Variability of the water column sound speed profile and its effect on acoustic propagation during the Shallow Water 2006 Experiment (SW06)

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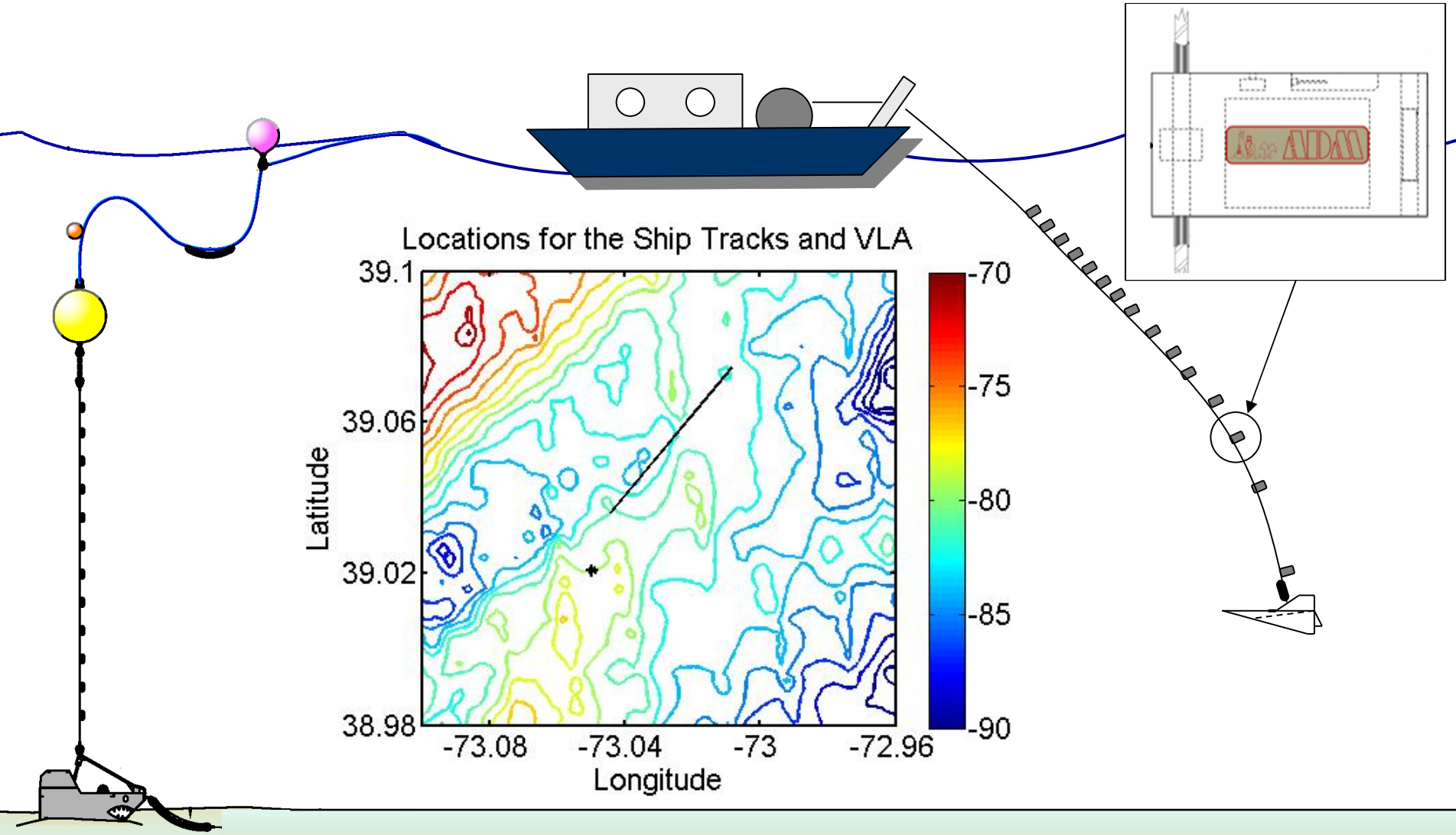
Outline

- Oceanographic Measurements
  - Towed CTD Chain (source location)
  - Shark VLA (receiver location)
- Acoustic Measurements
  - Continuous Tones
- Effect of Water Column Variability on
  - Modal Propagation
  - Transmission Loss
- Detailed Water Column Measurements allow for accurate predictions of experimental data

Oceanographic Measurements

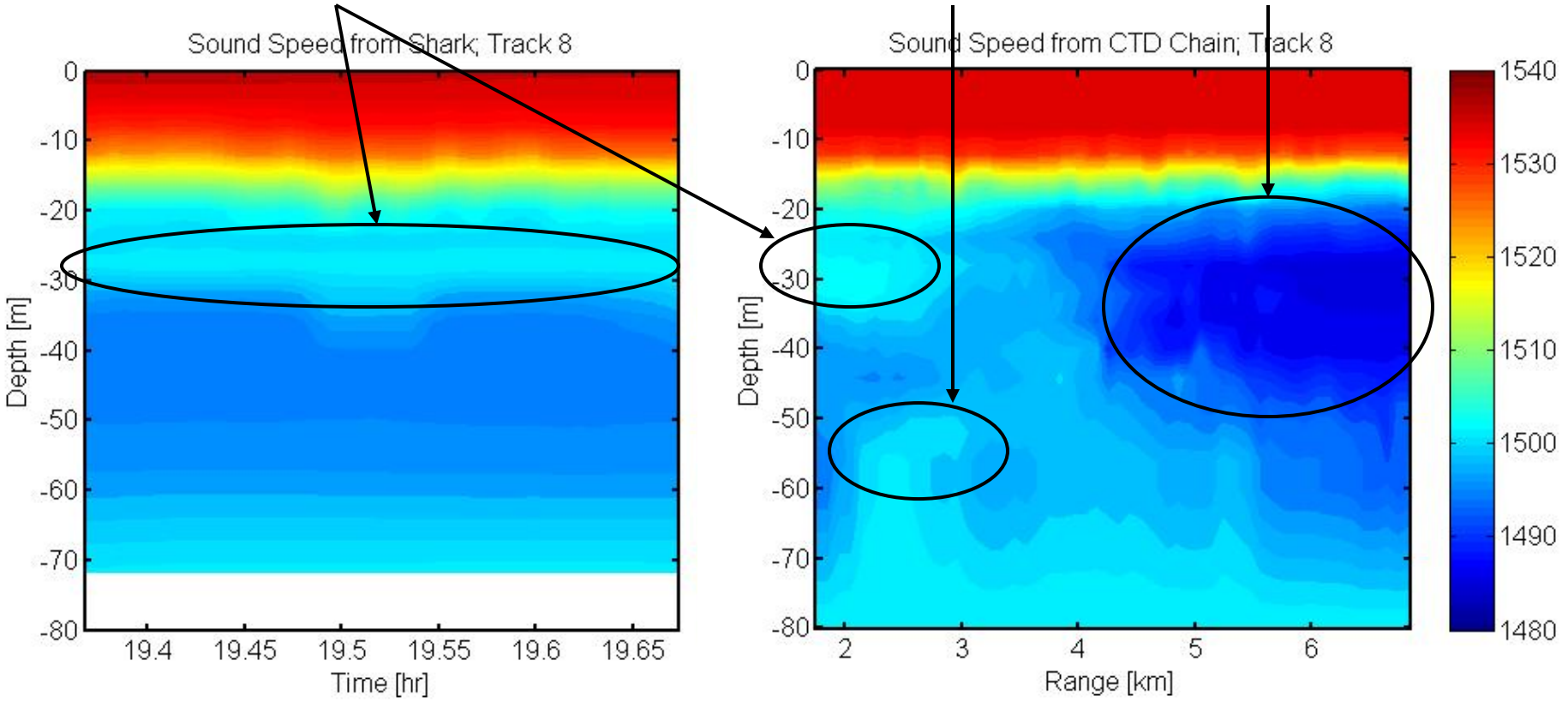


Spatial Variability Over Time

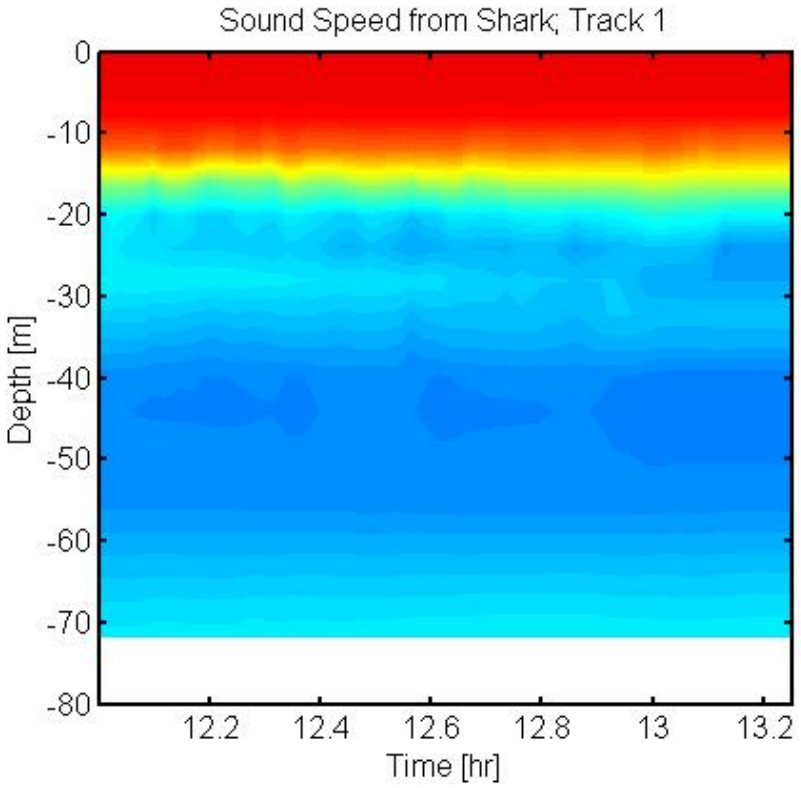
The next slides show sound speed measured by the Shark as a function of time and by the CTD chain as a function of range.

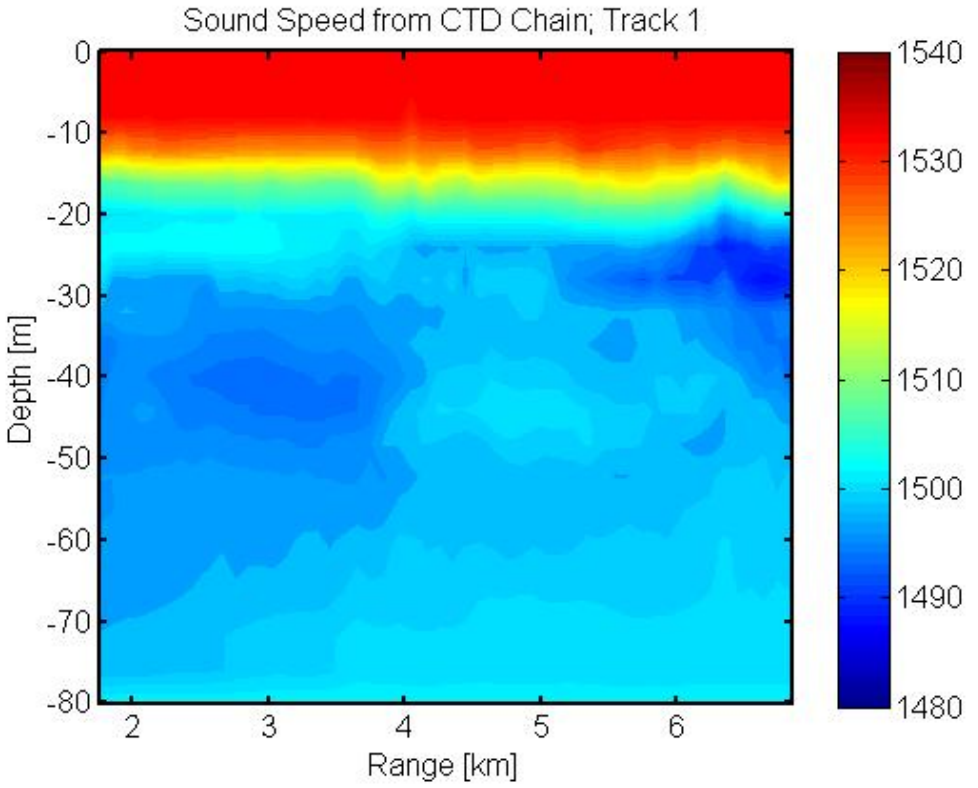
Some features to watch for:

Sub-pycnocline intrusion Thermohaline intrusion Cold water mass

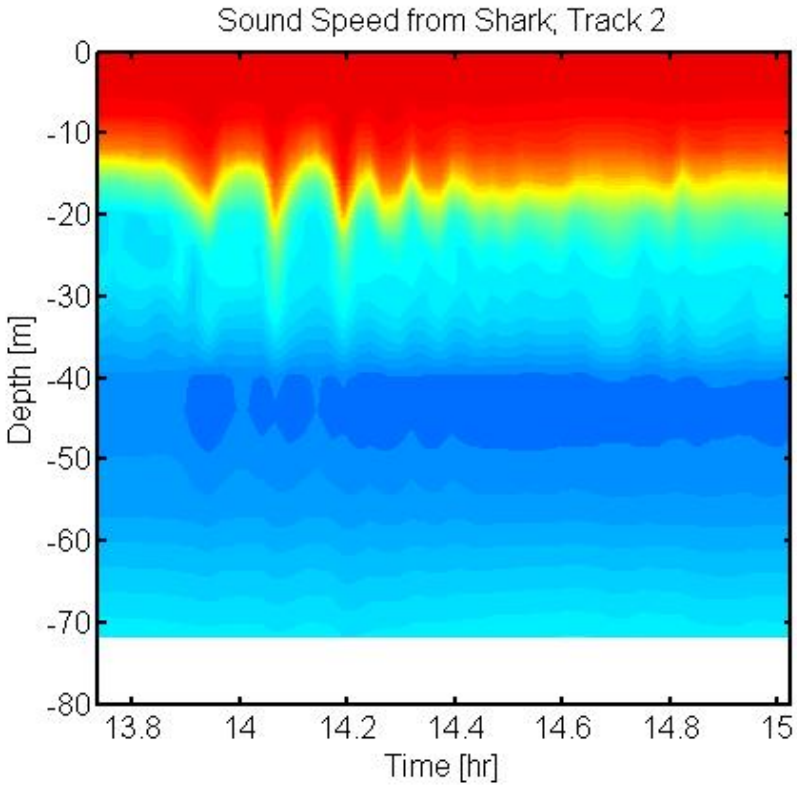


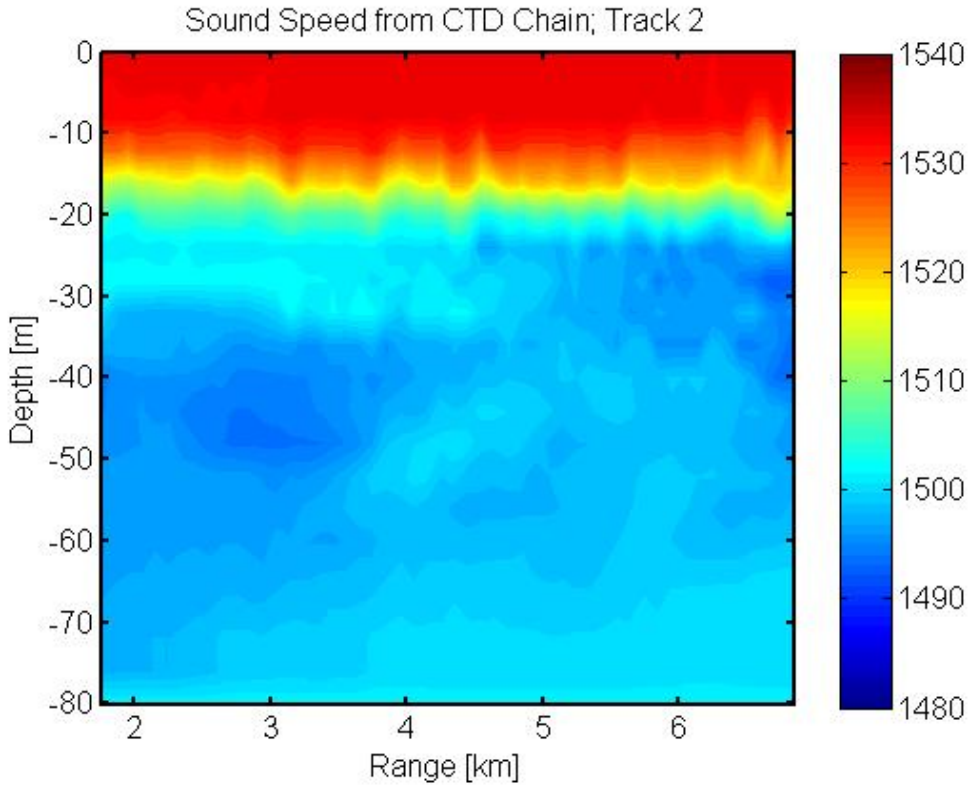
Track 1


Sound Speed from Shark; Track 1
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
12.2
12.4
12.6
12.8
13
13.2
Time [hr]

