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

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Methods of estimating sound attenuation in marine sediment :

- For attenuation at high frequencies (f > 10 kHz):

  In situ measurements by using two embedded probes

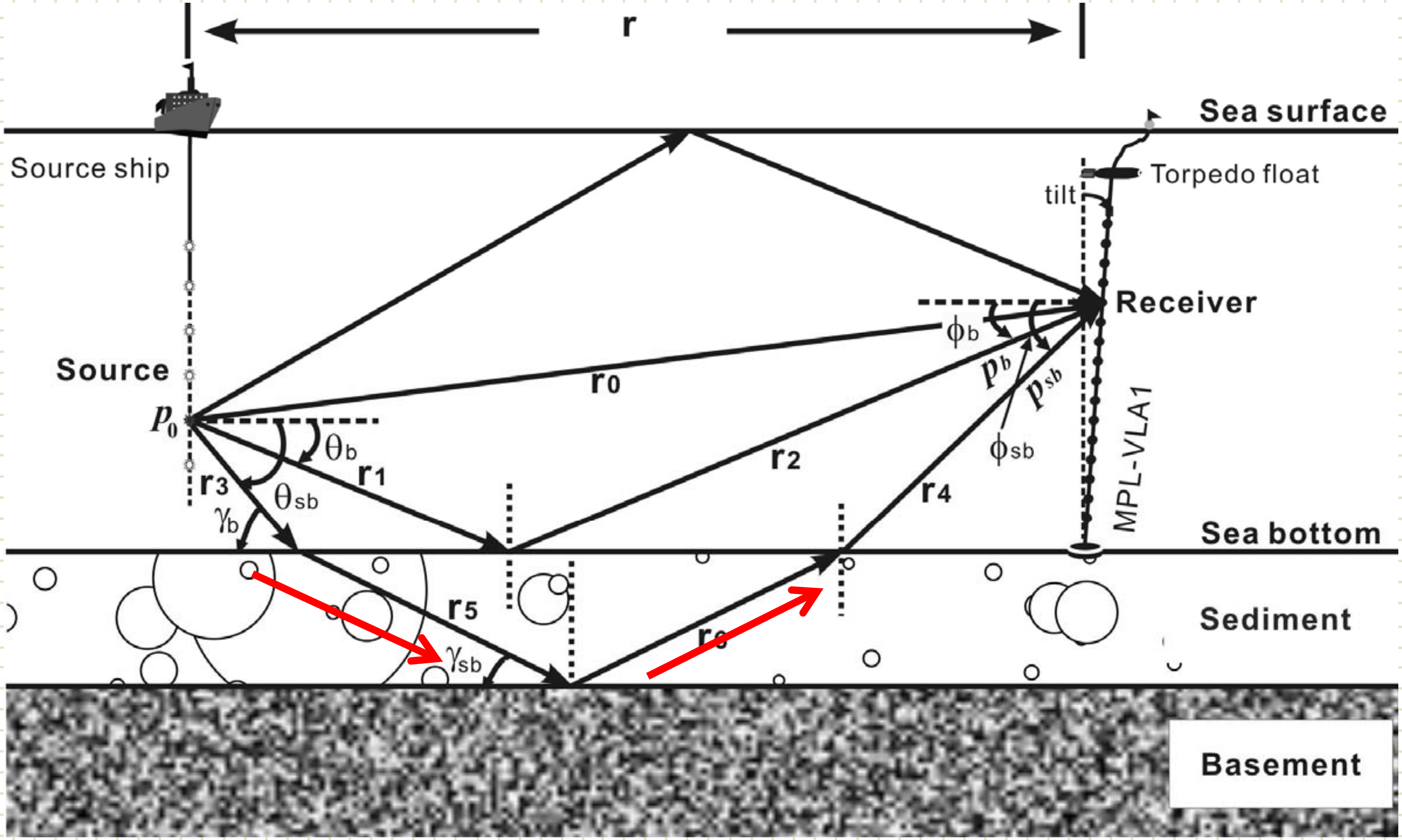
- For attenuation at low frequencies (f < 1 kHz):

