Accounting for Spatiotemporal Variability in Shallow-Water Waveguides for Prediction and Inversion

Kyle M Becker

NURC-NATO Undersea Research Centre
19126 La Spezia (SP) Italy

Megan S Ballard

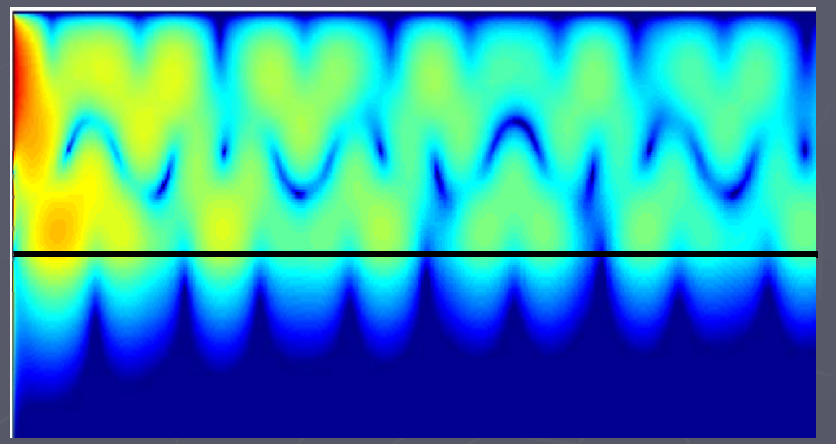
Applied Research Laboratories
University of Texas at Austin

MREA10, Villa Marigola, Lerici, Italy – 22 Oct. 2010

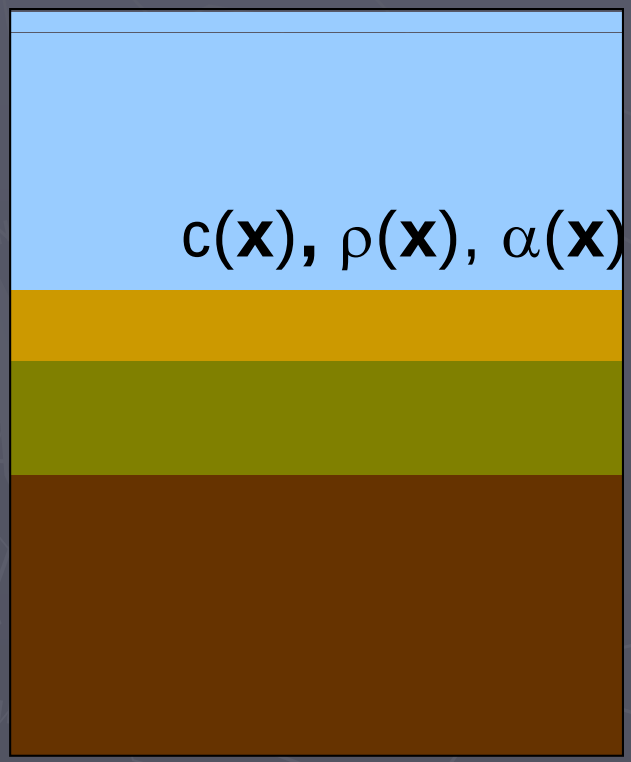
becker@nurc.nato.int

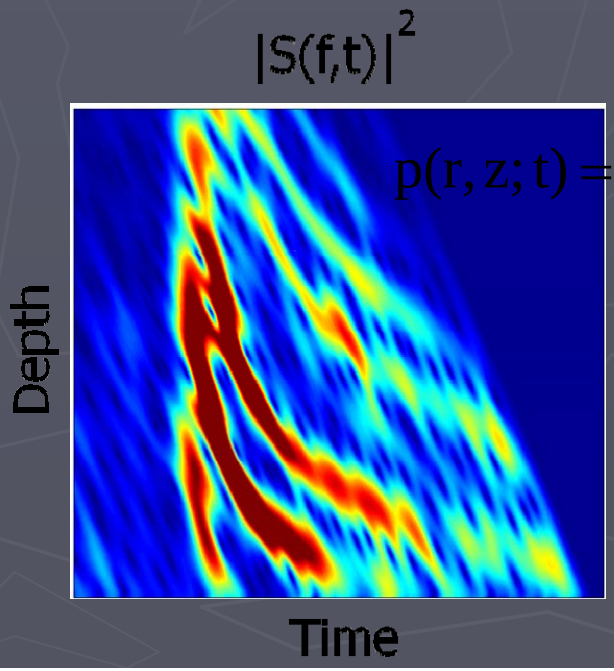
Overview – Prediction/Inversion
(Decision Aids)

$$p(r,z) \propto \frac{1}{\rho(z_s)} \sum_{n=1}^{N} Z(z_s) Z(z) \frac{e^{i\int_0^R k_n(s)ds}}{\sqrt{k_n r}}$$



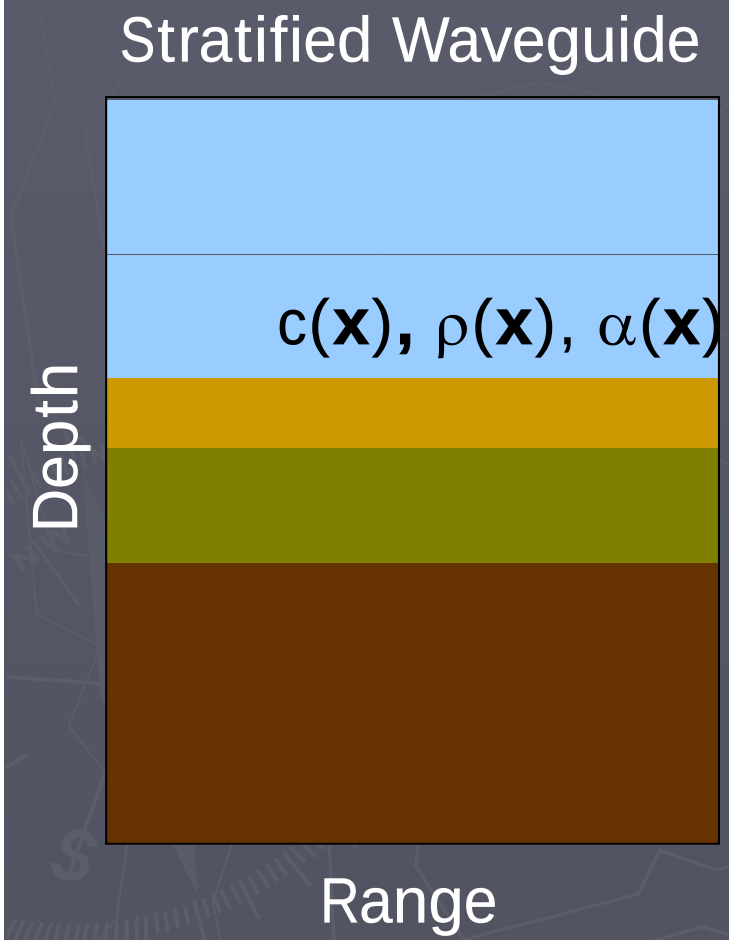
Stratified Waveguide





$$p(r,z;t) = \mathrm{IFFT}\{p(r,z;\vec{\omega})\}$$

Overview – Prediction/Inversion



Environment: Inputs/Characterize

Water Column (Dynamic)

- Space/Time variability
- CTD/XBT/Moored/Towed
- Climatology

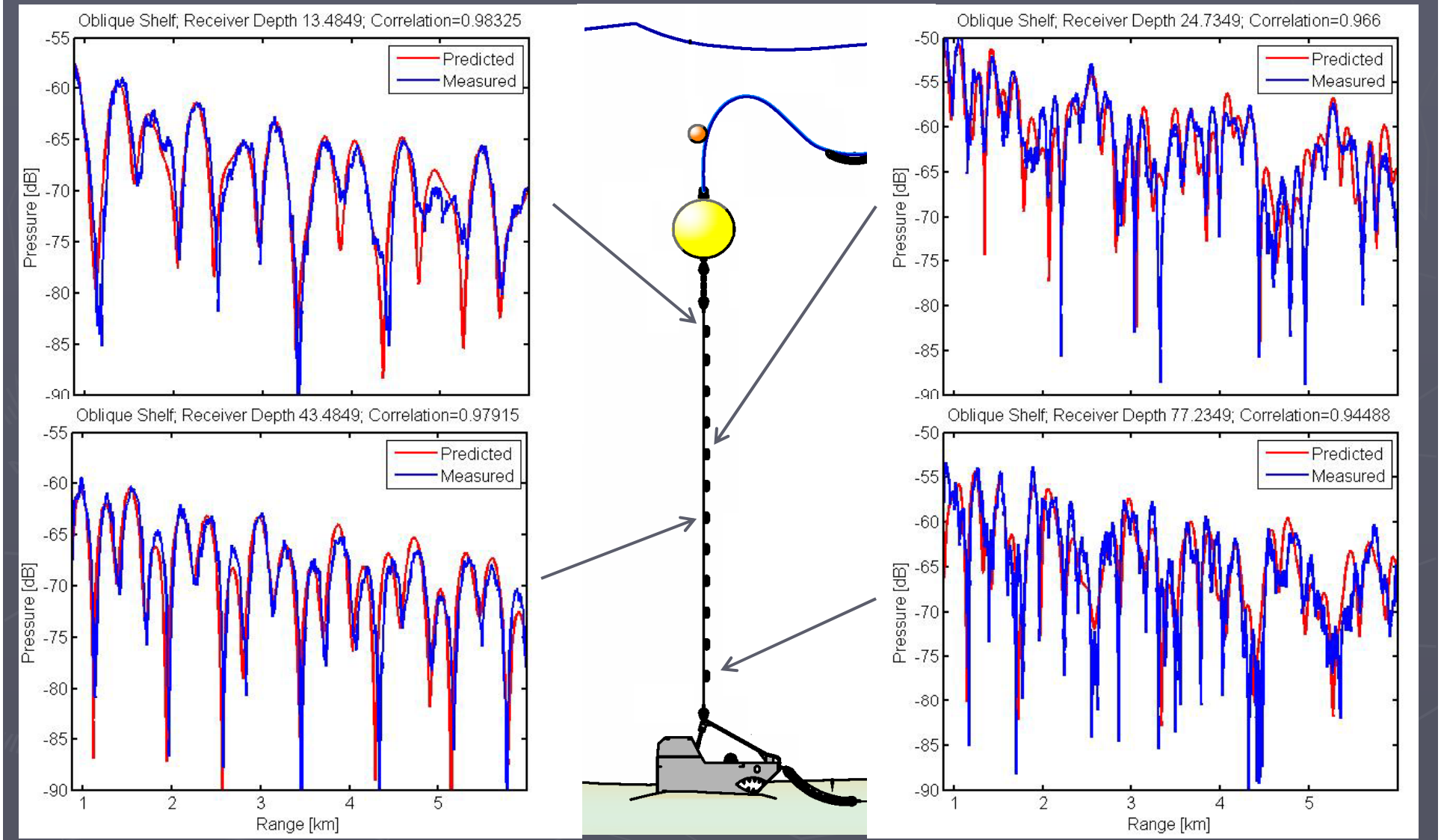
Bottom (Stationary)

