Geoacoustic tomography and high-resolution acoustic measurements during the ONR Sediment Characterization Experiment

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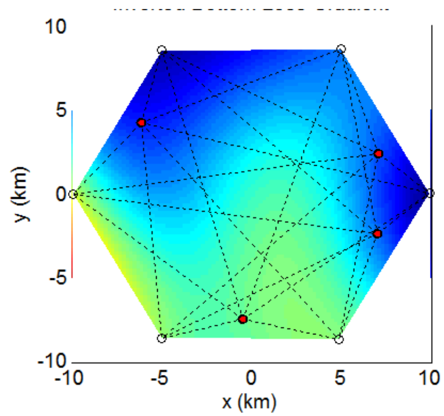
ONR SEDIMENT CHARACTERIZATION WORKSHOP



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Mandex, Arlington, VA

Outline:

Geoacoustic tomography (NRL base proposal):

•**Scientific Goal:** Effects of range/bearing-dependent seafloor on signal excess (SE)

•**Experimental Goal:** Rapid characterization of seabed within 20 km x 20 km area

•**Measurements:** Broadband TL (direct-blast) and RL measurements with distributed sources and receivers

High-resolution acoustic measurements (collaboration with C. Holland):

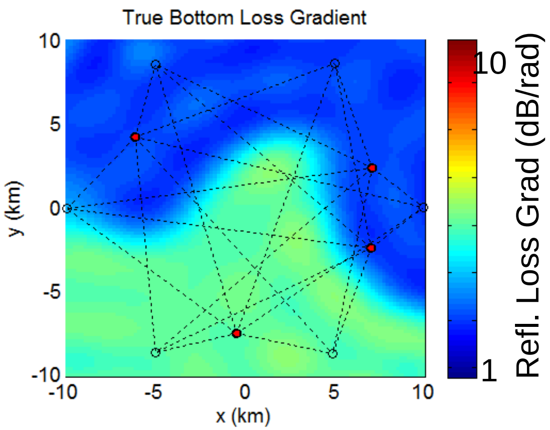
•**Scientific Goal:** Frequency dependency of sound speed and attenuation in marine sediments with arbitrary pore-size distribution

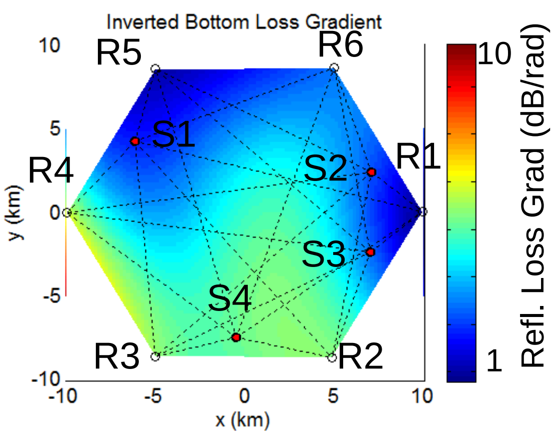
•**Experimental Goal:** Relating measured frequency-dependency of sound-speed and attenuation to pore-size distributions obtained from sediment cores

•**Measurements:** Simultaneous measurements using acoustic probes and chirp sonar. Geotechnical measurements of sediment cores.

Geoacoustic Tomography:

Example:
Bottom-Loss-Gradient Tomography:





$$\log 10[\sqrt{\tau}\, p(\tau)] = -\log 10(e)\frac{c\tau}{rH}\sum_{i}^{N} \alpha_i \Delta r$$

Underdetermined minimization problem:

$$\bar{\mathrm{m}} = \arg\min_{\mathrm{m}} \| \mathrm{Am\text{-}d} \|^2 \qquad \text{(may diverge)}$$

A: measurement matrix, m: model, d: data

l_2- norm penalty:

$$\bar{\mathrm{m}} = \arg\min_{\mathrm{m}} \| \mathrm{Am\text{-}d} \|^2 + \mu \| \mathrm{m} \|^2$$

(Tikhonov regularization)

l_1- norm penalty:

(Sparse model in wavelet basis, a few non-zero coefficient)

