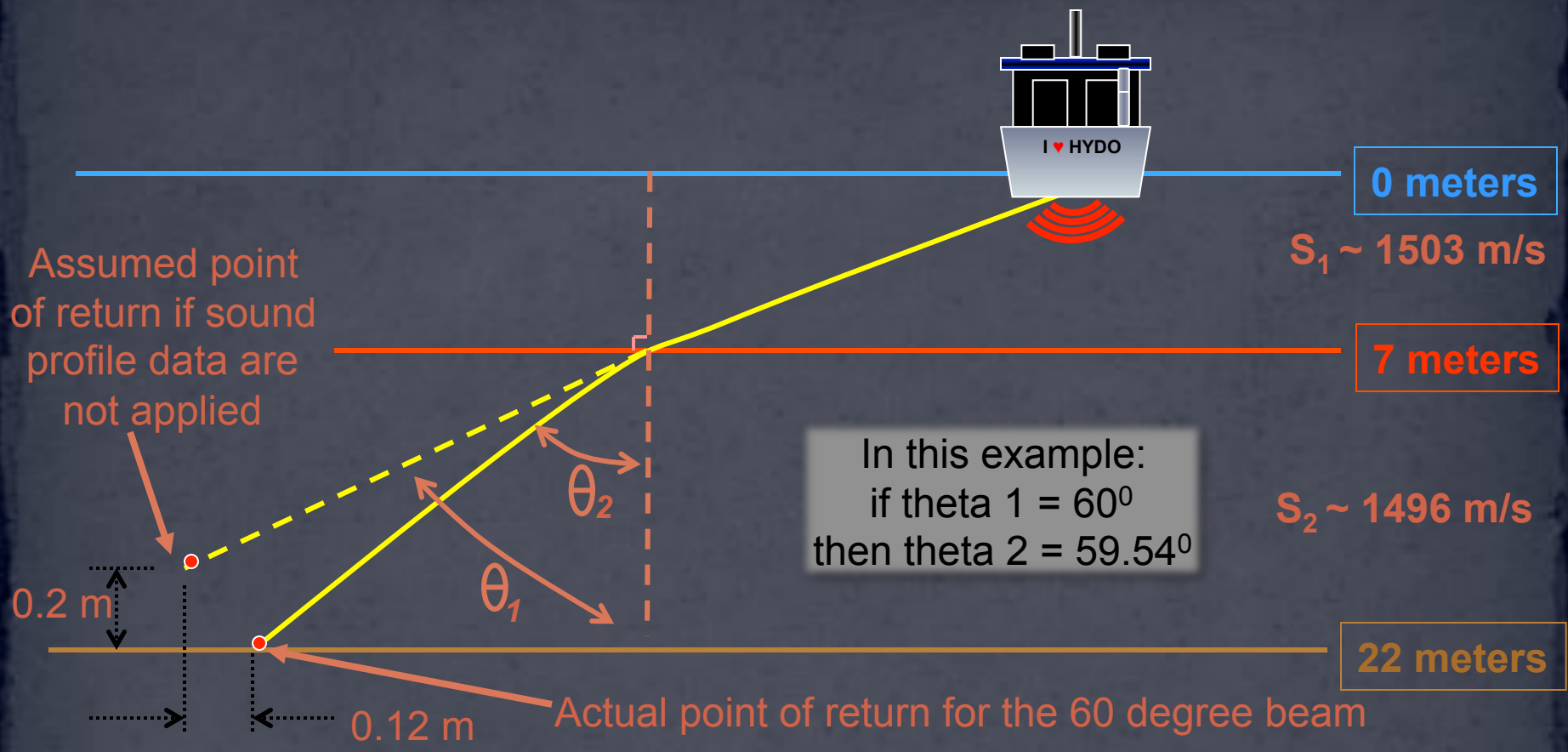


Snell's Law:

$$\frac{\sin\theta_1}{S_1} = \frac{\sin\theta_2}{S_2}$$

In this example:
if theta 1 = 60^0
then theta 2 = 59.54^0

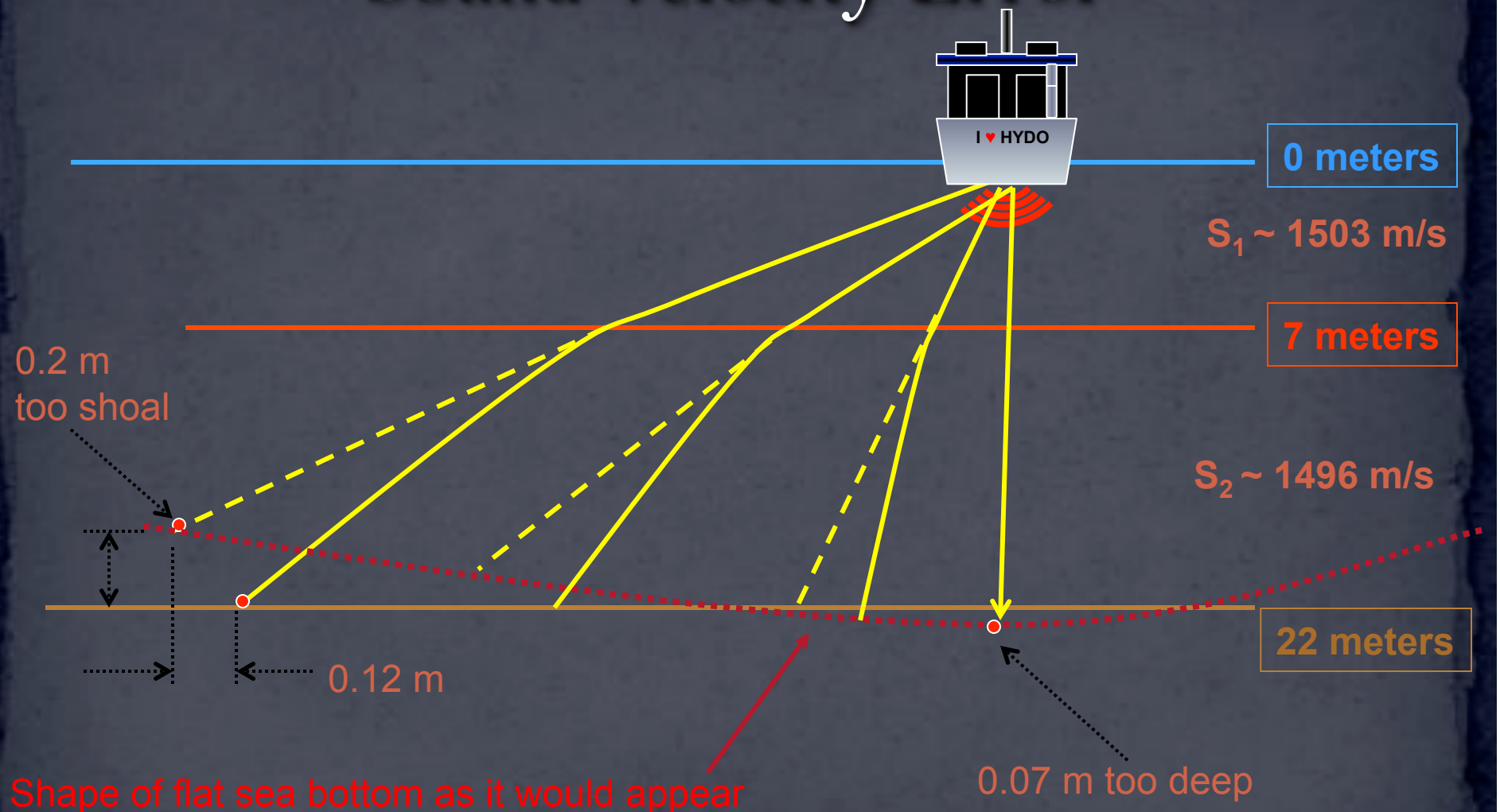
Snell's Law of Refraction



Almost a 1% depth error for the 60 degree beam

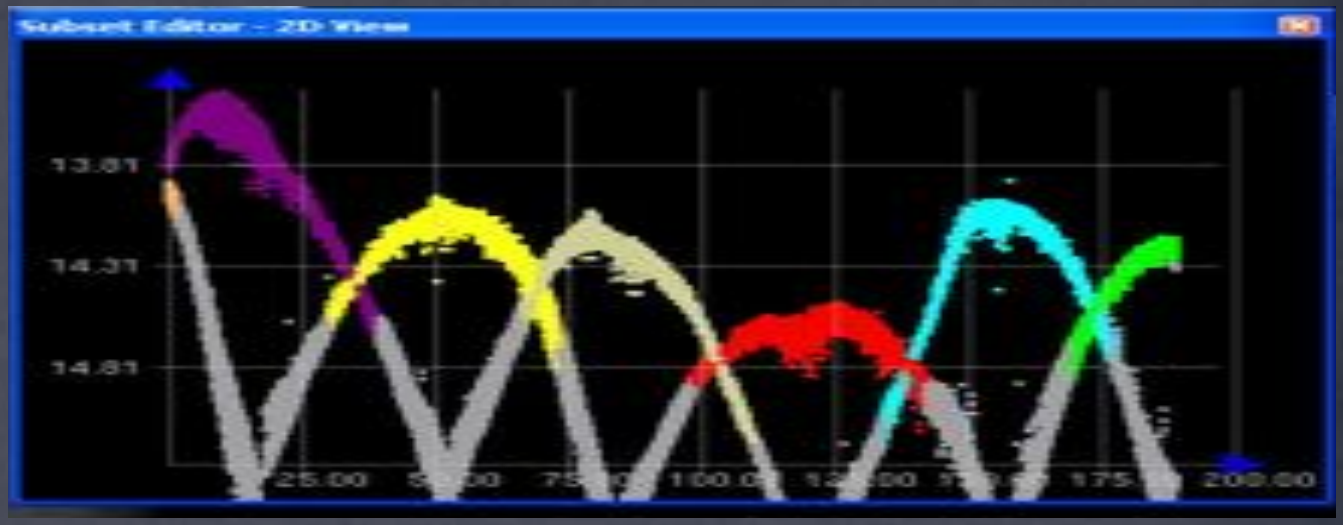