  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

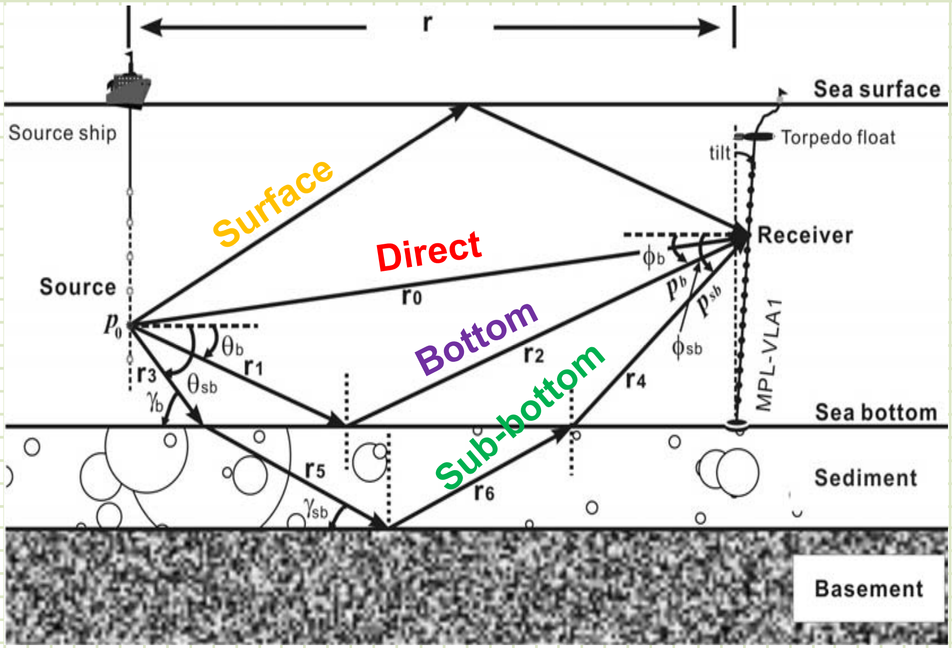
Surface reflection

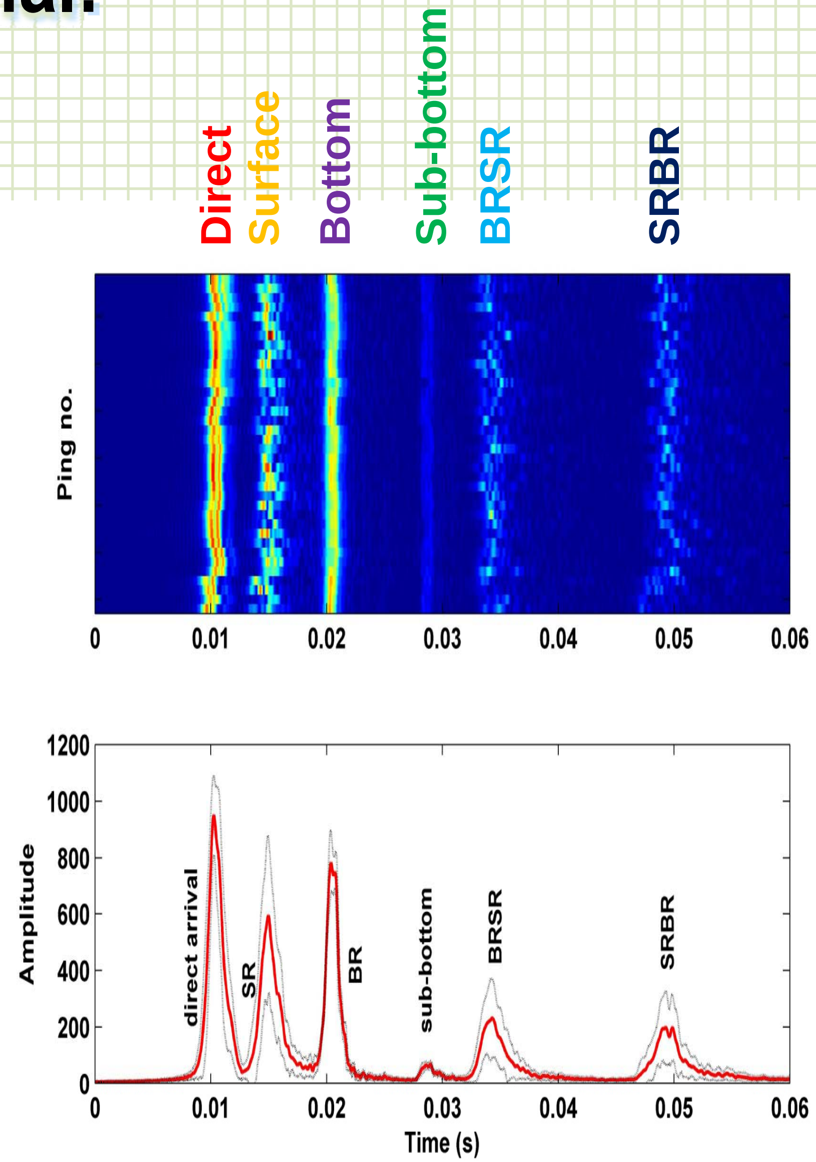
Bottom reflection

Sub-bottom reflection

Bottom reflection surface reflection

Surface reflection bottom reflection





Method of estimating sediment attenuation:

Signal from bottom reflection:

$$p_b(f) = \frac{p_0 V_b D^{Src}(f,\theta_b,\xi) D^{\mathrm{Re}\,c}(f,\phi_b,\eta)}{r_1 + r_2} \cdot e^{-\alpha_w^{(neper)}(r_1+r_2)}$$

D^{Src} - **Directional response of source**

Signal from sub bottom reflection:

$$p_{sb}(f) = \frac{p_0 T_{ws} T_{sw} V_{sb} D^{Src}(f,\theta_{sb},\xi) D^{\mathrm{Re}\,c}(f,\phi_{sb},\eta)}{r_3 + r_4 + r_5 + r_6} \cdot e^{-\alpha_w^{(neper)}(r_3+r_4)} \cdot e^{-\alpha_{sb}^{(neper)}(f)\cdot(r_5+r_6)}$$

