SCAE16
Seabed geoacoustic characterization measurement proposal

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Measurement objectives

1. Dispersion in fine-grained sediment: how does in-situ mud sound speed and attenuation vary with frequency?
2. What scattering mechanism(s) are important: interface(s), volume?
3. What effect does range-dependent (RD) mud layer structure have on propagation / reverberation?, consider not only RD layer thickness, but also RD sound speed, density and attenuation within a layer unit.
4. What are acoustic implications of layering structure and gradients within the mud layer for propagation?

Measurement challenges

sediment dispersion

Challenge 1: Numerous frequency-dependent mechanisms must be separated to obtain unbiased sound speed and attenuation dispersion

Non-sediment related biases:

1. Sea surface forward scattering, roughness/bubbles
2. effects of space/time-dependent ocean dynamics, e.g., internal waves
3. effects of biologics

Sediment related biases:

4. Sound speed and attenuation gradients (smoothly changing from e.g., overburden pressure)
5. Discrete layers, these must be resolved down to approx $\lambda/8$
6. Scattering from layer interface roughness
7. Scattering from sediment volume inhomogeneities
8. Effects of shear waves and associated gradients, esp shear speed
9. Seabed range-dependence

Measurement challenges

sediment dispersion

Challenge 2: attenuation in mud expected to be very small, recent shallow water measurements 0.009±0.003 dB/m/kHz (1-3.6 kHz)

Low frequencies

Low attenuation means long path lengths so that attenuation is detectable. However, long path lengths tend to create high uncertainties since many other mechanisms can come into play (sea surface, biologics, very fine-scale layering …) which may be difficult to detect or separate out or model properly.

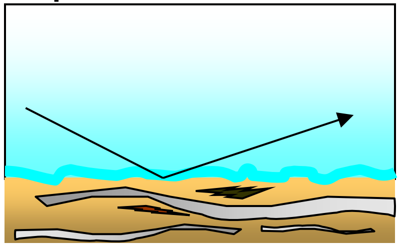
High frequencies

High frequency attenuation measurements reported by Hamilton generally biased by scattering from granular component (Bowles, JASA, 1997) even when granular component is minor.

Experimental Approach

I. Single-interaction reflection, scattering to separate/quantify mechanisms

II. Long-range measurements (TL,RL) to address effects of range-dep



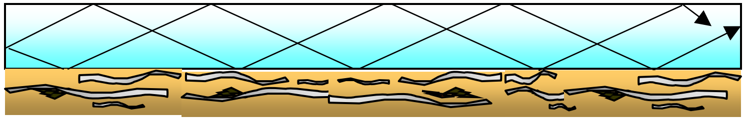
I. single-interaction measurements

a. Substantially reduces or eliminates non-sediment-related biases

- Sea surface, ocean dynamics, biologics play minor/non-existent role wrt geoacoustic uncertainties

b. Can resolve/ separate various sediment-related mechanisms, via

- High vertical resolution (~0.03 m) which permits quantifying role of layering, gradients
- Wide angular coverage, permits quantifying angular dependent phenomena, e.g., scattering mech.
- High lateral resolution (~10 m scale), permits separation of range-dependent effects
- Scattering measurements can isolate role of interface vs volume scatter



II. long-range measurements

Long-range propagation and reverberation measurements

- Address impact of vertical structure (layers, gradients) and range dep, structure on TL,RL, clutter
- Under certain conditions (mud over sand) long path lengths yield low uncertainties for estimating attenuation (Holland, Dosso, JASA, 2013)