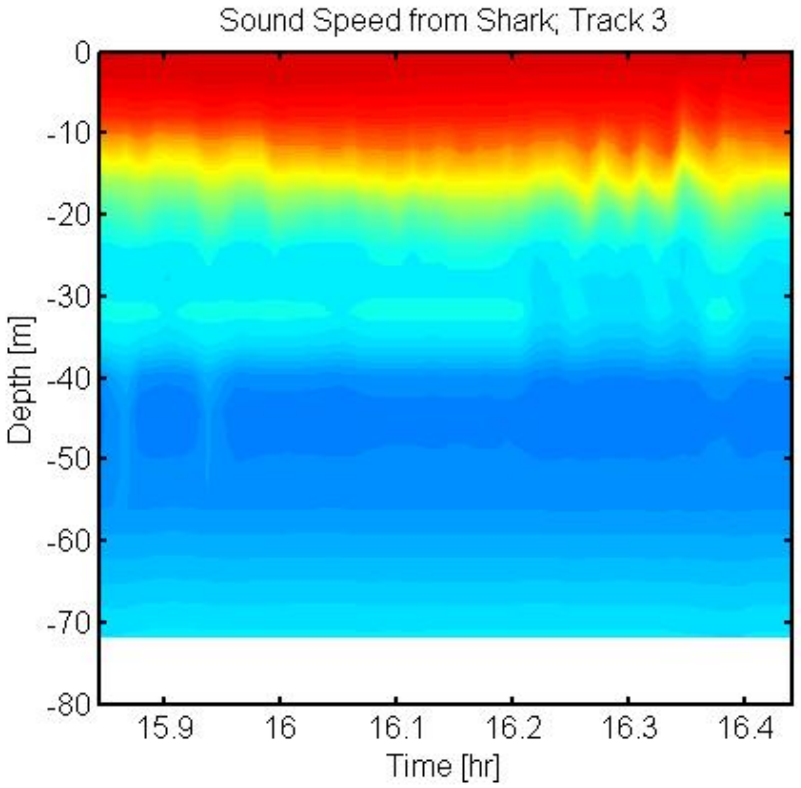

Sound Speed from CTD Chain; Track 1
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
2
3
4
5
6
Range [km]
1540
1530
1520
1510
1500
1490
1480

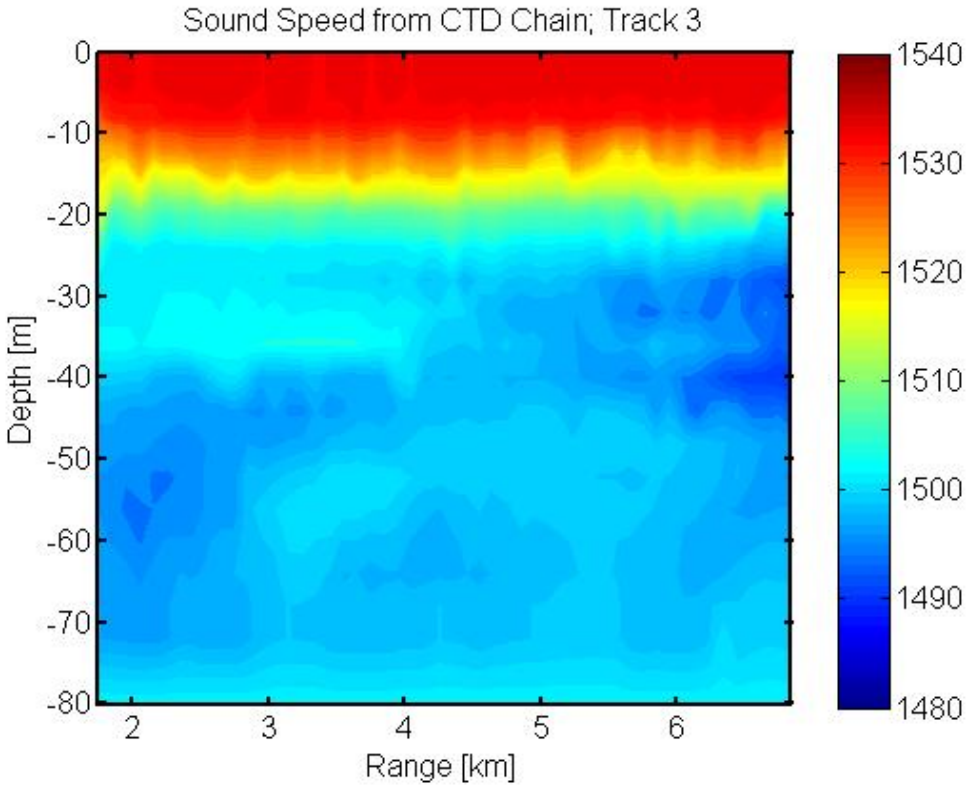
Track 2


Sound Speed from Shark; Track 2
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
13.8
14
14.2
14.4
14.6
14.8
15
Time [hr]

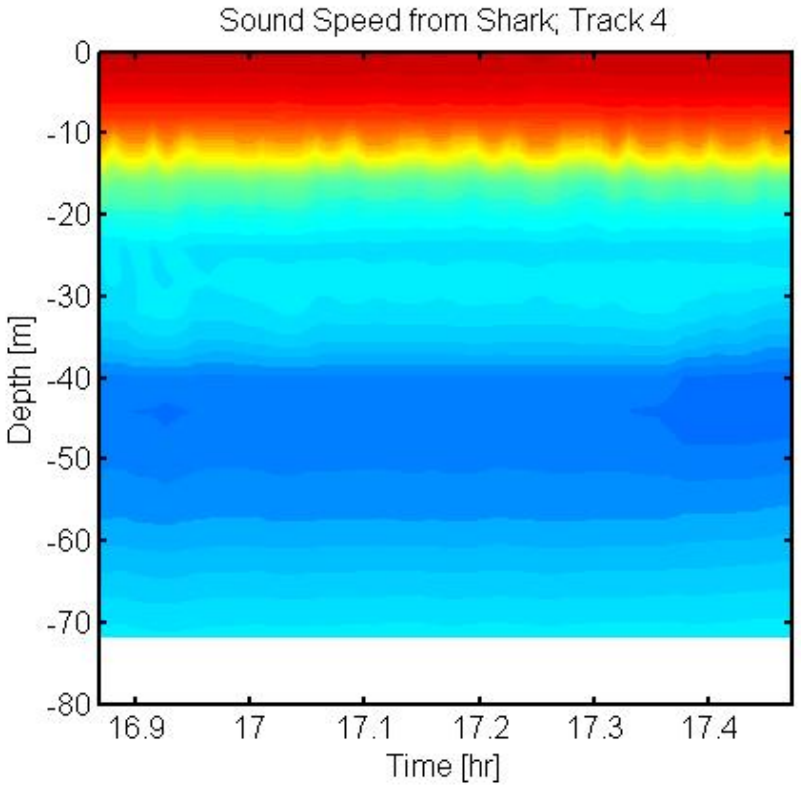

Sound Speed from CTD Chain; Track 2
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
2
3
4
5
6
Range [km]
1540
1530
1520
1510
1500
1490
1480

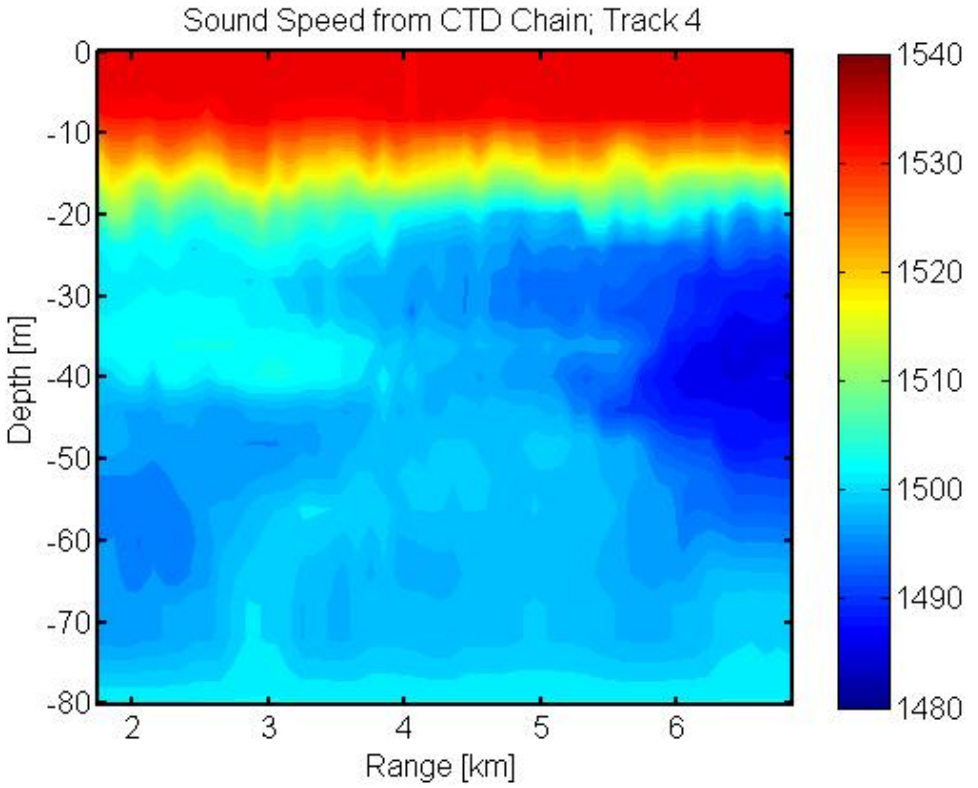
Track 3


Sound Speed from Shark; Track 3
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
15.9
16
16.1
16.2
16.3
16.4
Time [hr]

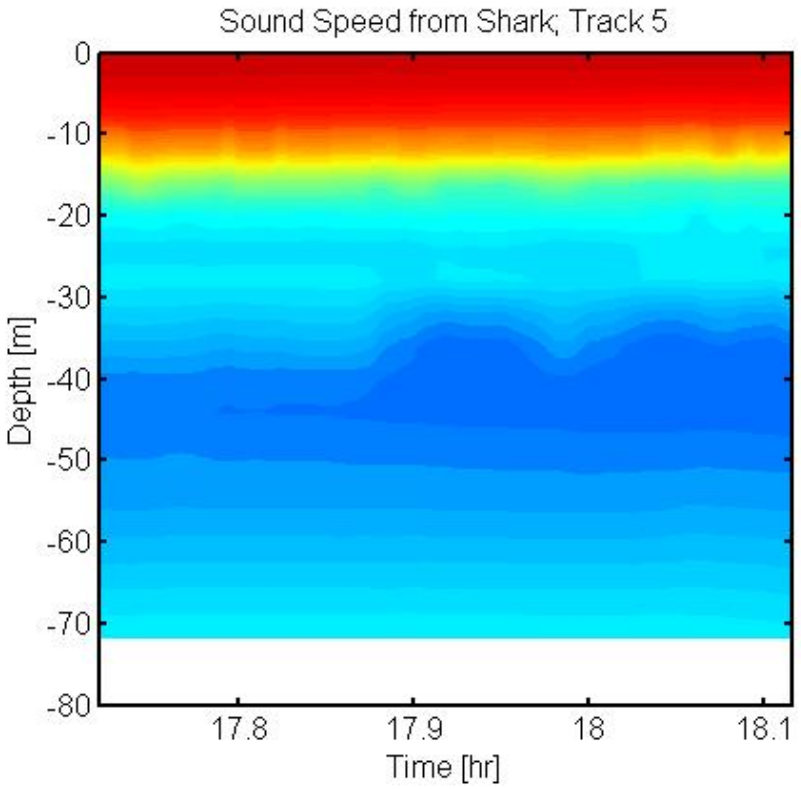

Sound Speed from CTD Chain; Track 3
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
2
3
4
5
6
Range [km]
1540
1530
1520
1510
1500
1490
1480

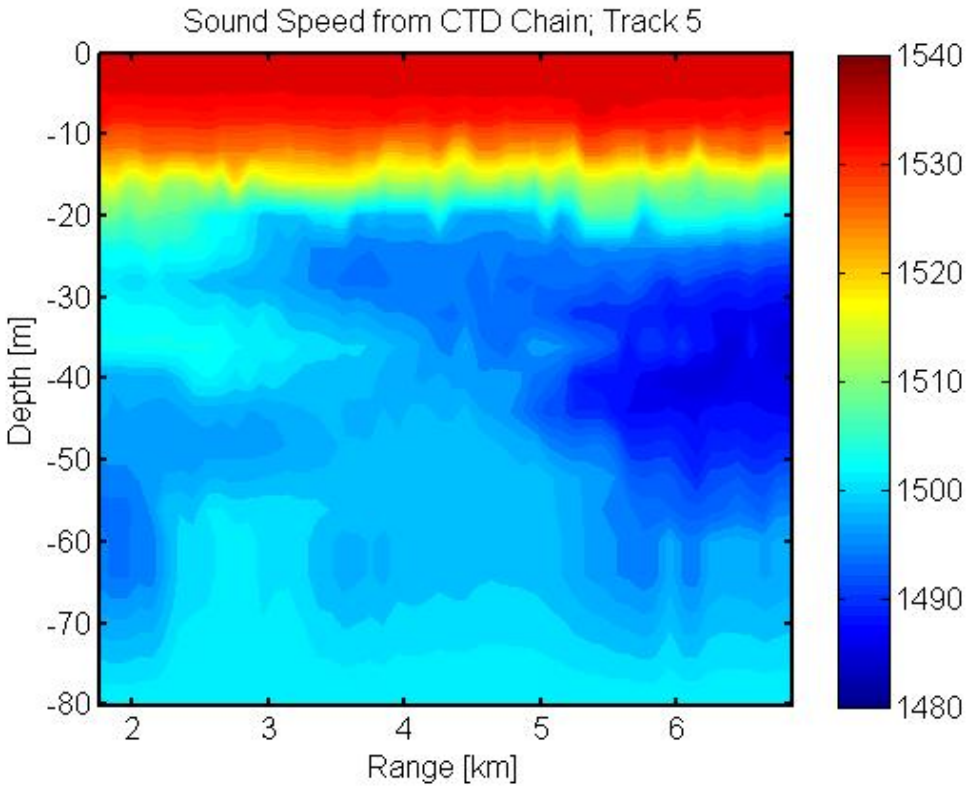
Track 4


Sound Speed from Shark; Track 4
Depth [m]
0
-10
-20
-30
-40
-50
-60
-70
-80
16.9
17
17.1
17.2
17.3
17.4
Time [hr]