- Spatial variability
- Databases/Sed types/geoacs/ halfspace/layered model

Prediction/Evaluation

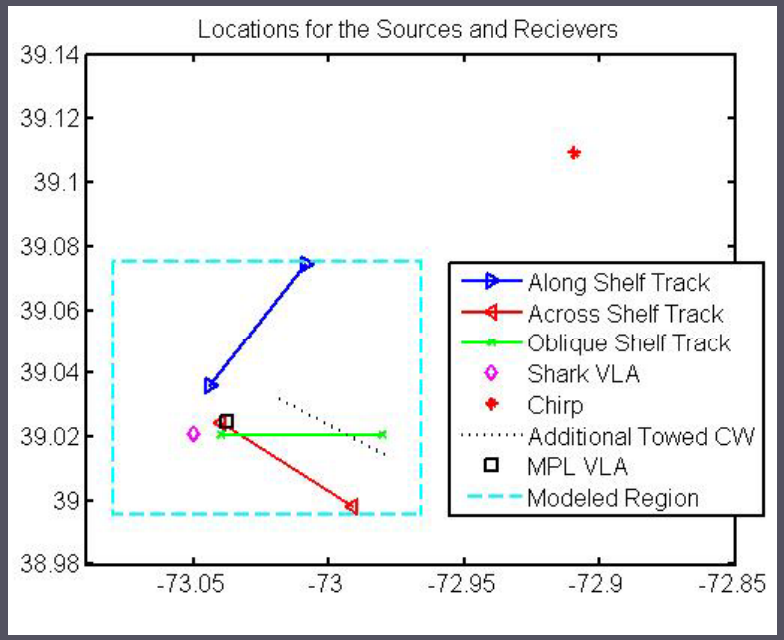
50 Hz

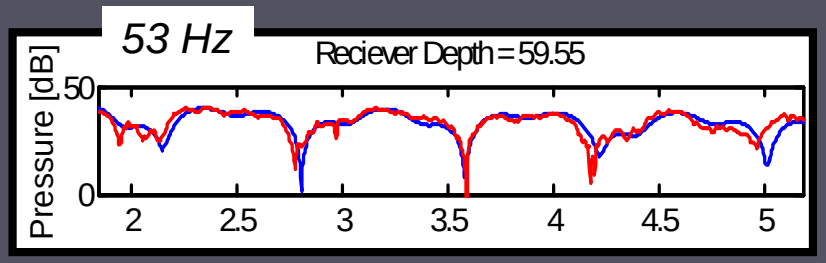
125 Hz

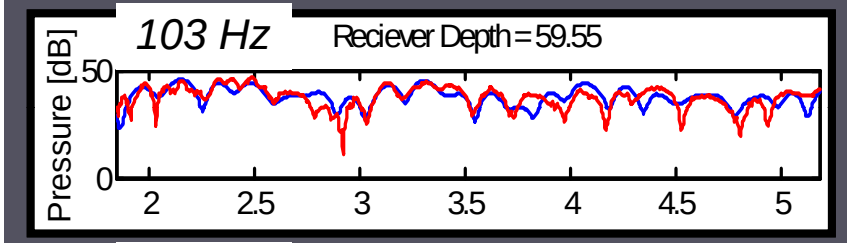


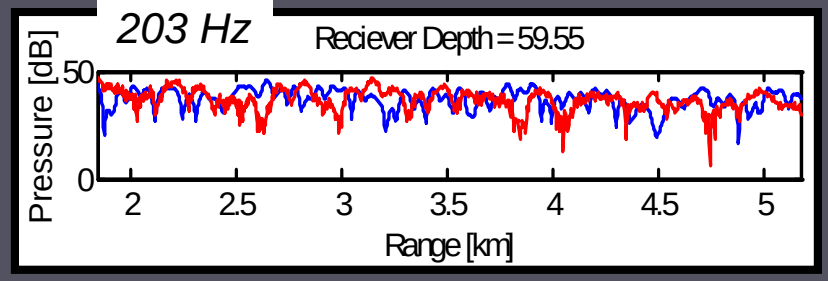
Prediction

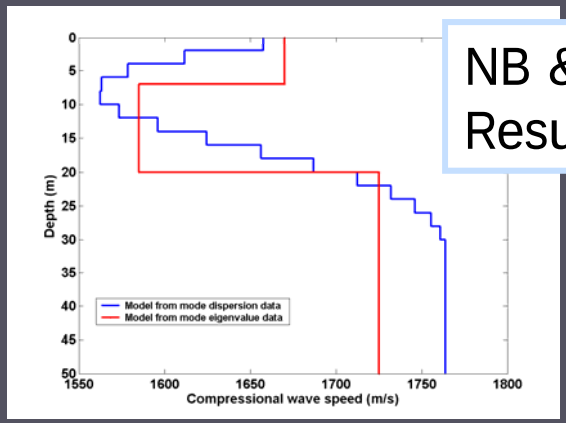
Prediction/Data Compare: Hodgkiss/Chapman/Knobles Data











NB & BB Results

- *19 Days after previous work*
- *Correlation decreases w/ Increasing frequency*
  - Water Column effect

NATO OTAN

NURC

PARTNERING FOR MARITIME INNOVATION

Inversion Approach

Perturbative Inversion:

Iterative approach; linear relationship between small change in background model to small change in data.

Inversion based on Modal Wave Number Estimates

$$\Delta k_n = \frac{1}{k_n}\int_0^\infty \rho^{-1}(z) Z_n^2(z) k^2(z) \frac{\Delta c(z)}{c_0(z)} dz$$

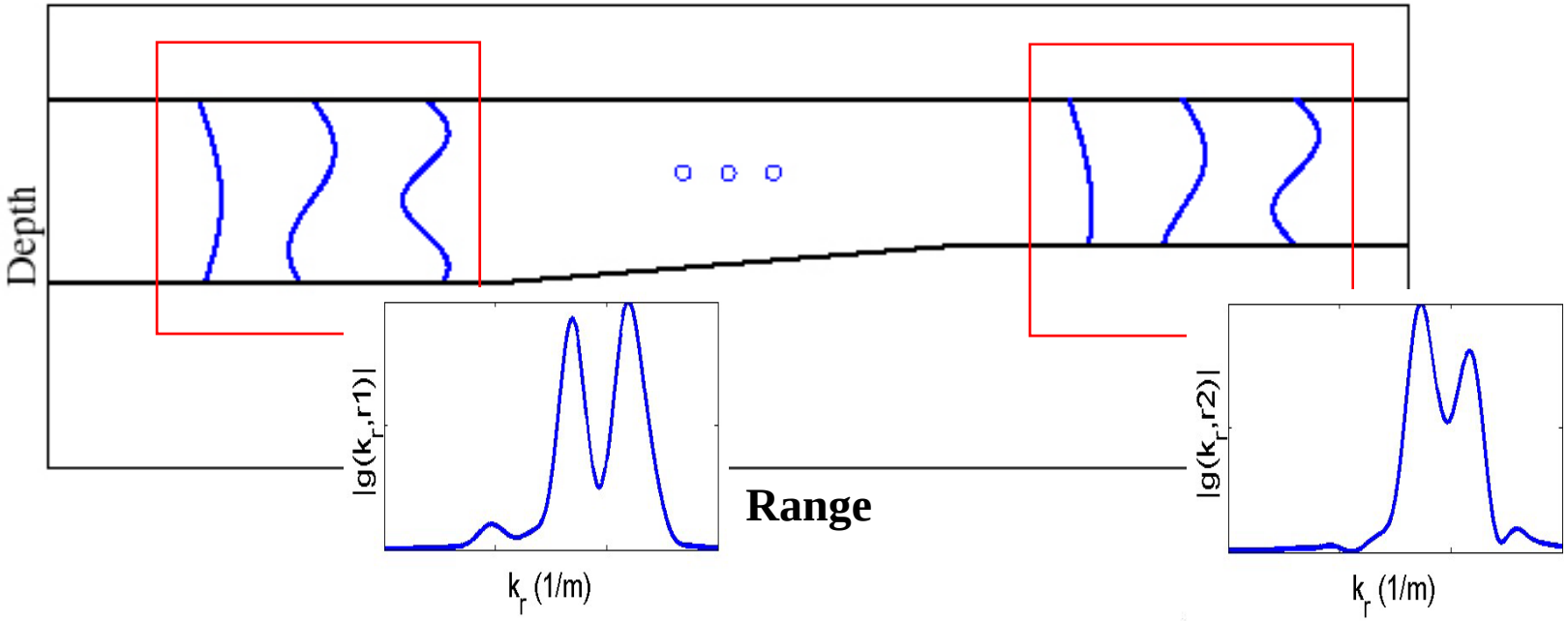
Inversion based on Modal Arrival Time Differences

$$dt_n = \frac{\partial \Delta\theta_n}{\partial \omega} = \frac{\partial}{\partial \omega}\int_0^r\int_0^\infty \frac{\rho^{-1}(z)}{k_n(\omega)} Z_n^2(z) k^2(s,z) \frac{\Delta c(s,z)}{c_0(s,z)} dsdz$$