Proposed Experiments

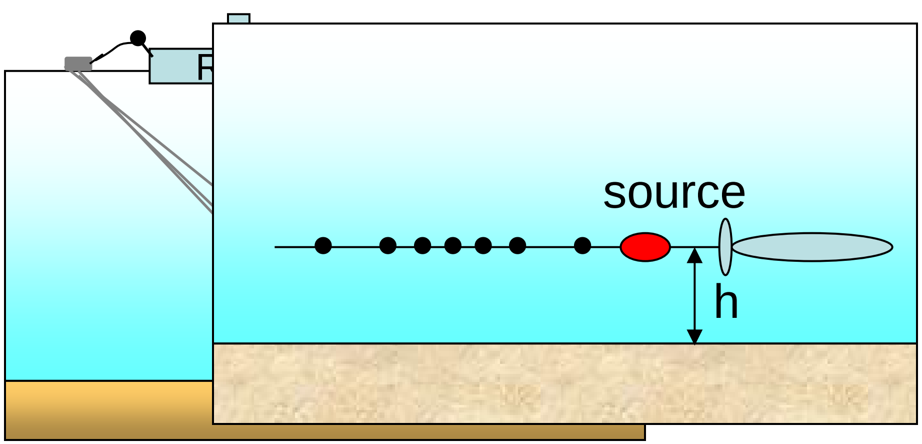
I. Single Interaction

Reflection R(θ,f,***r***) and scattering S(θ_i,θ_o,ϕ,f,***r***) – *direct path*

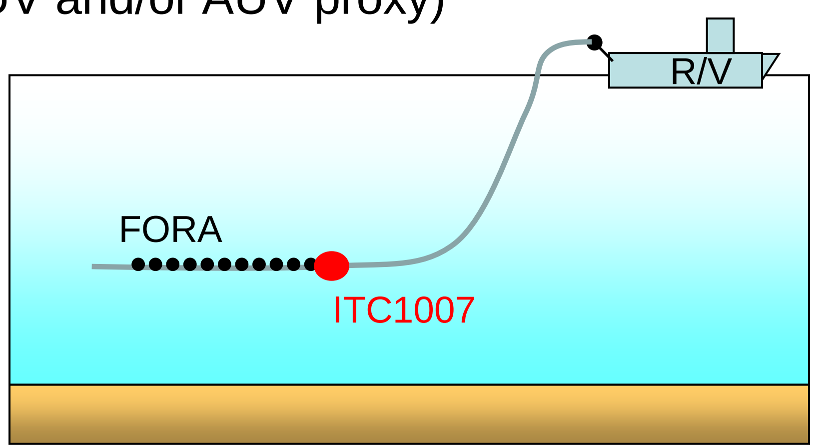
1. FIXED: R(5–90º,0.1–10 kHz), yields $c_p(z,f)$, $c_s(z,f)$, $\alpha(z,f)$, $\rho(z)$ explicitly including layers, gradients, information to ~40 m sub-bottom, depth resolution ~0.03 m, lateral resolution ~100 m

2. MOVING: R([24º–60º], 1–10 kHz, ***r***), S(10–50º, 110–175º, 1–10 kHz, ***r***) yields joint estimates of $c(z,f,r)$, $\alpha(z,f,r)$, $\rho(z,r)$ and $w_2(r;z_1,z_2)$, $\gamma_2(r;z_1,z_2)$, $L_2(r;z_1,z_2)$ and/or $w_3(r;z_1,z_2)$, $\gamma_3(r;z_1,z_2)$, $L_3(r;z_1,z_2)$, lateral res ~10m

FIXED



MOVING: (AUV and/or AUV proxy)