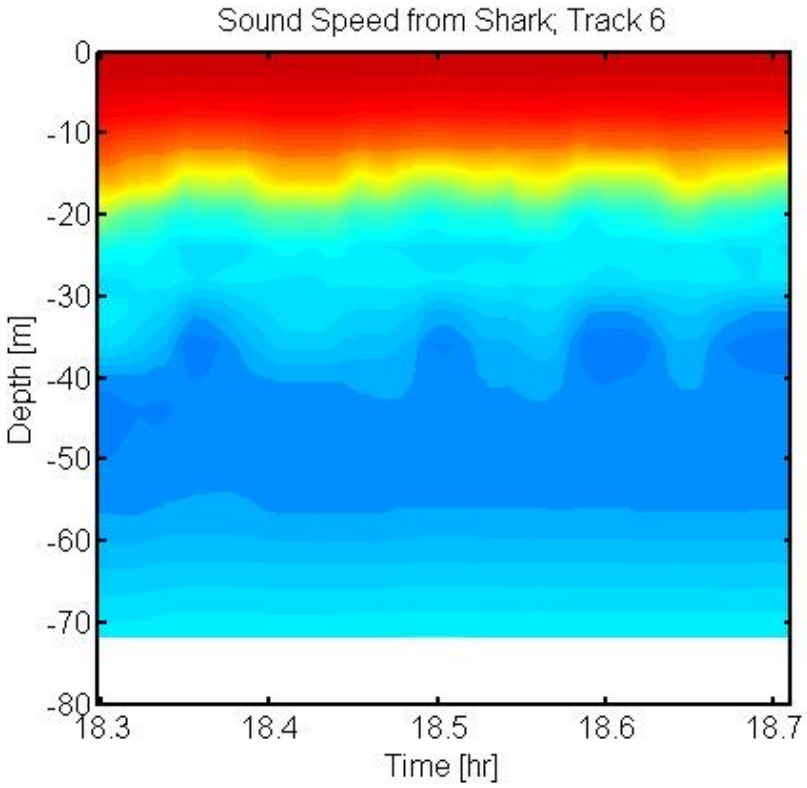

Sound Speed from CTD Chain; Track 4
Depth [m]
0
-10
-20
-30
-40
-50
-60
-70
-80
2
3
4
5
6
Range [km]
1540
1530
1520
1510
1500
1490
1480

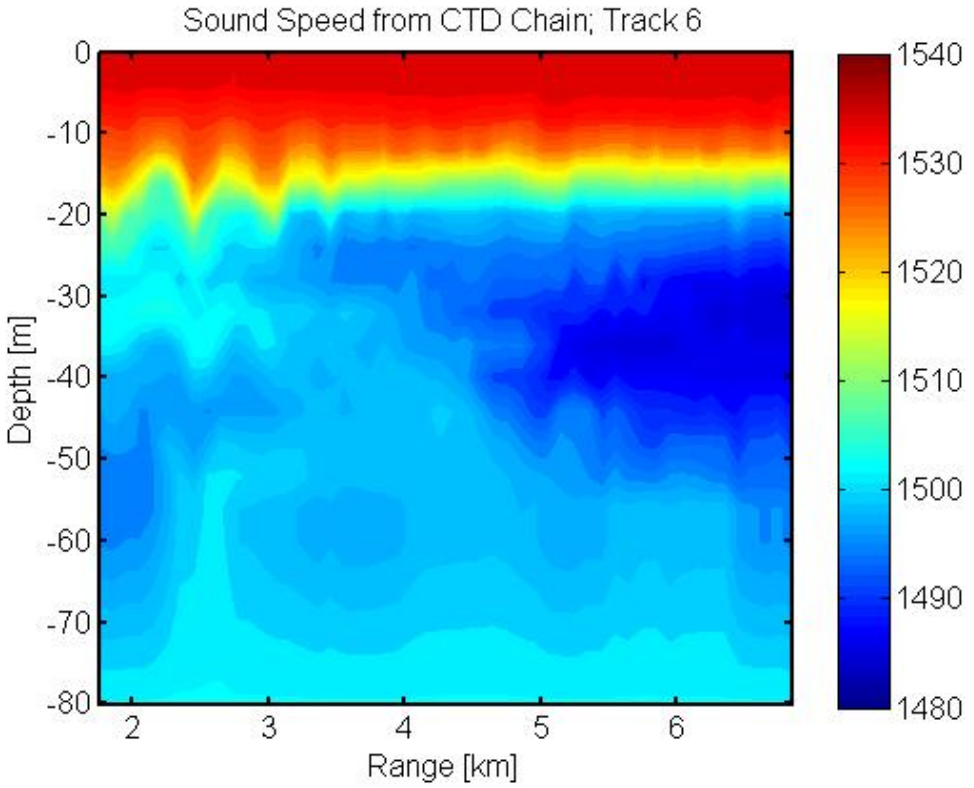
Track 5


Sound Speed from Shark; Track 5
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
17.8
17.9
18
18.1
Time [hr]

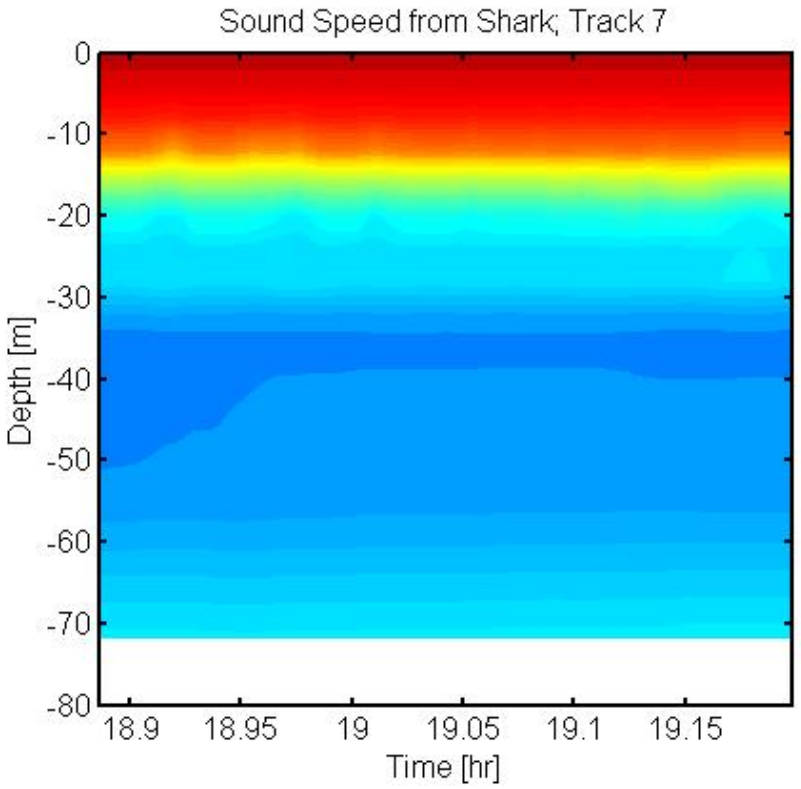

Sound Speed from CTD Chain; Track 5
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
2
3
4
5
6
Range [km]
1540
1530
1520
1510
1500
1490
1480

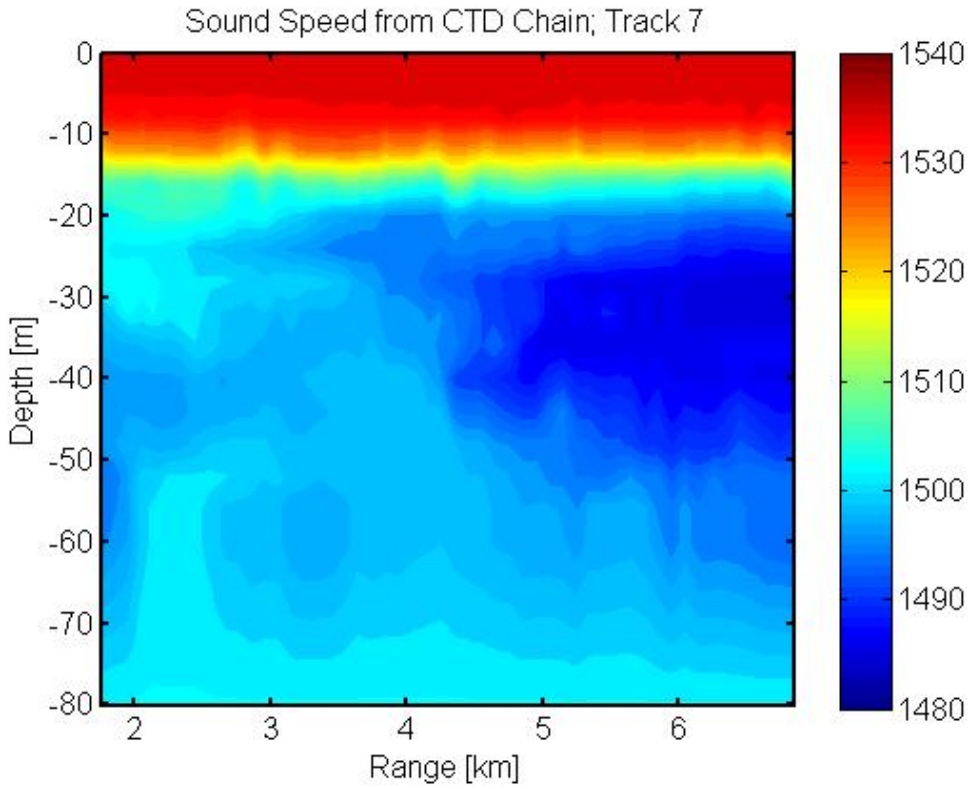
Track 6


Sound Speed from Shark; Track 6
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
18.3
18.4
18.5
18.6
18.7
Time [hr]

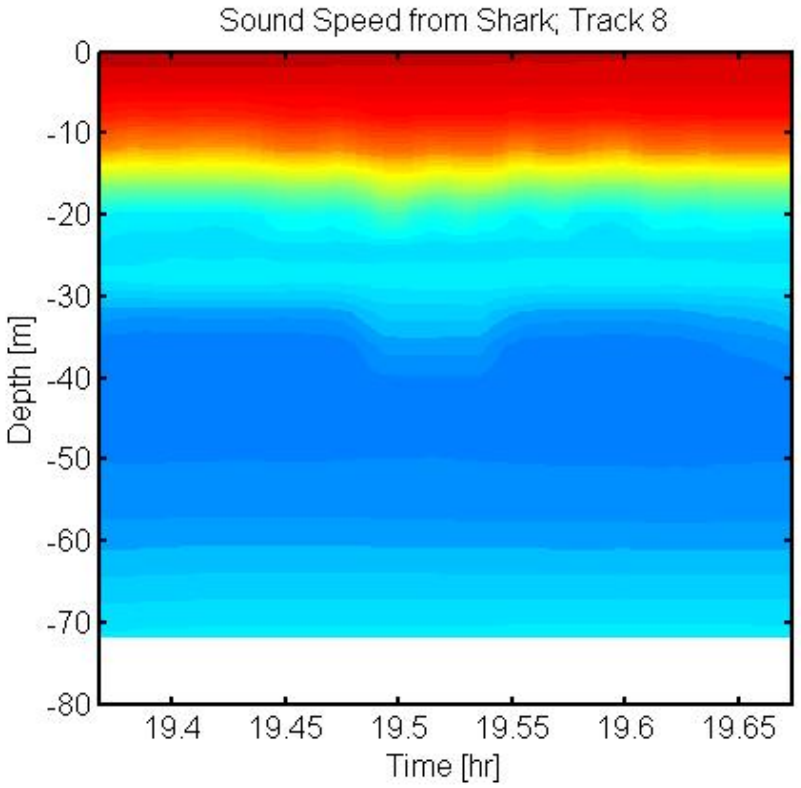

Sound Speed from CTD Chain; Track 6
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
2
3
4
5
6
Range [km]
1540
1530
1520
1510
1500
1490
1480

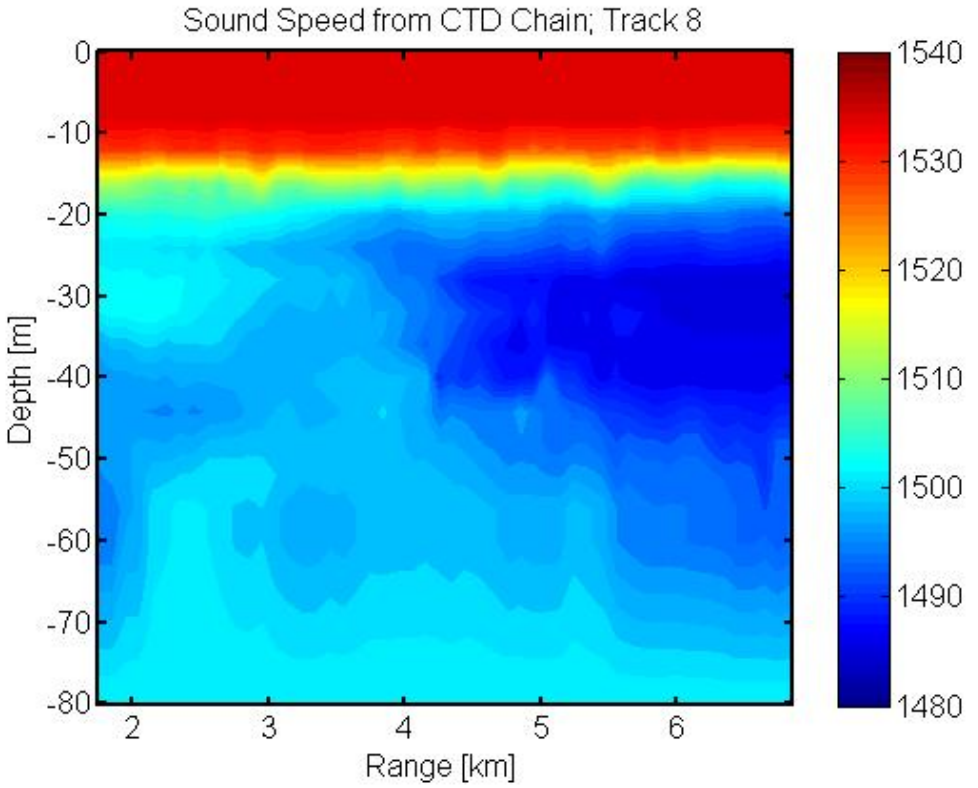
Track 7


Sound Speed from Shark; Track 7
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
18.9
18.95
19
19.05
19.1
19.15
Time [hr]

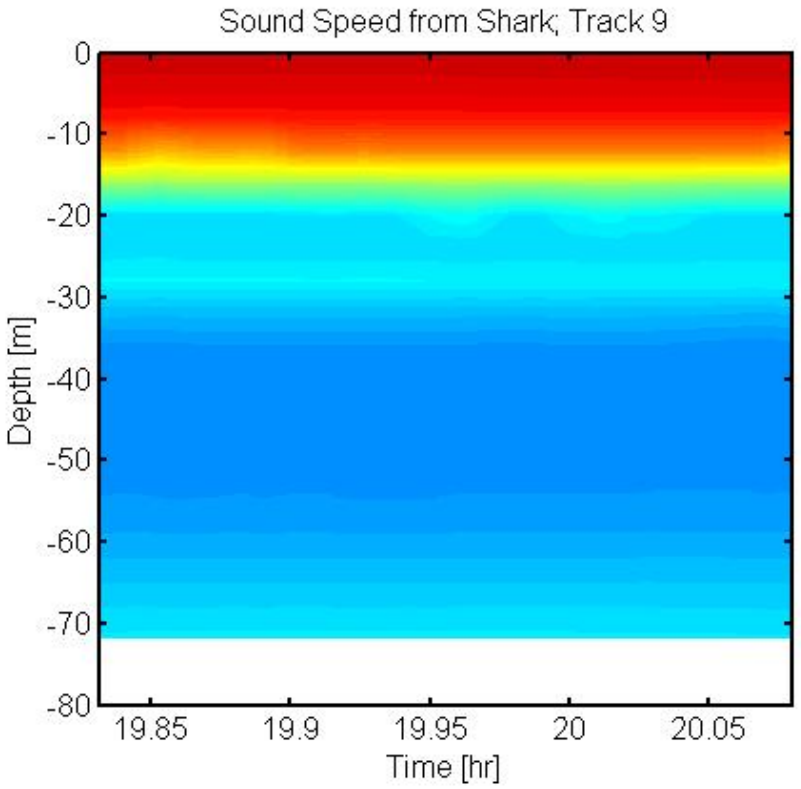

Sound Speed from CTD Chain; Track 7
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
2
3
4
5
6
Range [km]
1540
1530
1520
1510
1500
1490
1480