$\mathrm{w} = \mathrm{Wm}$ wavelet coefficients of m

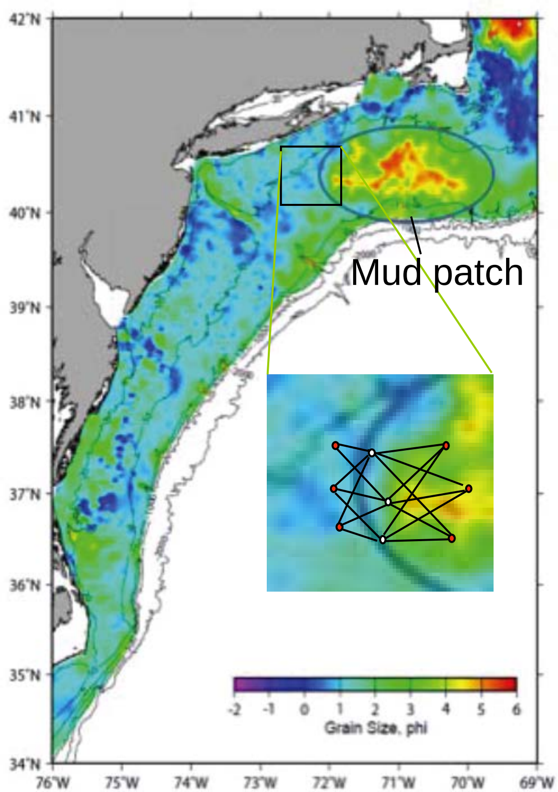
$$\bar{\mathrm{w}} = \arg\min_{\mathrm{m}} \| \mathrm{Aw\text{-}d} \|^2 + 2\mu \| \mathrm{w} \|_1, \quad (\bar{\mathrm{m}} = \mathrm{W}^{-1}\bar{\mathrm{w}})$$

W: wavelet decomposition matrix, $\mathbf{W}^{-1}$: wavelet synthesis operator

Noise-free model reconstruction (noise may not be sparse)

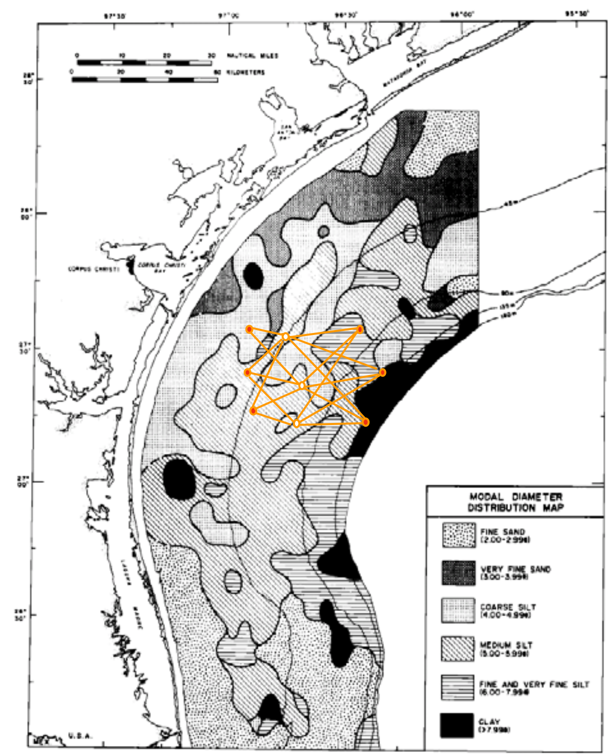
Range/Bearing-dependence of seafloor:

Mid Atlantic Bight
(Grain size distribution)



Palamara et al., in prep, (from J. Goff)

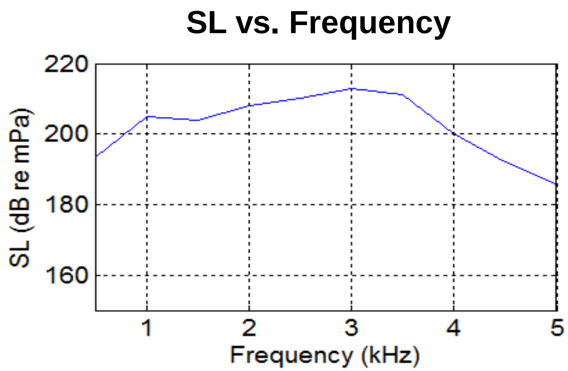
Central Texas Shelf
(Sediment type)

