SCAE16
Seabed geoacoustic characterization measurement proposal

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Collaboration w/ John Preston, Chad Smith, ARL-PSU and Jan Dettmer (U. Vic), Stan Dosso (U. Vic), Samuel Pinson (U. Florianopolis) and others

Science challenges

Objective: measure sediment (sound speed, attenuation) dispersion

Challenge 1: Numerous frequency-dependent mechanisms must be separated to obtain unbiased sediment complex sound speed

Non-sediment related biases:

1. Sea surface forward scattering, roughness/bubbles
2. effects of range-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

Science challenges

Objective: measure sediment (sound speed, attenuation) 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 attenuation suggests that path lengths that are LONG so that attenuation is easily detectable at low frequencies.

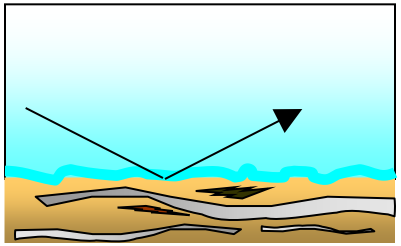
However, long path lengths tend to create high uncertainties since many other mechanisms can come into play (sea surface, biologics, very fine-scale layering …) which may be difficult to detect or separate out or even model properly.

High frequency attenuation measurements 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) for validation



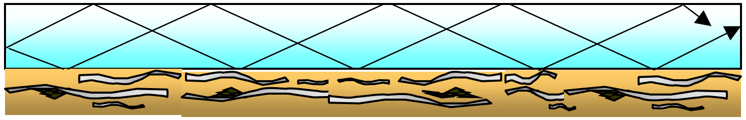
I. single-interaction measurements

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

- provide basis for validating role of sediment dispersion (and other mechanisms)
- Under certain conditions (mud over sand) long path lengths yield low uncertainties for estimating attenuation (Holland, Dosso, JASA, 2013)

