Geoacoustic tomography and high-resolution acoustic probe measurements during NRL MEC/ANEX2015 Experiments

Altan Turgut
Naval Research Laboratory
Acoustics Division, Washington DC 20375

ONR SEDIMENT CHARACTERIZATION WORKSHOP

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Multi-static Environmental Characterization Experiment:

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

**Experimental Goal:** Rapid characterization of seabed within 30 km x 30 km area

**Measurements:** Broadband transmission-loss and reverberation measurements with limited number of sources and receivers

High-resolution acoustic probe measurements:

**Scientific Goal:** Frequency dependency of sound speed and attenuation in marine sediments

**Experimental Goal:** In-situ sound-speed and attenuation measurements in muddy, silty, and sandy sediments

**Measurements:** Simultaneous measurements of acoustic probes and chirp sonar. Geotechnical measurements of sediment cores.
NRL MEC/ANEX2015 Experimental Sites:

Mid Atlantic Bight
(Grain size distribution)

Palamara et al., in prep, (from J. Goff)
Pulse Decay vs. Bottom Type (Simulation)

\[ p(\tau) = \left( \frac{c}{2r\tau} \right)^{1/2} \exp \left( -\frac{c}{H} \alpha_{\text{eff}} \tau \right) \]

\[ \alpha_{\text{eff}} = \frac{1}{R} \int_0^R \alpha(r) dr \]

\( r = 10 \text{ km}, \ f = 900-1000 \text{ Hz} \)

Pulse decay vs. sediment type:

Data points from different combinations of sediments:

- Sand/Sand
- Sand/Silt
- Silt/Sand
- Silt/Silt

Parameters:

- \( c \): Sound speed
- \( r \): Range
- \( H \): Water depth
- \( \tau \): Pulse-decay time
- \( \alpha \): Bottom-loss gradient

Simulation results showing depth, range, and intensity with respect to different sediment types.
Pulse Decay vs. Bottom Type (Data)

Table:

<table>
<thead>
<tr>
<th>Bottom Type</th>
<th>Sound Speed (m/s)</th>
<th>Absorp (dB/λ)</th>
<th>α (Np/rad)</th>
<th>θc (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>1700</td>
<td>0.5</td>
<td>0.3</td>
<td>30</td>
</tr>
<tr>
<td>Silt</td>
<td>1600</td>
<td>0.3</td>
<td>0.8</td>
<td>20</td>
</tr>
<tr>
<td>Clay</td>
<td>1510</td>
<td>0.1</td>
<td>5.0</td>
<td>5</td>
</tr>
</tbody>
</table>
Geoacoustic Tomography:

Example: Bottom-Loss-Gradient Tomography:

\[
\log 10 \left[ \sqrt{\tau} p(\tau) \right] = -\log 10(e) \frac{ct}{\tau} \sum_{i}^{N} \alpha_i \Delta r
\]

Underdetermined minimization problem:

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

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

\(l_2\)- norm penalty:

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

(Tikhonov regularization)

\(l_1\)- norm penalty:

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

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

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

W: wavelet decomposition matrix, \(W^{-1}\): wavelet synthesis operator

Noise-free model reconstruction (noise may not be sparse)
MEC/ANEX2015 Acoustic Experimental Assets (1)

Monostatic (towed)

- 2-channel source array (XF4)
- 72-channel receiver array

Multi-static (moored)

- Four moored source/4-ch receivers
- One 32-channel VLA
- Four 4-ch receiver arrays
- Several 2-ch acoustic data loggers
EARS Buoys (3)

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

NRL VLA (1)

Vertical Array, 32 ch, d=2.5m
Thermistors placed between phones

ITC-2010/ 4-elm. VLA (4)

ITC-2010
4-element VLA

SLED
NRL Chirp Sonar and GeoProbe

NRL Chirp Sonar

NRL Geoprobe

Sound Speed (m/s)

- Site-1
- Site-2

Reflection Coefficient

- Site-1
- Site-2

Attenuation (dB/m)

- Site-1
- Site-2
GeoProbe Measurements

NRL Deep-Sea GeoProbe System

BLUE10 Gulf of Mexico experiment (d=900 m)

Latest additions:
1) Linear actuator for probe penetration
2) Sidescan/chirp sonar
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
- 10-% duty cycle
- Elements individually controllable
- 440-V power

At ≤ 3.5 kHz, can operate at full power

<table>
<thead>
<tr>
<th>f (kHz)</th>
<th>Max SL (dB)</th>
</tr>
</thead>
<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>
</tr>
<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>
Summary:

• Transmission Loss measurements up to 30 km range (0.3-5.0 kHz)
• Multistatic Reverberation Level measurements (0.3-5.0 kHz)
• Ambient Noise Level measurements (0.1-10.0 kHz)
• Moored VLA with thermistor pods, towed source/array with CTD
• Limited Chirp/Sidescan Sonar measurements
• Limited Geoprobe measurements