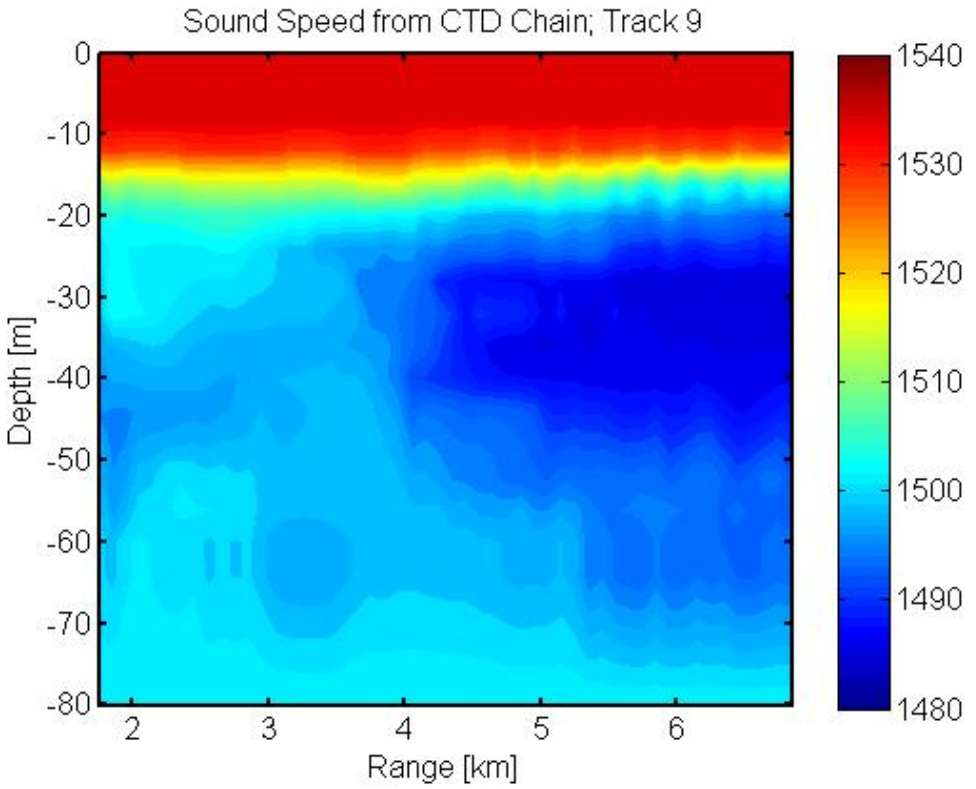
Track 8


Sound Speed from Shark; Track 8
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
19.4
19.45
19.5
19.55
19.6
19.65
Time [hr]

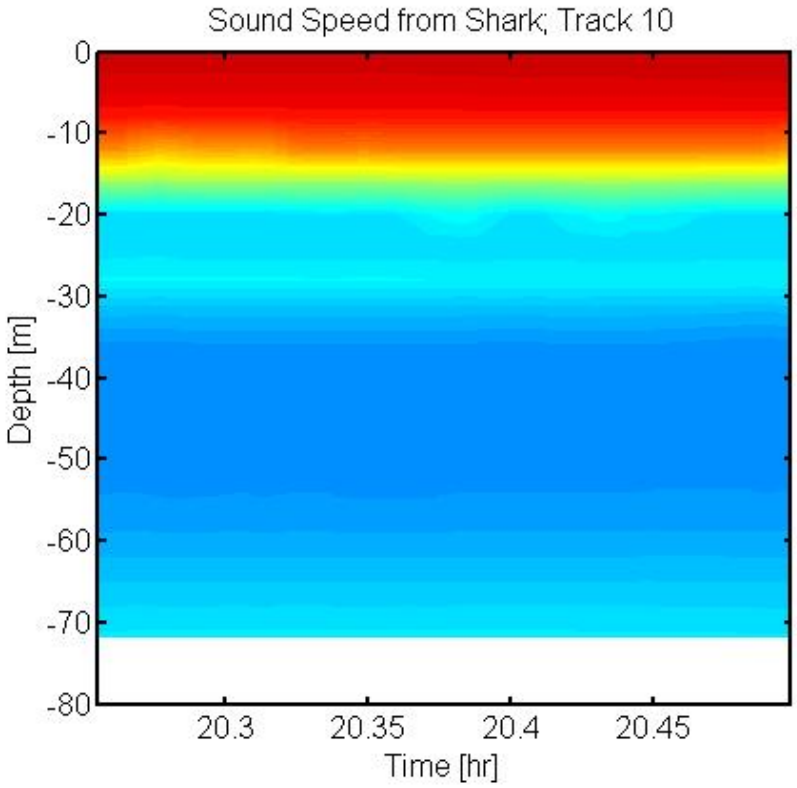

Sound Speed from CTD Chain; Track 8
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
2
3
4
5
6
Range [km]
1540
1530
1520
1510
1500
1490
1480

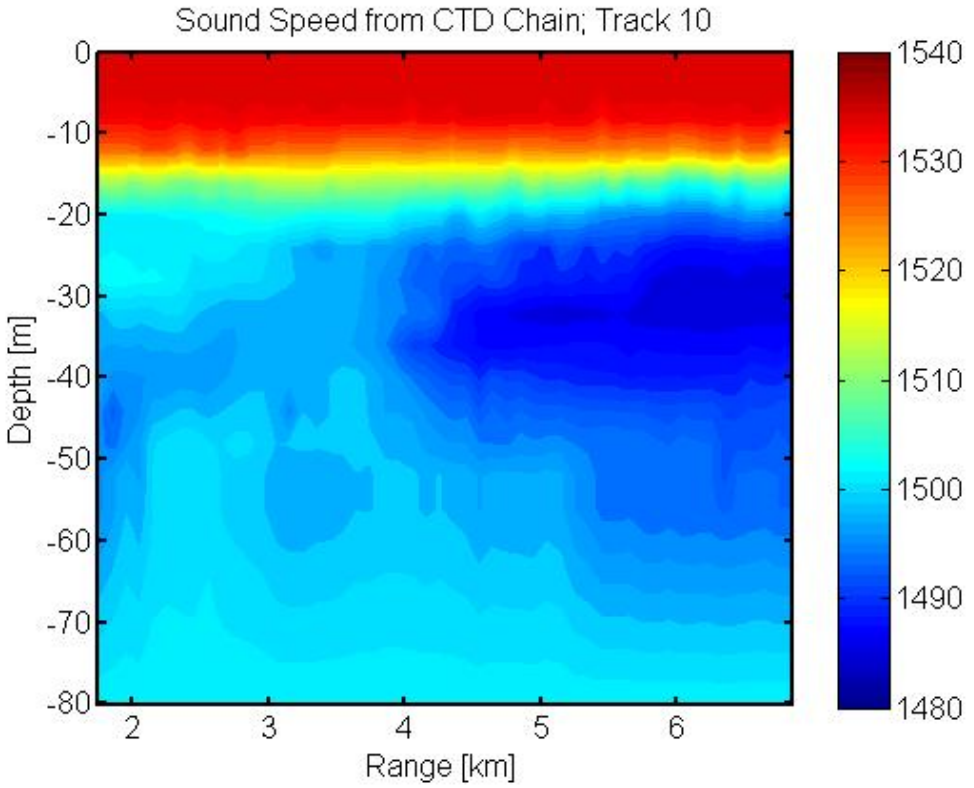
Track 9


Sound Speed from Shark; Track 9
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
19.85
19.9
19.95
20
20.05
Time [hr]


Sound Speed from CTD Chain; Track 9
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
2
3
4
5
6
Range [km]
1540
1530
1520
1510
1500
1490
1480

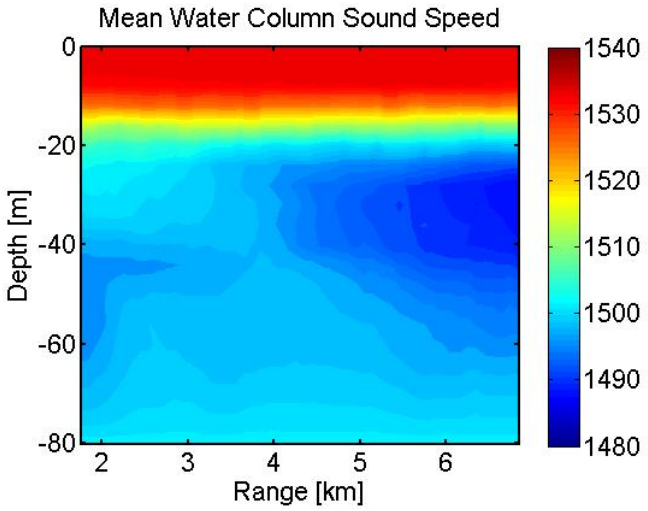
Track 10

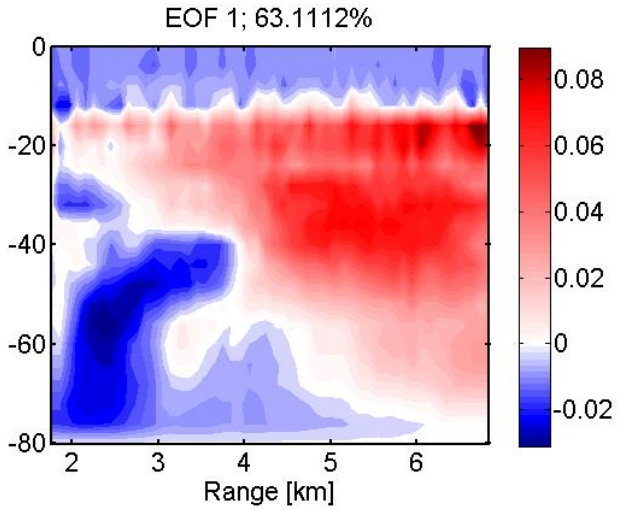

Sound Speed from Shark; Track 10
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
20.3
20.35
20.4
20.45
Time [hr]

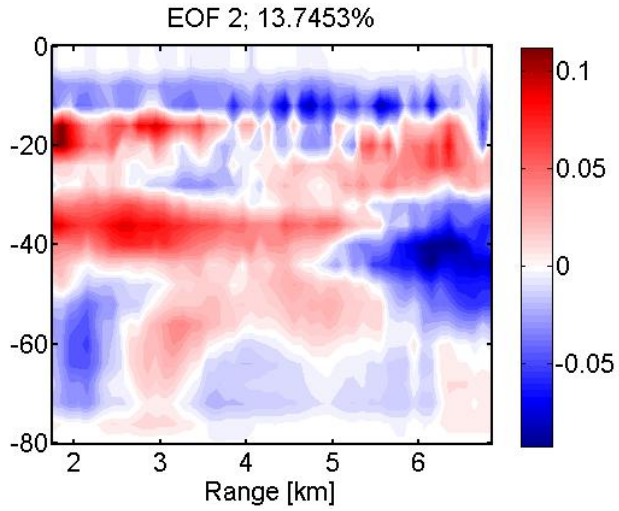

Sound Speed from CTD Chain; Track 10
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth [m]
2
3
4
5
6
Range [km]
1540
1530
1520
1510
1500
1490
1480

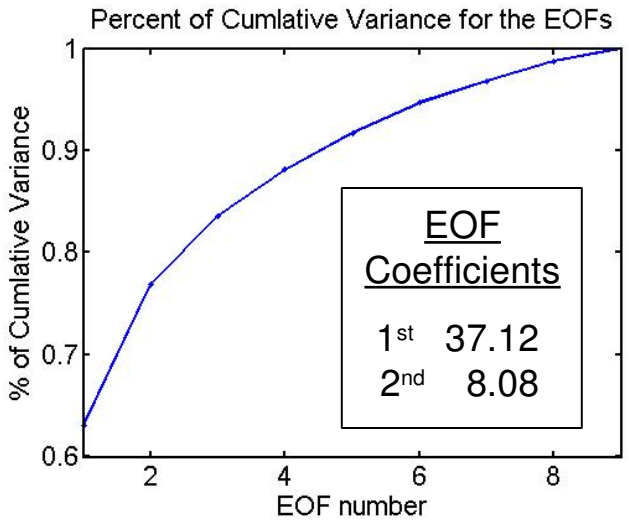
Empirical Orthogonal Functions

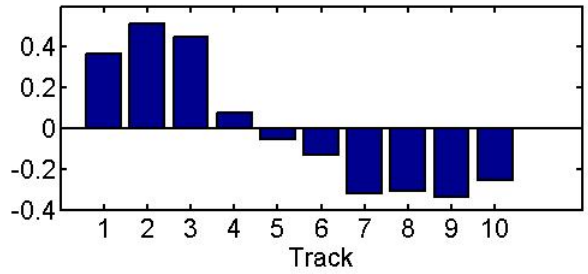
(EOF)

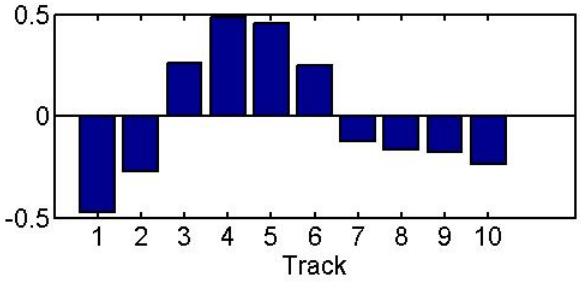










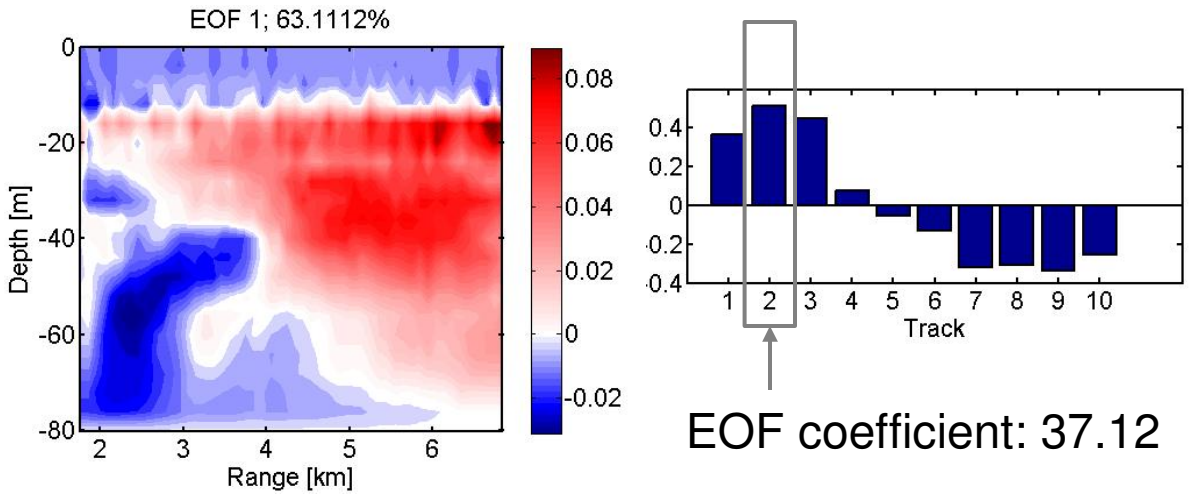


The 1st EOF shows

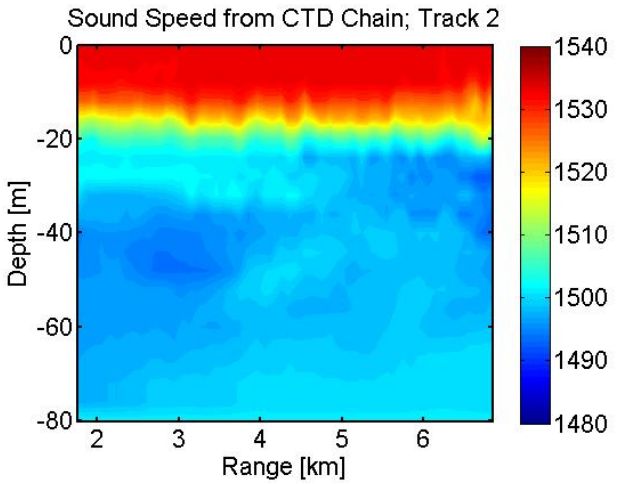
- Entrance of the cold water mass
- Path of the thermal haline intrusion
- Presence of the sub-pycnocline intrusion
- Heating of the water above the thermalcline

