Low-frequency shallow water reverberation and bottom scattering model

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Introduction

• The problems of reverberation model
  • Propagation model
  • Bottom parameters
  • Scattering model
    • Angle relationship
    • Frequency relationship
    • Physical mechanism

• Motivation of this talk
  • The ASIAEX01 reverberation data are used to validate different bottom scattering models.
Contents

• Middle frequency (700Hz to 2000Hz, in this report) reverberation loss to validate different bottom scattering models.
• Low frequency (<700Hz) reverberation loss and sediment-basement combined scattering model.
1. Middle Frequency reverberation data
Experimental Data
Data analysis procession

Recorded data $x(t)$

Narrow band filtering $y(t) = \text{filter}(x(t))$

Short time energy average $I(t_0) = \text{mean}(y^2(t))$

$t = t_0 \text{ to } t_0 + dt$

Reverberation loss $RL(t) = 10 \times \log_{10}(I(t)) - SL$
Reverberation loss vs. time (Bomb 1)
Reverberation loss vs. time
(Bomb 1/2/3, Frequency 1kHz)
Model/data comparison procession (mathematically)

Have several different expressions of bottom scattering coefficient

Put those expressions into Reverberation model to get numerical results

Compare the numerical results with the experimental data to find out the best expression for this experiment
Sound Speed Profile
Bottom parameters

- Bottom speed, 1610.8 m/s
- Bottom density 1.86 g/cm³
- From Geoacoustic Inversion by Dr. Zhenlin Li
The discrete sediment inhomogeneous scattering model
For signal scatterer, \( \sigma \propto k^4 \)

Neglect multiple scattering, the above expression approximates to the sediment inhomogeneous model from Jackson, etc.

\[
\sigma(\theta_i, \theta_s) = B_L k_2^2 |1 + R_{i-2}(\theta_i)|^2 |1 + R_{i-2}(\theta_s)|^2 \frac{1}{2 \left[ \text{Im} \sqrt{\left( \frac{k}{k} \right)^2 - \cos^2 \theta_i \right] + \text{Im} \sqrt{\left( \frac{k}{k} \right)^2 - \cos^2 \theta_s \right]}}
\]

The above expression also approximates to the perturbation bottom roughness model from Jackson, etc. \( W(k) \propto 1/k^0 \)

The above expression also approximates perturbation heightness model from Jackson, etc. \( W(k) \propto 1/k^1 \)
Published mathematical expressions of bottom scattering coefficient (incomplete)

1. \( \sigma (\theta_i, \theta_s) = \mu \sin(\theta_i) \sin(\theta_s) \)

2. \( \sigma (\theta_i, \theta_s) = \mu \sin^{1/2}(\theta_i) \sin^{1/2}(\theta_s) \)

3. \( \sigma (\theta_s, \theta_i) = \mu \sin \left( \frac{\theta_i + \theta_s}{2} \right) \)

4. \( \sigma = \mu \left[ \frac{\sin(\theta_i) \sin(\theta_s)}{(\sin(\theta_i) + \sin(\theta_s))} \right]^{1/4} \)

5. \( \sigma (\theta_s, \theta_i) = \mu \sin \left( \cos^{-1} \left( \frac{\cos(\theta_i) + \cos(\theta_s)}{2} \right) \right) \)

6. \( \sigma (\theta_i, \theta_s) \approx \frac{1}{4\pi} a \left( \frac{\sin(\theta_i) + \sin(\theta_s)}{2} \right)^2 \)

7. \( \sigma (\theta_i, \theta_s) = B_L k_2^3 \left| 1 + R_{i-2} (\theta_i) \right|^2 \left| 1 + R_{i-2} (\theta_s) \right|^2 \cdot \frac{1}{2} \left[ \text{Im} \sqrt{\left( \frac{k}{k} \right)^2 - \cos^2 \theta_i} + \text{Im} \sqrt{\left( \frac{k}{k} \right)^2 - \cos^2 \theta_s} \right] \)
The criterion for Model/data comparison

- Minimum Standard Deviation criterion

$$\text{Min}(SD) = \text{Min}(\sqrt{\text{sum}(RL_e(t_i) - RL_n(t_i))^2/N}))$$
Standard Derivations for different expressions (2-15s, 700 to 2kHz)

Frequency independent

Frequency dependent
• The bottom scattering coefficient has a strong frequency relationship.
• For explaining 700Hz to 2000Hz experimental RL data, the discrete sediment inhomogeneous model is best model among the models shown in this paper.
The bottom scattering coefficient
The bottom scattering coefficient (Grazing angle is 10 degree)
Model/data comparison (700Hz)
Model/data comparison (1000Hz)
Model/data comparison (1500Hz)
Model/data comparison (1900Hz)

![Graph showing reverberation loss over time at 1900Hz](image)
2. Low Frequency reverberation data
Model/data comparison (500Hz)
Model/data comparison (400Hz)
Model/data comparison (300Hz)
Model/data comparison (200Hz)
The sediment-basement combined scattering model

Sediment inhomogeneous

Surface roughness

Basement roughness

D=15m
The sediment-basement combined scattering model

• Bottom scattering includes the scattering from the sediment inhomogeneous and the basement roughness.

\[
\sigma(\theta_i, \theta_s) = B_L k_2^3 \left| 1 + R_{1-2}(\theta_i) \right|^2 \left| 1 + R_{1-2}(\theta_s) \right|^2 \frac{1}{2 \left[ \text{Im} \sqrt{\left( \frac{k}{k} \right)^2 - \cos^2 \theta_i } \right] + \text{Im} \sqrt{\left( \frac{k}{k} \right)^2 - \cos^2 \theta_s } } \\
+ B_L \left| 1 + R_{1-2}(\theta_i) \right|^2 \left| 1 + R_{1-2}(\theta_s) \right|^2 \exp(-2\gamma D) W(k) F(k) \right|^2
\]

«Ivakin, JASA, 1998, vol. 103»

• D=15m
Model/data comparison (200Hz)
Model/data comparison (300Hz)

Frequency, 300Hz

Reverberation Loss, (dB)

Time, (s)

Experimental data
Sediment scattering
Sediment-basement combined
Model/data comparison (400Hz)
Model/data comparison (500Hz)
Model/data comparison (2000Hz)
Bottom scattering coefficients

- Frequency, 200Hz
  - Sediment-basement combined
  - Sediment inhomogeneous

- Frequency, 300Hz
  - Sediment-basement combined
  - Sediment inhomogeneous

- Frequency, 400Hz
  - Sediment-basement combined
  - Sediment inhomogeneous

- Frequency, 500Hz
  - Sediment-basement combined
  - Sediment inhomogeneous
Summaries

- The bottom scattering coefficient has a strong frequency relationship ($f^3$).
- For 700Hz to 2000Hz experimental RL data, the discrete sediment inhomogeneous model is best model among the models shown in this paper.
- The scattering from deeper layer may be a dominating effect for low frequency reverberation data.
Other open problems!

- Can this model predict the reverberation correlation?
- How to distinguish the sediment inhomogeneous and surface roughness
- The multiple scattering effect?
- Comparison with the other scattering data?
Other open problems!

- Geoacoustic model
  - Basement is not rigid?
  - Sound speed has a positive gradient in the sediment?
  - There is a scattering layer at about 15m?

Seafloor to TST isopach or layer thickness of the top layer of sand-silt in meters. (from L. Bartek)
Thanks