FORA

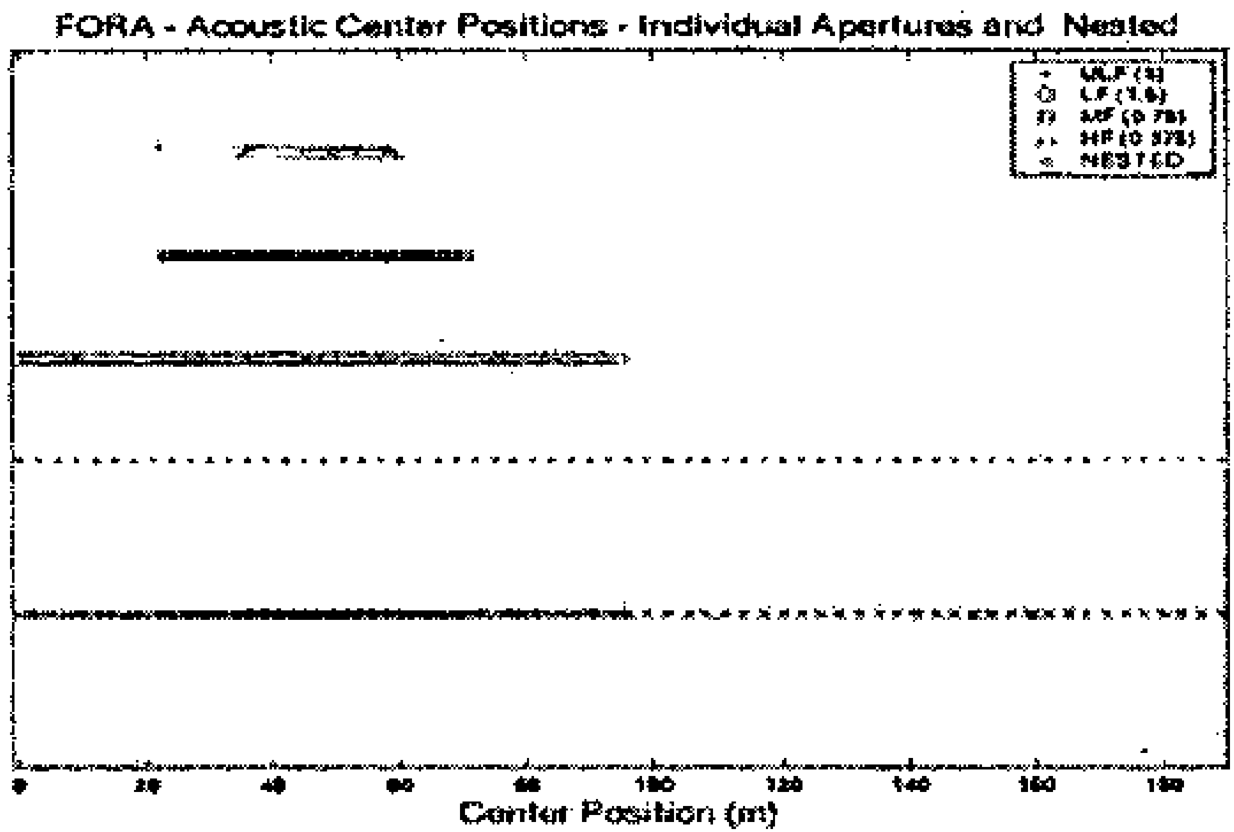
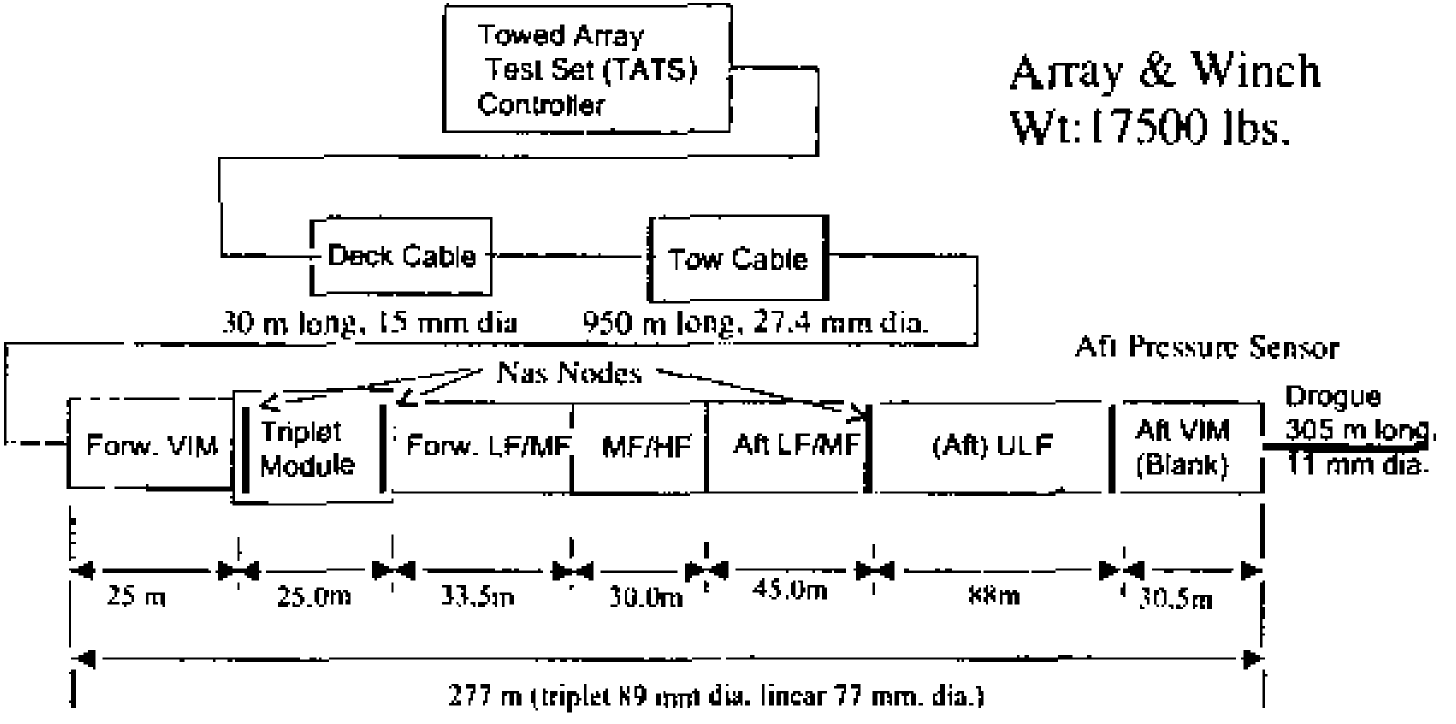


Fig. 2. FORA acoustic aperture layout showing both individual apertures and nested configuration relative to the first ULF hydrophone.

FORA

FORA System Module Layout*

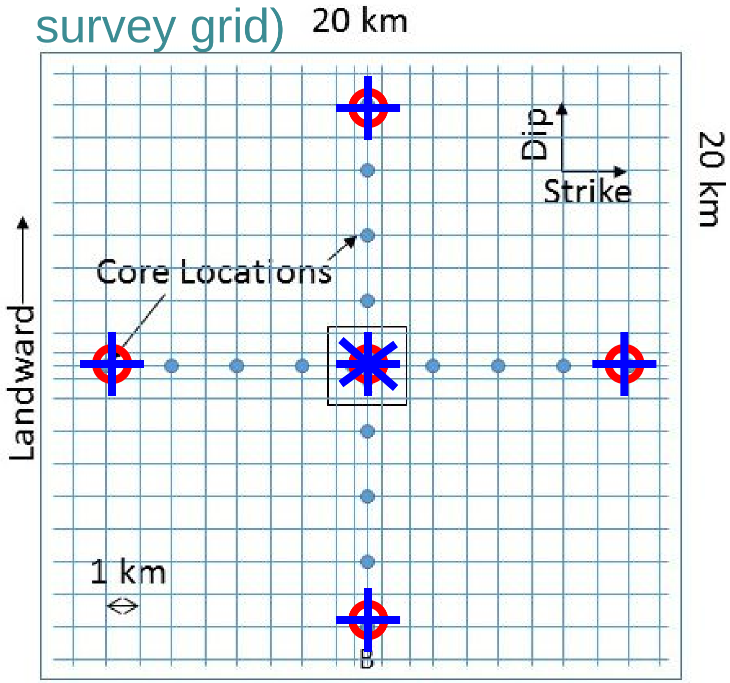


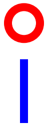
*not the same as acoustic apertures

Experiment Design

FIXED reflection mooring sites

Goff chirp survey grid)