Understanding EOF Analysis

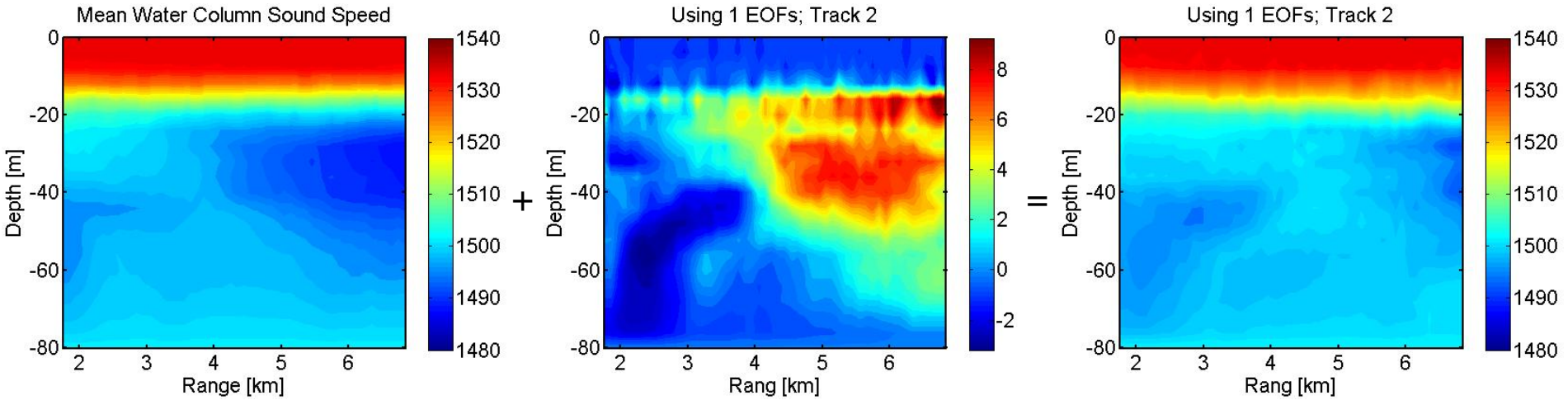
1st EOF and PC



Original Data

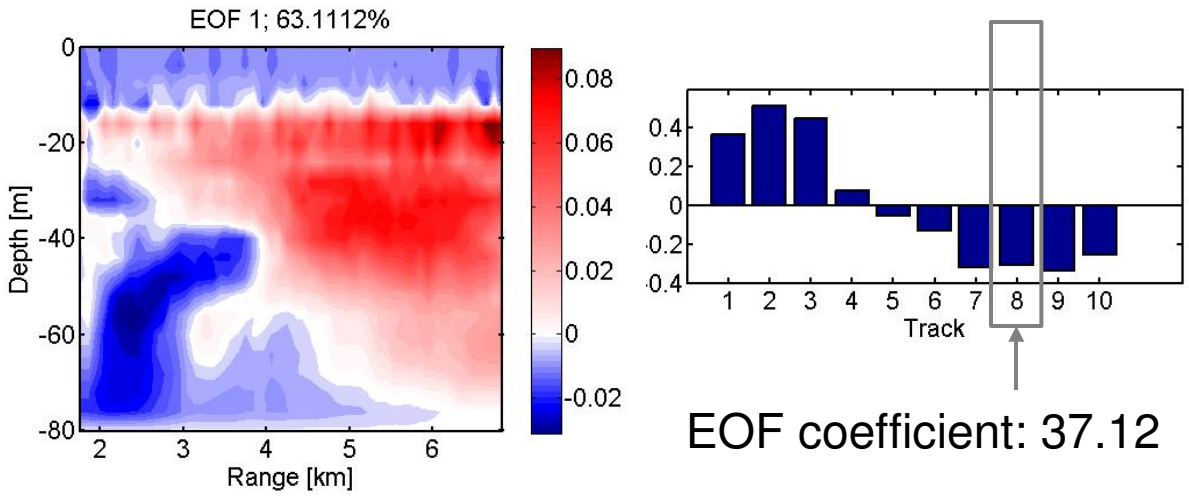


Recreated using 1st EOF

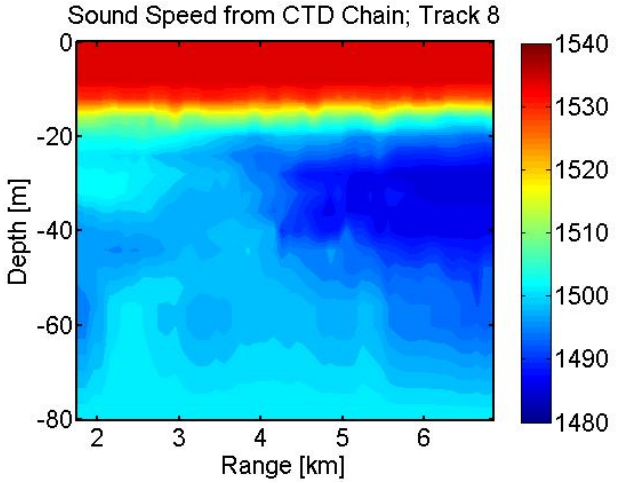


Understanding EOF Analysis

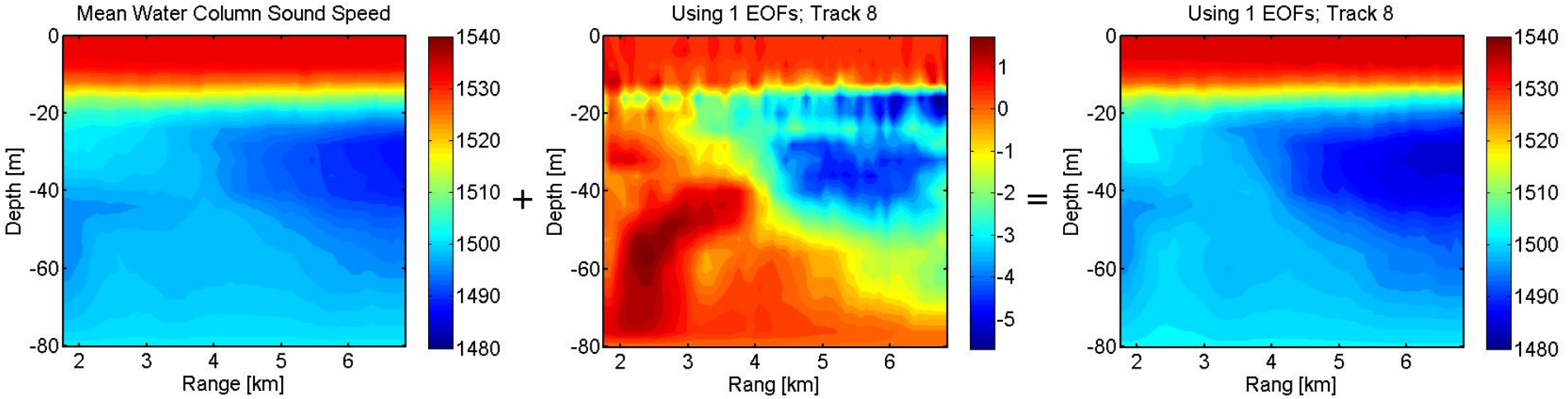
1st EOF and PC



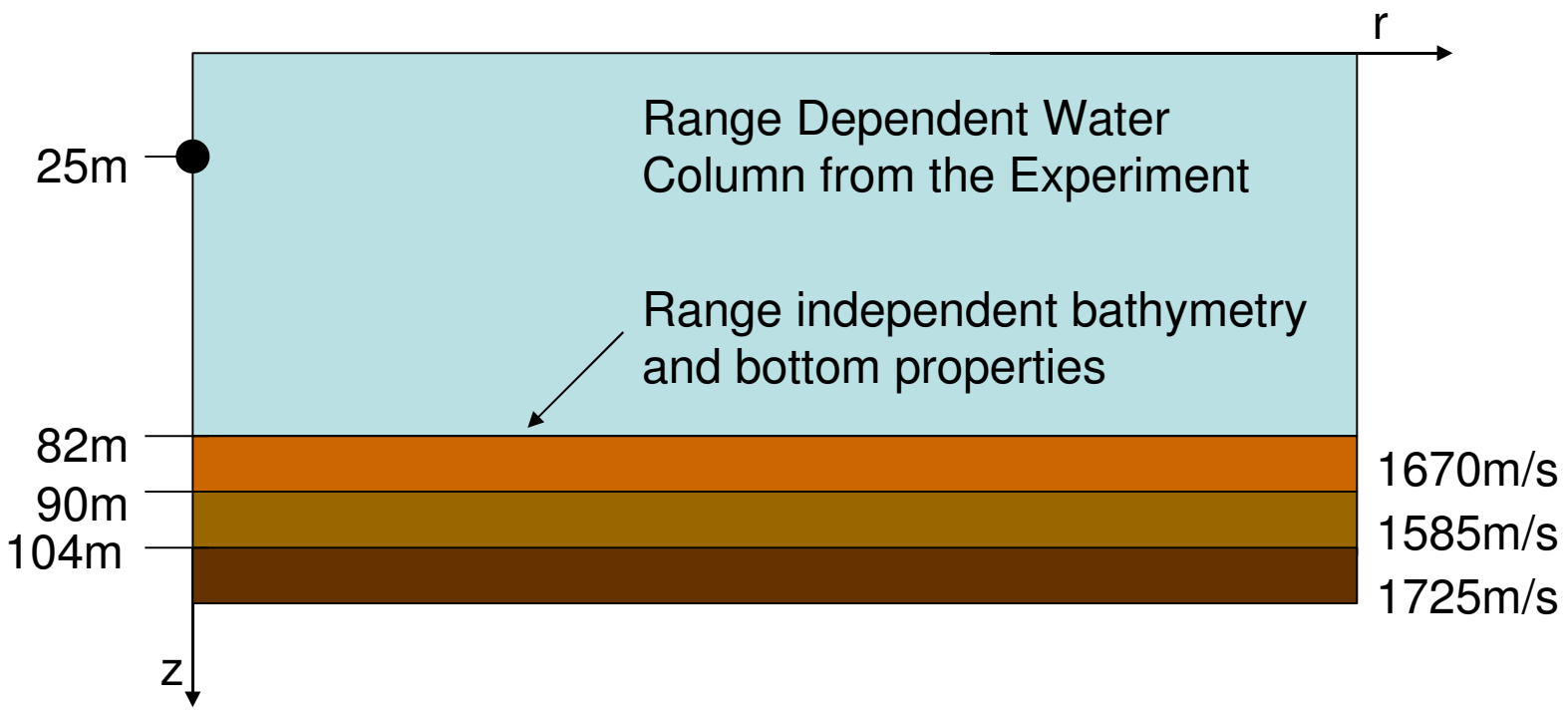
Original Data



Recreated using 1st EOF



Acoustic Propagation



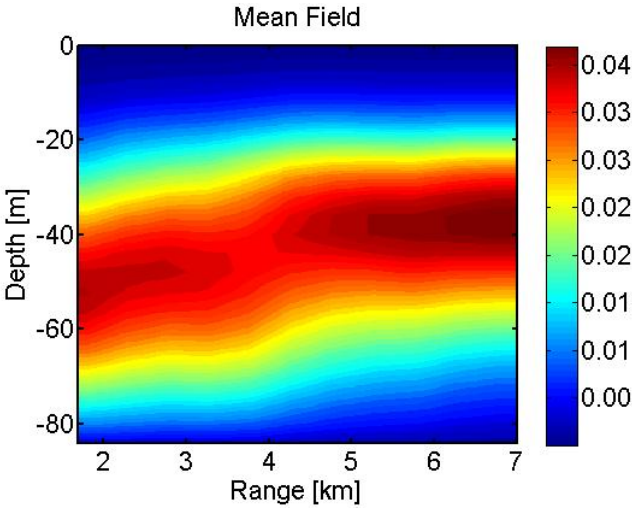
Source depth is 25m.
Receivers are spaced 4m vertically between 0 and 80m
and are spaced 70m horizontally between 1.8 and 7km.

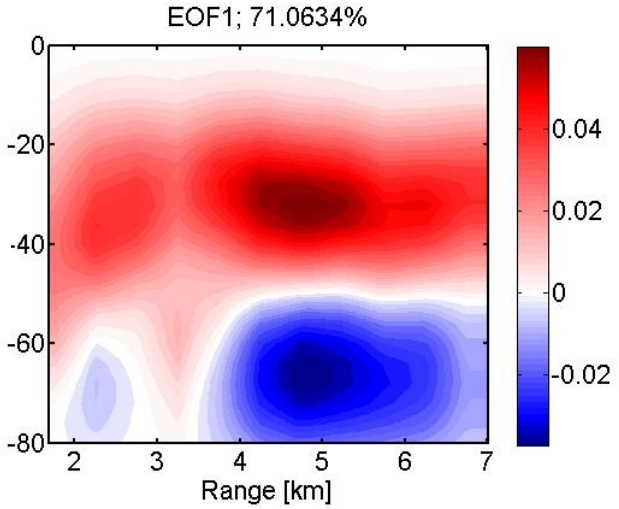
Frequency of 175 Hz, produces 11 propagating modes.

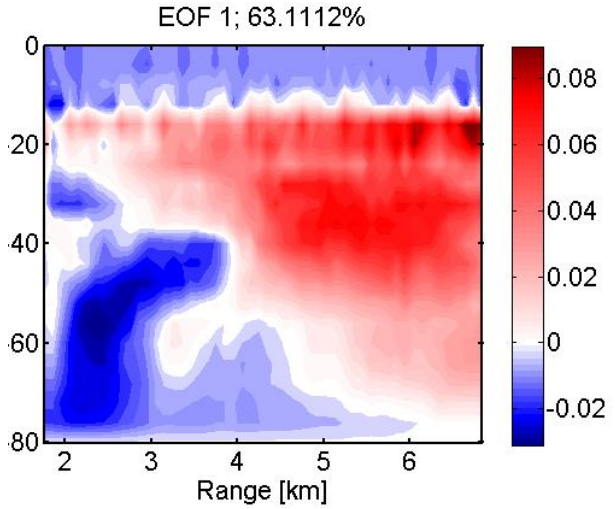
Acoustic EOF: Mode 1

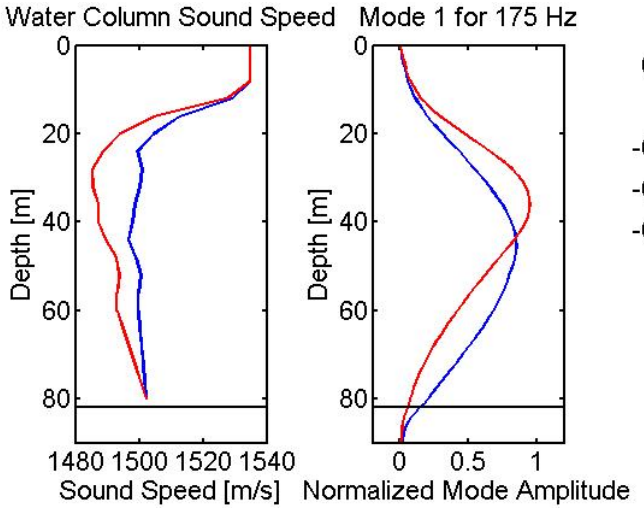
Acoustics

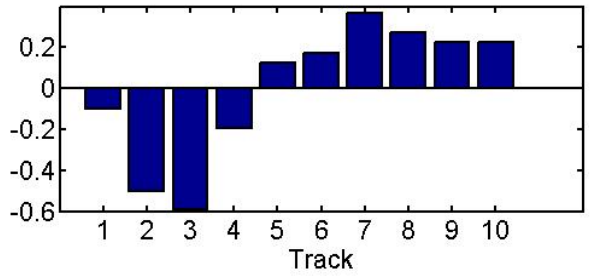
Ocean Sound Speed

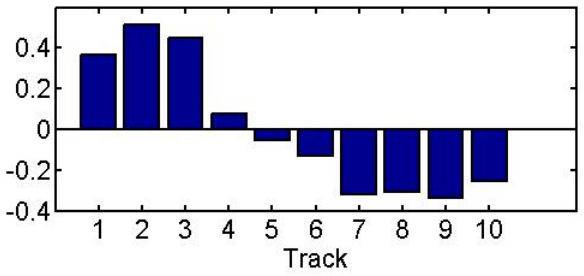












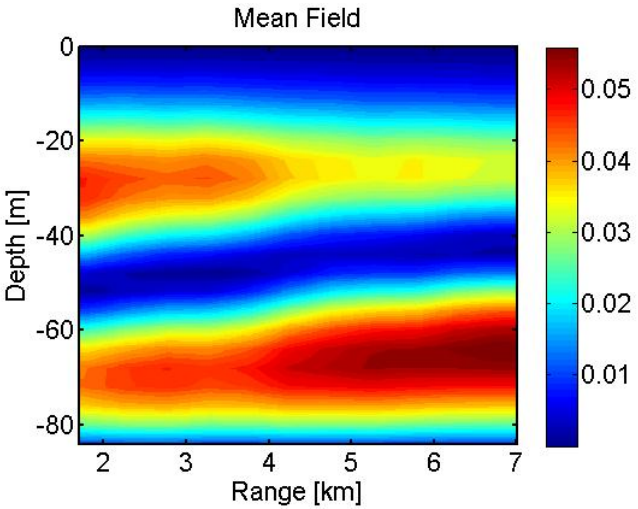
Increasing pressure in upper half of the waveguide.