$D^{\mathrm{Re}\,c}$ - **Directional response of receiver**

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:**

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

$\alpha_{sb}^{(f)}$ **is in dB/m•kHz**

$\alpha_{sb}^{(\lambda)} = \alpha_{sb}^{(f)} \cdot c_{sb}/1000$ **in dB/λ**

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

$\alpha_{sb}^{f_0}$ **is in dB/m @1 kHz, f_0 is 1 kHz**

The uncertainty of attenuation estimate:

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

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

in dB/m•kHz

$$\Delta P(f) = \frac{1000\cdot(r_5+r_6)}{c_{sb}} \cdot \alpha_{sb}^{(\lambda)} \cdot f + B$$

in dB/λ

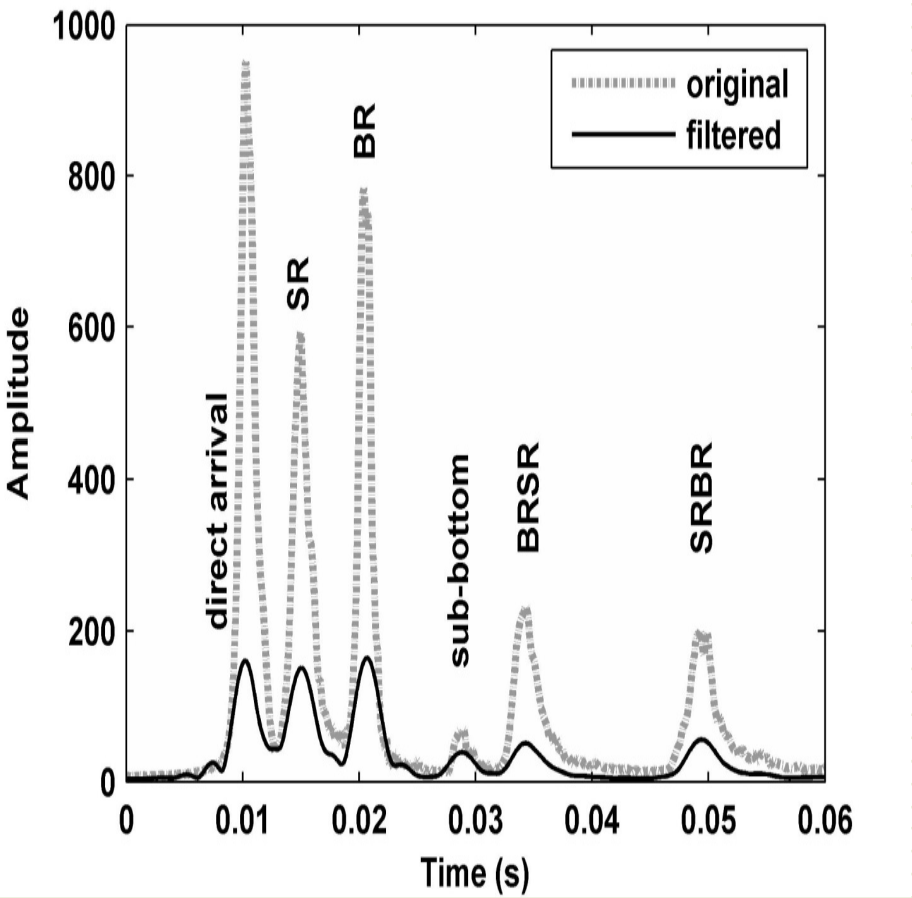
$$\Delta P(f) = (r_5 + r_6)\cdot \alpha_{sb}^{f_0} \cdot (f/f_0)^{\beta} + B$$