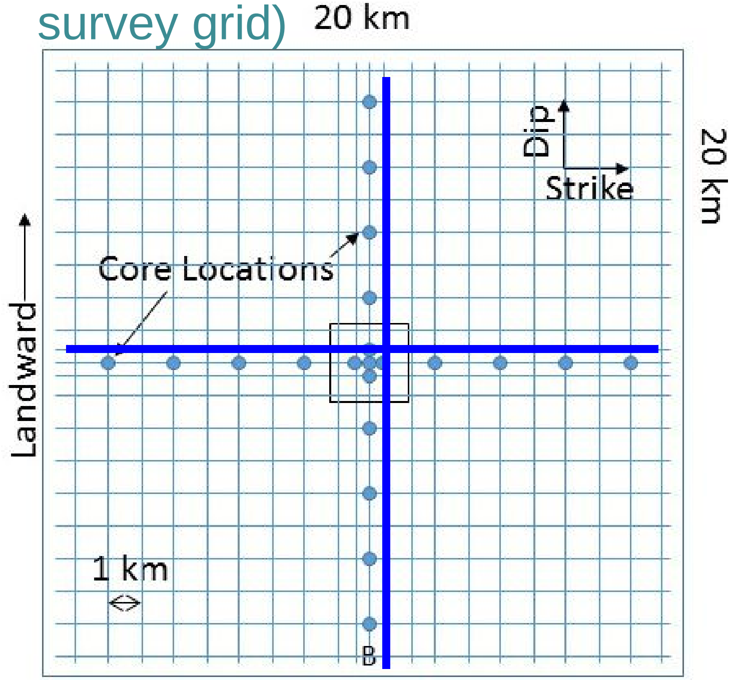


- Reflection measurements require 4-5 hours per site (incl. deployment/ recovery)
- 2 sites will be repeated in order to examine one aspect of measurement uncertainty.

Experiment Design

MOVING: reflection and scattering (FOR A and/or AUV)

Goff chirp survey grid)



Source/rec tow track, @ 4 knots
low source level for scattering
(slightly offset to see cores)

- measurements require ~11 hours (incl. deployment/recovery, ~3.5 hours)
- 1 line will be repeated in opposite direction order to examine one aspect of measurement uncertainty, 6 hours

Uncertainties

Evidence

Research Group	Prior Information	Model Selection	Data misfit	Parameter Estimation	Uncertainty estimation
Dettmer/ Dosso/ Holland	1) Several physics theories under consideration, including fluid, visco-elastic and poro-elastic layers 2) Physical parameter upper and lower bounds 3) Empirical parameter inter-relationships based on Hamilton's compilations	1) Evidence computation to determine physics model best supported by data 2) Trans-dimensional inversion for environmental parameterization (e.g., sample over number of layers)	1) Likelihood function based on estimated data error statistics and/or sampling over variance/covariance	1) Maximum a posteriori model from trans-dimensional PPD sampling (see uncertainty estimation)	1) Bayesian uncertainty analysis 2) Trans-dimensional PPD sampling (Markov-chain Monte Carlo, importance sampling, and sequential Monte Carlo) 3) Hierarchical data error models

Model Parameterization

Parameter	Reflection	Scattering
Layering and c and ρ gradients	yes	Yes (jointly with reflection)
Attenuation gradients	yes	Yes (jointly with reflection)
Sediment interface scattering	no	Yes (jointly with reflection)
Sediment volume scattering	no	Yes (jointly with reflection)
range-dependence	resolve 100m laterally for Uniboom; 1-10 m for moving source-receiv.	resolve 5-10 m scale range-dependence for moving source moving receiver
Shear	Yes, but possibly low sensitivity, *best from OBS data*	no
Sediment models	fluid, Biot, EDFM, GS, **VGS**	fluid, solid
water-air roughness	not applicable	Not applicable

Proposed Experiments

II. Long-range measurements

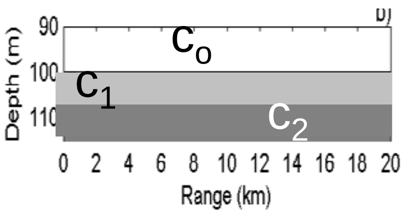
Transmission Loss TL(r,f) and reverberation RL(t,f), $0.1<f<10$ kHz
Likely in collaboration with other PIs

Sources: ITC-1007, lightbulbs

Receivers: self-recording hydrophone string (other labs VLA)

Analysis goals:

1. Understand impact of mechanisms (identified from direct path measurements) and range-dependencies on long-range measurements
2. Estimate depth integrated attenuation in mud-layer(s) via theory
3. Verify scattering mechanism (from direct path measurements)
4. Determine if clutter events arise from slow range-dependence of mud layer (as predicted in Holland, Ellis JASA, 2013)



fluid layer RI

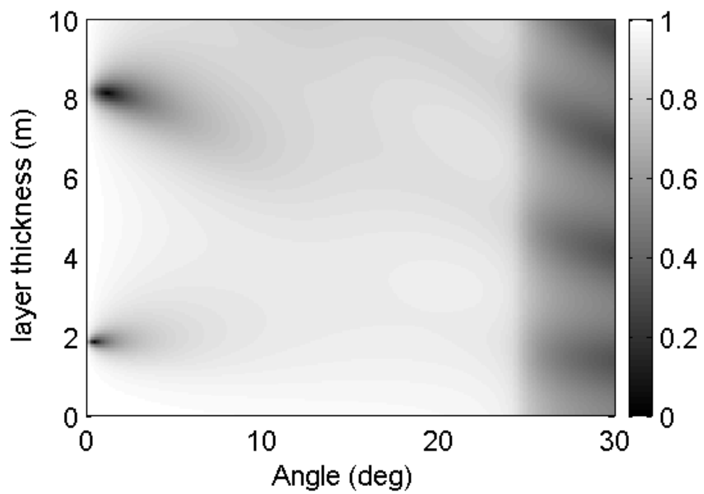
c2>co>c1; silty clay over sand

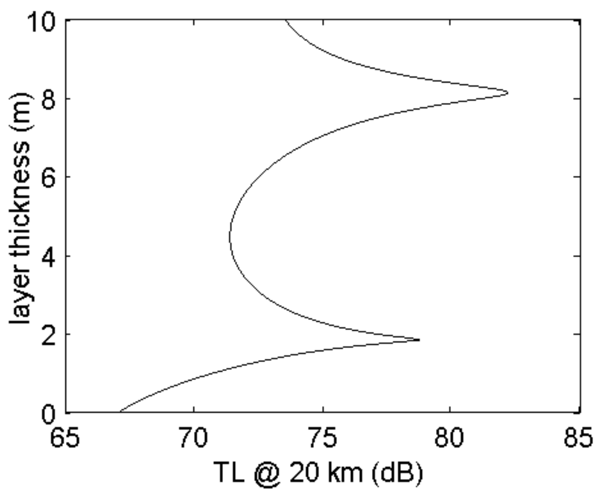
	Sound Speed m/s	Density g/cm^3	Attenuation dB/m-kHz
water c_o	1512	1	0
silty-clay c_1	1470	1.4	0.05
sand c_2	1660	1.8	0.1

$$R = \frac{R_{01} + R_{12} e^{i2k_{1z}d}}{1 + R_{12} R_{01} e^{i2k_{1z}d}}$$

$$k^{(n)} d \sim \frac{\pi(2n+1)}{2\cos^{-1}(c_1/c_0)} - \frac{2\rho_2}{\rho_1 \cos^{-1}(c_1/c_2)};\ n = 0,1,2\ldots$$

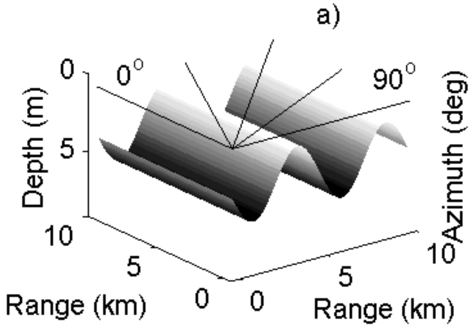
500 Hz





Hastrup, first studied the null in R and postulated that they might lead to nulls in propagation. Rubano first observation in data.

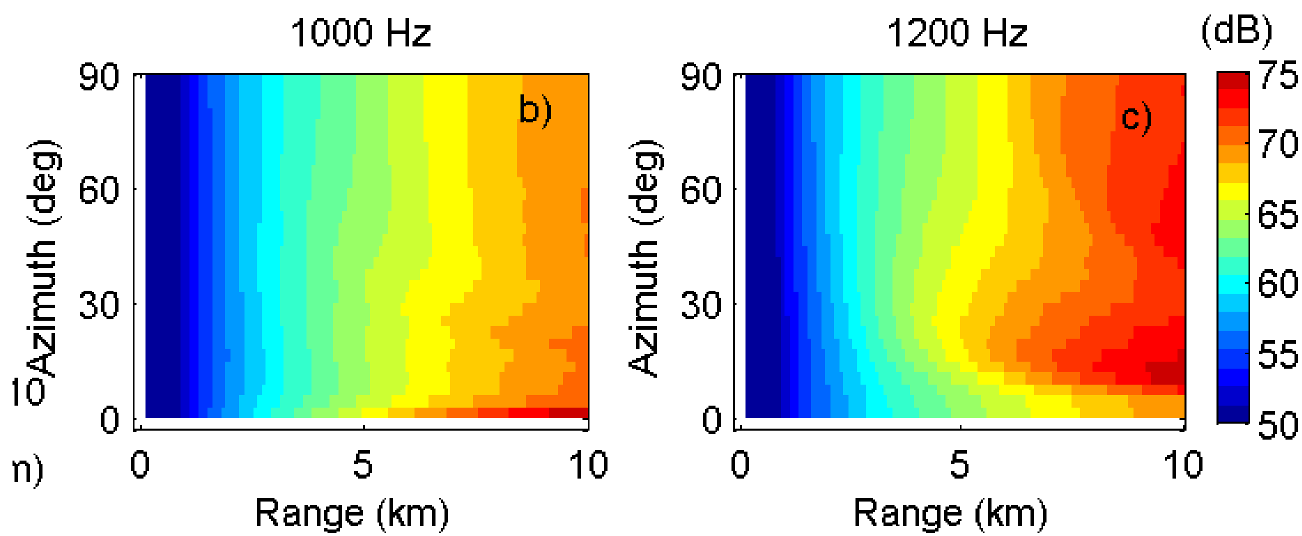
What will happen if *d* depends on range?? Do nulls wash out or no?