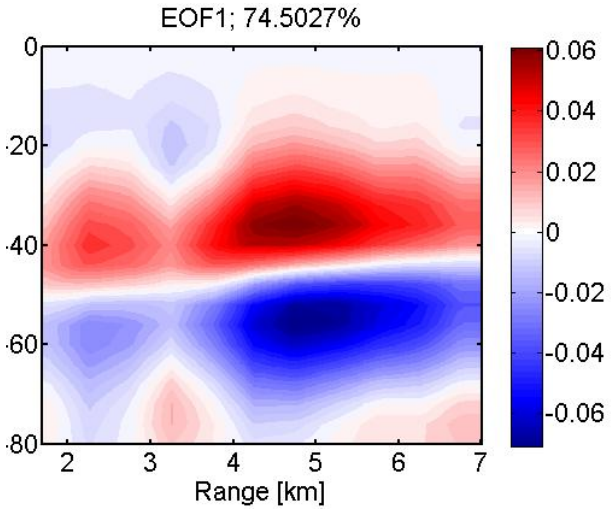
Cooling of the waveguide as the cold water mass moves in.

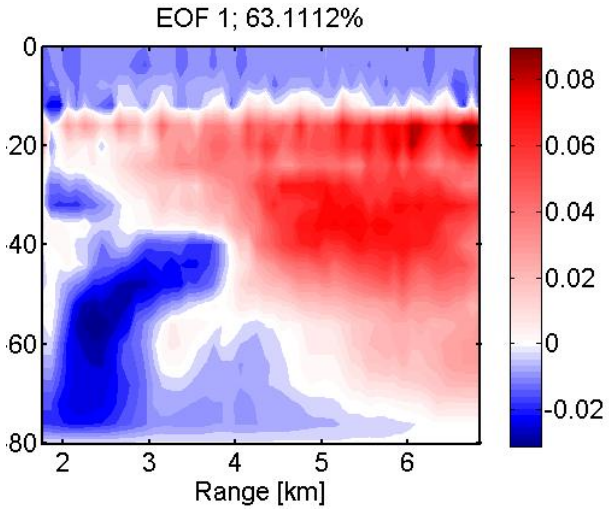
Acoustic EOF: Mode 2

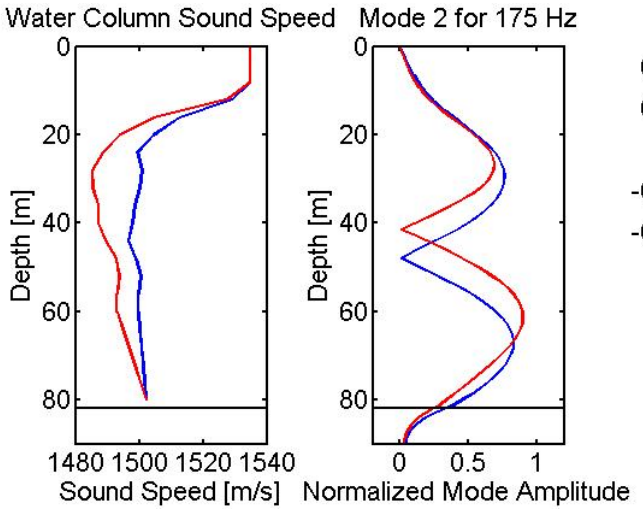
Acoustics

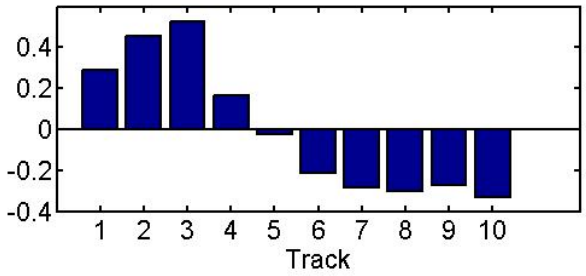
Ocean Sound Speed

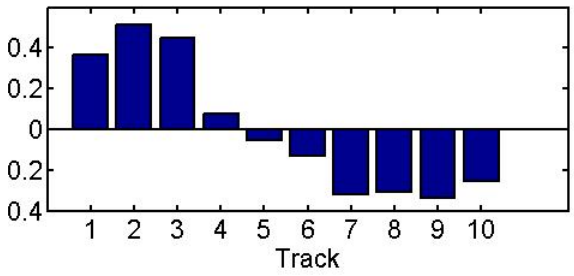












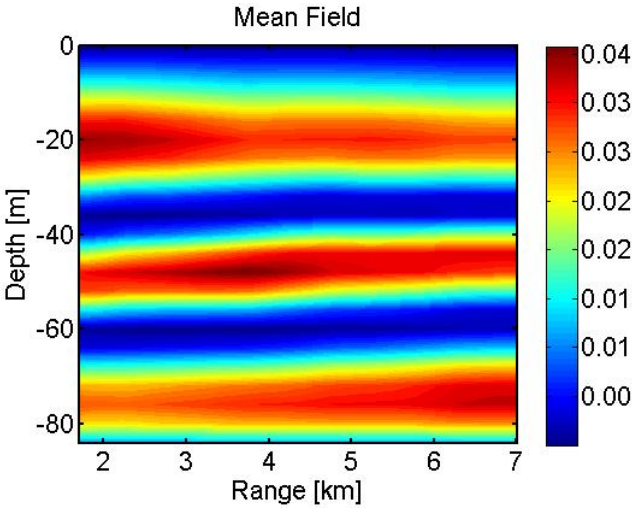
Decreasing pressure in upper half of the waveguide.

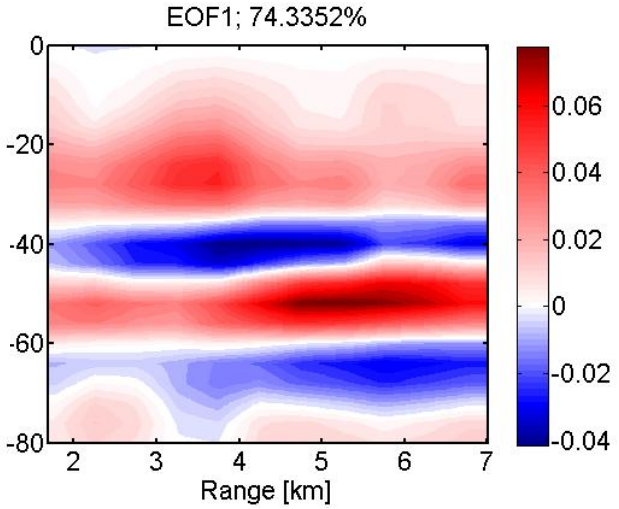
Cooling of the waveguide as the cold water mass moves in.

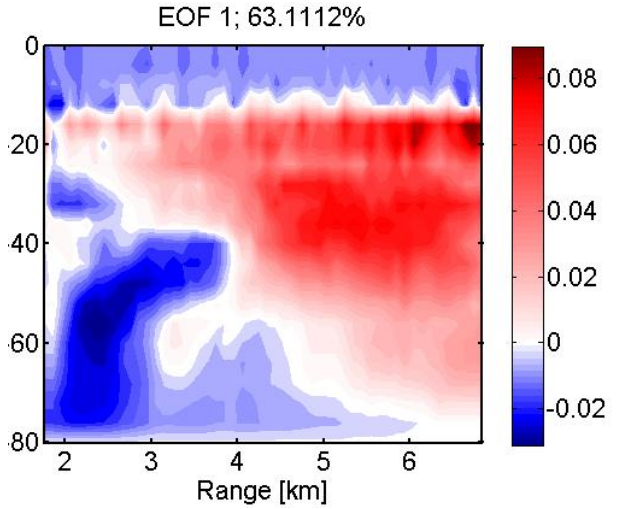
Acoustic EOF: Mode 3

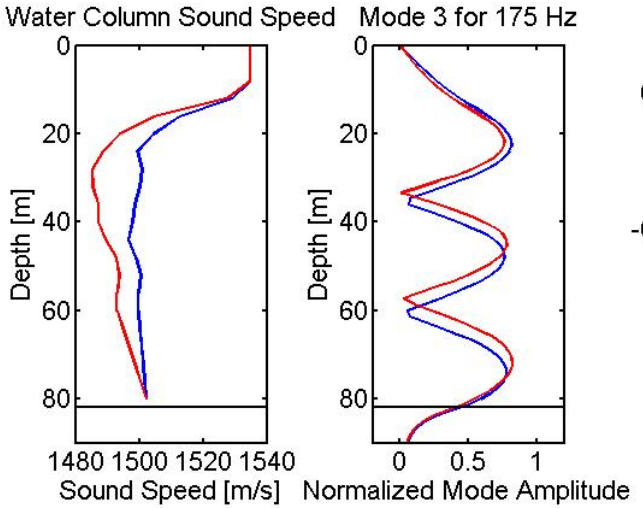
Acoustics

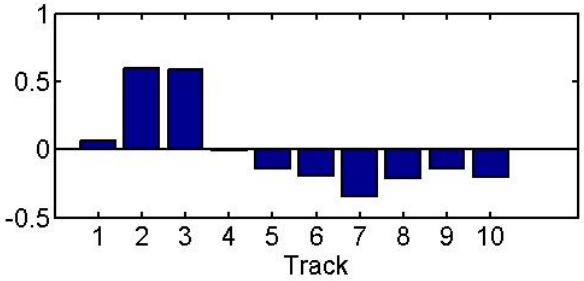
Ocean Sound Speed

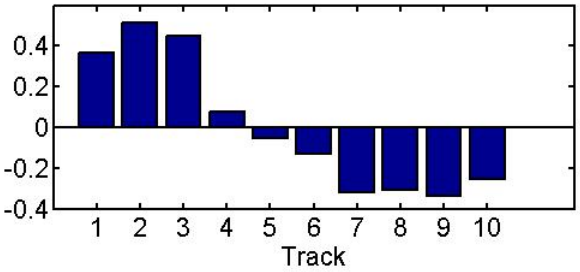










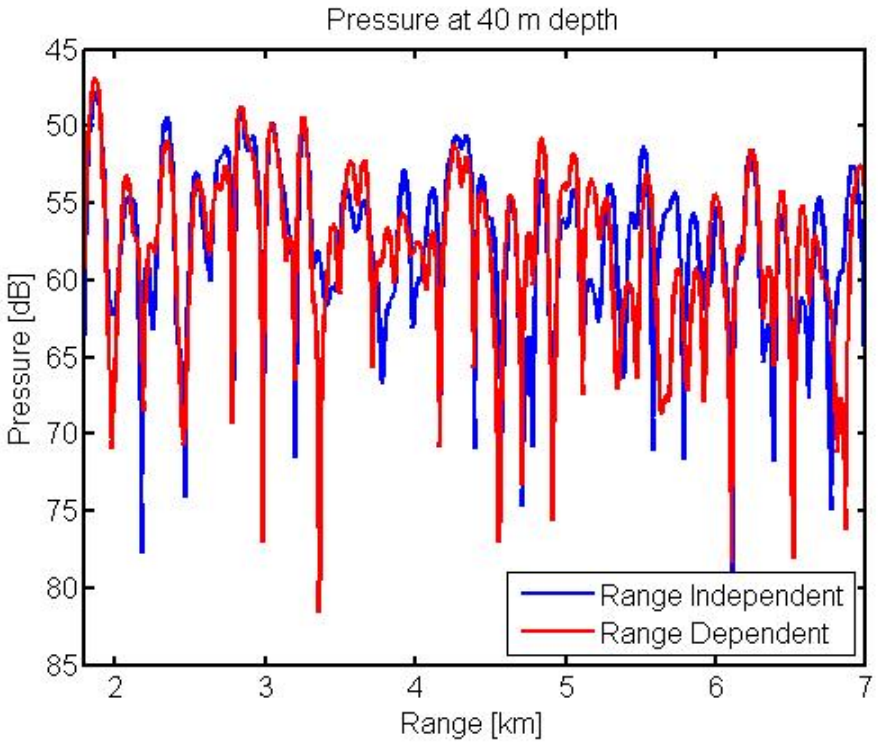


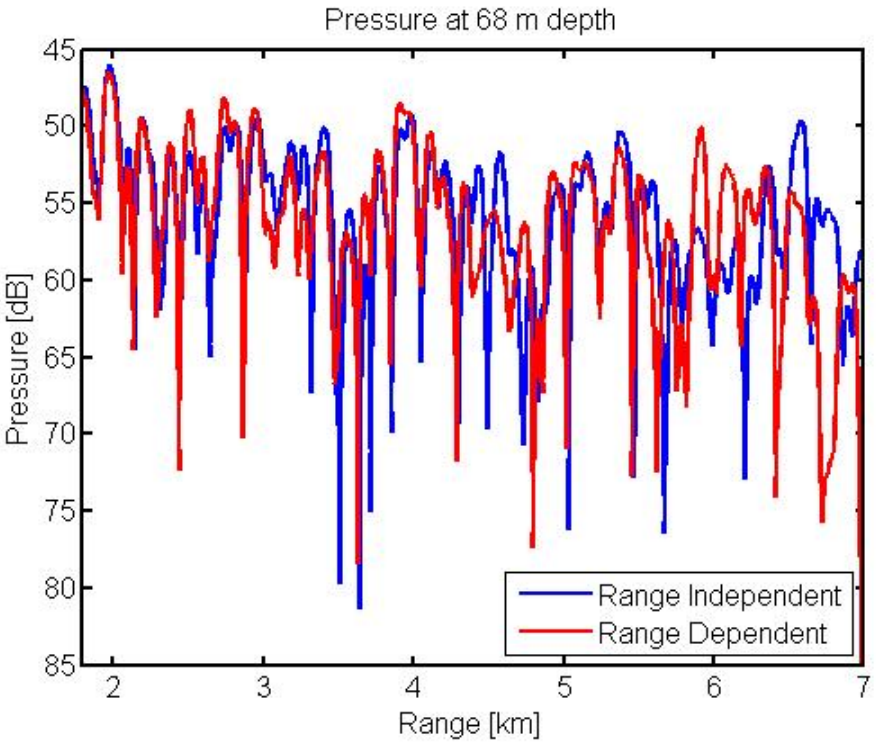
Decreasing pressure in upper half of the waveguide.

Cooling of the waveguide as the cold water mass moves in.