Fredholm Integral Equation of First Kind

$$d_n = \int_0^\infty G_n(z) m(z) dz \qquad n = 1, \cdots, N$$

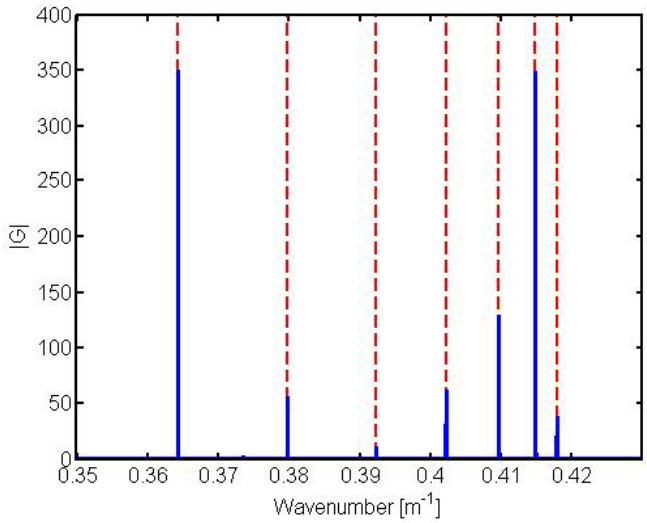
Wave Number Estimation - Input Data



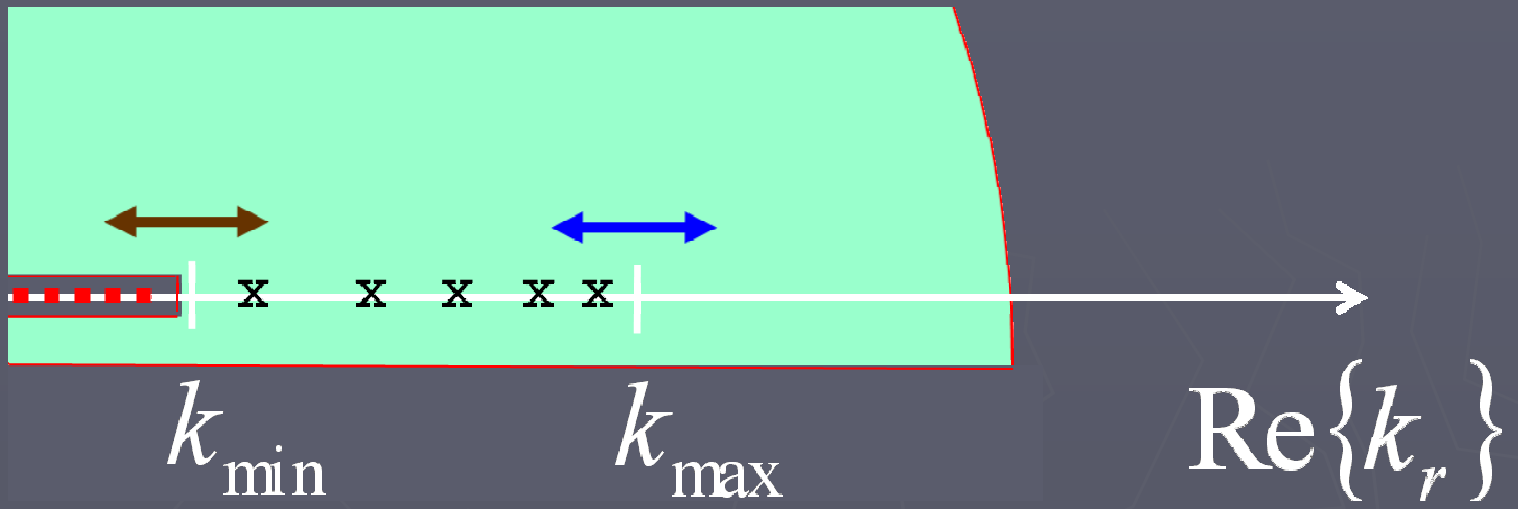
$$g(k_r;\hat{r},z,z_0)=\frac{e^{i\pi/4}}{\sqrt{2\pi k_r}}\int_{-\infty}^{\infty} w_L(r;\hat{r})\,p(r;z,z_0)\sqrt{r}e^{-ik_r r}\,dr$$

$$x_n=\sum_{k=1}^{p} a_k x_{n-k}$$

$$P_{AR}=\frac{\sigma^2 T}{\left|1+\sum_{k=1}^{p} a_k e^{-i2\pi fkT}\right|^2}$$



Horizontal Wave Number Domain



$$k_0 \cong k_{\max} = \frac{\omega}{c_{\min}}$$

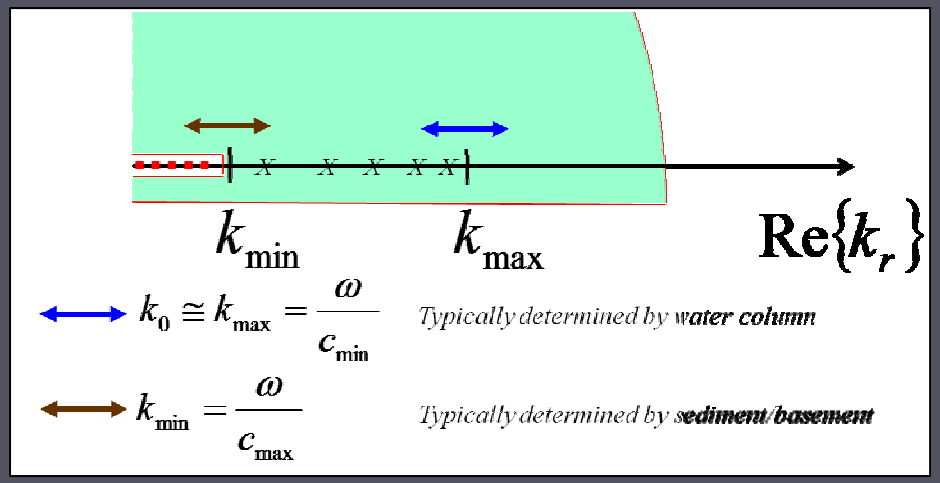
Typically determined by water column

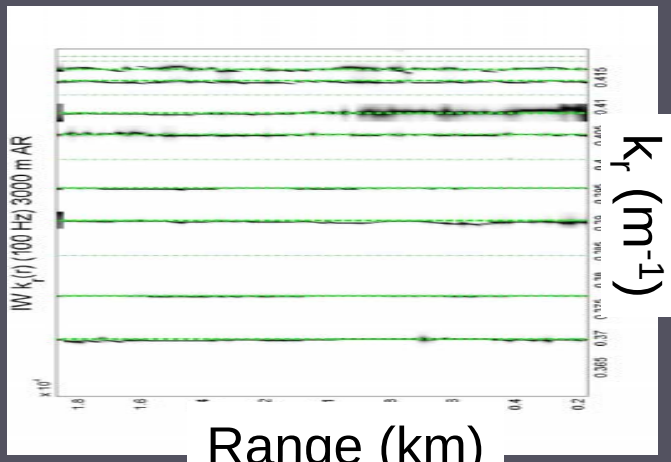
$$k_{\min} = \frac{\omega}{c_{\max}}$$

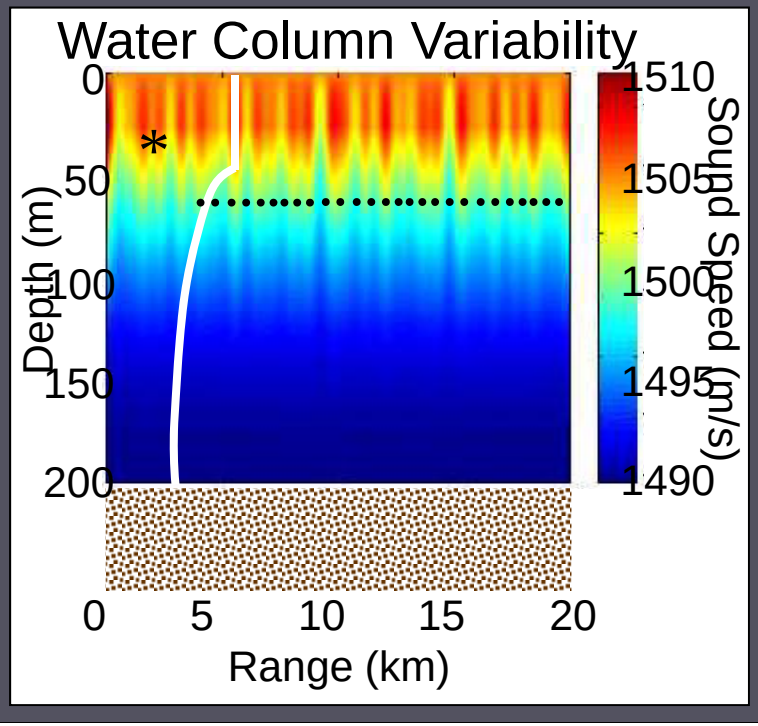
Typically determined by sediment/basement

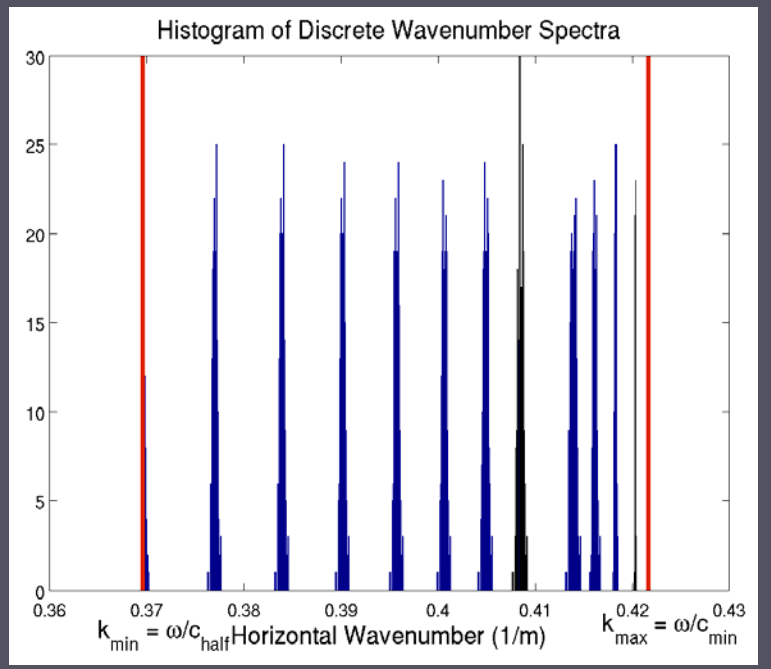
- Spectrum and Bandwidth determined by combination of water column and bottom properties plus frequency
- High-order modes more influenced by bottom characteristics

