Acoustic Data Analysis and Modeling

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Data Sets
(M-sequence q=4)

• **SW06**
  - Continuous transmission to SHRU receivers. 50 hours
    → temporal properties – fluctuations, coherence in time
  - Periodic transmission to SHARK VLA and HLA
    → spatial properties

• **FSPE** - Florida Straits Propagation Experiment
  - Continuous Transmission 2 -30 day periods.
    → temporal properties

• **AO** - Acoustic Observatory
  - Short 20 min Transmission 500 element - HLA
    → spatial properties 20 to 80 km.
Modes and Arrivals

Observed

Modelled

Shark VLA 100 Hz. m-sequence

SPL (dB re 1uPa)

Arrival Time (sec.)

Depth (m.)

Shark VLA 100 Hz. m-sequence

Transmission Loss (dB re 1m)

Time (sec.)

Depth (m.)

Note:

$c_b = 1600$ m/sec.
$PE = (\rho / 2)\eta^2 N^2$

$N$ is the buoyancy frequency

$\eta = \frac{T'}{dT/dz}$.

Signal Amplitude Data

\[ COH(t, \tau) = \frac{\left< p(t)^* p(t+\tau) \right>_{\Delta t, \Delta T}}{\left< p(t)^2 \right>_{\Delta t, \Delta T} \left< p(t+\tau)^2 \right>_{\Delta t, \Delta T}} \]
Temporal Coherence and Phase Wrapping

\[ COH(t, \tau) = \frac{\langle (p(t)^\ast p(t + \tau) \rangle_{\Delta T}}{\langle p(t)^2 \rangle_{\Delta T} \langle p(t + \tau)^2 \rangle_{\Delta T}} \]

Coherence is a statistical measure of the change of a waveform with time

Causes:

1. Multimode interference
   - Separate modes

2. Slow phase shifts of undistorted waveform
   - Compute for all phase shifts or phase track.

3. Random waveform distortion
   - Unrecoverable

- COH varies from both slow phase shifts in time that cause multipath/mode cancellation and from true randomizing effects.
- Both usually happen at the same time (Phase wrapping, Flatte)
Removing Phase Wrapping

Approach:
• Back out all possible dT/dt
• Loop through small increments of linear time shifts and re-compute COH
• Look for maximum.

Each pulse \( p(t) \) is time shifted by \( \tau \) using the shifting theorem.

\[
F^{-1}\left( F(p(t)) e^{i\omega \tau} \right)
\]
200 Hz. Pulse Response
200 Hz. Pulse Response
800 Hz.

shru3 sw53 Pulse Response 800 Hz.

shru3 sw53 Temporal Coherence 800 Hz.
Florida Straits Propagation Experiments
and the
Acoustic Observatory
Acoustic Observatory Receiving Arrays
CALOPS Sept 07
Shipboard Suspended and Towed Transmissions
Pulse response from 118 phones along the array
Signal Amplitude Data

\[
COH(t, \tau) = \frac{\left\langle \left( p(t) * p(t+\tau) \right)^2 \right\rangle_{\Delta t, \Delta T}}{\left\langle p(t)^2 \right\rangle_{\Delta t, \Delta T} \left\langle p(t+\tau)^2 \right\rangle_{\Delta t, \Delta T}}
\]

Change tau to dx - distance along the array

Same calculation yields spatial coherence for every arrival of the pulse response!
- Not aligned (steered) with wave front
- Phase changing along the array causing the coherence calculation to cycle.
- Steer the array by small time shift each phone and re-compute coherence
- Look for alignment
1. Lower order modes are more spatially coherent than higher order modes
2. All modes have same angle of arrival
80 km m-sequence reception
1. No recognizable modal structure
2. Different angles of arrival – bundles.
SHARK HLA
SHARK VLA 200Hz.

Shark VLA 200 Hz. m-sequence

Transmission Loss (dB re 1m)
Two shallow water experimental sites

Same experimental method -- data

Different environments.
Acoustic propagation shallow shelves inside of western boundary currents

Prograde vs Retograde fronts

**Florida Straits - Prograde Front**
Sea of Japan, East China Sea near the Kuroshio and the South China Sea seasonally.

**Mid-Atlantic Bight - Retograde Front**
Yellow Sea, East China Sea and the South China Sea seasonally.
Seasonal Internal Wave Sub-inertial
\[ \eta' = \frac{T'}{dT/dz} \]

[\[ PE = \frac{\rho}{2} N^2 \eta^2 \]]
Miami Sound Machine

\[ F_c = 100, 200, 400, 800, 1600, 3200 \text{ Hz.} \]
\[ B_w = 25, 50, 100, 200, 400, 800. \]

STATUS

DURIP – \( \frac{1}{2} \$ \) for SW06 preparation.
\( \frac{1}{2} \$ (40k) \) package redesign.
Publications

   Topic -- FSPE and AO data analysis of spatial and temporal coherence
   Status – Submitted

   Topic -- MSM to SHRU’s transmission data analysis - temporal coherence
   Status – Submitted

3. Spatial Coherence of Mode Arrivals. DeFerrari, Colis, Duda, Newhall
   Topic -- MSM to Shark - Coherence of mode arrivals.
   Status – Early draft.

   Topic -- Comparison of internal wave fields and effects of propagation for two types of environments.

5. Limitations of Spatial Coherence in Shallow Water.
   Topic – Angular spreading for long range transmission

6. Active Sonar Using M-Sequences. JUA -- Special Issue on Active and Marine Mammals
   Topic -- SW06 Data for feasibility
shru2252 Pulse Response 100 Hz. Hr 2200 7/29