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

Altan Turgut
Naval Research Laboratory
Acoustics Division, Washington DC 20375

ONR SEDIMENT CHARACTERIZATION WORKSHOP

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**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:

\[
\vec{m} = \arg \min_{m} \| A_m - d \|^2 \quad \text{(may diverge)}
\]

\[A: \text{measurement matrix, } m: \text{model, } d: \text{data}\]

\[l_2- \text{norm penalty:} \]

\[
\vec{m} = \arg \min_{m} \| A_m - d \|^2 + \mu \| m \|^2
\]

\[(\text{Tikhonov regularization})\]

\[l_1- \text{norm penalty:} \]

\[(\text{Sparse model in wavelet basis, a few non-zero coefficient})\]

\[
w = Wm \quad \text{wavelet coefficients of } m
\]

\[
\vec{w} = \arg \min_{m} \| A_w - d \|^2 + 2\mu \| w \|_1, \quad (\vec{m} = W^{-1}\vec{w})
\]

\[W: \text{wavelet decomposition matrix, } W^{-1}: \text{wavelet synthesis operator}\]

Noise-free model reconstruction (noise may not be sparse)
Range/Bearing-dependence of seafloor:

- Mid Atlantic Bight
  *(Grain size distribution)*

- Central Texas Shelf
  *(Sediment type)*

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

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

SL vs. Frequency

Monostatic ↔ Multistatic

x (km): 0, 50
y (km): 0, 50
Sediment pore-size distribution
(New Jersey Shelf core samples)

Log-normal ($\phi$-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:

$$r = r_0 e^{-\frac{p}{\sigma}} \quad (p = \sigma \ln 2)$$

(BIOT MODEL)

Viscosity correction factor:

$$\bar{F}(\kappa) = \frac{1 + \kappa \left( 1 + i \left( \frac{4}{3} e^{5p^2/2} - e^{-3p^2/2} \right) + i \kappa^2 \left( \frac{4}{3} e^{4p^2/2} - 1 \right) \right)}{1 + \kappa \left( 1 + i \left( \frac{4}{3} e^{5p^2/2} - e^{-3p^2/2} \right) \right)}$$
Phase velocities and attenuation coefficients (Biot model)
Frequency-Dependency of Attenuation and Sound-Speed Dispersion

\[ \sigma = 0.0 \]
\[ \sigma = 0.75 \]
\[ \sigma = 1.5 \]

\[ a \sim k f^{1.0} \]
\[ a \sim k f^{0.6} \]
\[ a \sim k f^{1.8} \]
\[ a \sim k f^{1.6} \]
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):

**EARS Buoys (6)**
- 4-element hydrophone array
- 10-day deployment @ 50 kHz sampling
- Deep-water capability (3000 m)

**XF-4s (2)**
- 16-element hydrophone array
- 3-day deployment @ 20 kHz sampling

**SCRIPPS VLAs (2)**
- 16-element hydrophone array
- 4m phone spacing, 12m aperture

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**Figure 1:**
- XF-4 Source Calibration
- Graph showing source level vs. frequency
- 31.25m from seafloor
- Single Stack (not to scale)
- 1m main float
- 6.25m EARS Buoy
- 4m phone spacing, 12m aperture
- 12m float acoustic release anchor
- 16 channels Hydrophone interval: 3m
- 2.5m Battery & Data Acquisition frames
- 1.55m Acoustic release
- 1.94m Weight
- 5.99m Total
2) Chirp Sonar and GeoProbe

NRL Chirp Sonar

NRL GeoProbe

Reflection Coefficient

Sound Speed (m/s)

Attenuation (dB/m)
3) Automated light-bulb implosion system

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

- Direct
- Bottom
- R-reflector (x3)

Noise
0.11 dB/m/kHz
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

At ≤ 3.5 kHz, can operate at full power

<table>
<thead>
<tr>
<th>Frequency (kHz)</th>
<th>Max SL (dB)</th>
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<tbody>
<tr>
<td>1.5</td>
<td>196</td>
</tr>
<tr>
<td>2.0</td>
<td>201</td>
</tr>
<tr>
<td>2.5</td>
<td>204</td>
</tr>
<tr>
<td>3.0</td>
<td>208</td>
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<tr>
<td>3.5</td>
<td>215</td>
</tr>
<tr>
<td>3.8-5.5</td>
<td>216</td>
</tr>
<tr>
<td>5.5-9.0</td>
<td>213</td>
</tr>
<tr>
<td>9.5</td>
<td>210</td>
</tr>
</tbody>
</table>
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