Water Column Effects







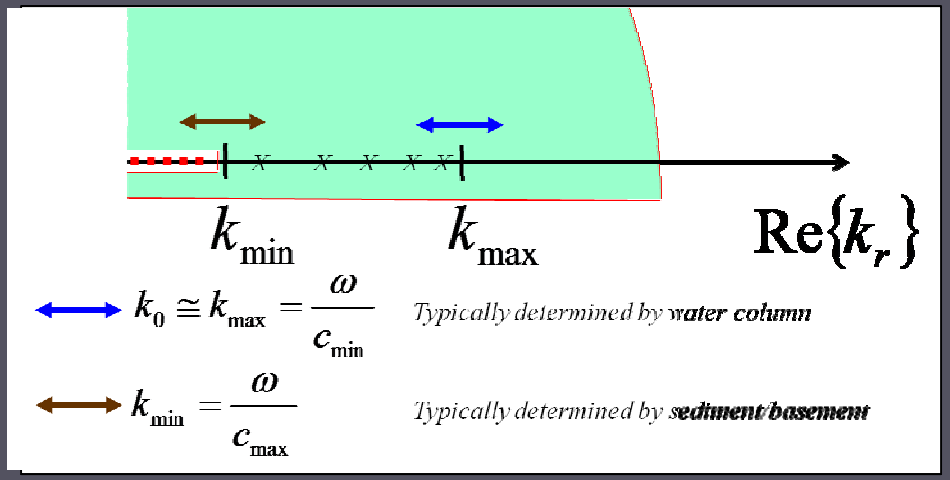


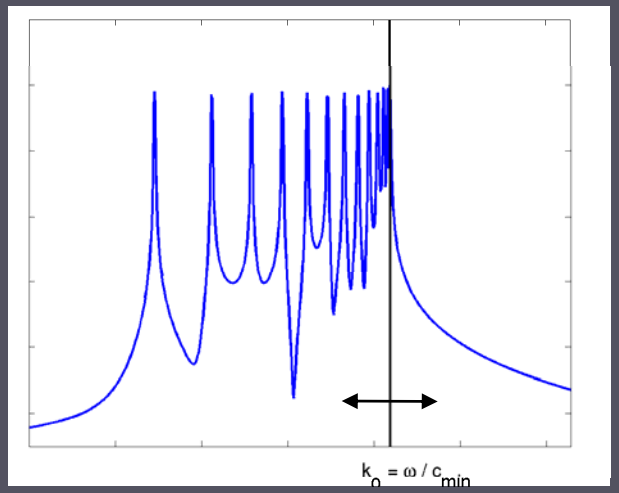
NATO OTAN

NURC

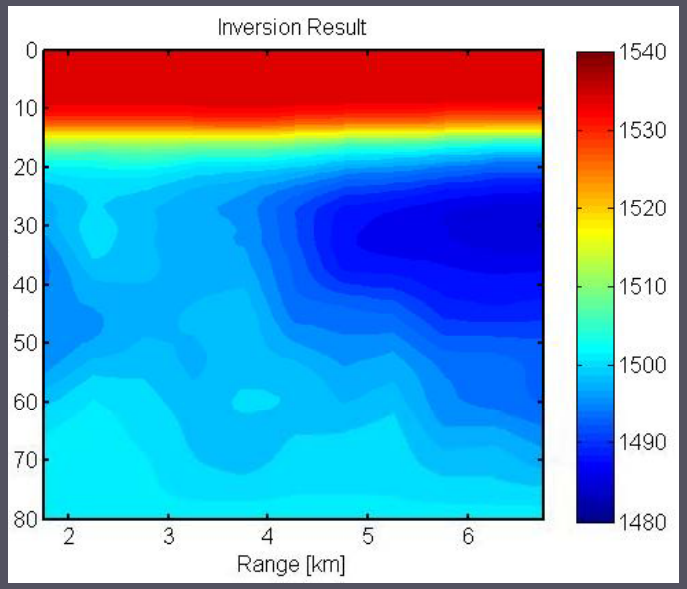
PARTNERING FOR MARITIME INNOVATION

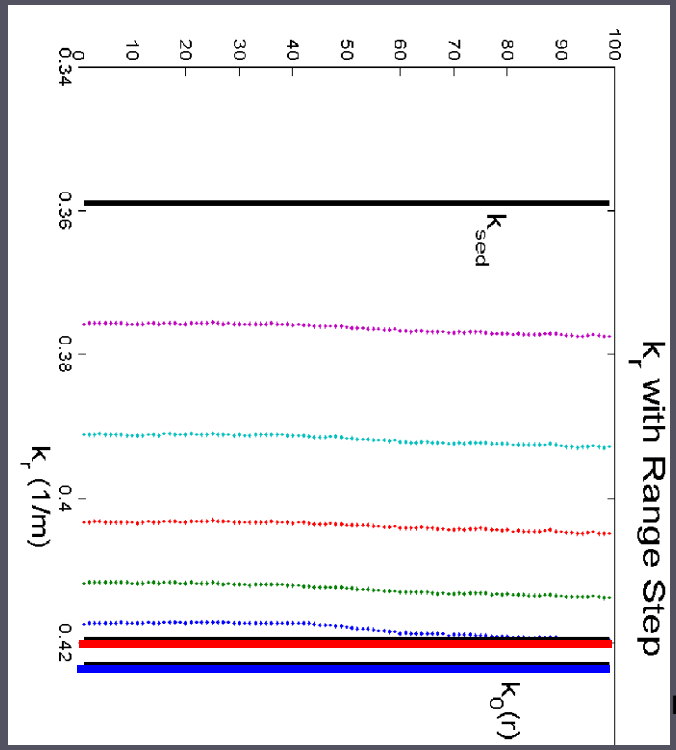
Water Column Effects





Wave number response to cooler water at far end of the track.





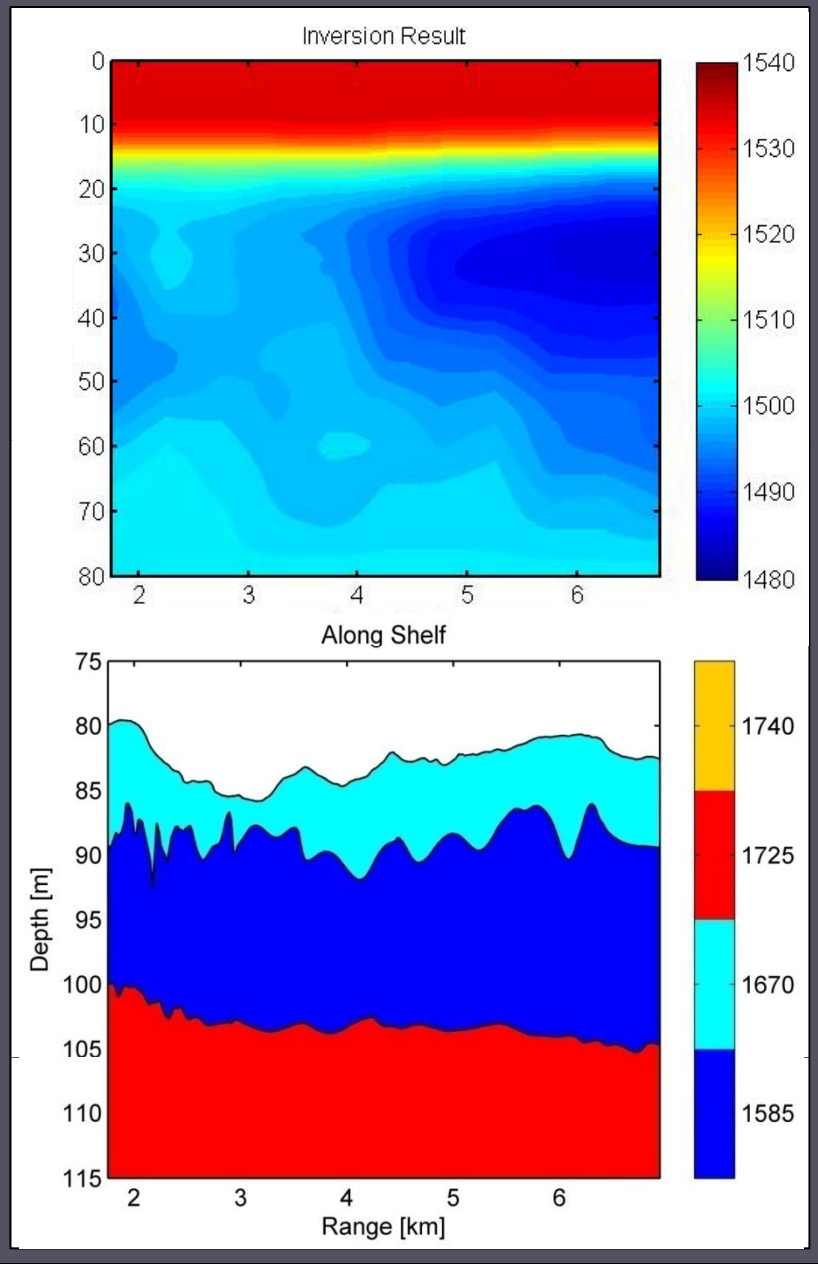
NATO OTAN

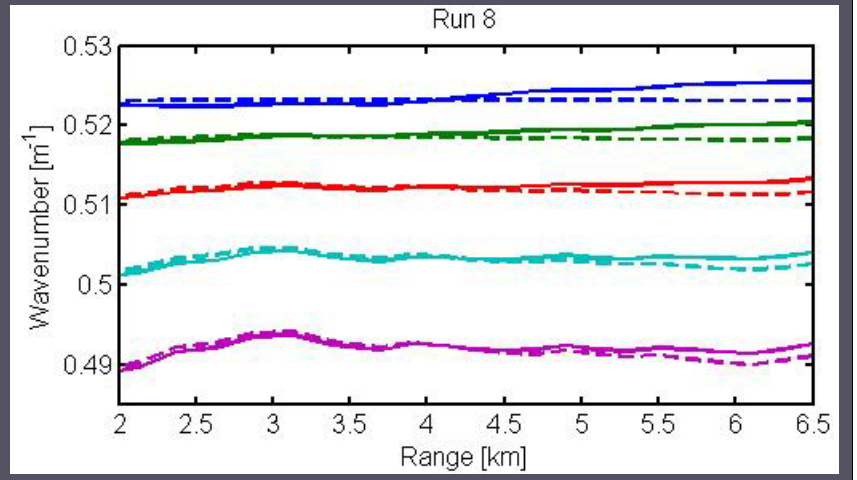
NURC

PARTNERING FOR MARITIME INNOVATION

ED

Water Column and Seabed





- - Range dependent bathymetry and seabed (range independent water column)
— Fully range dependent