is in dB/m @1 kHz, f_0 is 1 kHz

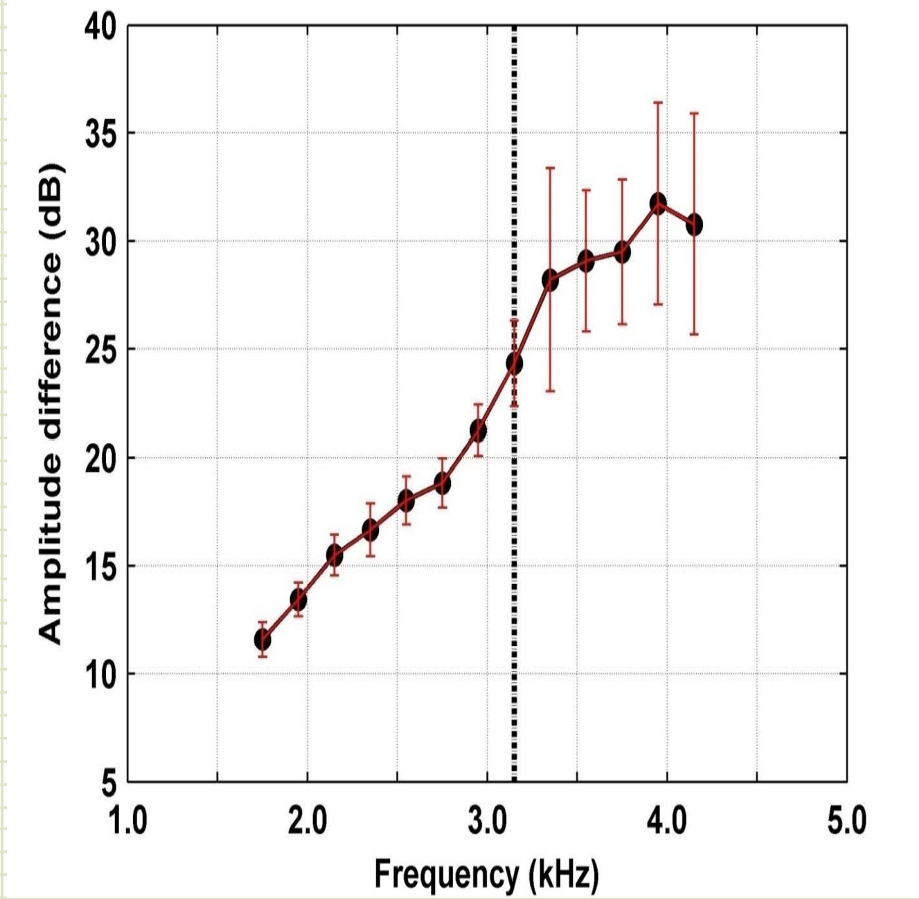
The uncertainty of the attenuation estimate:

- **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

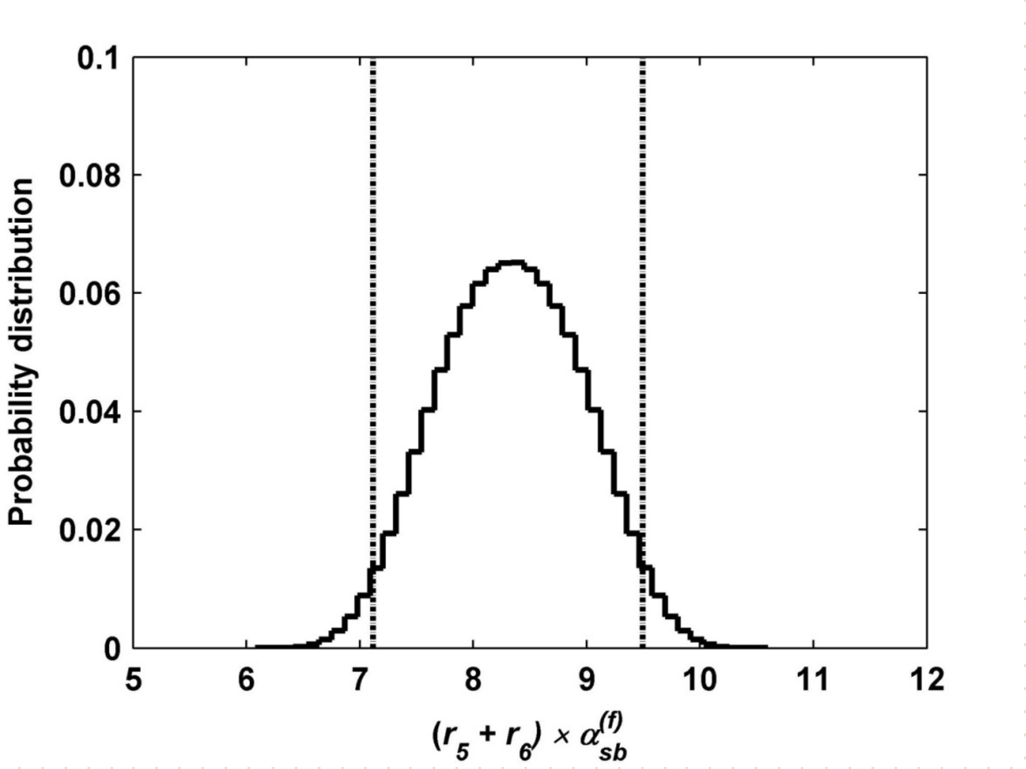


$\Delta P(f)$ at different frequencies

Example of uncertainty due to signal fluctuation

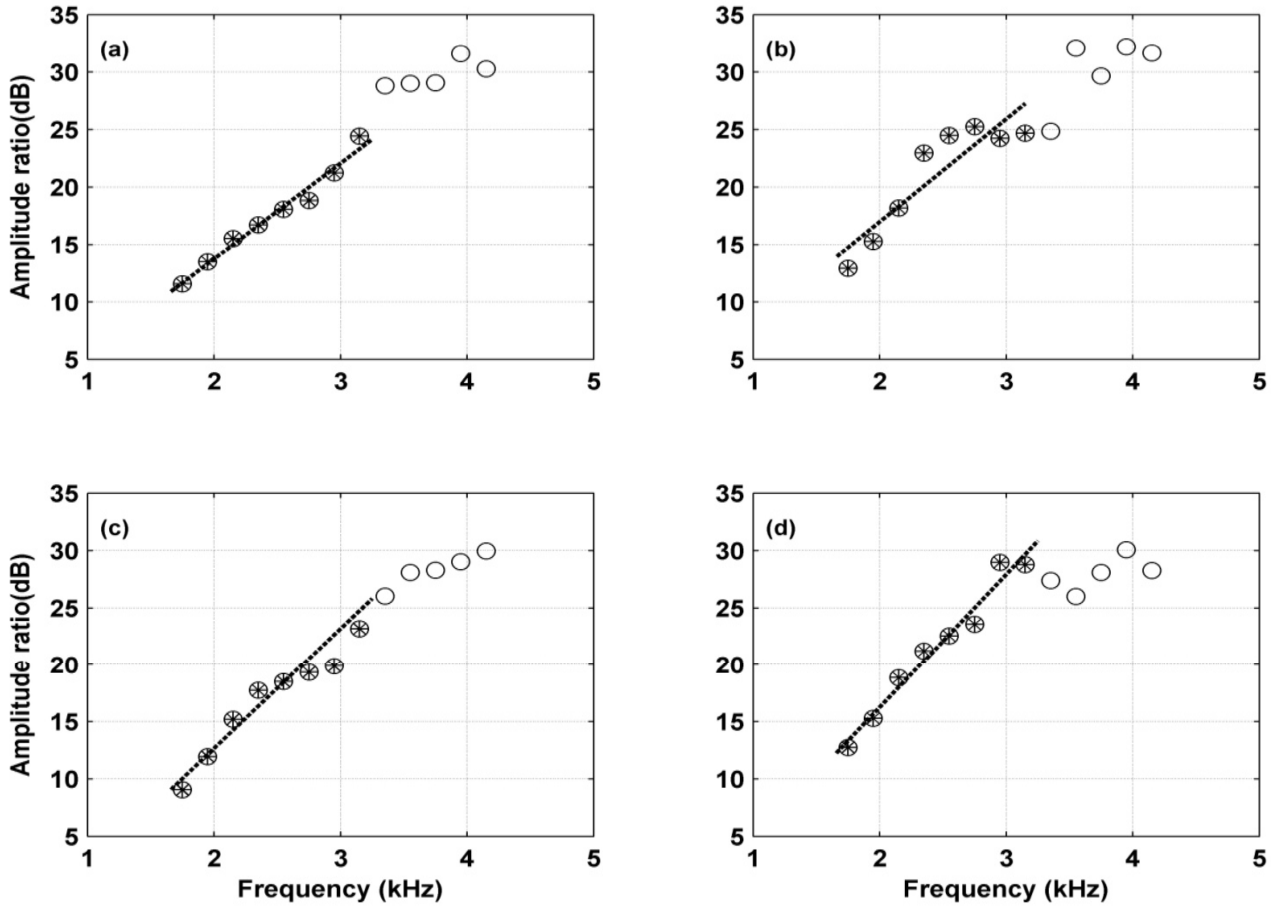
Determine the frequency dependence of the attenuation in terms of:

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

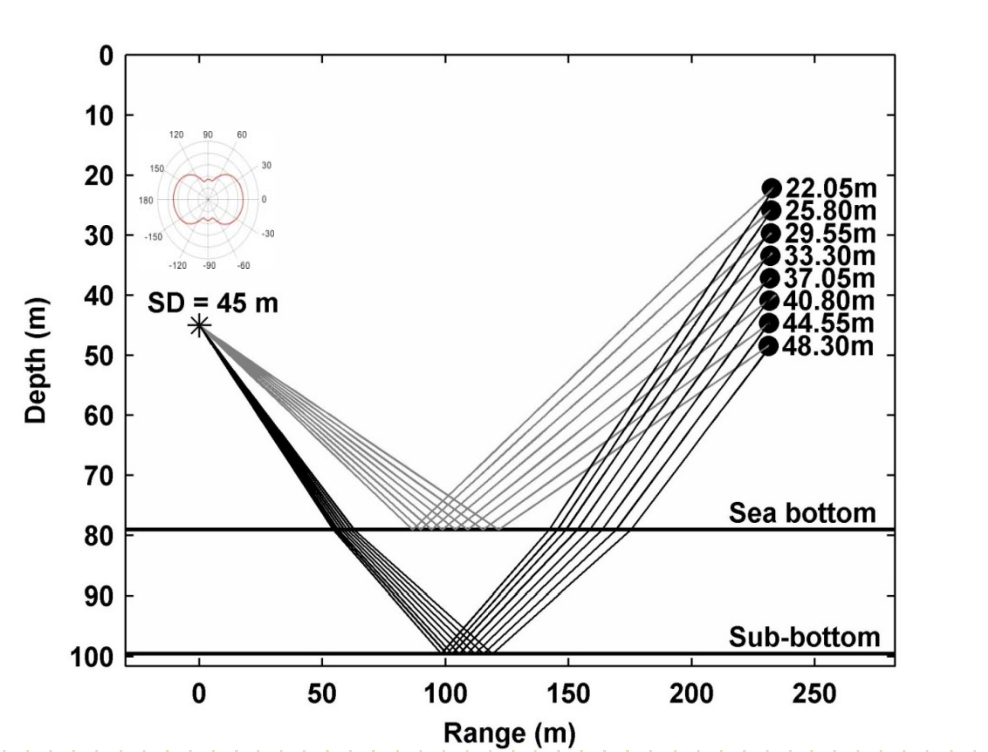


Monte Carlo approach, linear fitting

Linear fitting for data from four source-receiver pairs



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