Lines not to scale

Sound Velocity Error

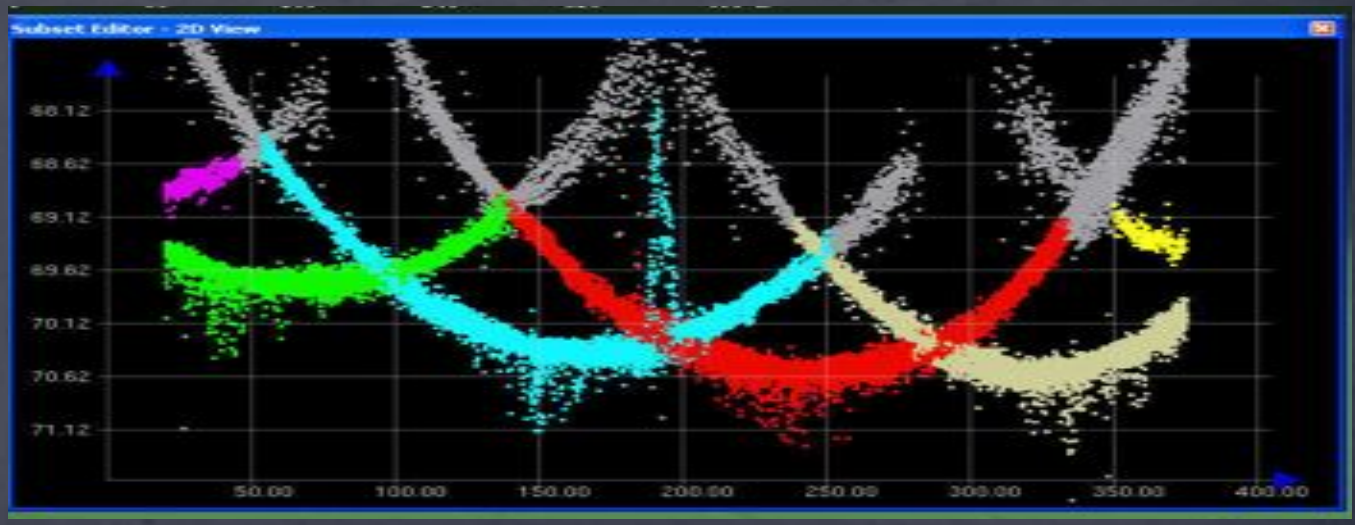


Signature of Sound Speed Artifacts

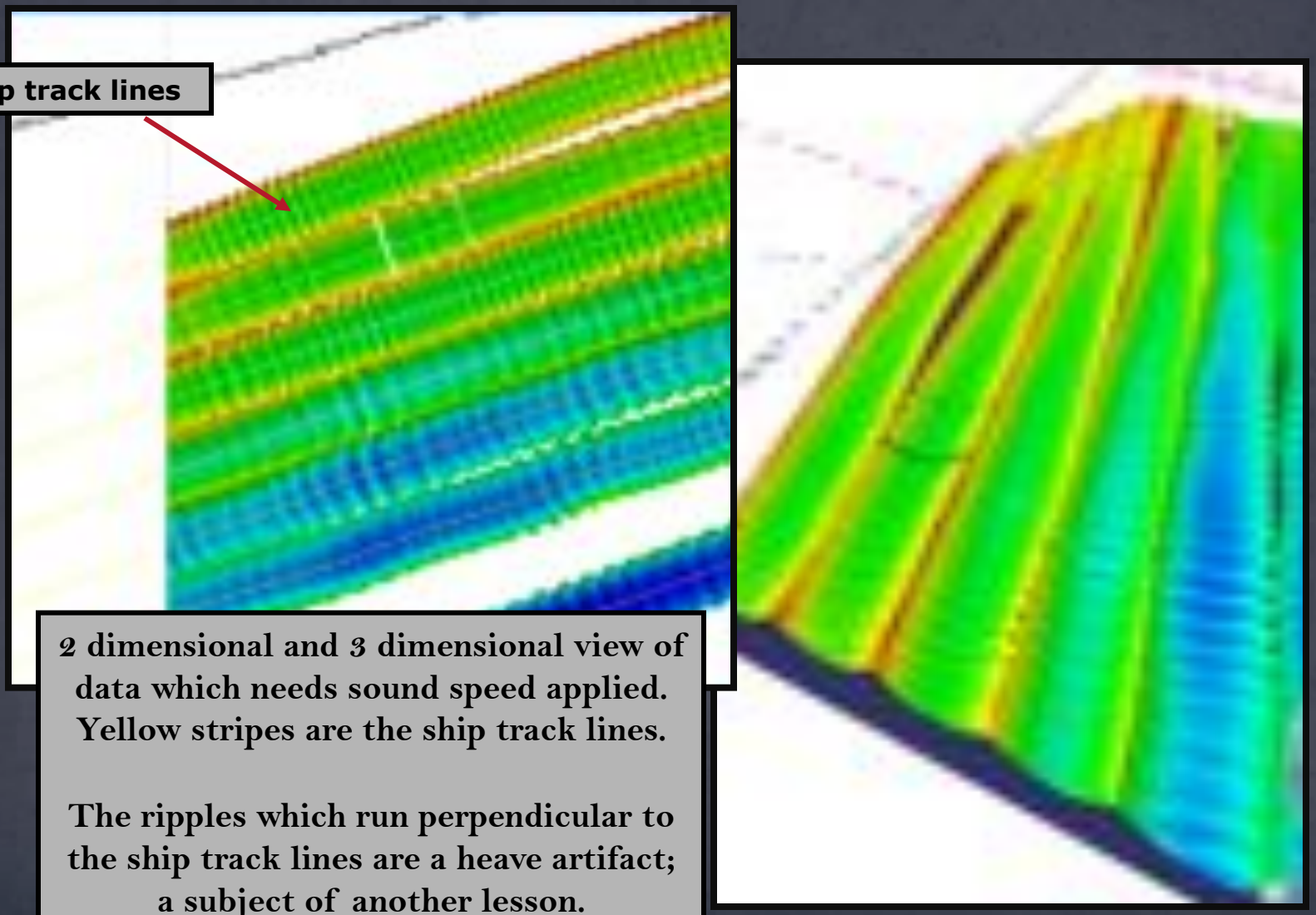
Frowning data



Smiling data



Visual of Sound Speed Error



2 dimensional and 3 dimensional view of data which needs sound speed