NATO UNCLASSIFIED

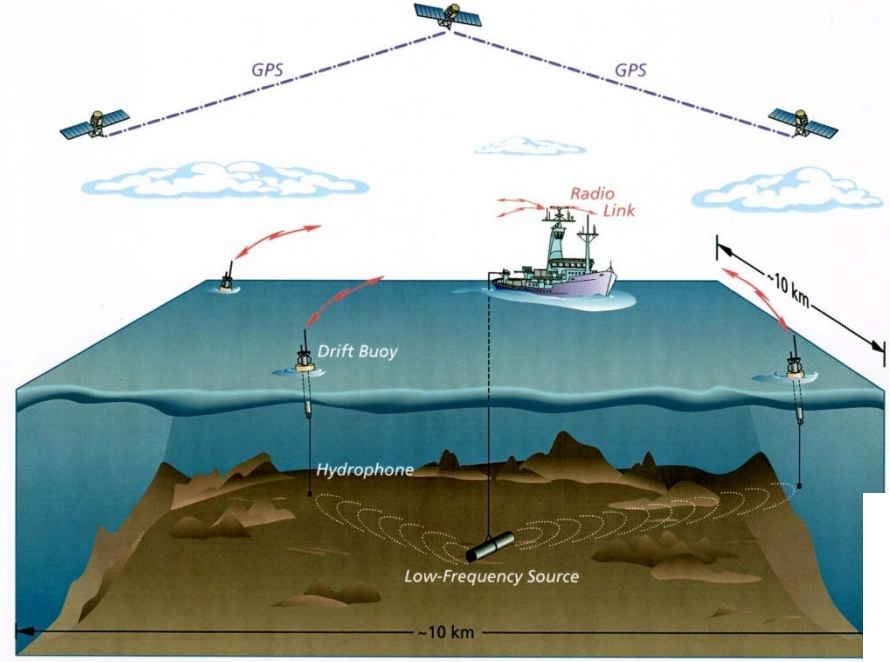
NATO OTAN

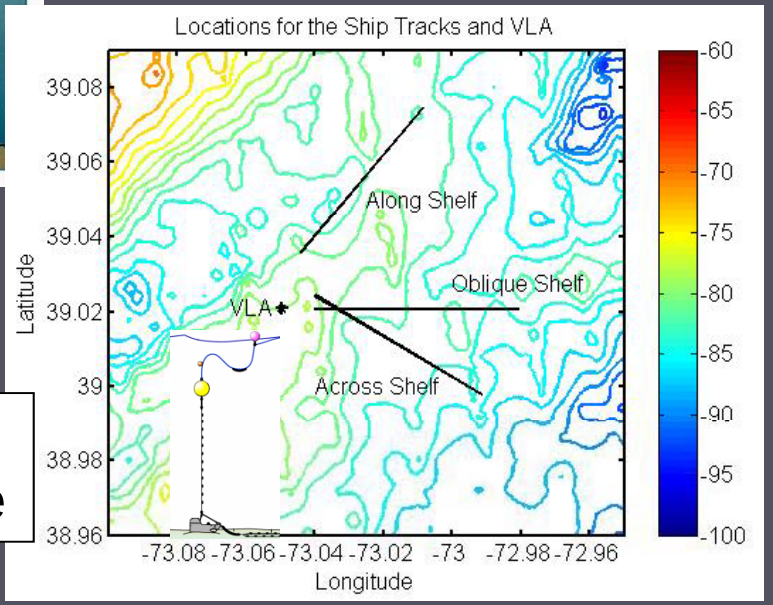
NURC

PARTNERING FOR MARITIME INNOVATION

Experimental Configurations

Modal Mapping Experiments
- Drifting buoys/Moving Source





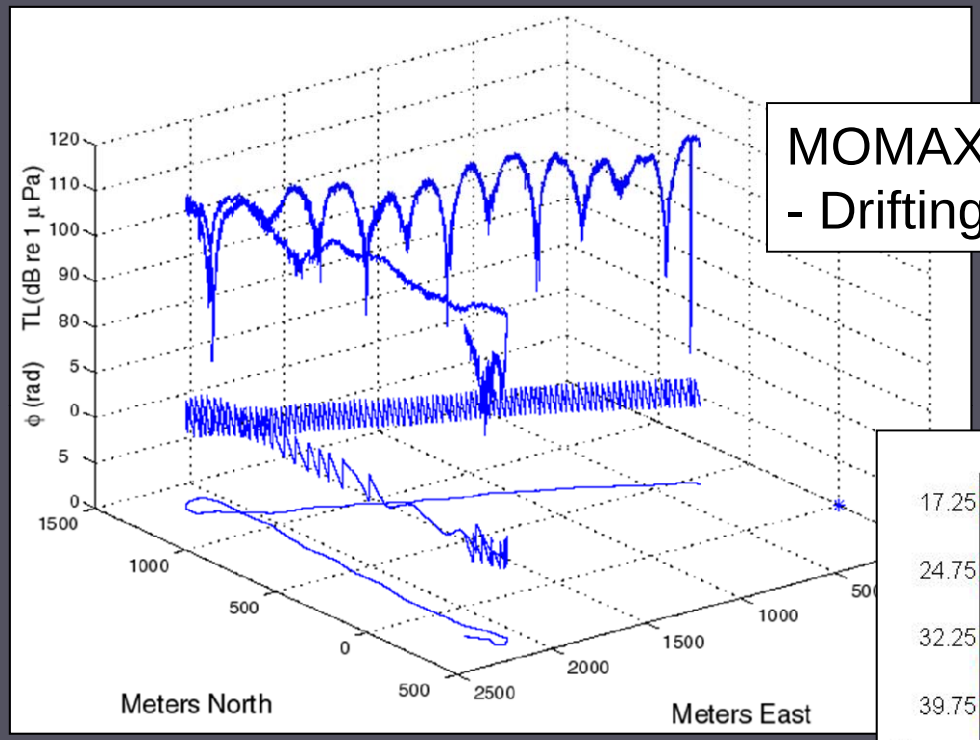
SW06-Mode Inverse Methods
- Fixed Receivers/Moving Source