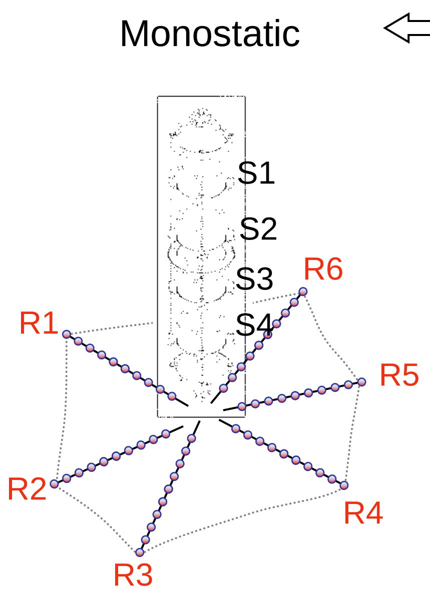


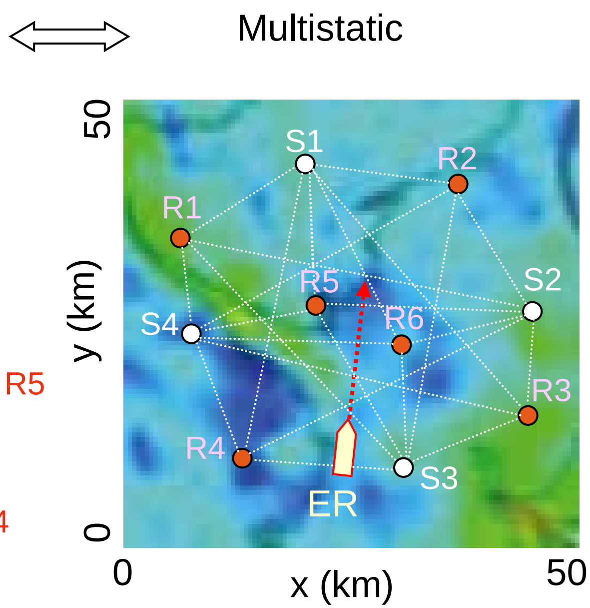
Shideler, 1978, (from J. Goff)

WIdeband DEployable Multistatic Active Sonar System (WIDE-MASS)

- 4-channel source array
- 72 channel receiver array
- Modular design for multiple configurations

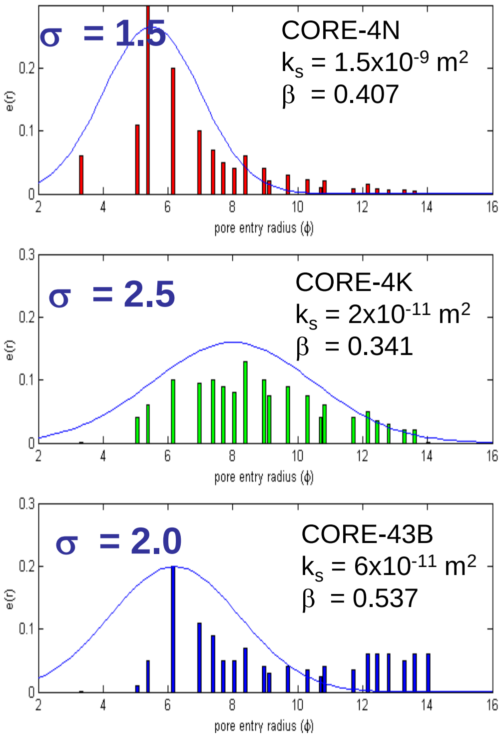






Sediment pore-size distribution

(New Jersey Shelf core samples)



Log-normal (ϕ-normal,) pore-size distribution;

$$(\phi = -\log_2 r)$$

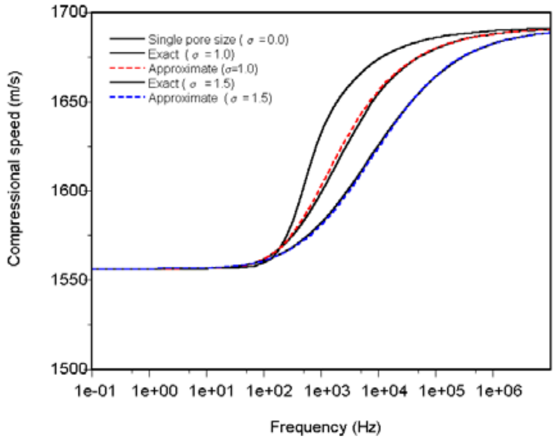
Permeability model: $k_s = \frac{\beta}{8}\int_0^\infty r^2 e(r)\,dr$

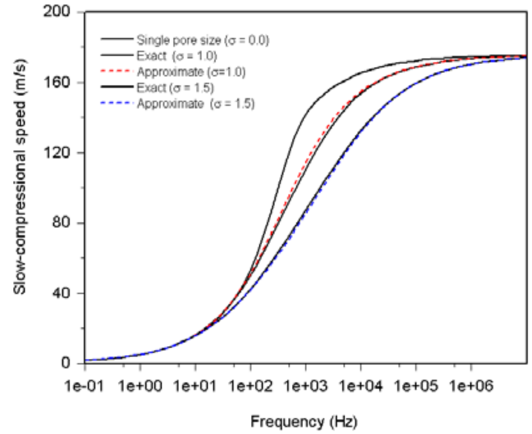
Median pore radius: $r = r_0\, e^{-p^2}$ $\quad (p = \sigma \ln 2)$

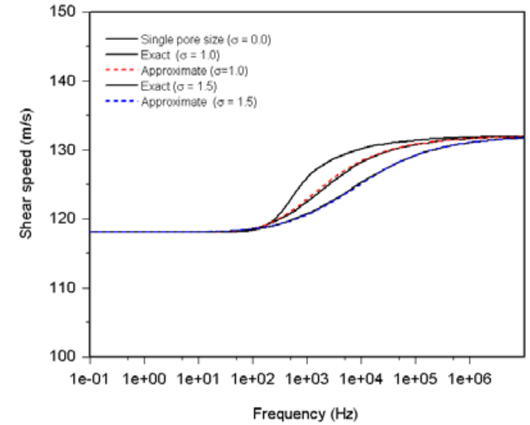
(BIOT MODEL)
Viscosity correction factor:

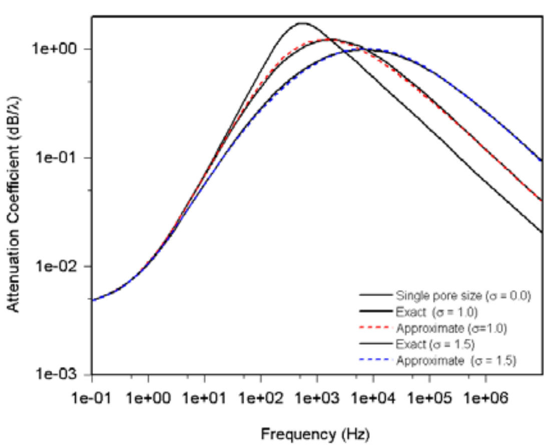
$$\tilde{F}(\kappa) = \frac{1+\frac{\kappa}{2}\left(\frac{1+i}{\sqrt{2}}\right)\left(\frac{4}{3}e^{5p^2/2} - e^{-3p^2/2}\right) + \frac{i\kappa^2}{8}\left(\frac{4}{3}e^{4p^2/2}-1\right)}{1+\frac{\kappa}{2}\left(\frac{1+i}{\sqrt{2}}\right)\left(\frac{4}{3}e^{5p^2/2}-e^{-3p^2/2}\right)}$$

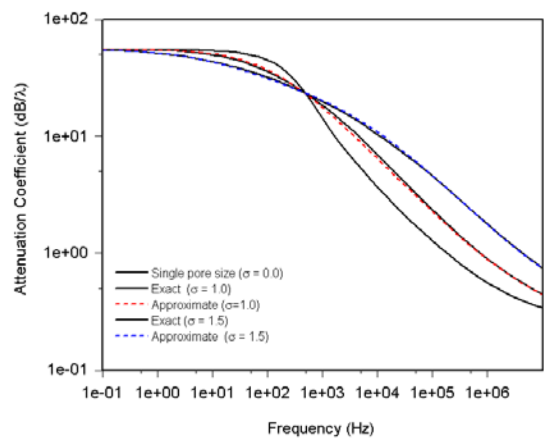
Phase velocities and attenuation coefficients (Biot model)