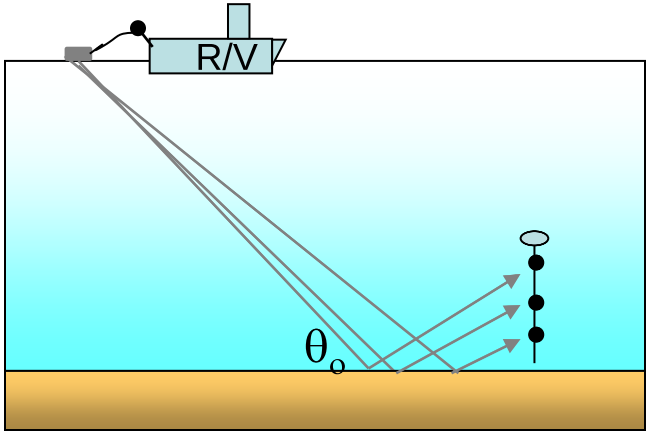
Planned Experiments

IA. Single Interaction, Fixed receiver

Reflection coefficient R(θ,f,***r***) – *direct path*

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

Source: Uniboom (0.20 m plate radius)
Receiver: bottom moored hyd string

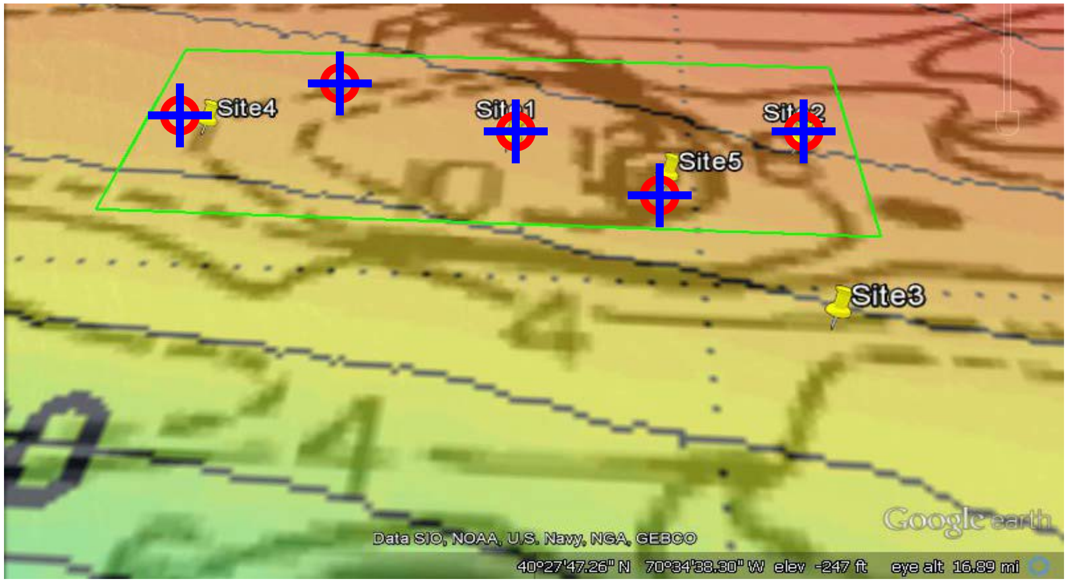


Requirements:

1. Very quiet tow vessel (low source levels, close range)
2. Low sea state (to avoid destruction of boomer plate)

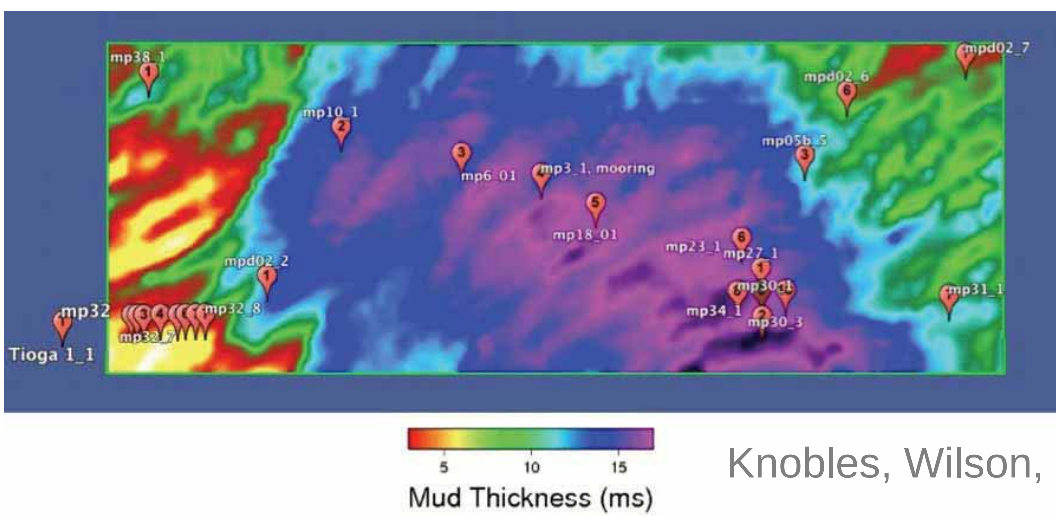
Proposed Experiment Sites

IA. Single Interaction, fixed receiver



- hydr. mooring
- Source tow track, ±1 km @ 3 knots

Probe similar & different sed thicknesses, to determine (1D) point estimates of sed spatial variability