NATO OTAN

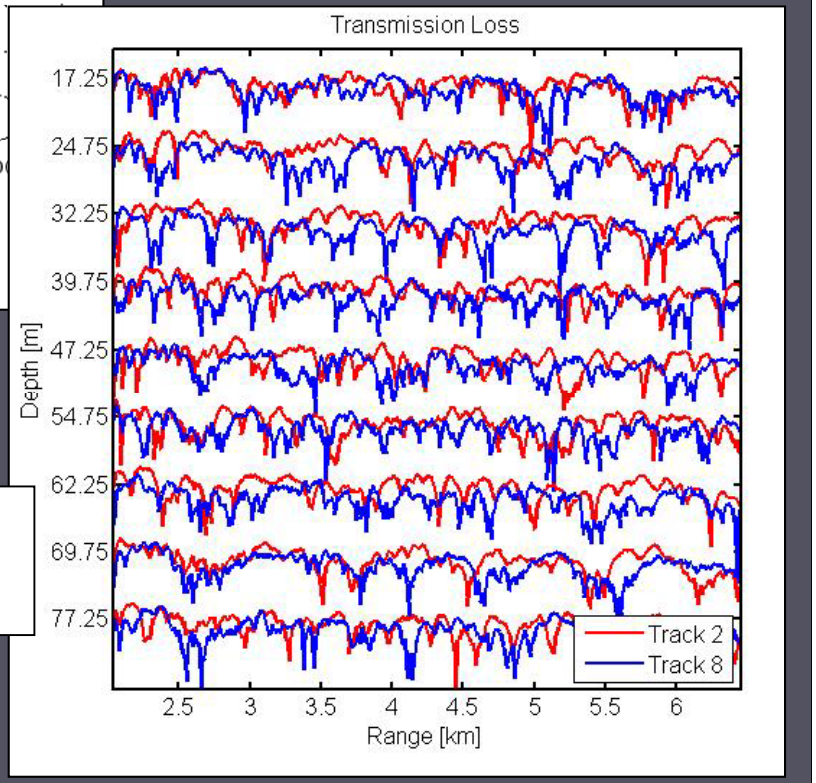
NURC

PARTNERING FOR MARITIME INNOVATION

Spatial Acoustic Pressure Data



MOMAX I Pressure Field (75 Hz)
- Drifting buoys/Moving Source



SW06 Pressure Field (125 Hz)
- Moored VLA/Moving Source

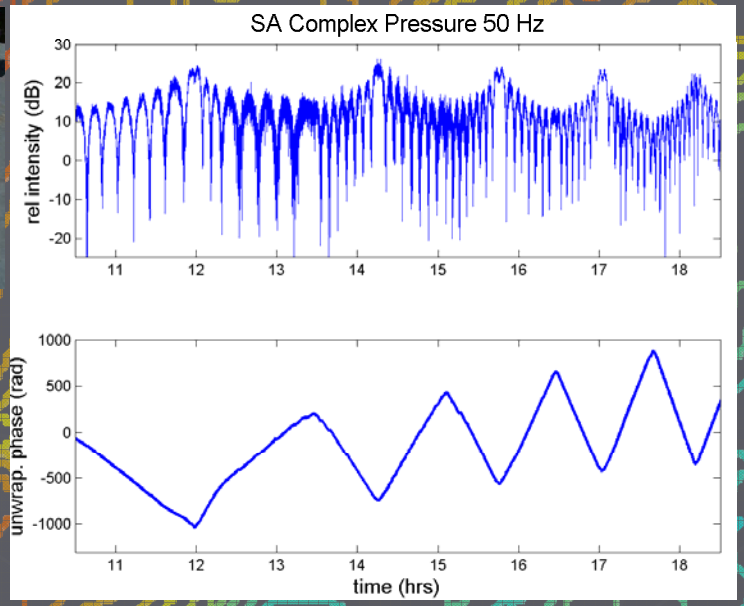
NATO OTAN

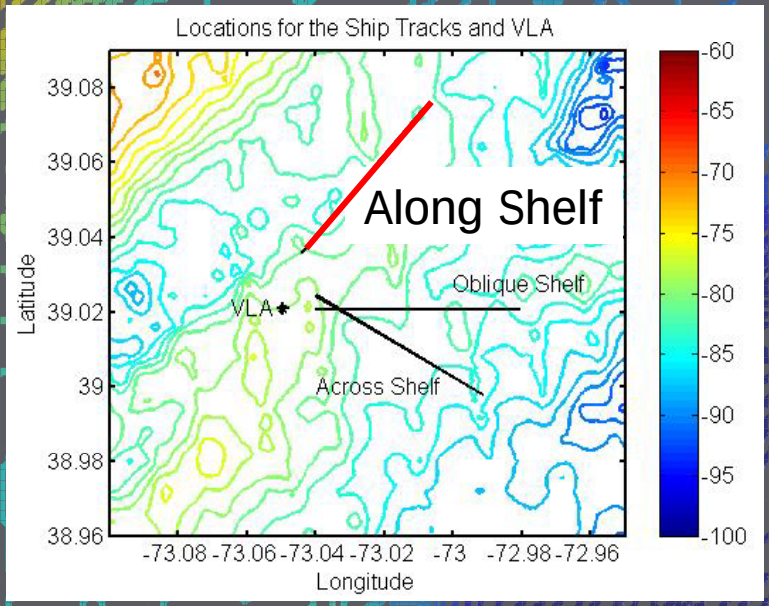
NURC

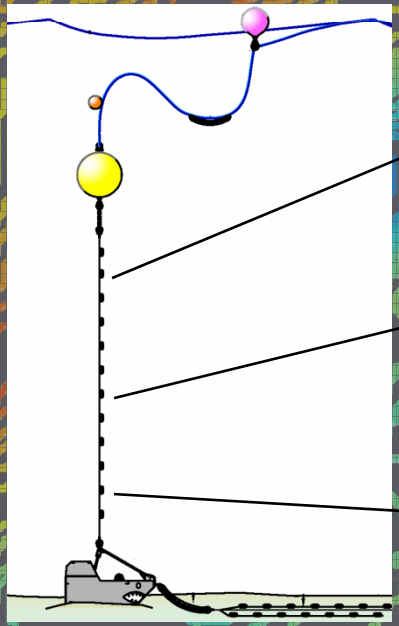
PARTNERING FOR MARITIME INNOVATION

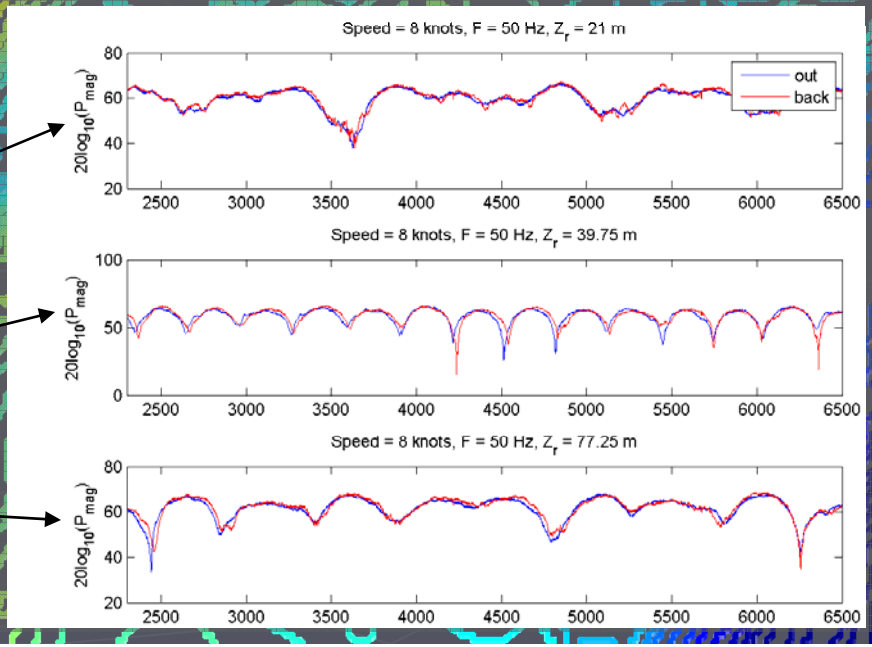
SW06 CW Experiments

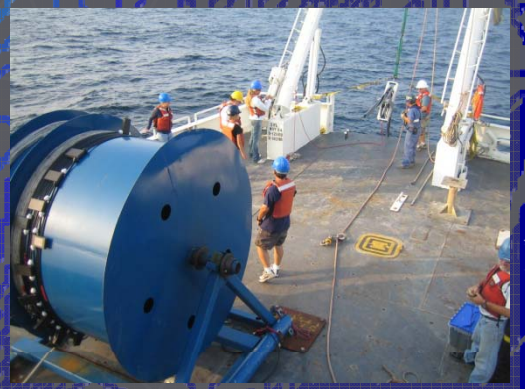
- 16 depths
- out/back
- 5 speeds



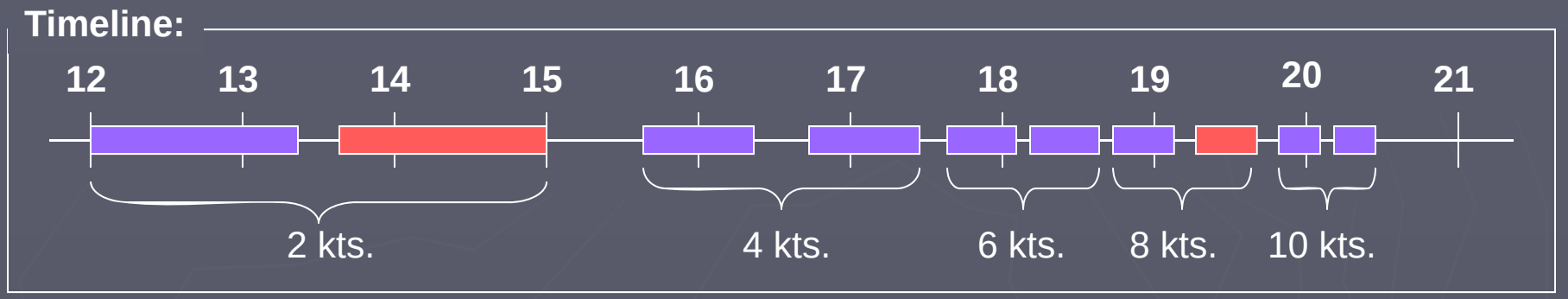


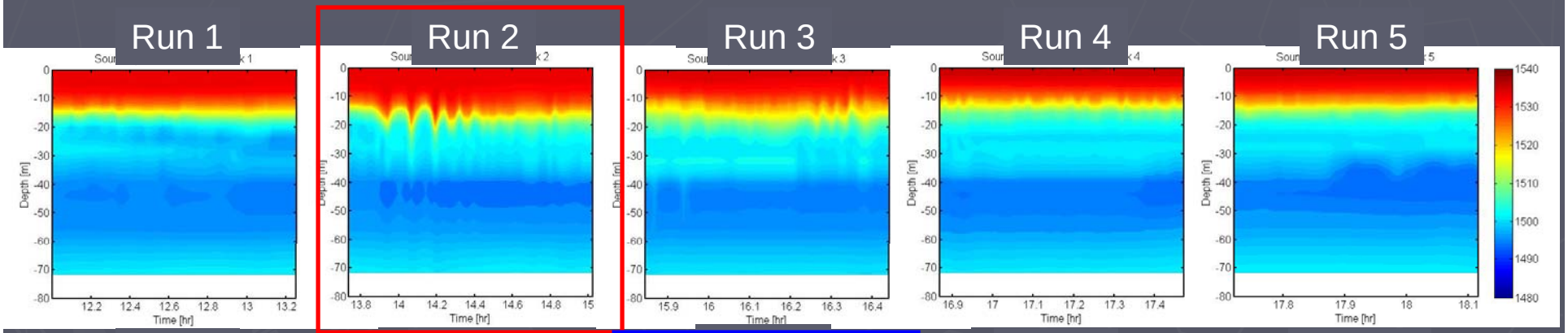


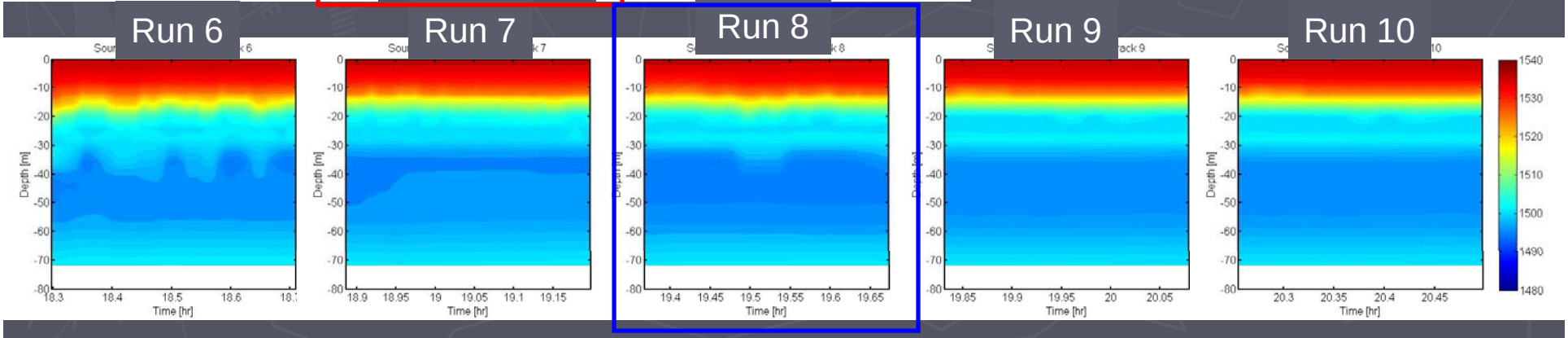




Water Column at the Receiver

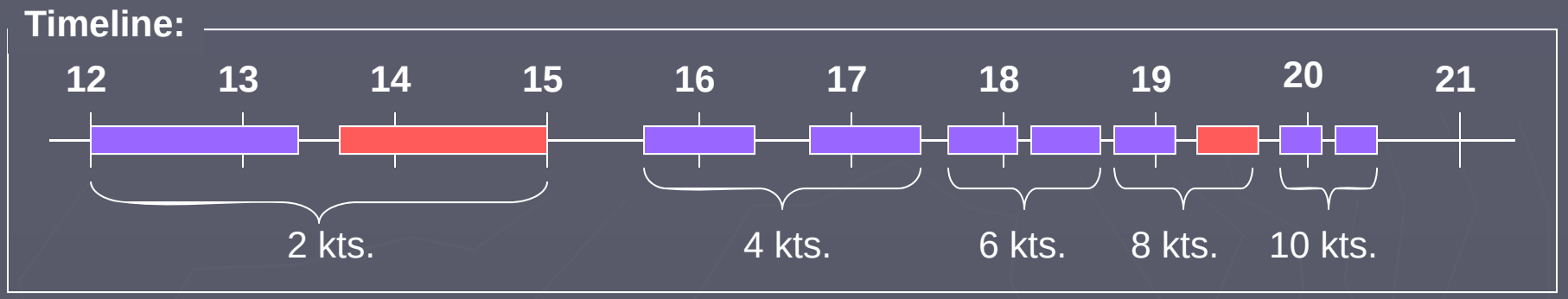


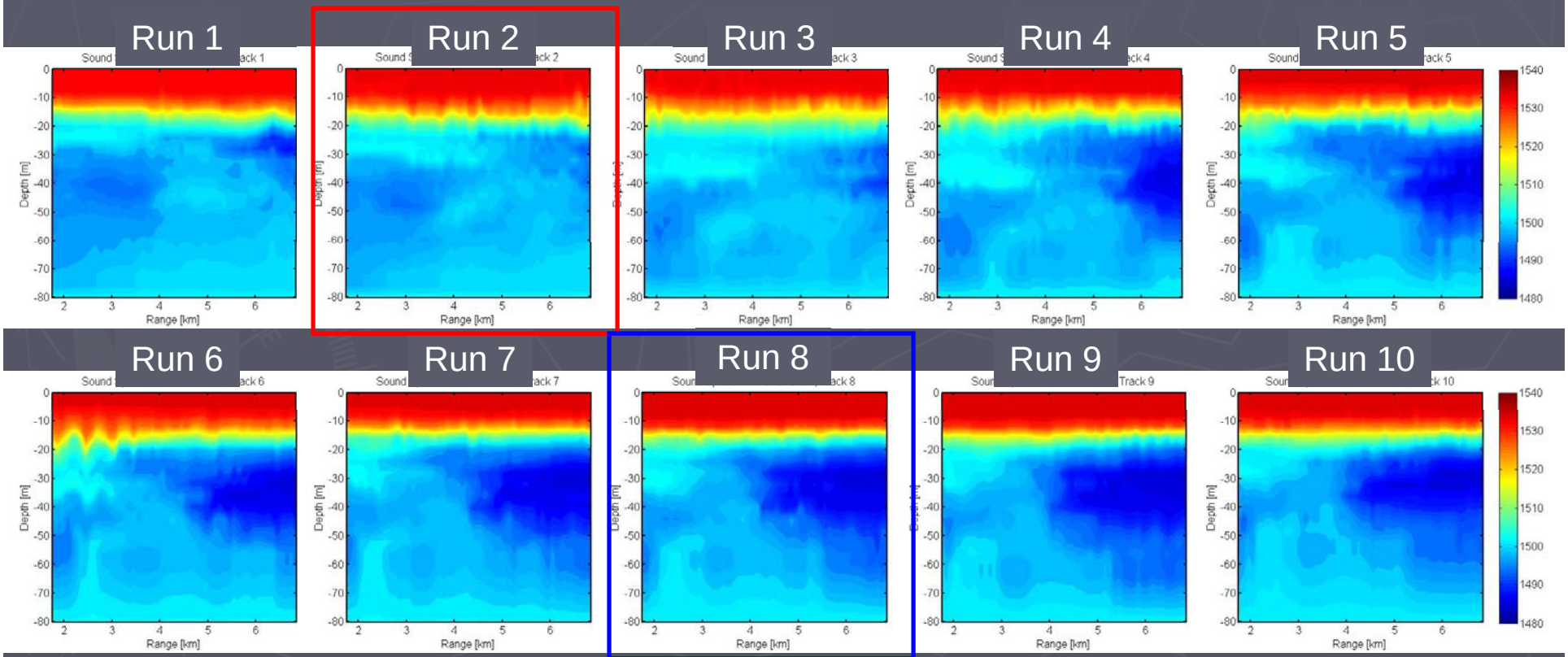




x-axis = time (hrs) – changing scale from run 1 to 10; y-axis = depth (m)