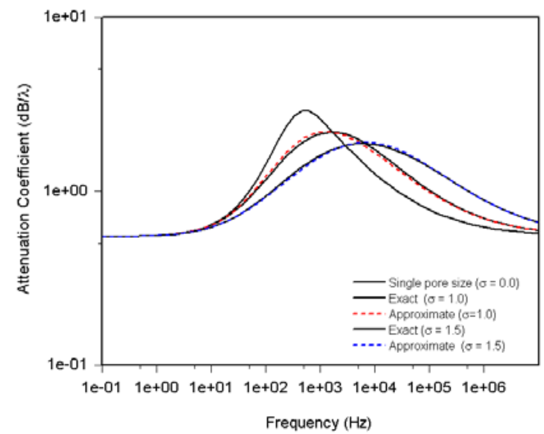




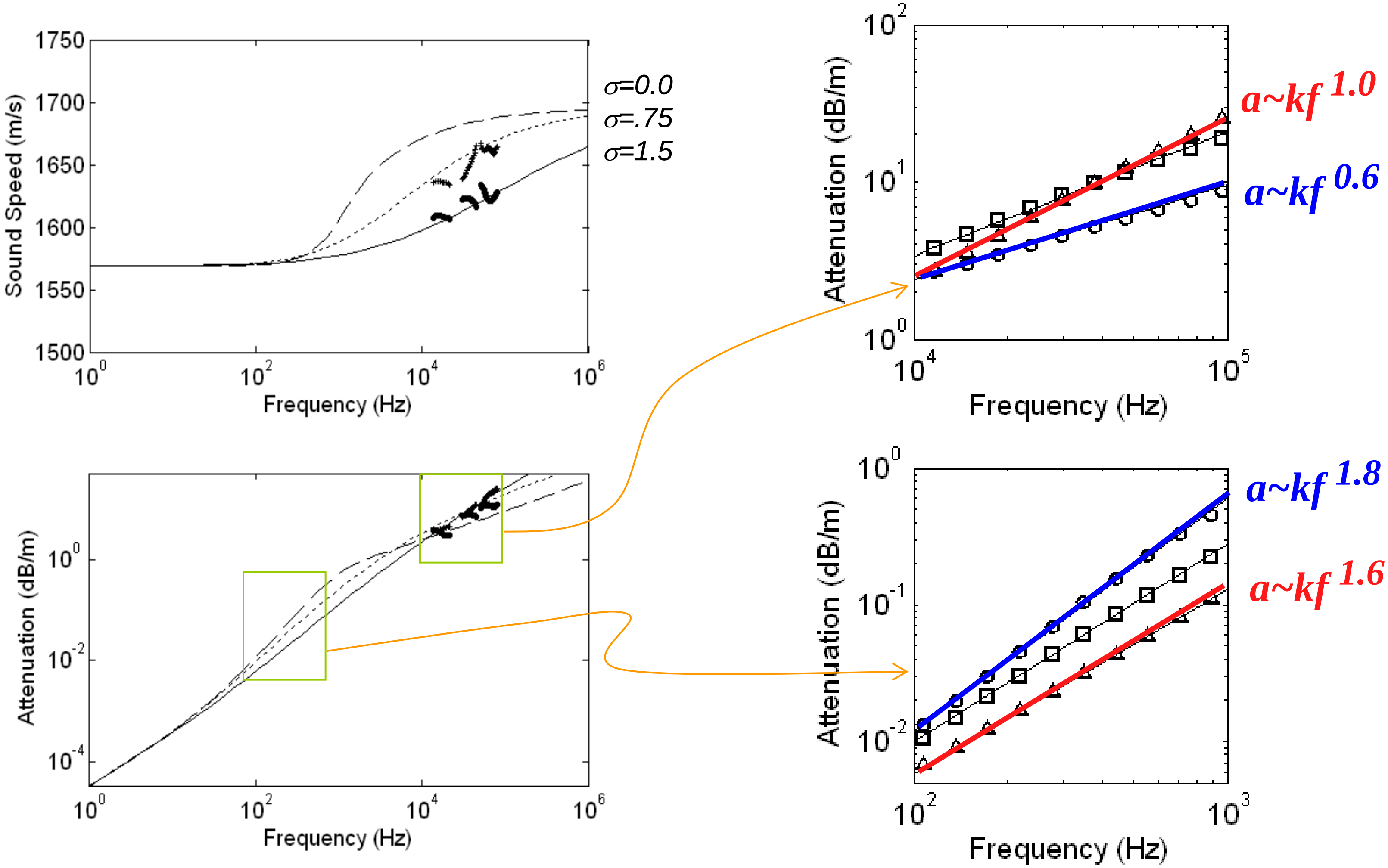






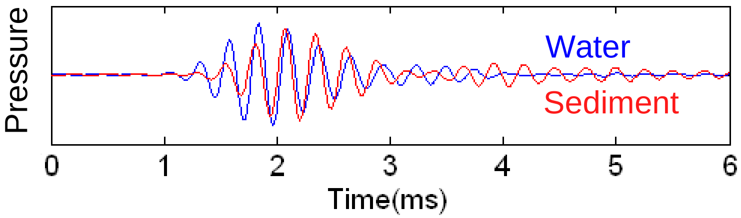


Frequency-Dependency of Attenuation and Sound-Speed Dispersion

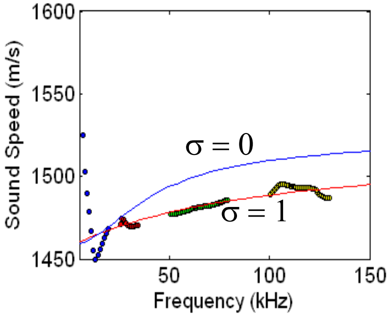


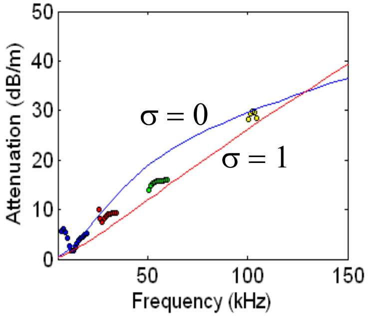
GeoProbe Measurements

NRL Deep-Sea GeoProbe System



BLUE10 Gulf of Mexico experiment



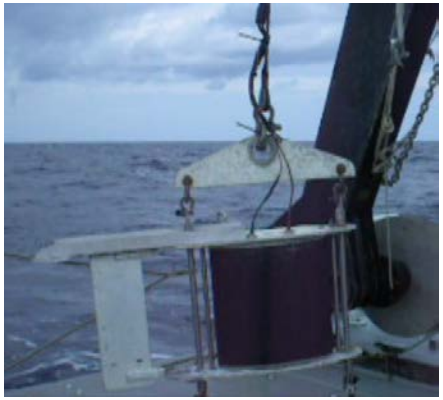


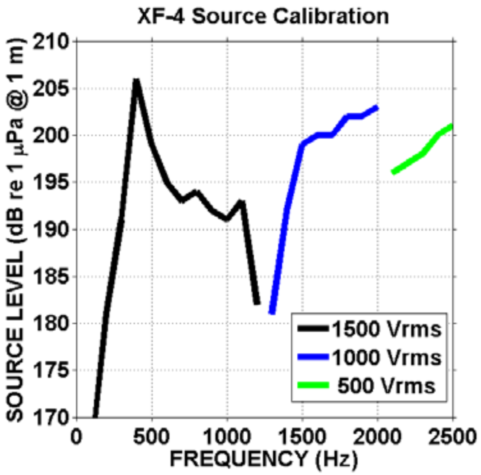
Latest additions:

1) Linear actuator for source probe
2) Vector sensors

Additional NRL Experimental Assets (1):

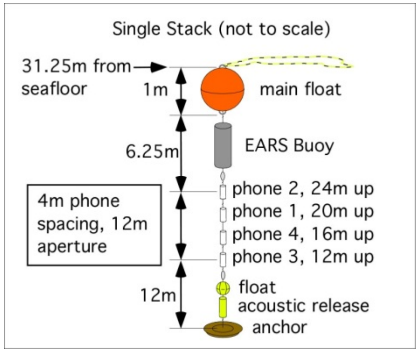
XF-4s (2)





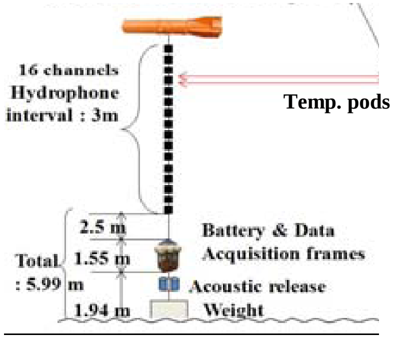
EARS Buoys (6)

- 4-element hydrophone array
- 10-day deployment @ 50 kHz sampling
- Deep-water capability (3000 m)



SCRIPPS VLAs (2)

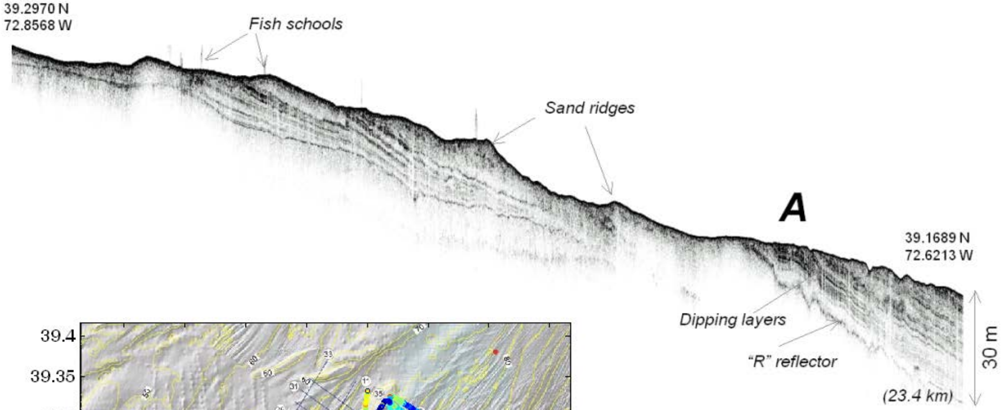
- 16-element hydrophone array
- 3-day deployment @ 20 kHz sampling