ship time: 4 days

Knobles, Wilson, 2016; data and analysis from J. Goff

Planned Experiments

IB. Single Interaction, Moving receiver

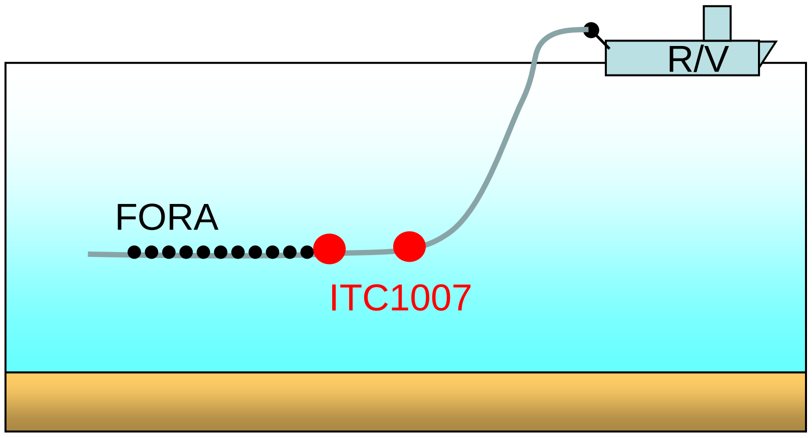
Reflection $R(\theta,f,\boldsymbol{r})$ and scattering $S(\theta_i,\theta_o,\phi,f,\boldsymbol{r})$ – *direct path*

$R(34\text{–}53/63^o, 1.5\text{–}6\ \text{kHz}^*, \boldsymbol{r})$,
$S(10\text{–}50^o, 110\text{–}175^o, 1.5\text{–}6\ \text{kHz}^*, \boldsymbol{r})$

53/63, 1 or 2 sources
* possibly only 4 kHz

yields joint estimates of $c(z,f,r)$, $\alpha(z,f,r)$, $\rho(z,r)$ and $w_2(r)$, $\gamma_2(r)$, $L_2(r)$ and/or $w_3(r)$, $\gamma_3(r)$, $L_3(r)$.

FORA towed array, cardioid section only

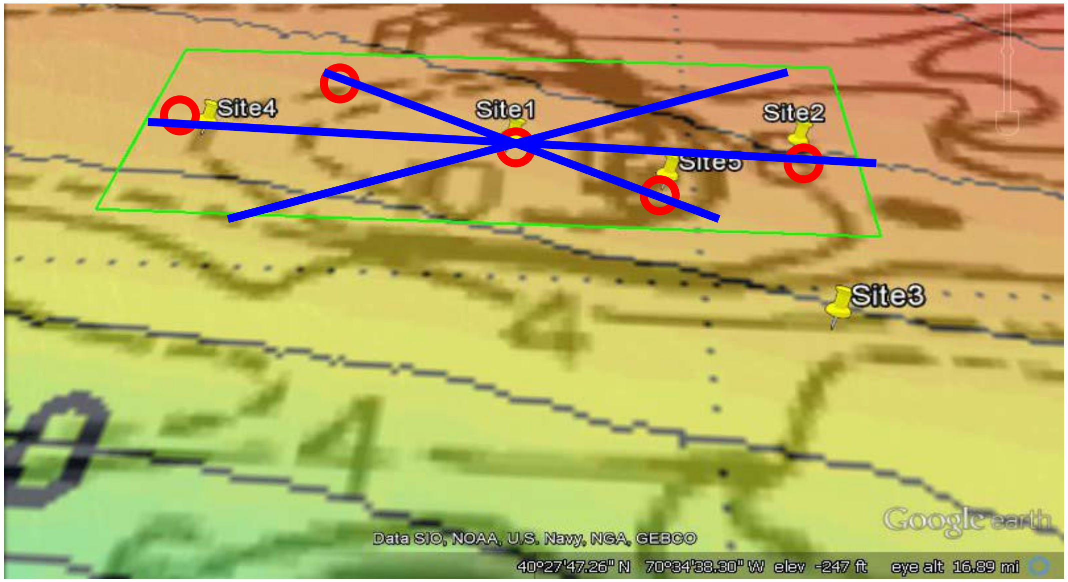


Requirements:

1. Quiet ship (low source levels, close range)
2. Low-moderate sea state (towing array close to seabed)

Proposed Experiment Sites

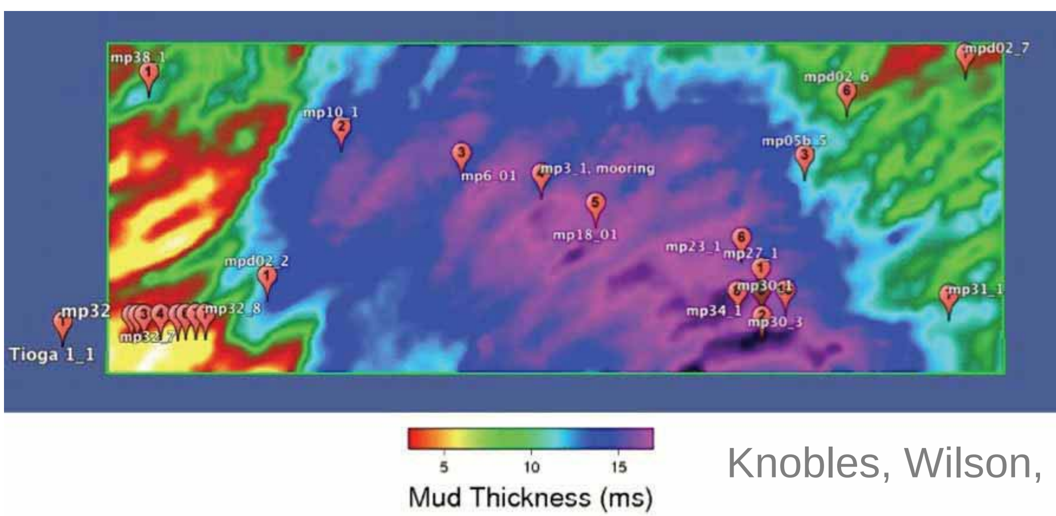
IB. Single Interaction, moving receiver



o hydr. mooring

| Source/rec tow track @ 3.5 knots

Probe similar & different sed thicknesses, to determine **Nx2D** estimates of sed spatial variability



ship time: 4 days

Knobles, Wilson, 2016; data and analysis from J. Goff

Planned Experiments

II. Long Range Experiments (collaborative)

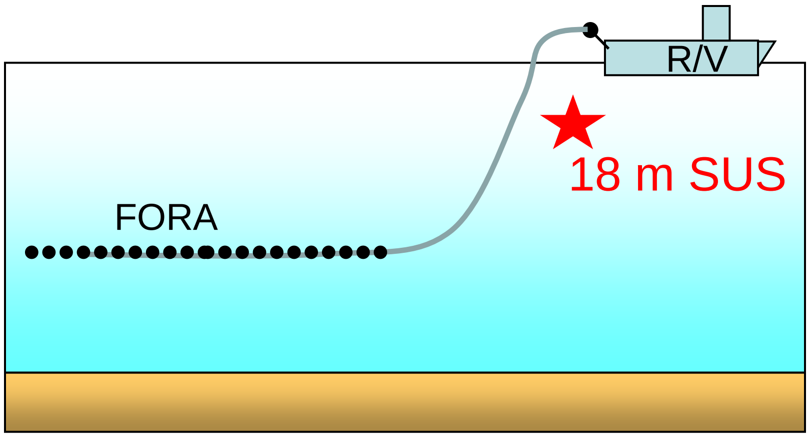
Measurements: Propagation and Reverberation

Sources: SUS

Receivers: FORA, VLAs, HLAs (from FFI, ARL-UT, WHOI, Scripps,…)