Transmission Loss

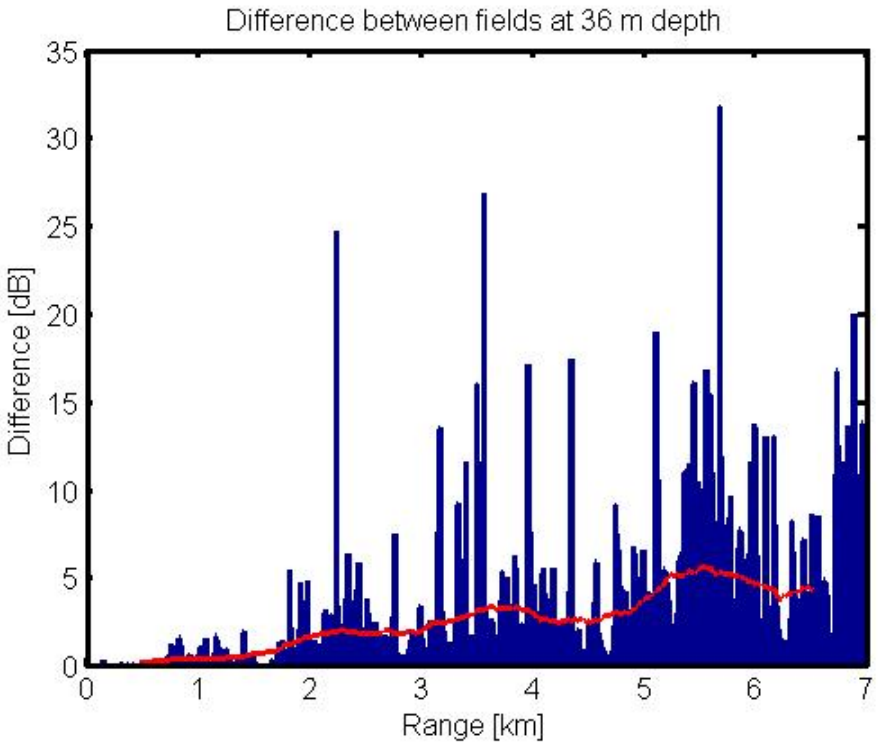
Mismatch caused by range independent propagation using water column data recorded at the VLA.

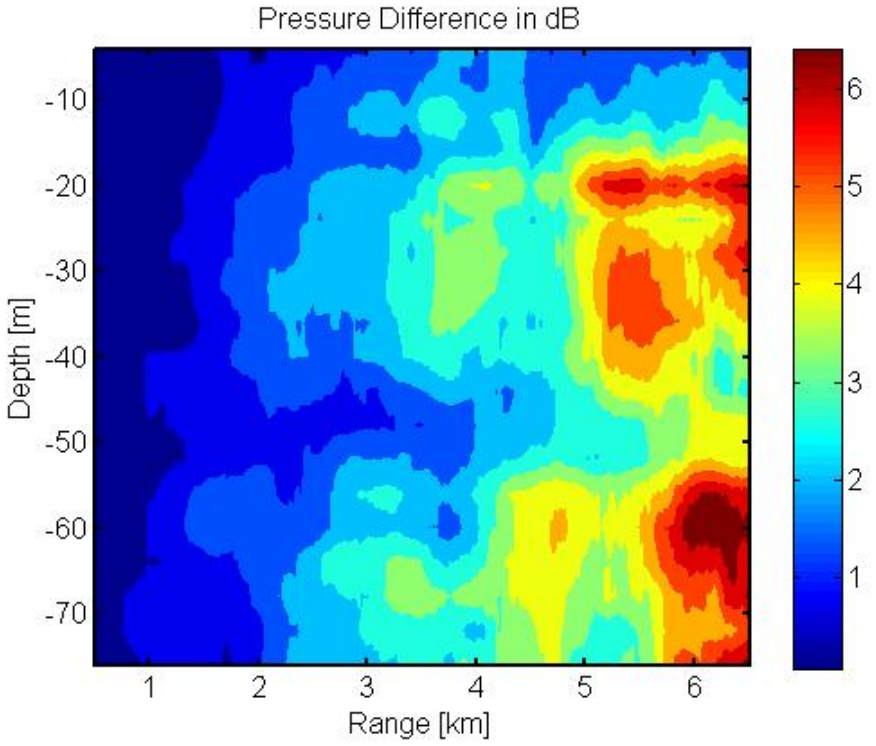




Range independent bottom, range dependent water column from track 8.

Transmission Loss





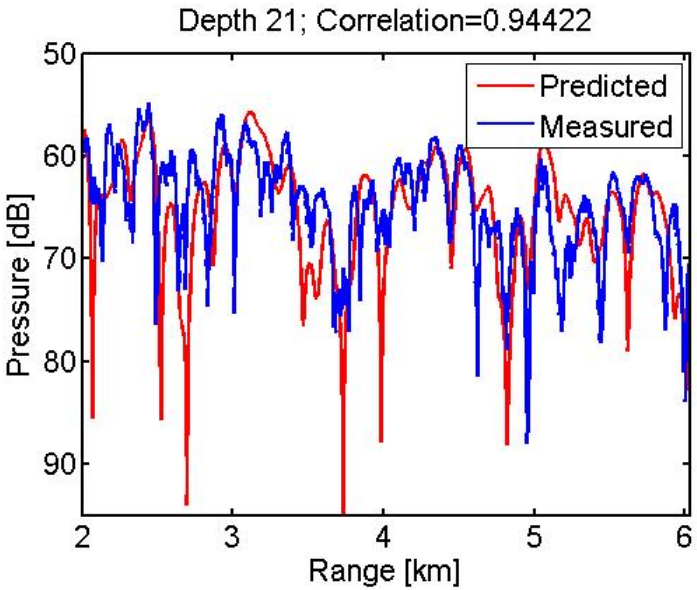
The large errors are caused by differences in locations of the nulls. Low pass filtered to get a range averaged pressure error (red line).

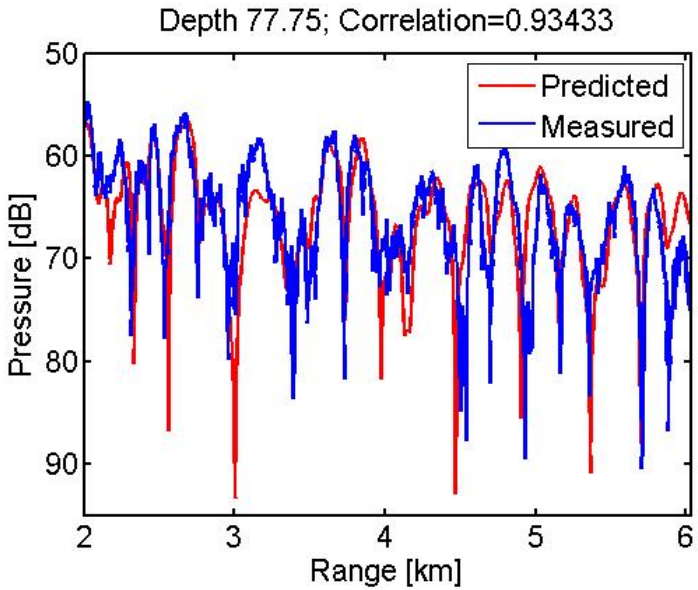
Range averaged pressure difference vs. depth.

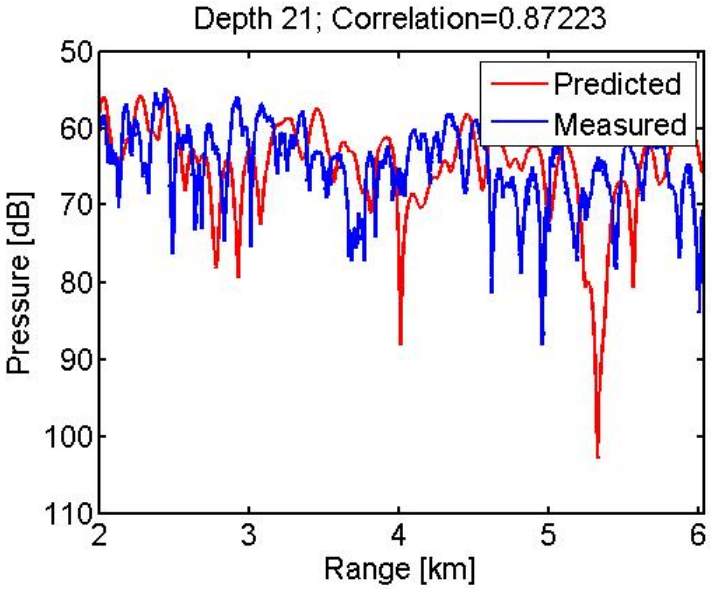
Prediction of Experimental Data

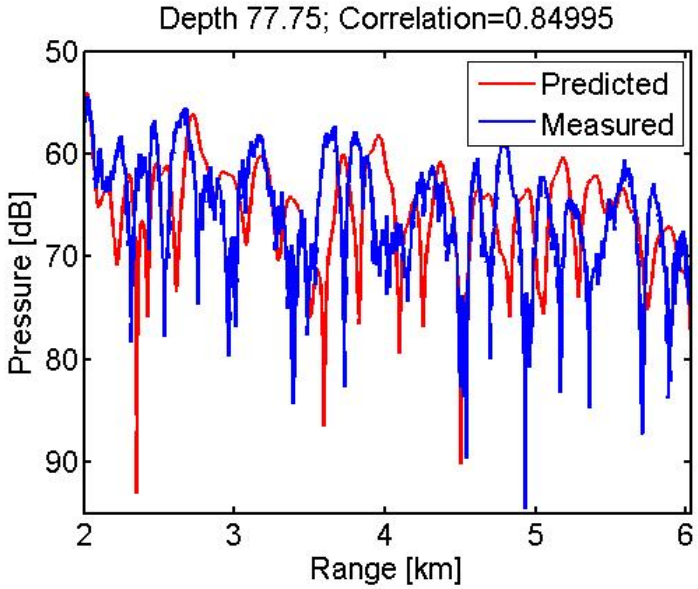
<u>Top Row</u>
Predictions using range dependent sound speed measurements recorded by the towed chain.

<u>Bottom Row</u>
Predictions using range independent sound speed measurement recorded at the VLA.







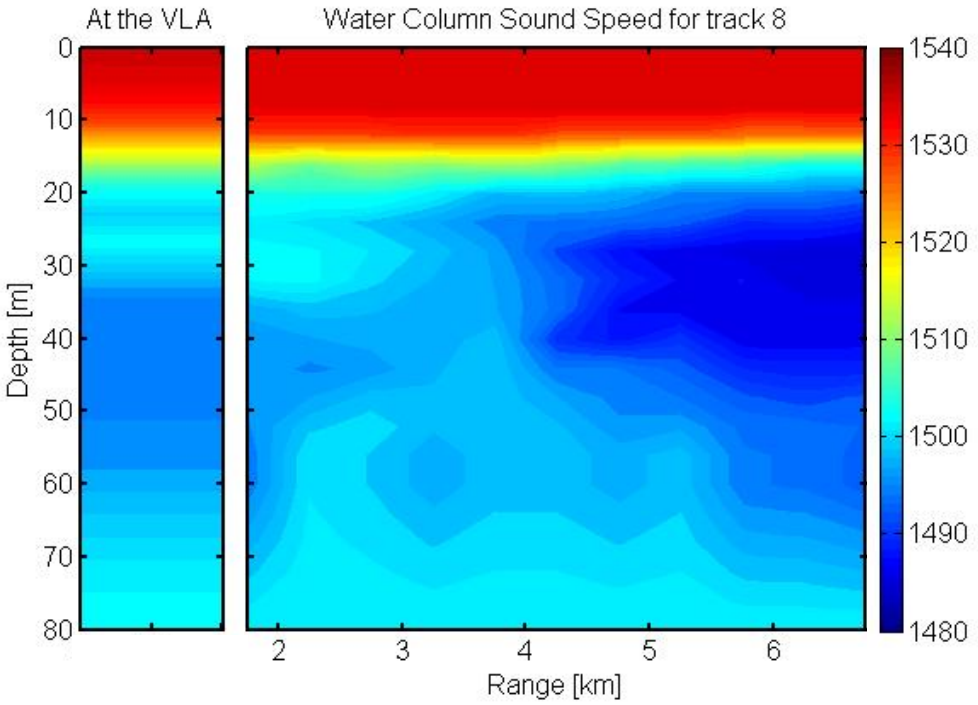


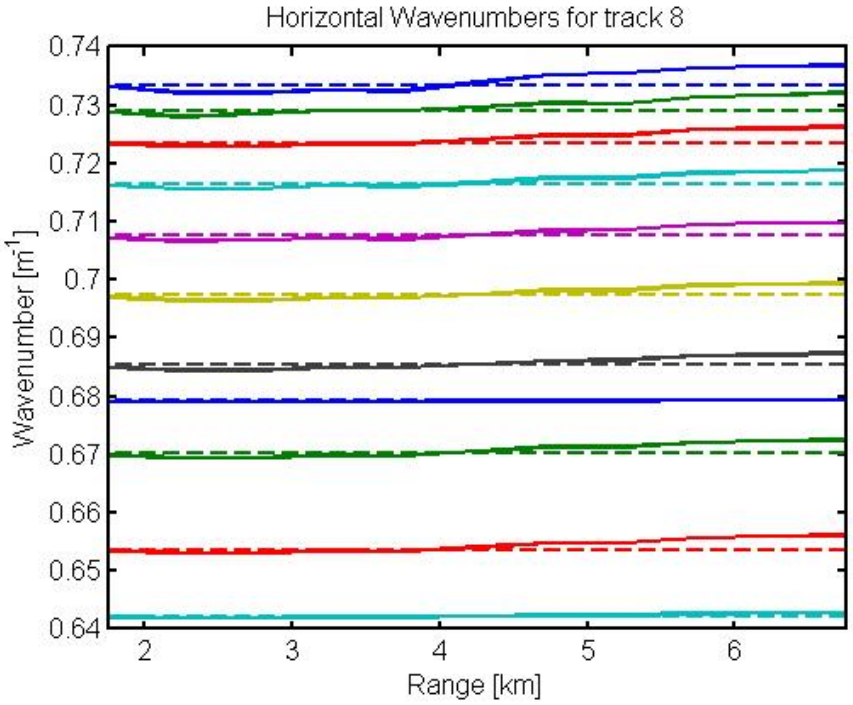
Conclusions

- The effects of water column variability on acoustic signals was examined using EOFs
  - Association of water column variability and acoustic variability
  - Revealed the complicated structure of the pressure field as modal components are affected differently by changes in the water column
- The effects of spatial extrapolation from the water column measurements at the Shark VLA (>7km away)
  - More than 6dB of difference for CW tones
- Predictions of experimental data are improved when the range dependence of the sound speed profile is considered
  - This was shown for towed CW

Back Up Slides

Horizontal Wavenumbers





Measured sound speed profile for track 8

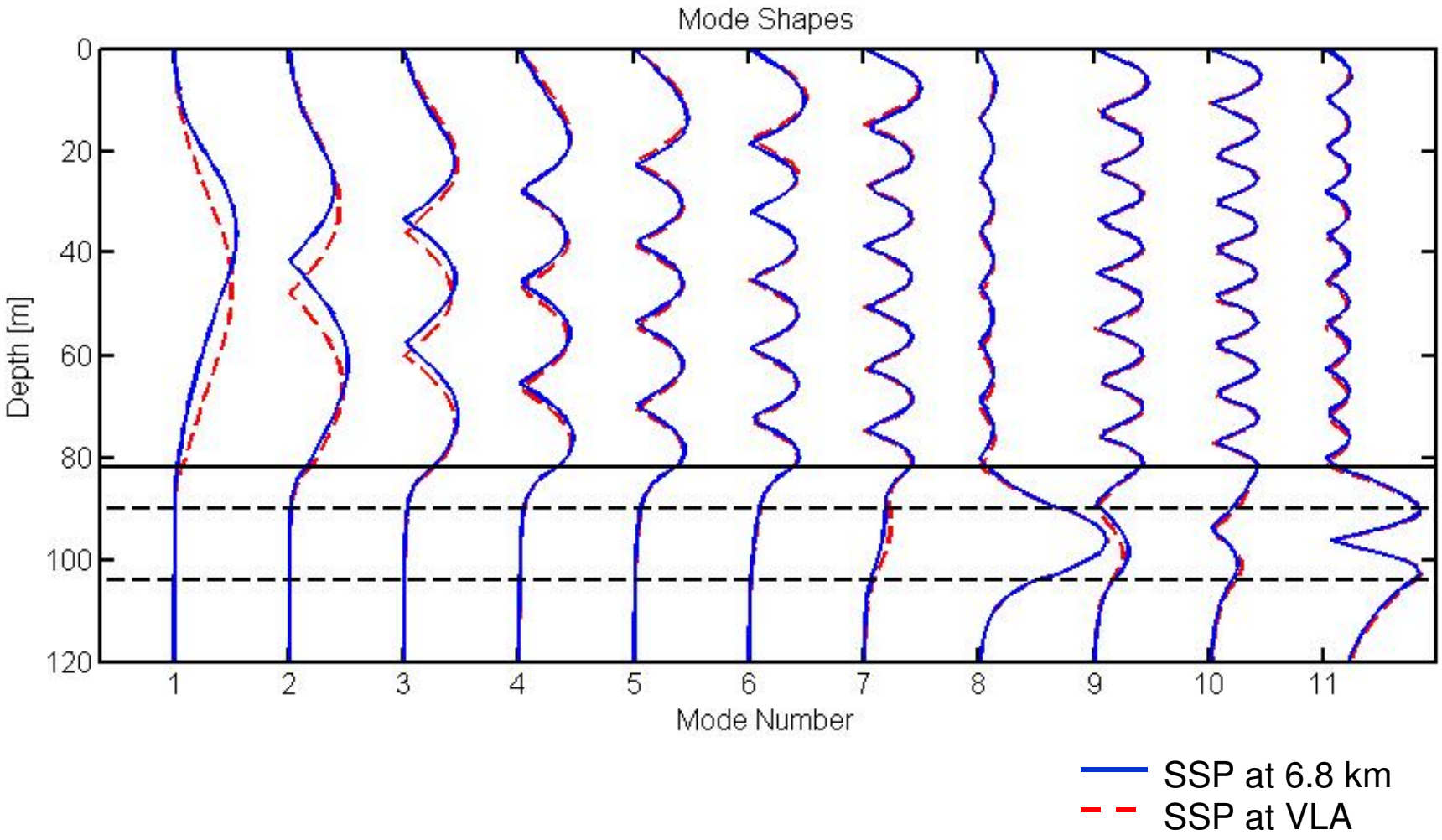
- left plot is time averaged measurement at VLA location
- right plot is range dependent measurement at the chain location