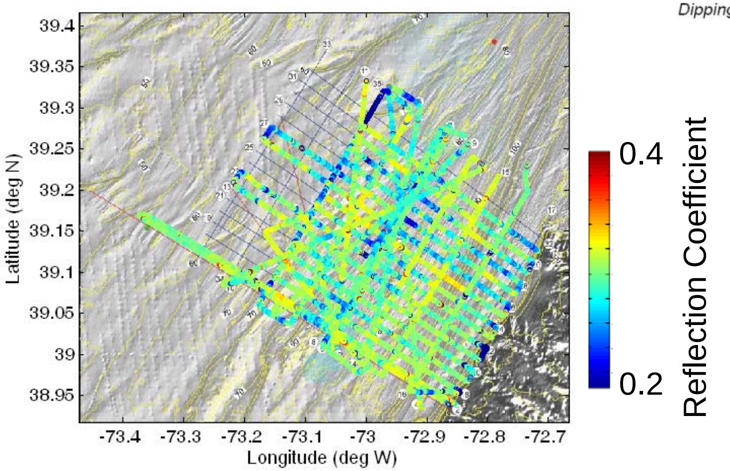


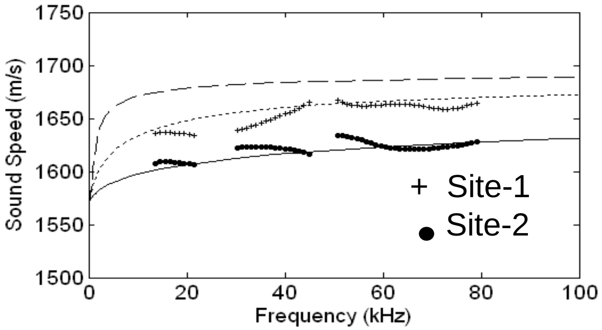
2) Chirp Sonar and GeoProbe

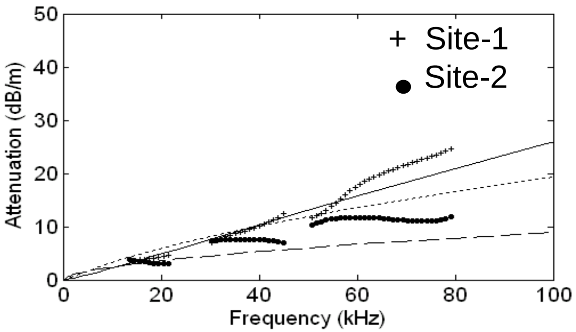
NRL Chirp Sonar

NRL GeoProbe

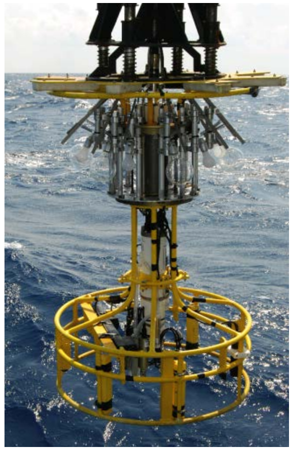




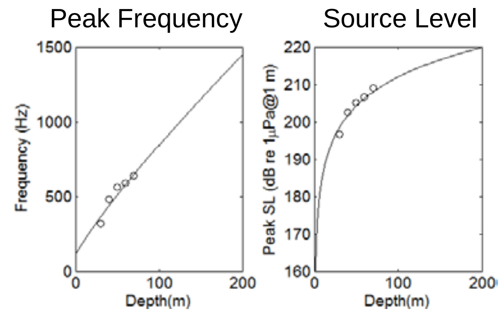


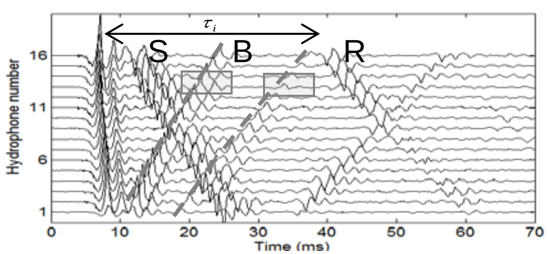


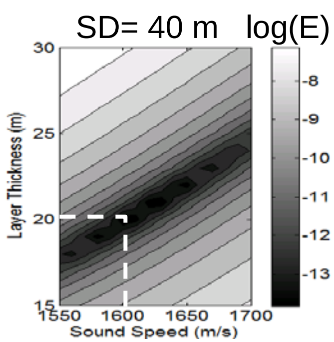
3) Automated light-bulb implosion system

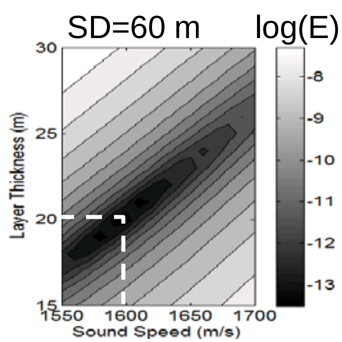


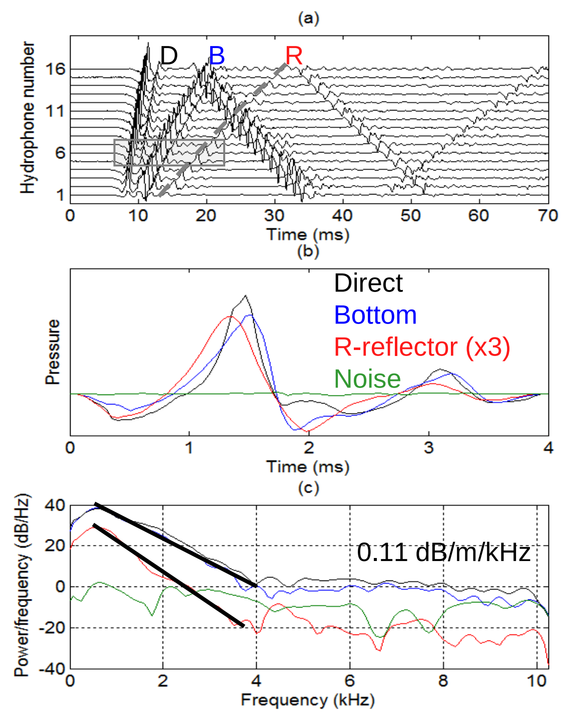
1. Accurate positioning
2. Accurate trigger time and depth
3. Simultaneous CTD