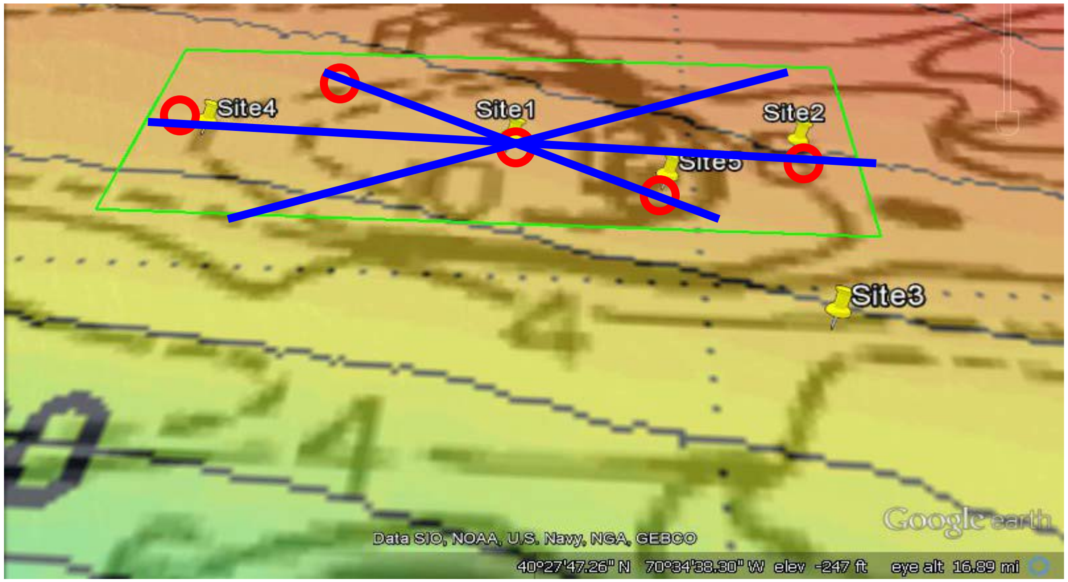
Analysis goals:

1. Understand impact of mechanisms (identified from direct path measurements) 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 and Ellis JASA, 2013)



Proposed Experiment Sites

II. Long range experiments (propagation, reverberation)

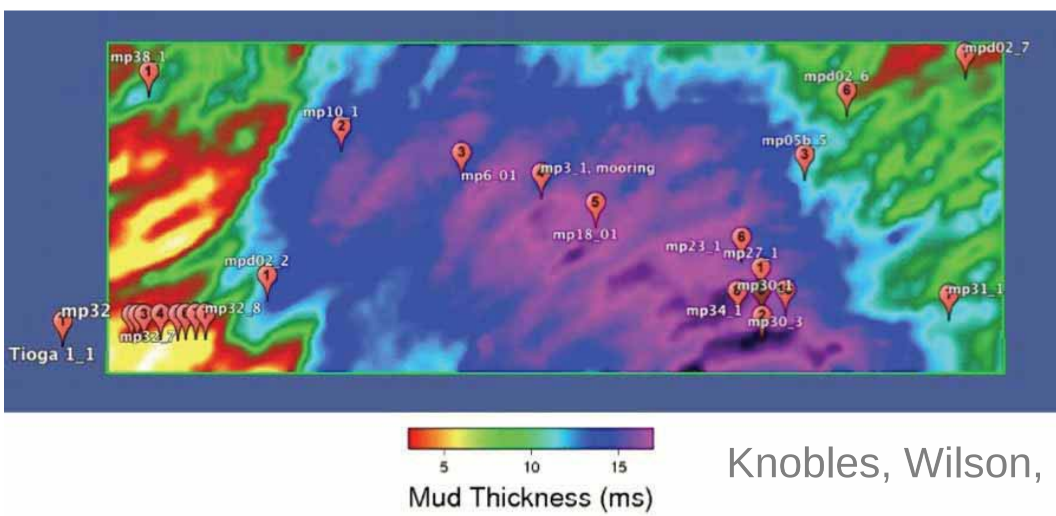


o hydr. mooring

| Source/rec tow track @ 3.5 knots

Tracks can be discussed with other researchers interests

ship time: 2 days



Knobles, Wilson, 2016; data and analysis from J. Goff

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	VGS, fluid, Biot, EDFM, GS,...	fluid, solid
water-air roughness	not applicable	Not applicable