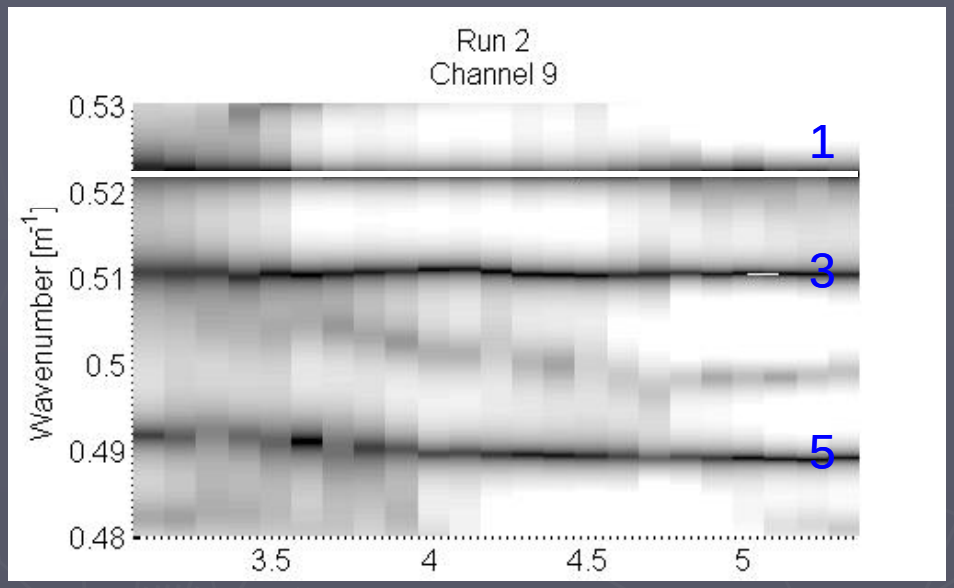
Water Column at the Source

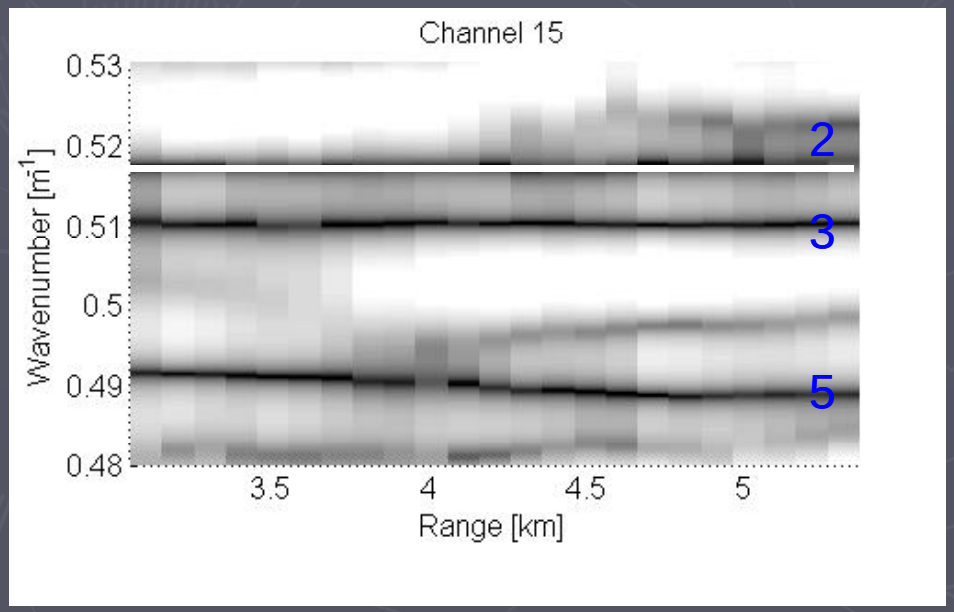


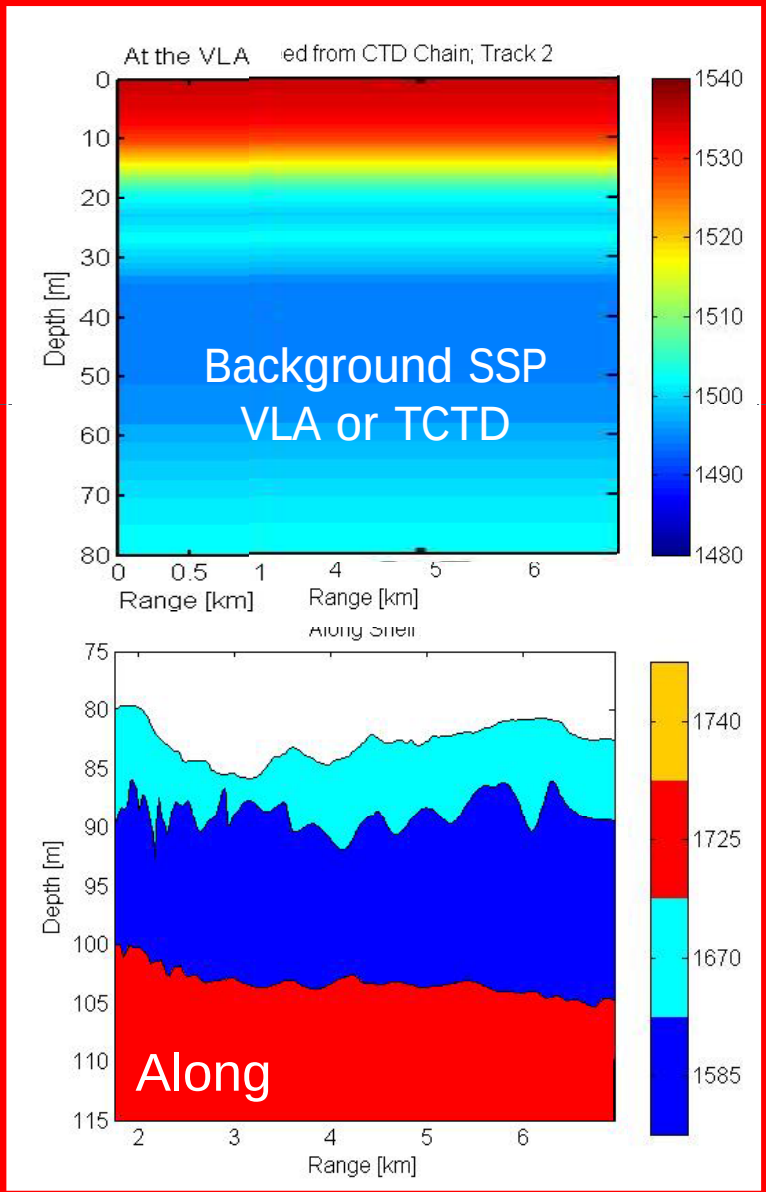


x-axis = range (km) – fixed scale from run 1 to 10; y-axis = depth (m)