applied. Yellow stripes are the ship track lines.

The ripples which run perpendicular to the ship track lines are a heave artifact; a subject of another lesson.

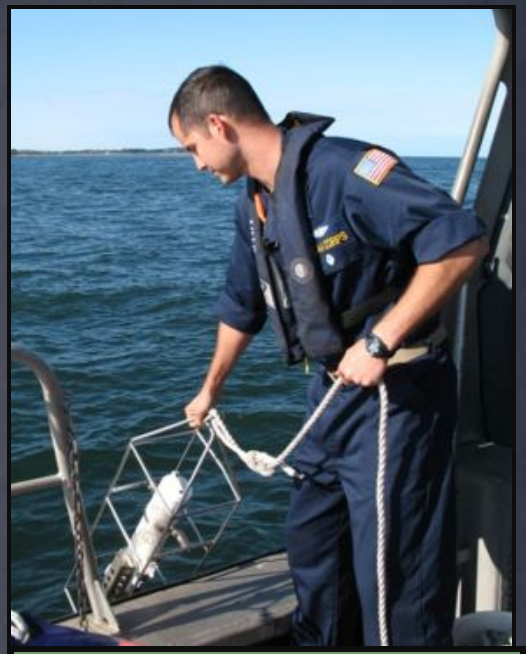
How do we measure sound speed?

Tools:

- Velocimeters
  - Sound speed and depth
- CTDs
  - Conductivity (salinity)
  - Temperature
  - Pressure (depth)
- XBT
  - Temperature only
- TSG (Thermo-Salino Graphs)
  - Temperature
  - Conductivity (Salinity)

Moving Vessel Profiler (MVP) casts velocimeter without stopping the ship.

Can be a significant time Saver.