fluid sinusoidal layer

c2>co>c1; silty clay over sand

impact on propagation (Nx2D) of sinusoidal variations
Peak-to-peak variation 2m to 6m sub-bottom.



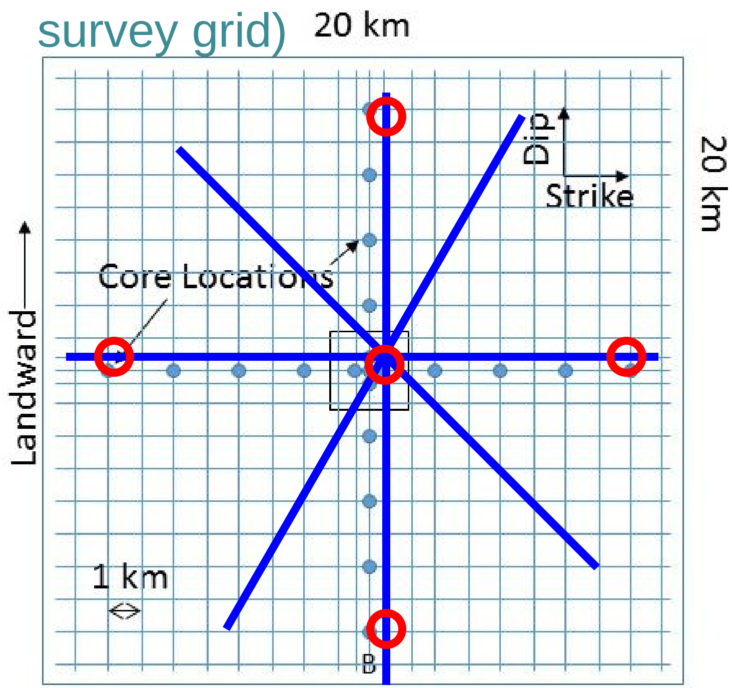
The richness of propagation in range, azimuth and frequency can be understood, by appeal to simple ‘principles’:

- Lossy seds (e.g., R nulls) tend to control RD propagation
- RD prop is independent of number of variability periods

Experiment Design

Long-range TL and RL

Goff chirp
survey grid)



Hyd/VLA moorings

Source tow track @ 4 knots
Higher source level for TL and reverb
(slightly offset to see cores)

- measurements require ~16 hours (incl. deployment/recovery)
- 1 main line will be repeated in opposite direction order to examine one aspect of measurement uncertainty (requires an additional 4 hours not incl. deployment/recovery)

Requested seabed ‘direct’ measurements

Gravity and piston cores

- porosity/density
- compressional speed 50, 100, 200, 400 kHz
- compressional attenuation 50, 100, 200, 400 kHz
- shear wave speed and attenuation
- grain size analysis vs depth in core, including any large shell or rock fragments
- Permeability and tortuosity, would also be very useful.

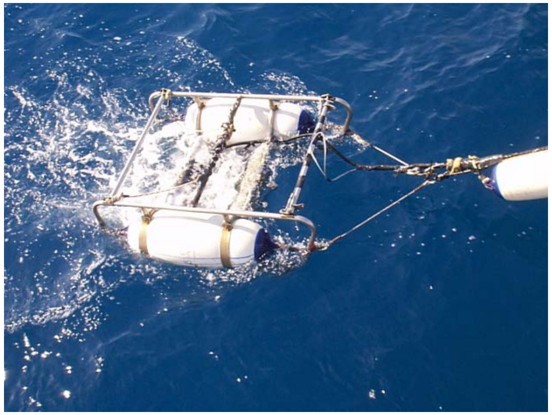
Box cores to measure sediment volume heterogeneity