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

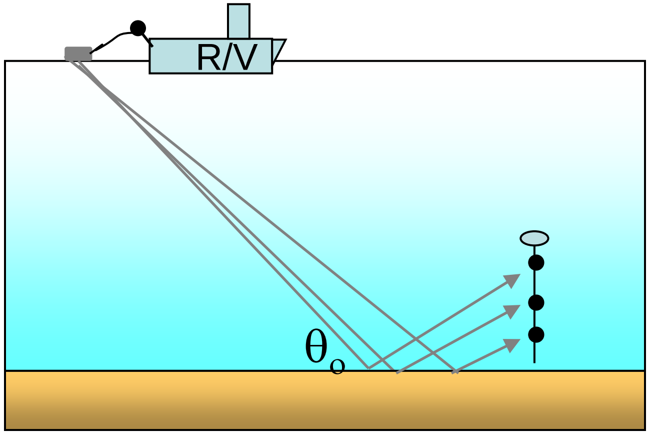
Planned Experiments
I. Single Interaction

Reflection $R(\theta, f, \boldsymbol{r})$ and scattering $S(\theta_i, \theta_o, \phi, f, \boldsymbol{r})$ – *direct path*

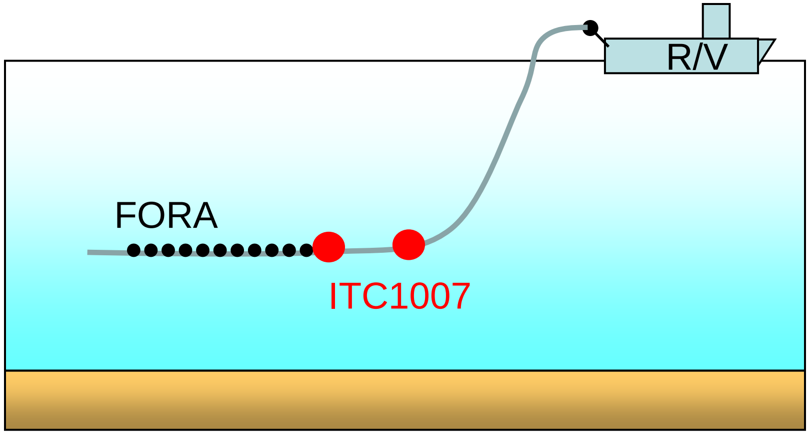
1. UniBoom R(5–90º,0.1–10 kHz), yields $c_p(z,f)$, $c_s(z,f)$, $\alpha(z,f)$, $\rho(z)$ explicitly including layers, gradients, information to ~60 m sub-bottom, depth resolution ~0.03 m, lateral resolution ~100 m

2. FORA R([45–76º], 1.5–6* kHz, ***r***), S(10–50º, 110–175º, 1–6 kHz, ***r***) yields joint estimates of $c(z,f,r)$, $\alpha(z,f,r)$, $\rho(z,r)$ and $w_2(r)$, $\gamma_2(r)$, $L_2(r)$ and/or $w_3(r)$, $\gamma_3(r)$, $L_3(r)$. (*possibly only 4 kHz)

Uniboom with single or multi phone rcvr



ship-based (FORA) towed array



Planned 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

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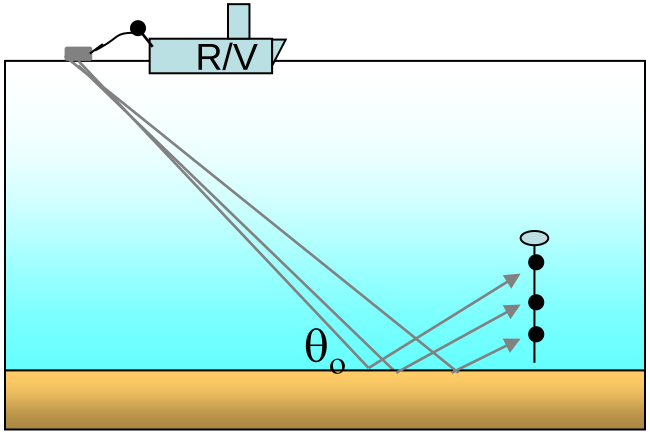