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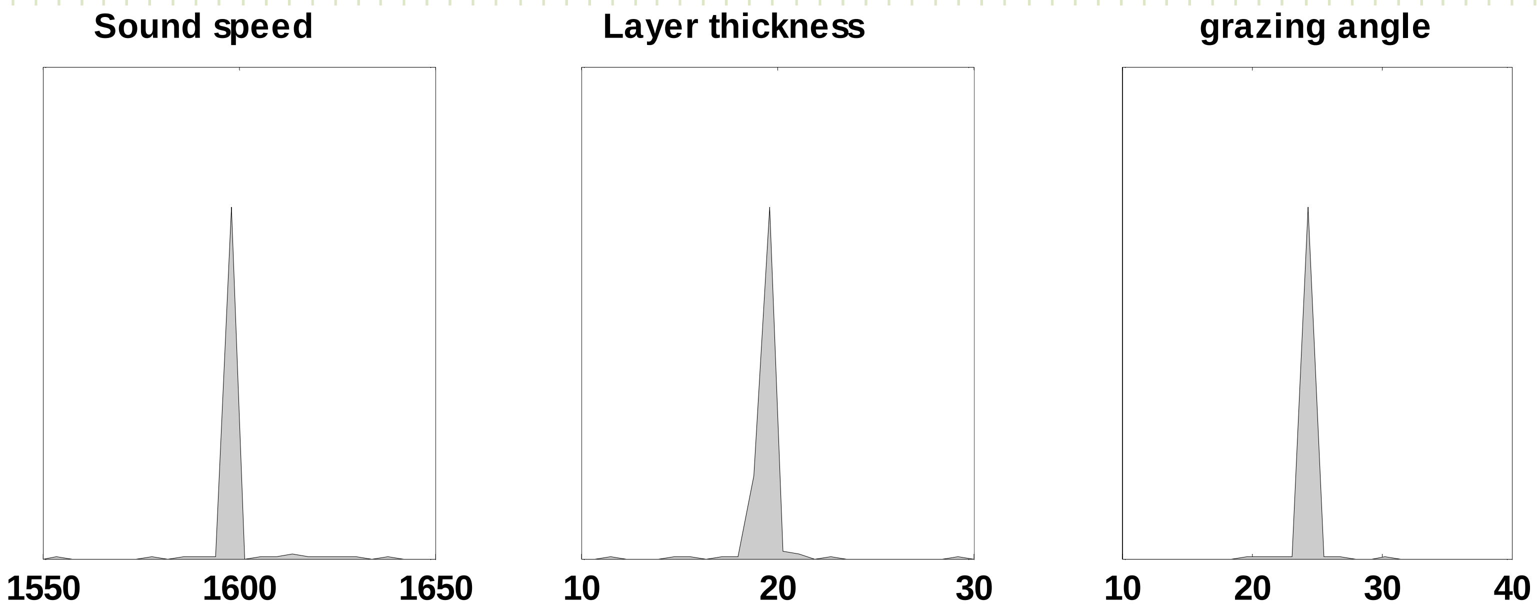
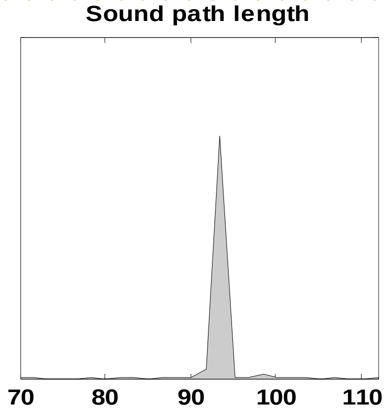
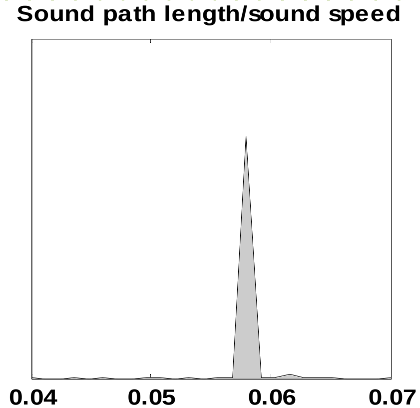
Uncertainty of sediment sound speed and layer thickness estimates from Bayesian travel time inversion:



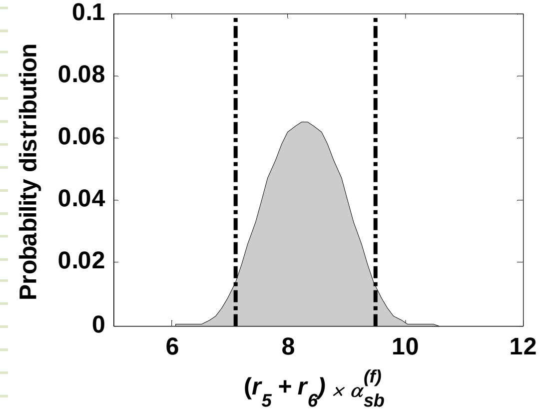
Example of uncertainty of attenuation estimate:



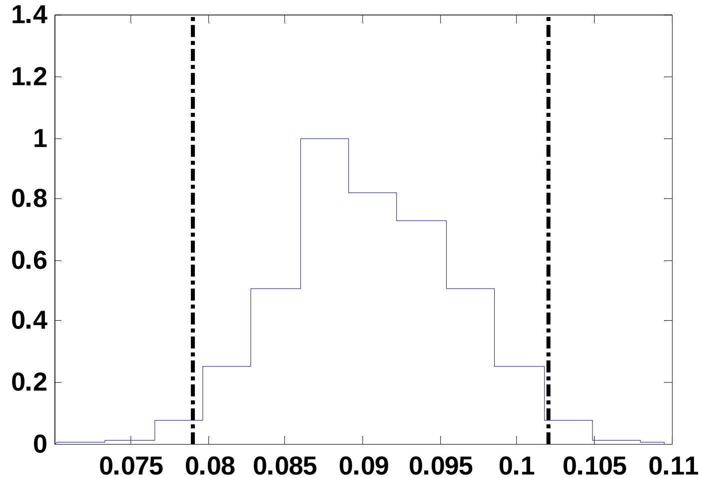
$(r_5 + r_6)$



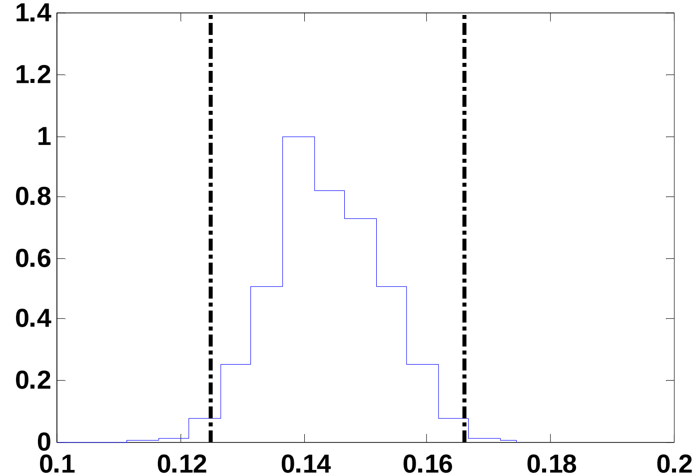
$(r_5 + r_6) / c_{sb}$



$(r_5 + r_6) \cdot \alpha_{sb}^{(f)}$



$\alpha_{sb}^{(f)}$ **in dB/m•kHz**



$\alpha_{sb}^{(\lambda)}$ **in dB/λ**

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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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