Uncertainty of low frequency sound attenuation estimate in marine sediment

Yong-Min Jiang and N. Ross Chapman

University of Victoria, Victoria, BC, Canada

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Objective:

• Measurement of marine sediment attenuation at frequencies lower than 5 kHz
• Evaluation of the uncertainty of the attenuation estimate

Outline:

• Experimental geometry
• Sediment attenuation estimation method
• Factors that affect the uncertainty of attenuation estimates
  • fluctuation of the signals
  • uncertainties of sediment sound speed and layer thickness
• The results
• Summary and acknowledgements
Methods of estimating sound attenuation in marine sediment:

• For attenuation at high frequencies (f > 10 kHz):
  *In situ* measurements by using two embedded probes

• For attenuation at low frequencies (f < 1 kHz):
  Inferences from different kinds of inversions of sound propagation data

• An alternate way of estimating the sediment attenuation:
  The signal used in this study is LFM pulse with frequency bandwidth of 1.5 kHz to 4.5 kHz
Experimental geometry:

Sound travel path in the sediment
Example of the received signal:

Direct arrival
Surface reflection
Bottom reflection
Sub-bottom reflection
Bottom reflection surface reflection
Surface reflection bottom reflection
Method of estimating sediment attenuation:

Signal from bottom reflection:

\[ p_b(f) = \frac{p_0 V_b D^{Src}(f, \theta_b, \xi) D^{Rcr}(f, \phi_b, \eta)}{r_1 + r_2} \]

Signal from sub bottom reflection:

\[ p_{sb}(f) = \frac{p_0 T_{ws} T_{sw} V_{sb} D^{Src}(f, \theta_{sb}, \xi) D^{Rcr}(f, \phi_{sb}, \eta)}{r_3 + r_4 + r_5 + r_6} \cdot e^{-\alpha_{w}^{(neper)}}(r_1 + r_2) \cdot e^{-\alpha_{sb}^{(neper)}}(f)(r_5 + r_6) \]

The ratio of reflections from bottom to sub bottom (dB):

\[ \Delta P(f) = 20 \log_{10} p_b(f) - 20 \log_{10} p_{sb}(f) = B + \alpha_{sb}(f) \cdot (r_5 + r_6) \]

Linear frequency dependence: or

Nonlinear frequency dependence:

\[ \Delta P(f) = (r_5 + r_6) \cdot \alpha_{sb}^{(f)} \cdot f + B \]

\[ \Delta P(f) = (r_5 + r_6) \cdot \alpha_{sb}^{f_0} \cdot (f/f_0)^\beta + B \]

\[ \alpha_{sb}^{(f)} \text{ is in dB/m}\cdot kHz } \]

\[ \alpha_{sb}^{(\lambda)} = \alpha_{sb}^{(f)} \cdot c_{sb} / 1000 \text{ in dB/\lambda} \]

\[ \alpha_{sb}^{f_0} \text{ is in dB/m @1 kHz, } f_0 \text{ is 1 kHz} \]
The uncertainty of attenuation estimate:

**Linear frequency dependence:** or **Nonlinear frequency dependence:**

\[
\Delta P(f) = (r_5 + r_6) \cdot \alpha_{sb}(f) \cdot f + B \quad \text{in dB/m-kHz}
\]

\[
\Delta P(f) = (r_5 + r_6) \cdot \alpha_{sb}^{f_0} \cdot (f/f_0)^{\beta} + B
\]

is in dB/m @1 kHz, \(f_0\) is 1 kHz

\[
\Delta P(f) = \frac{1000(r_5 + r_6)}{c_{sb}} \cdot \alpha_{sb}(\lambda) \cdot f + B \quad \text{in dB/\lambda}
\]

The uncertainty of the attenuation estimate:

- the measurement
  - signal amplitude fluctuation
- the uncertainty of sound speed and layer thickness estimates
  - Bayesian travel time inversion
Estimate attenuation from bottom and sub-bottom reflections:

Matched filtered waveforms

$\Delta P(f)$ at different frequencies
Example of uncertainty due to signal fluctuation

Determine the frequency dependence of the attenuation in terms of:

- the width of 95% of the credibility interval
- the consistency of the estimates from different source-receiver pairs

Monte Carlo approach, linear fitting
Linear fitting for data from four source-receiver pairs

(a) Amplitude ratio (dB) vs. Frequency (kHz)

(b) Amplitude ratio (dB) vs. Frequency (kHz)

(c) Amplitude ratio (dB) vs. Frequency (kHz)

(d) Amplitude ratio (dB) vs. Frequency (kHz)
The uncertainty of sediment sound speed and layer thickness estimates:

**Optimization:**
Water column SSP,
source & receiver geometry:
Range, Water depth, Array tilt
Source depth, Receiver depth

**Bayesian inversion:**
Uncertainty of sediment sound speed and layer thickness
Uncertainty of sediment sound speed and layer thickness estimates from Bayesian travel time inversion:

- Sound speed
- Layer thickness
- Grazing angle
Example of uncertainty of attenuation estimate:

\[
\frac{(r_5 + r_6)}{c_{sb}}
\]

\[
\frac{(r_5 + r_6)}{c_{sb}} \cdot \alpha_{sb}^\alpha
\]

\[
\alpha_{sb}^{(f)} \text{ in dB/m} \cdot \text{kHz}
\]

\[
\alpha_{sb}^{(\lambda)} \text{ in dB}/\lambda
\]
Summary:

- Marine sediment sound attenuation at low frequency is estimated from single bounce sub-bottom reflections.
- Frequency dependence of the attenuation is determined by the measured data.
- The uncertainty of the attenuation estimate is mapped from the fluctuation of measured signal and the uncertainty of the sediment property estimates from Bayesian travel time inversion.
- VLA and source at different depths experimental geometry.

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