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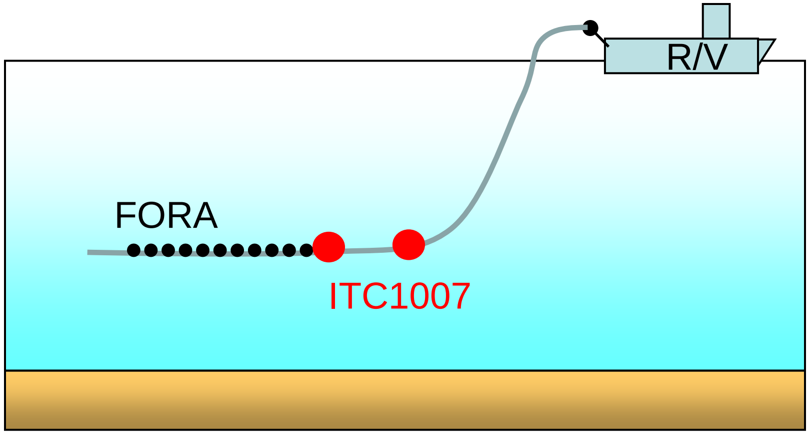
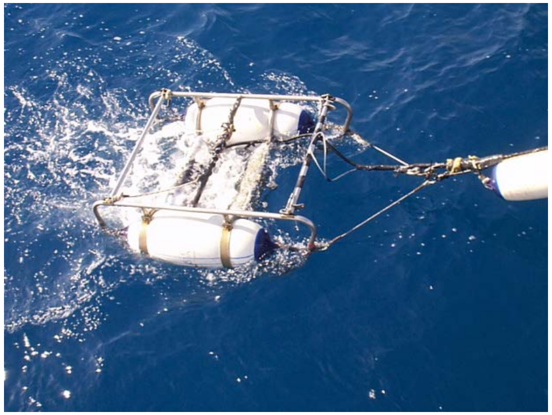
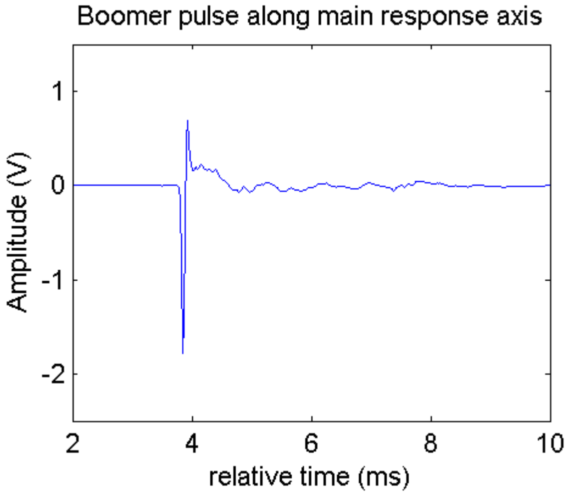
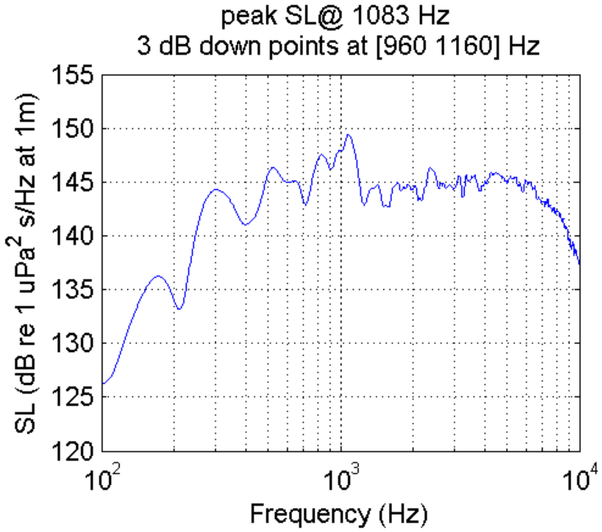