Horizontal wavenumbers

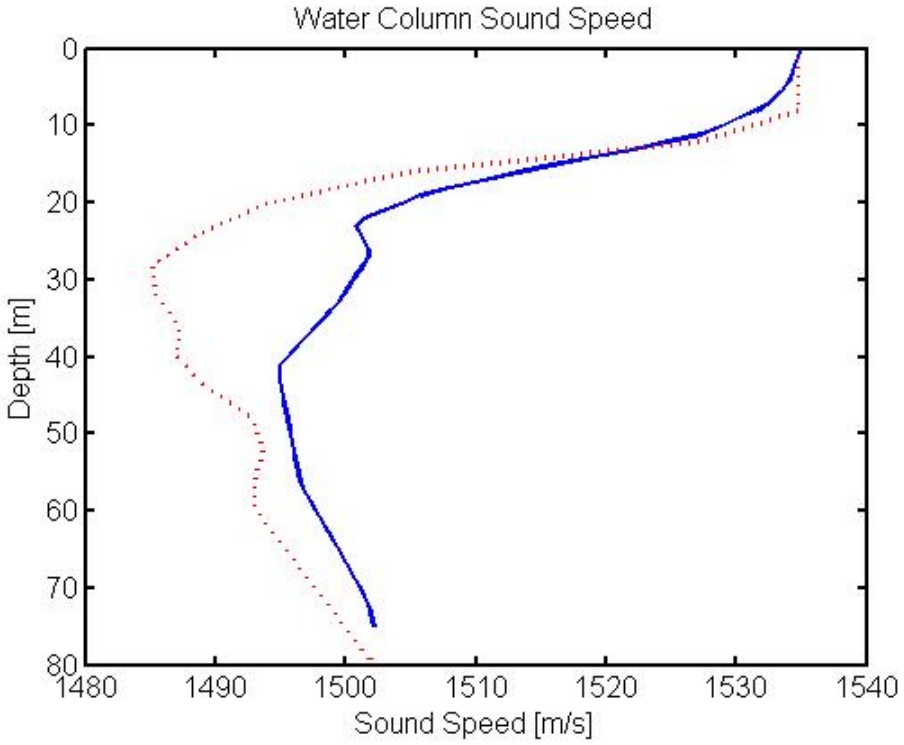
- dashed line corresponds to the water column at the VLA
- solid line corresponds to the water column at the chain

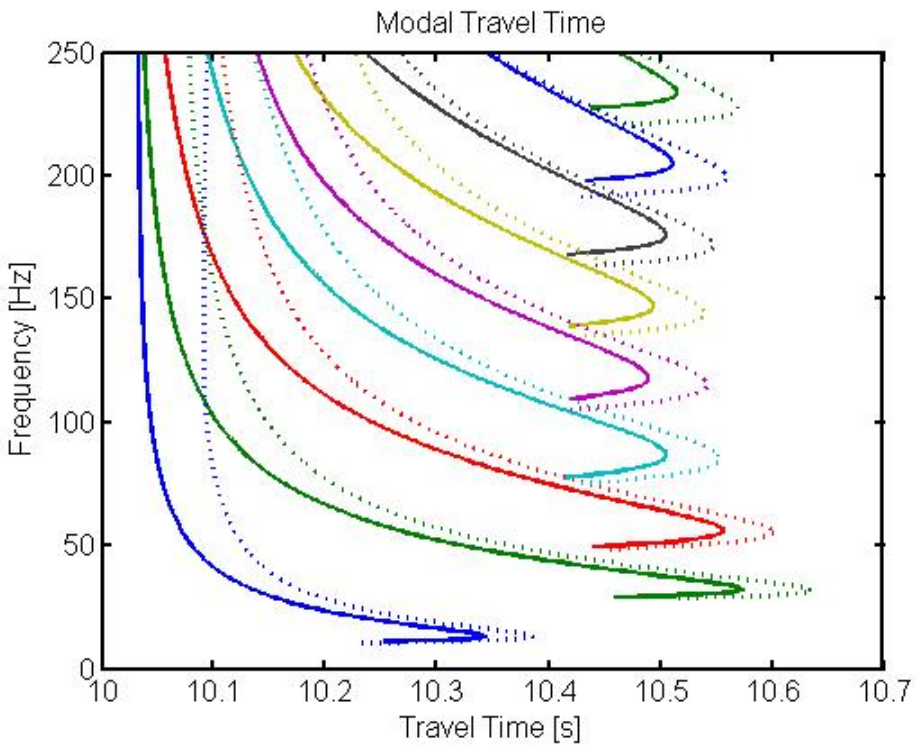
Horizontal Wavenumbers

The effect of water column sound speed on mode shapes



Travel Time



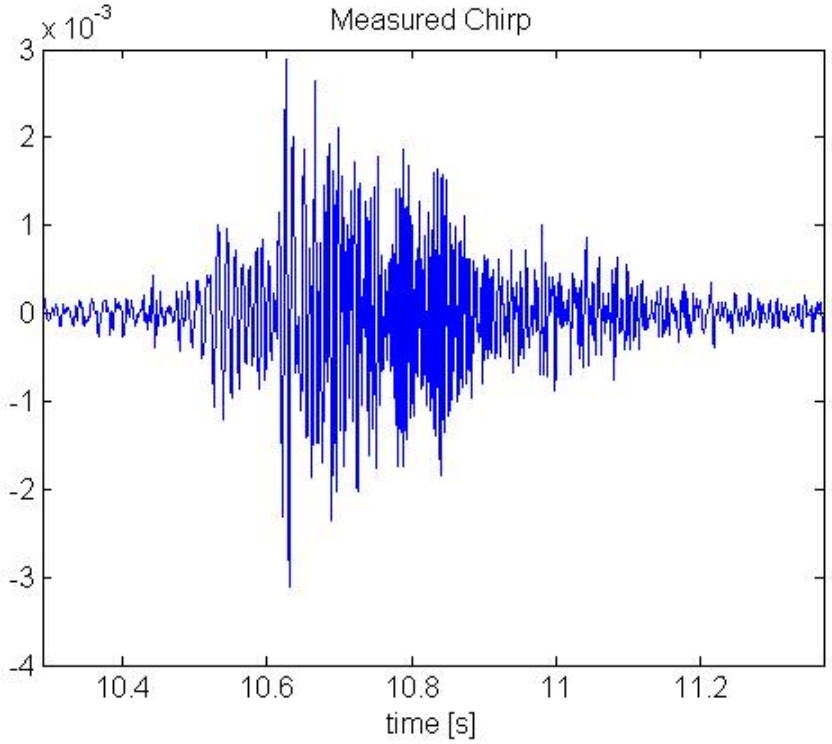


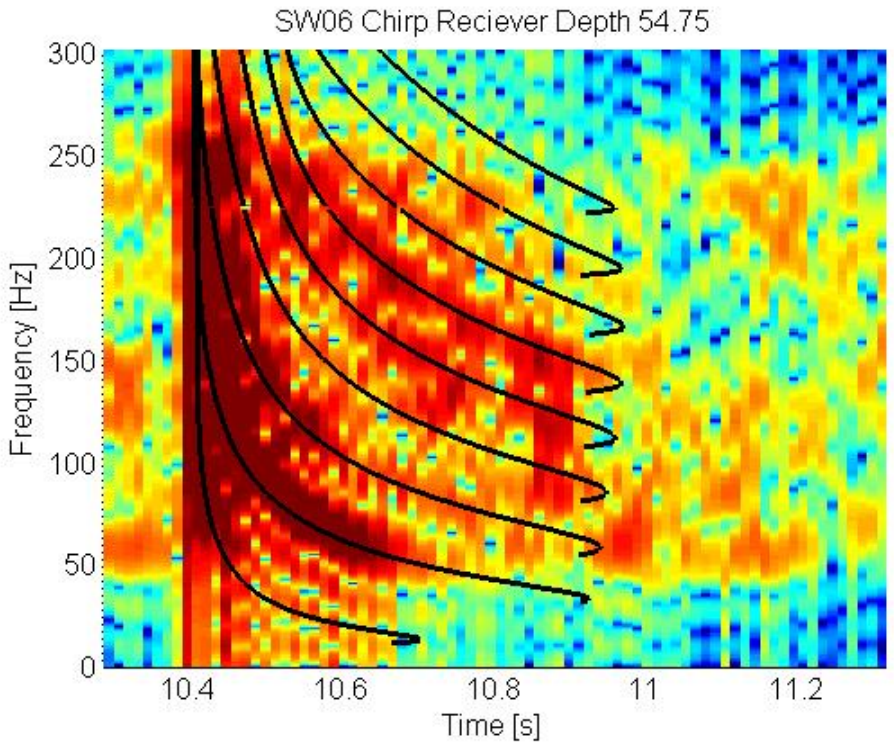
Water column sound speed measured at the VLA

Water column sound speed measured by the chain

Prediction of Experimental Data

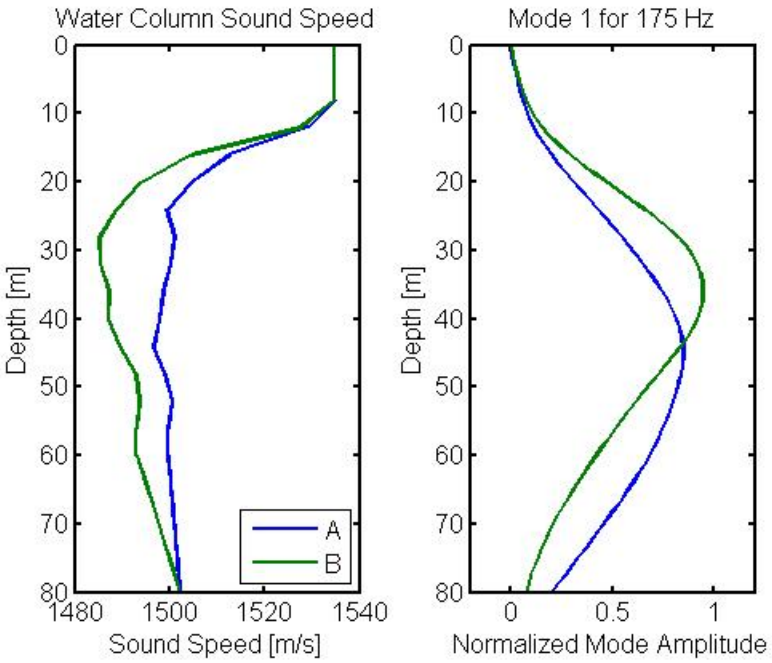
Good agreement between measure and predicted signals.

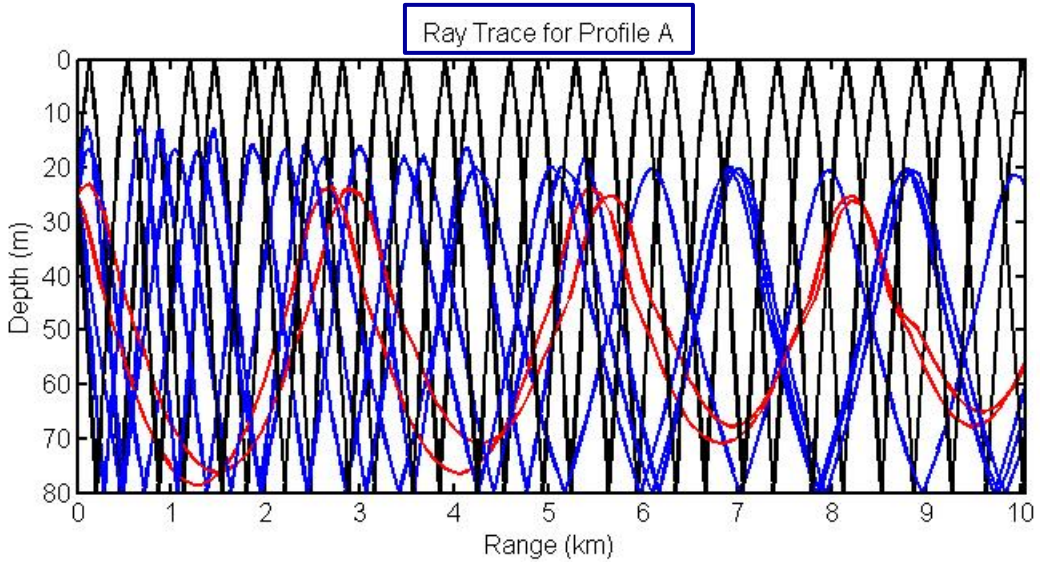


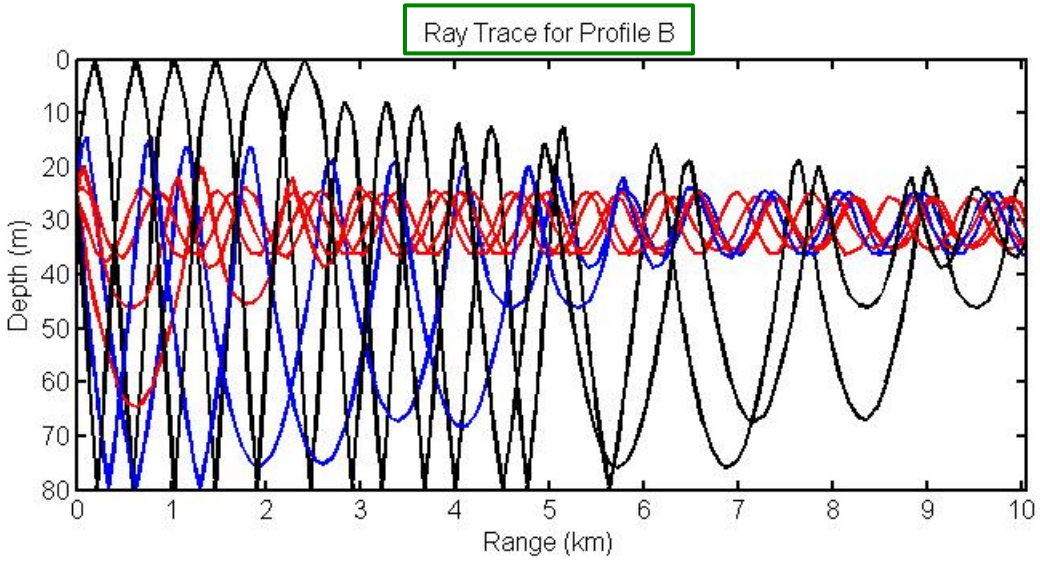


Ray Trace

Rays launched +/- 15 degrees







Cold water mass causes much stronger channeling of rays.