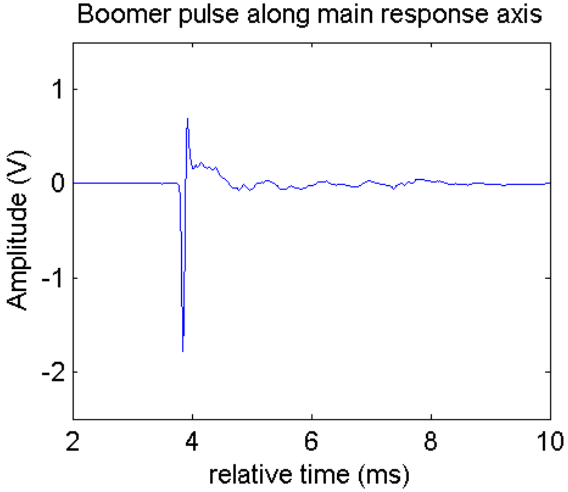
Sediment interface roughness

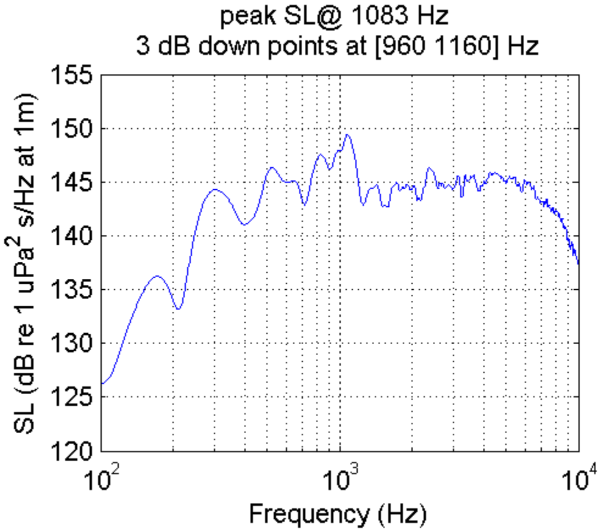
Extras

Equipment

Boomer







Relevant Theories

Sediment Acoustics

- Biot theory* and variants*, EDFM* (Williams), VGS* (Buckingham)
- New theories of wave propagation mud (Pierce, …)

Other

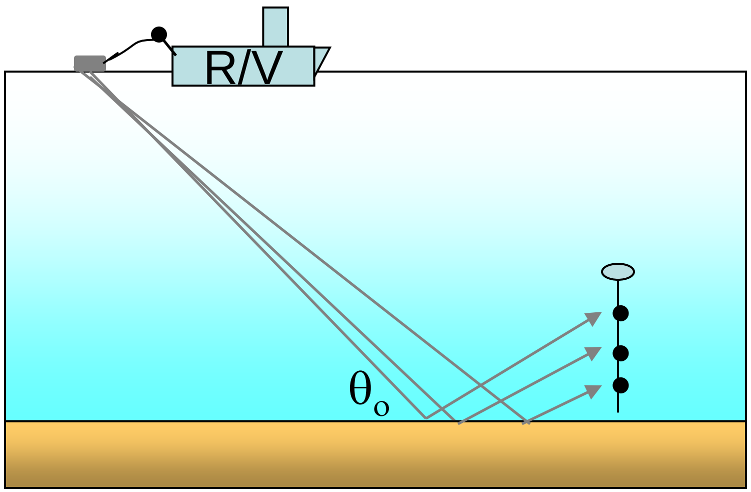
- Reflection from plane-layered media and plane-layered with roughness (based on Sommerfeld integral)
- Scattering from arbitrary layered media, using perturbation theory, small slope approx, and Kirchhoff approx. (Jackson, Ivakin, Thorsos,…)
- General time domain finite-difference models to treat arbitrary (realization-based) sediment structures

*NB: theories developed for sandy fabrics, not cohesive (clays, muds)

Proposed Experiments

Reflection R(θ,f)

1. R(5-90º,0.5-15 kHz), yields *c(z,f), α(z,f), ρ(z)* explicitly including layers, gradients, information to ~60 m sub-bottom, depth resolution ~0.03 m, lateral resolution ~100 m



Locations

- 5 key sites in experiment area

Requirements:

- Quiet R/V (low source level)
- Low sea state (boomer is surface towed)

Source deployed from catamaran ~10 m behind ship

- Uniboom, 0.5-15 kHz pulse

Receiver (●) Bottom moored with acoustic release

- 3-4 self-recording hydrophones

Science questions

1. How does mud sound speed and attenuation vary with frequency and how can that be measured? (i.e., disentangled from other frequency dependent mechanisms)
2. What effect does range-dependent (RD) layer structure have on propagation / reverberation?, consider not only RD layer thickness, but also RD sound speed, density and attenuation within a layer unit
3. What scattering mechanism(s) are important: interface(s), volume?
4. Is clutter observable from slowly varying RD mud layer as predicted by models?
5. To what extent can propagation and reverberation measurements be used to disentangle frequency dependent mechanisms?
6. What are acoustic implications of layering structure and gradients within the mud layer?