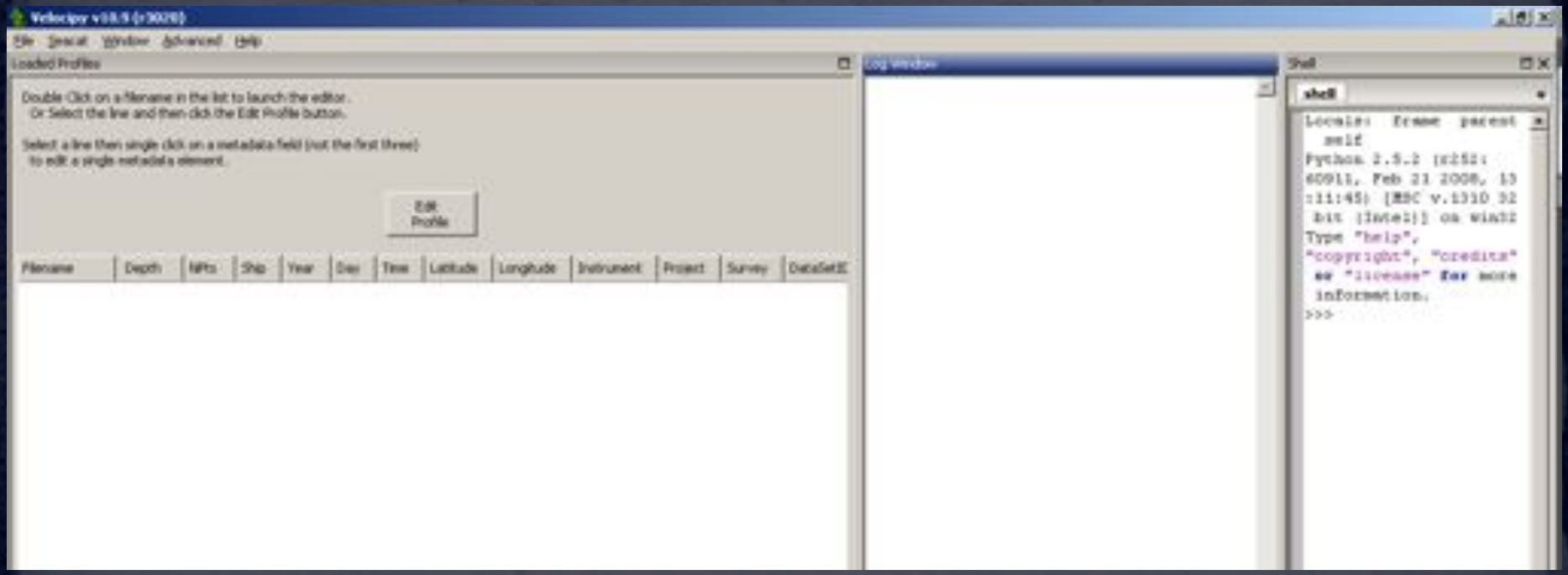


A Sea-Bird Electronics SBE-19*plus* CTD profiler may be deployed from a launch or ship.

Thermo-Salino Graphs (TSG) Using a water intake to measure sea surface temp and salinity.

Sound speed may be measured directly by casting a digibar which uses a velocimeter and pressure sensor.

How we download and process sound speed?



SVP Concatenation

Using a text editor, the .svp files for all of the casts from a survey platform are concatenated into one sound speed file for an entire survey. This file with all of the casts will be used in CARIS and applied to the MBES data.