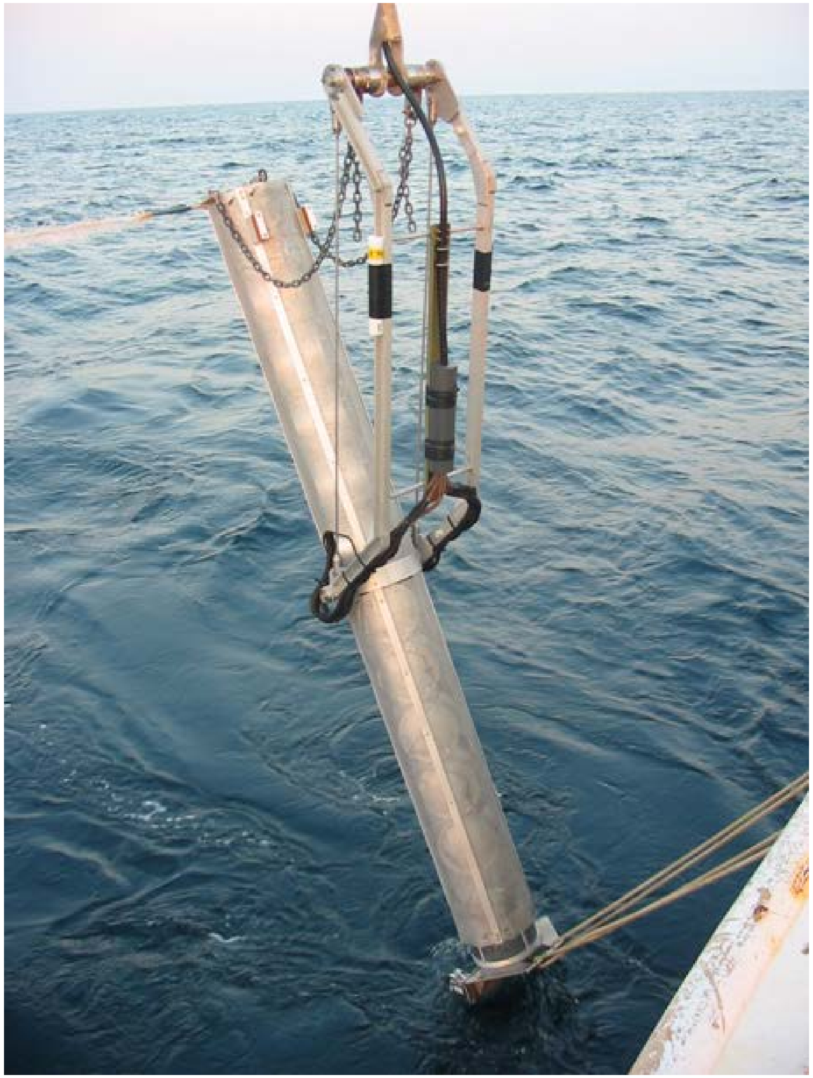


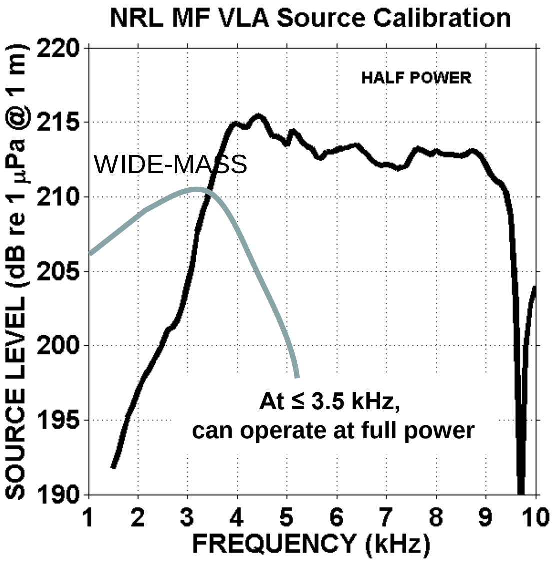


4) Mid-Frequency Source Array (Gauss)

10-transducer VLA
cut for ~3 kHz

- Frequency: 1.5-9.5 kHz
- Towable at up to 4 kts
- Depths 20-200 m
- 2 NAS suites (depth, tilt, etc.)
- 'Quasi-omni' azimuthally
- Typically 10-% duty cycle
- Elements individually controllable
- 440-V power





f (kHz)	Max SL(dB)
1.5	196
2.0	201
2.5	204
3.0	208
3.5	215
3.8-5.5	216
5.5-9.0	213
9.5	210

5) Mid-Frequency Receiver (Gauss)

Line Array Receiver

- 32 elements (w/ desen phone)
  (cut for 5 kHz: 0.1524-m spacing)
- HLA or VLA mode
- NAS sensors
- Hand deployed
- No VIMs, so 'sea-state sensitive'
- Max depths ~150 m or so
- 30-kHz typical sample rate

Typical NRL S/R Tow Configuration