Equipment

Boomer







Relevant Theories

Sediment Acoustics

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

Other

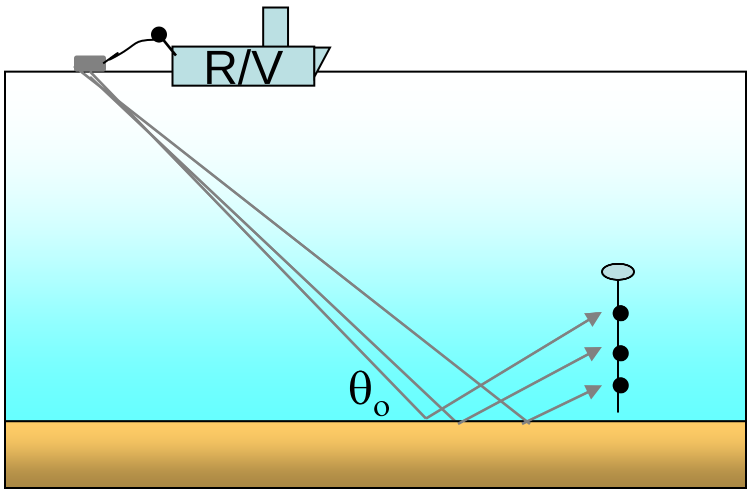
- Reflection from plane-layered media and plane-layered with roughness (based on Sommerfeld integral)
- Scattering from arbitrary layered media, using perturbation theory, small slope approx, and Kirchhoff approx. (Jackson, Ivakin, Thorsos,…)
- General time domain finite-difference models to treat arbitrary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

Proposed Experiments

I. Single Interaction

Reflection $R(\theta,f,\boldsymbol{r})$ and scattering $S(\theta_i,\theta_o,\phi,f,\boldsymbol{r})$ – *direct path*

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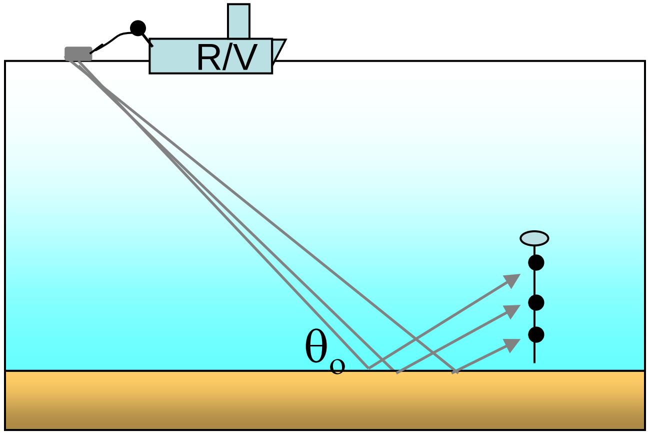
2. FORA $R([24–29^o\ 45–60^o], 1–10$ kHz$, \boldsymbol{r})$, $S(10–50^o, 110–175^o, 1–10$ kHz$, \boldsymbol{r})$ yields joint estimates of $c(z,f,r)$, $\alpha(z,f,r)$, $\rho(z,r)$ and $w_2(r)$, $\gamma_2(r)$, $L_2(r)$ and/or $w_3(r)$, $\gamma_3(r)$, $L_3(r)$.

Uniboom with single or multi phone rcvr



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