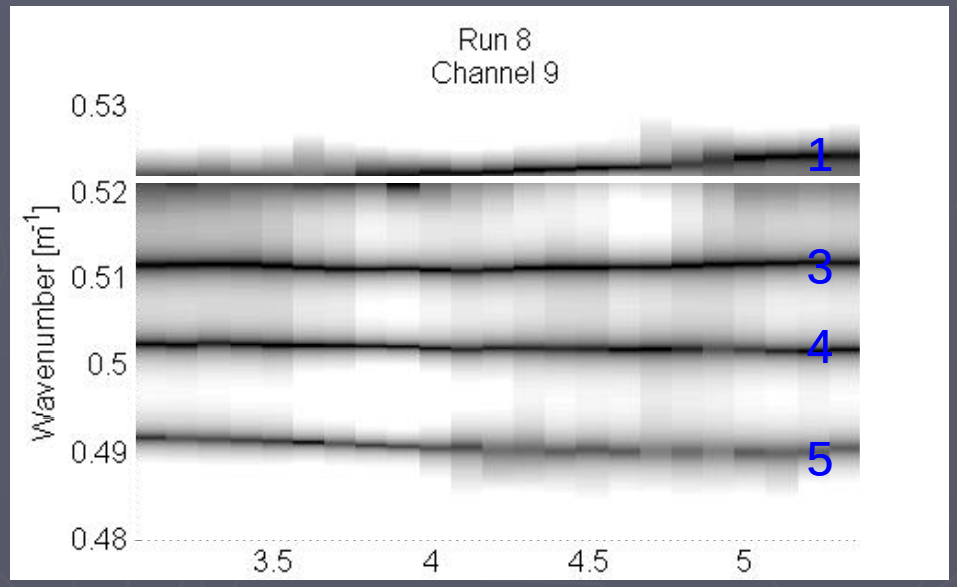
Inversion – Run 2

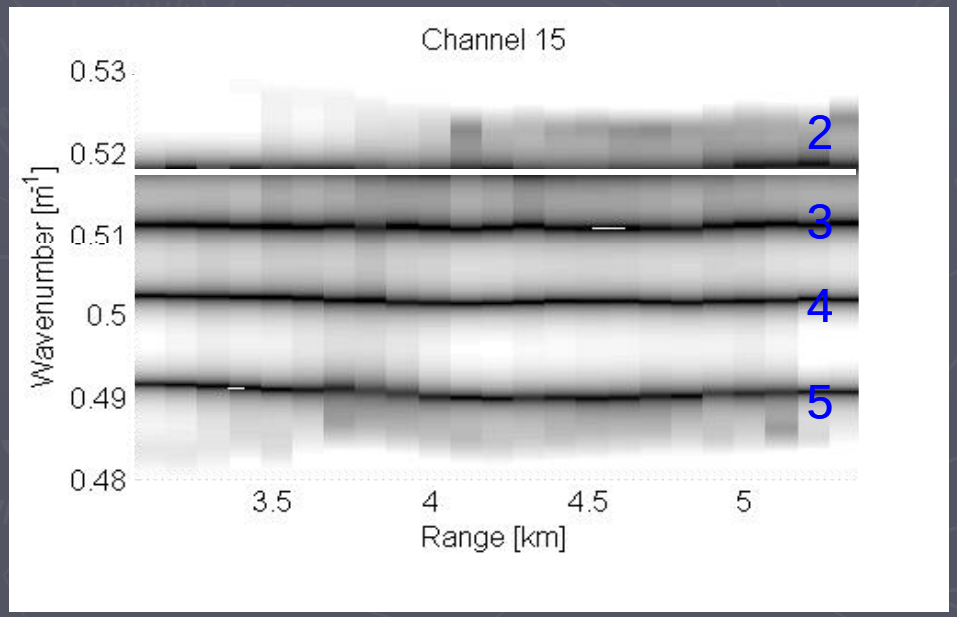


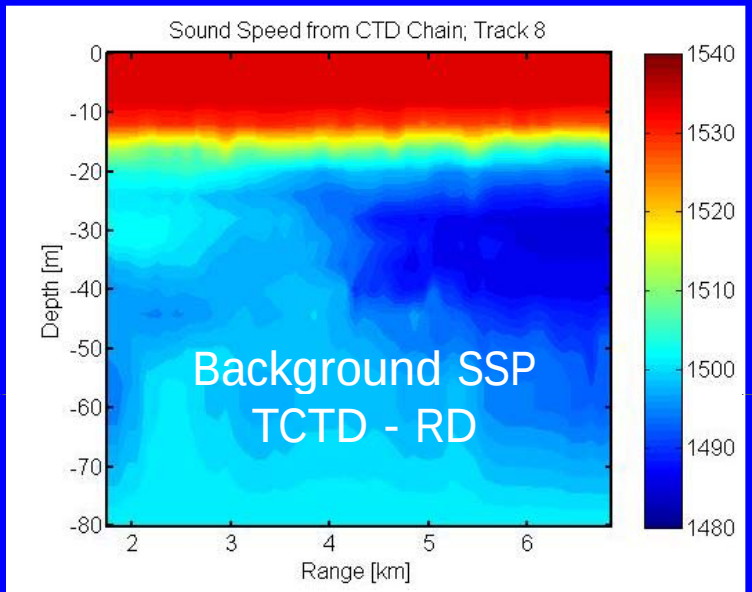


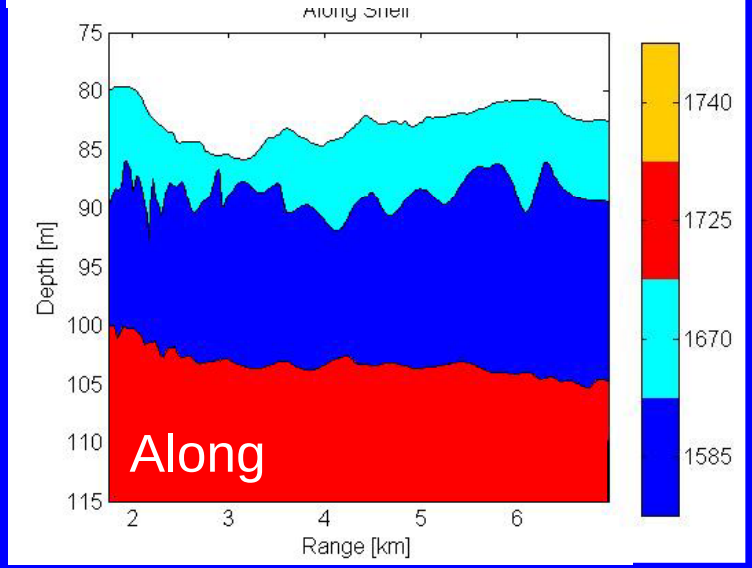


Inversion Source SSP – Run 8







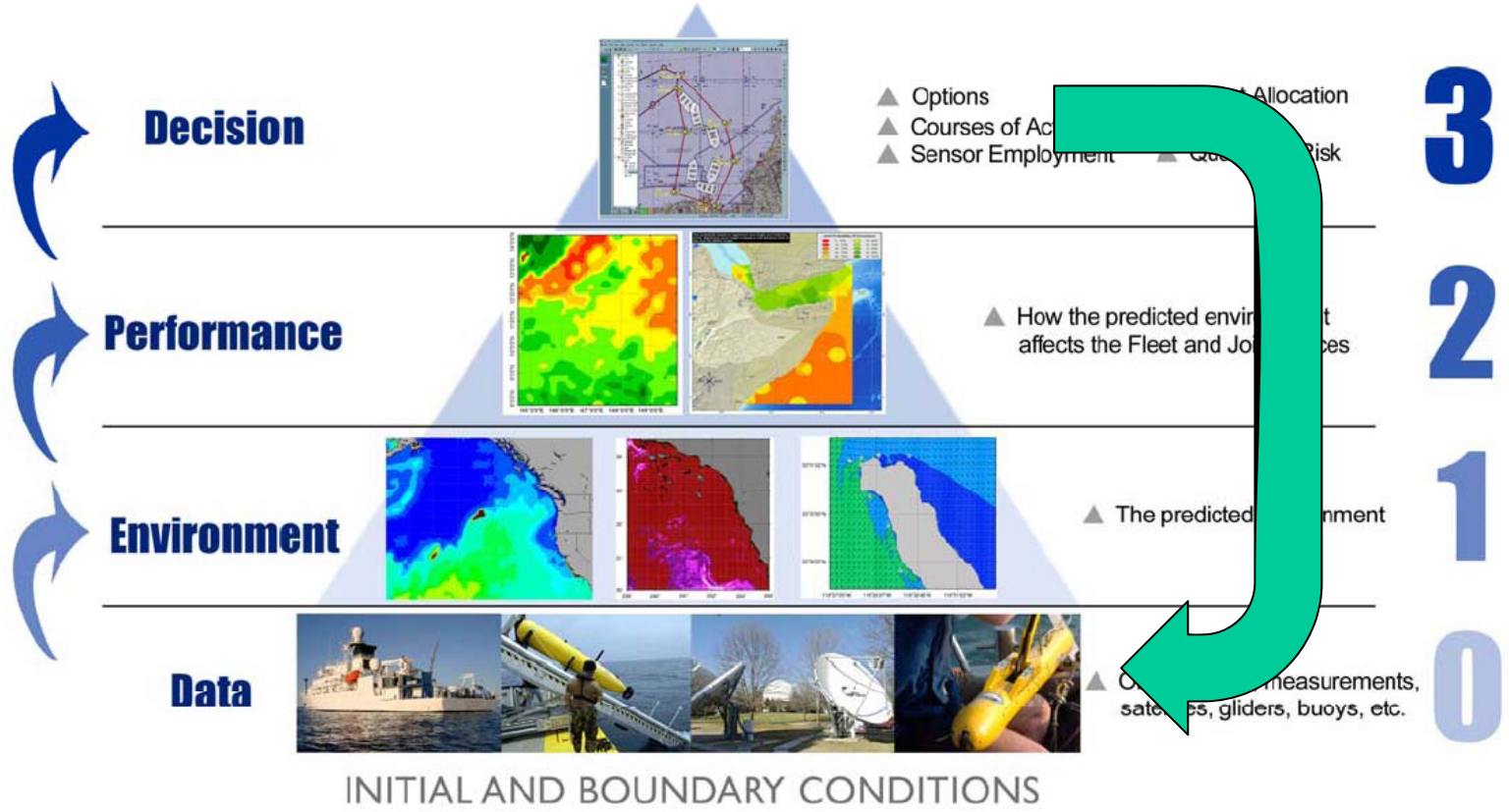


Where Do We Fit?

Battlespace on Demand

Turning forecasts into warfighting decisions

Battlespace On Demand (BonD) is Naval Oceanography's operational concept. It guides and informs our operational and technical domains, and drives our investment strategy. It enables us to keep the Fleet safe, and enhance warfighting effectiveness by achieving decision superiority.



NATO OTAN

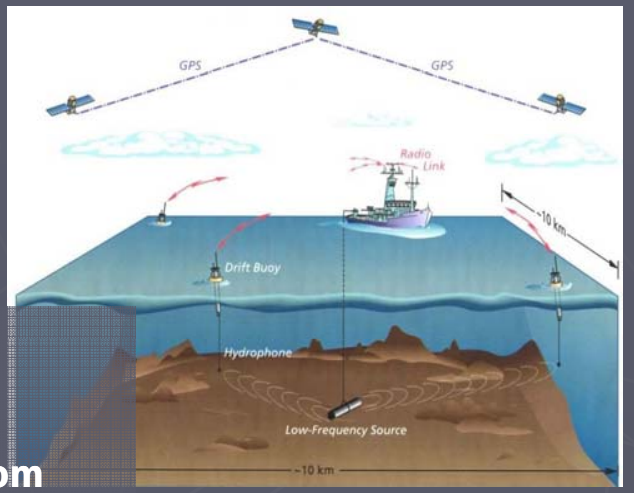
NURC

PARTNERING FOR MARITIME INNOVATION

6.2/6.4 Rapid Transition Process

Geoacoustic Inversion in Shallow Water Using Through-the-Sensor Signals

PI: K.M. Becker (ARL/PSU)
Co-Pi: G.V. Frisk (FAU)

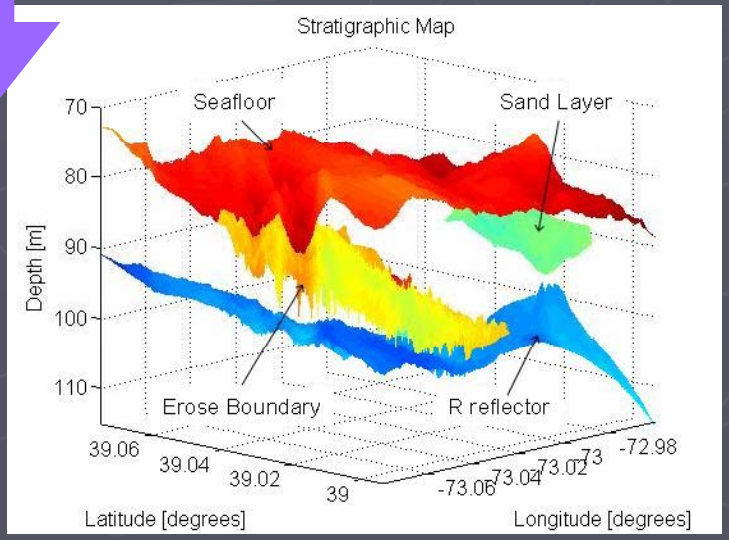


Technical Objectives

-Transition Modal Mapping Experiment (MOMAX) geoacoustic inversion methodology to operational use

- Demonstrate that inversion results from post-processed operational data can be incorporated into ocean bottom databases

3D sediment sound speed model determined by extrapolating previous results from MOMAX based algorithms



Overview

Background: Differences between modal wave numbers/travel times used as input to linear geoacoustic inversion algorithm.

Desired: Range-dependent characterization of sediment geoacoustic properties.

Required: Initial background model for waveguide.

Objective: Examine impact of spatiotemporal variability of water column on measurements and inversion for prediction

Method: Consider inversion of data collected along repeated source/receiver track