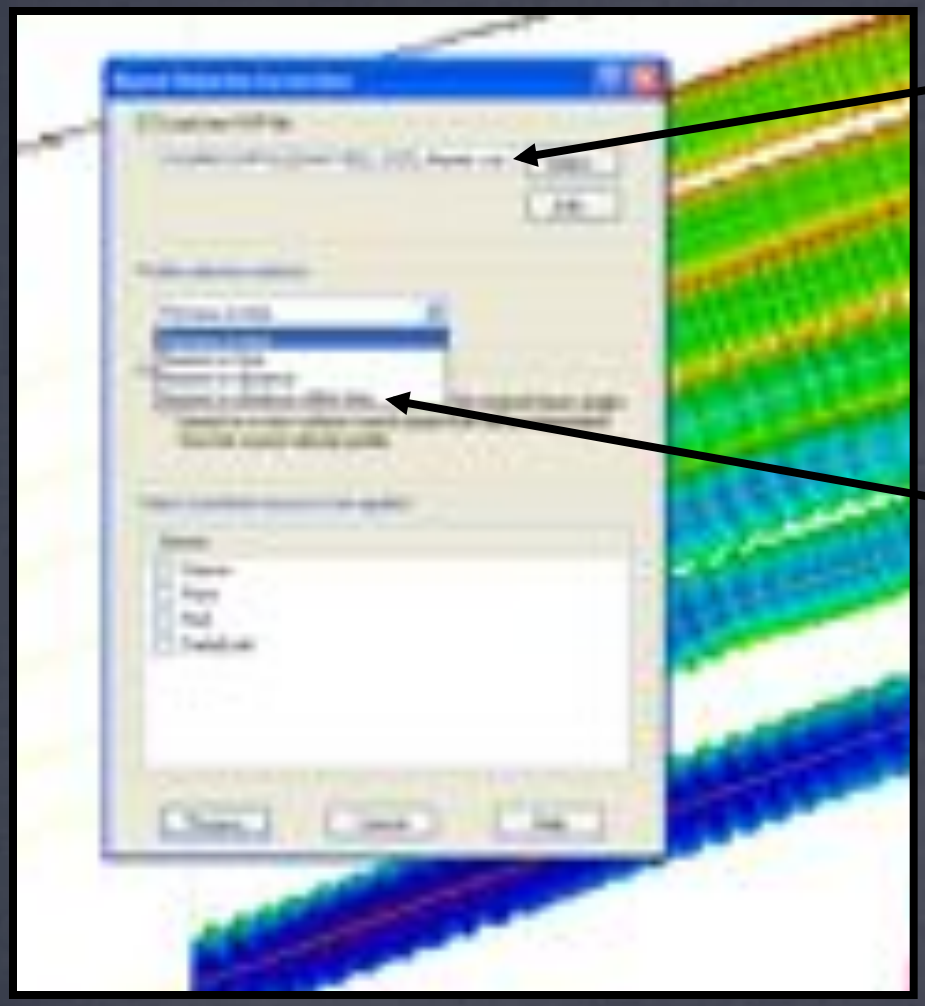
```
---
  20.45      1503.03
  20.55      1503.03
  26.72      1503.12
Section  2008-300  21:39   41:06:35  -072:24:10
   0.99      1502.24
   1.04      1502.28
   2.88      1502.35
   3.95      1502.38
   5.06      1502.41
   5.98      1502.44
   6.91      1502.49
   8.00      1502.53
   9.01      1502.56
  10.00      1502.58
  10.99      1502.62
  11.98      1502.69
  13.03      1502.81
  14.32      1503.07
  15.15      1503.22
  15.97      1503.27
  17.03      1503.31
  18.41      1503.36
  18.81      1503.37
  18.91      1503.37
  24.59      1503.73
Section  2008-301  12:51   41:06:26  -072:24:13
   0.80      1502.33
   0.85      1502.40
   2.97      1502.52
   4.04      1502.61
   4.98      1502.66
   5.97      1502.69
   6.98      1502.72
   8.01      1502.77
   8.97      1502.81
   9.94      1502.84
  11.01      1502.85
  12.05      1502.86
  13.00      1502.90
  13.96      1502.94
  14.97      1502.97
  16.03      1502.99
  16.96      1503.01
  18.04      1503.03
  19.52      1503.05
  20.35      1503.06
  20.66      1503.07
  20.85      1503.07
  27.10      1503.21
Section  2008-301  18:01   41:06:59  -072:24:29
   1.07      1502.77
   1.11      1502.76
   2.93      1502.52
```

One cast : the header lists date, time, lat/lon. CARIS HIPS needs this information to determine which cast to apply to a given line of MBES data.

Sound speed (m/s)

Depth (m)

Applying the Cast using HIPS:



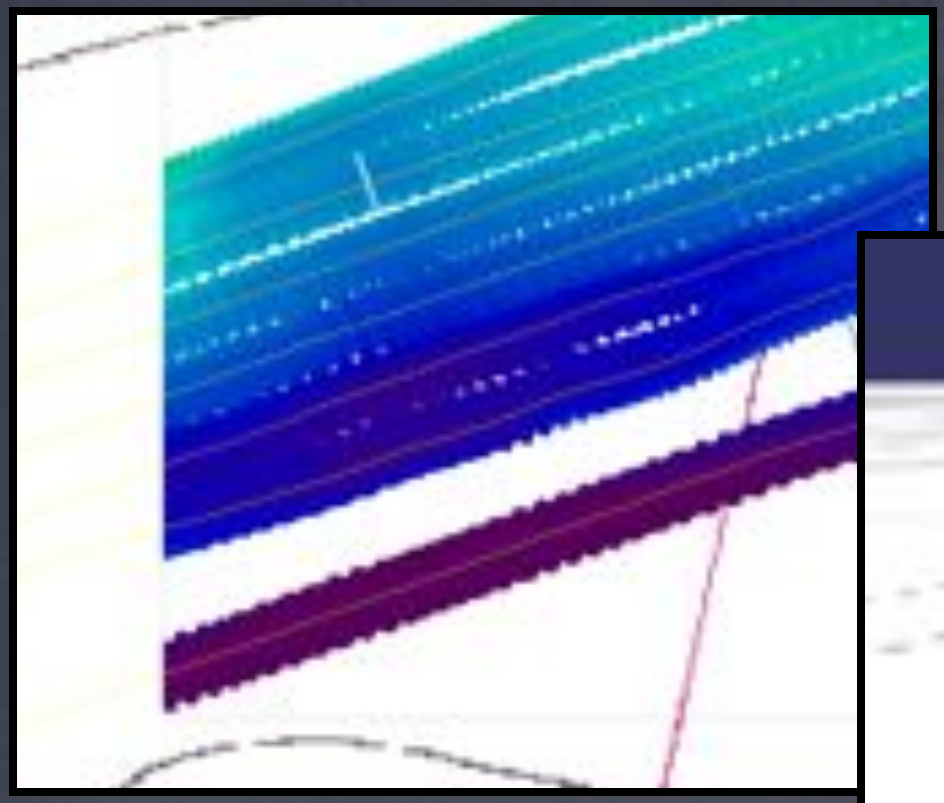
Concatenated .svp file for this ship

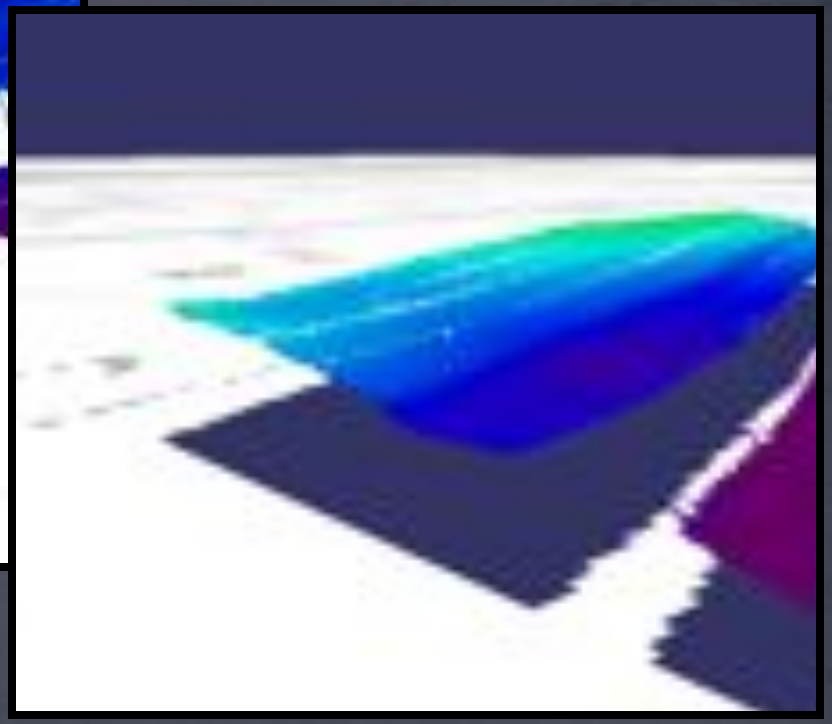
The .svp sound speed profile correctors are applied to the data with the CARIS HIPS program.

When there are several casts it is important to consider which one to use for any given line of SONAR data. Usually the cast applied is the nearest in distance within three hours.

If casts are made near each end of a line CARIS will divide the line and apply the nearer cast to each end.

Data After .svp is Applied





Surfaces are much smoother after the correction for sound speed is applied and surface is re-merged.

Questions?