Proposed Experiments

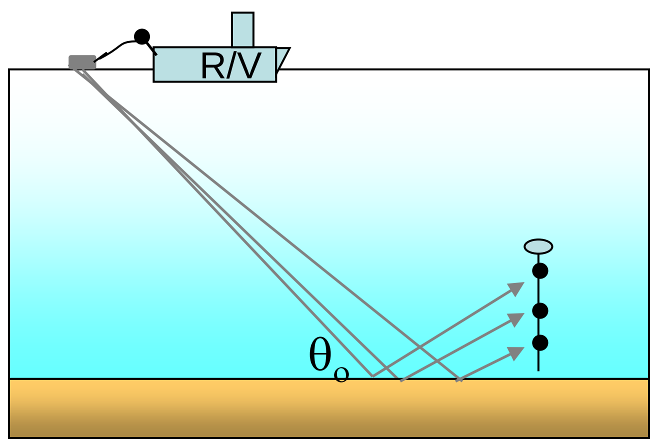
I. Single Interaction

Reflection R(θ,f,***r***) and scattering S(θ_i,θ_o,ϕ,f,***r***) – *direct path*

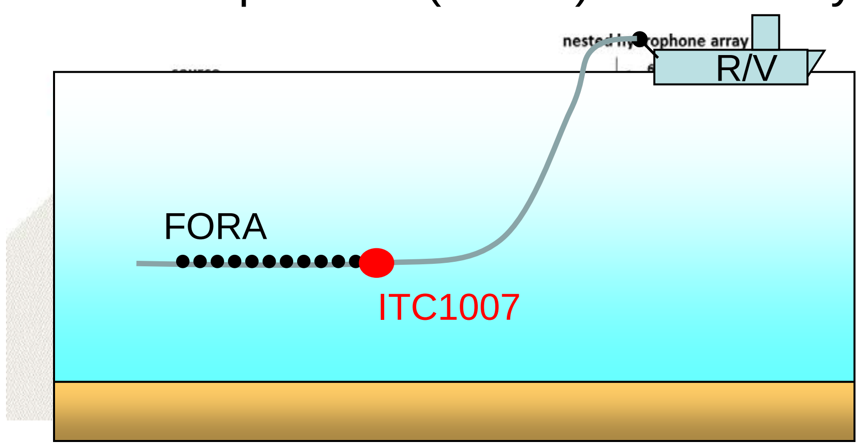
1. UniBoom R(5–90º,0.1–10 kHz), yields $c_p(z,f)$, $c_s(z,f)$, $\alpha(z,f)$, $\rho(z)$ explicitly including layers, gradients, information to ~60 m sub-bottom, depth resolution ~0.03 m, lateral resolution ~100 m

2. AUV R(25–50º,0.8–4 kHz, ***r***), S(5–30º, 90–170º, 0.8–4 kHz, ***r***)
   FORA R([24–29º 45–60º], 1–10 kHz, ***r***), S(10–50º, 110–175º, 1–10 kHz, ***r***)
   yields joint estimates of $c(z,f,r)$, $\alpha(z,f,r)$, $\rho(z,r)$ and w_2(r), γ_2(r), L_2(r) and/or w_3(r), γ_3(r), L_3(r) .

Uniboom with single or multi phone rcvr



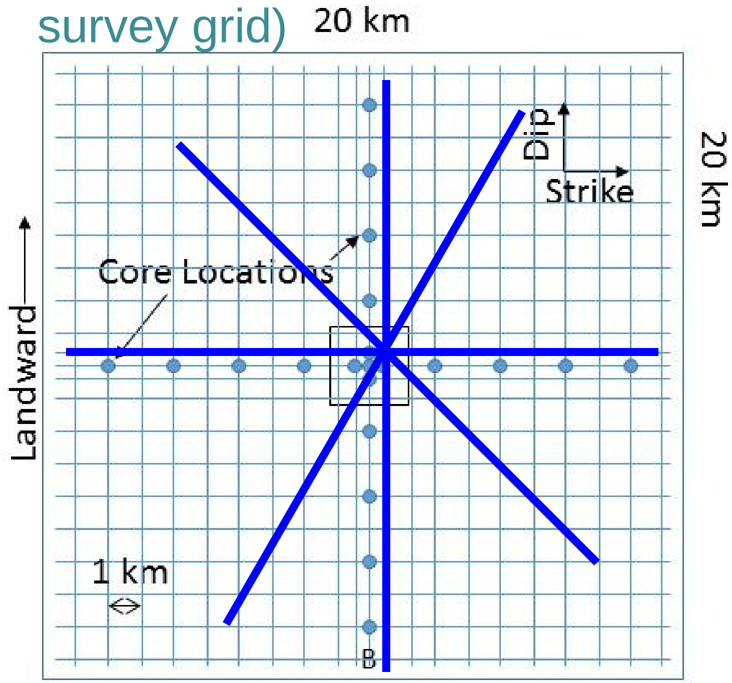
AUV or ship-based (FORA) towed array



Experiment Design

MOVING: reflection and scattering (FORA)

Goff chirp survey grid)



- Source/rec tow track, @ 4 knots low source level for scattering (slightly offset to see cores)

- measurements require ~16 hours (incl. deployment/recovery, ~3.5 hours)
- 2 lines will be repeated in opposite direction order to examine one aspect of measurement uncertainty (requires an additional 5.5 hours incl. another deployment/recovery)

Design connected with TL and RL experiment