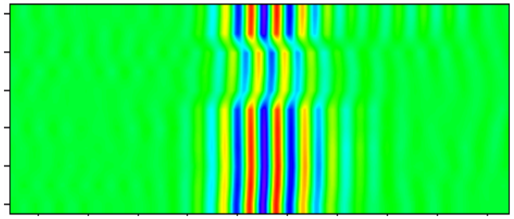
Wide-band Attenuation Measurements in New Jersey Shelf Sediments

Altan Turgut
Naval Research Laboratory
Acoustics Division, Washington DC 20375

(Work supported by the Office of Naval Research)



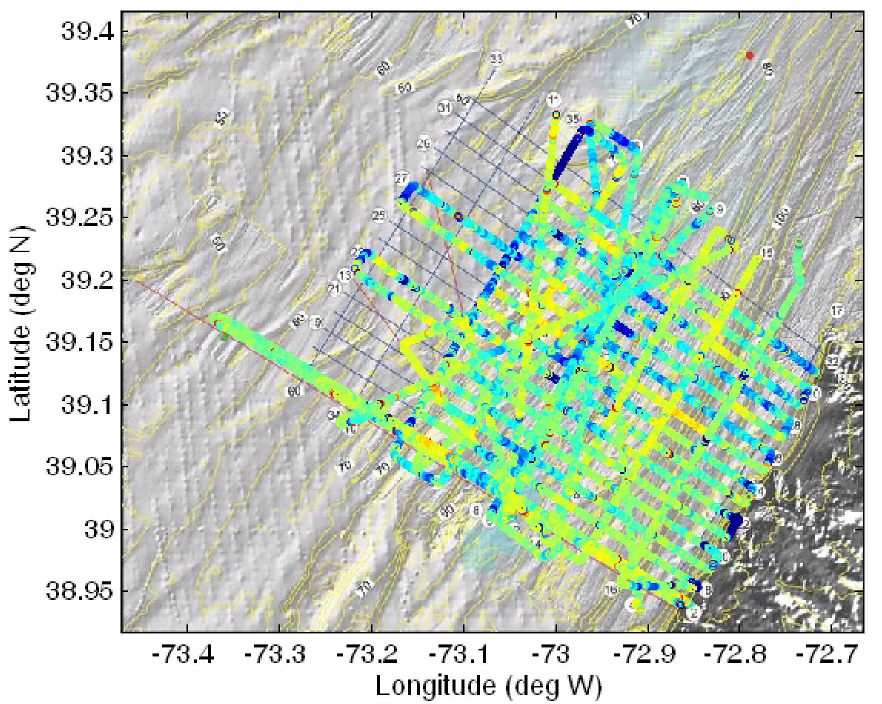
ASA 156th Meeting
Miami, FL
November 11, 2008

Outline

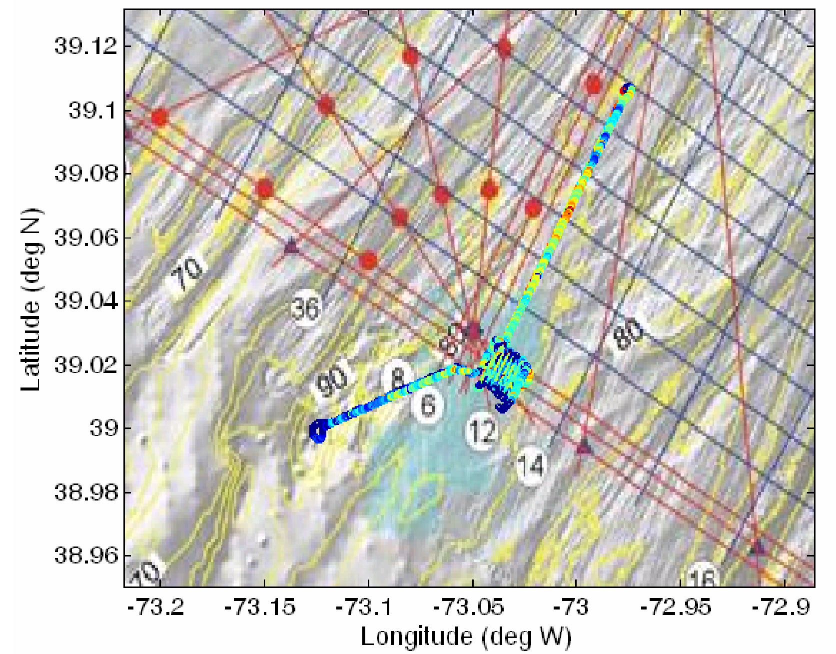
- SW06 GeoProbe measurements of sediment sound speed and attenuation (10-80 kHz)
  - Frequency-dependency of attenuation and sound-speed dispersion
  - Comparison with extended Biot theory predictions
- SW06 Chirp Sonar measurements (3-8 kHz)
  - Attenuation estimation from the frequency-shift method
  - Attenuation estimation from the spectral-ratio method

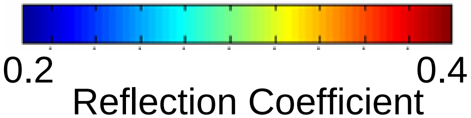
SW06 Chirp Sonar Bottom Reflection Coefficient Measurements

SW06 Large-Area Survey



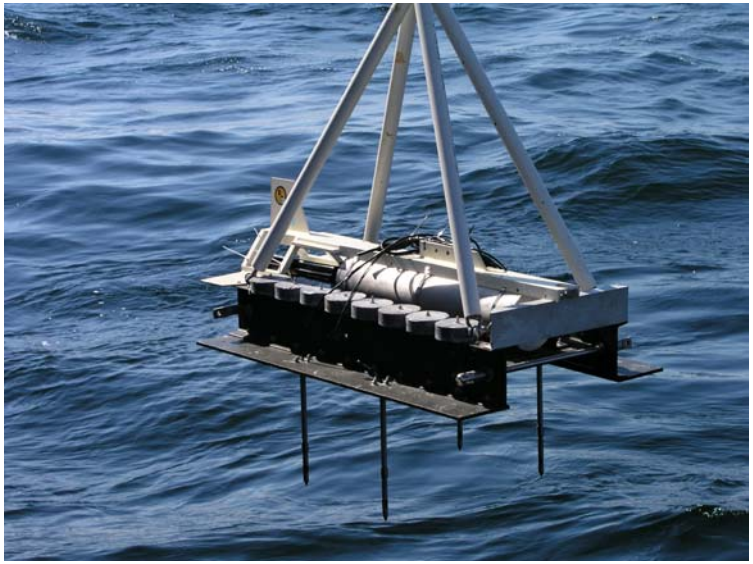
SW06 High-Resolution Survey



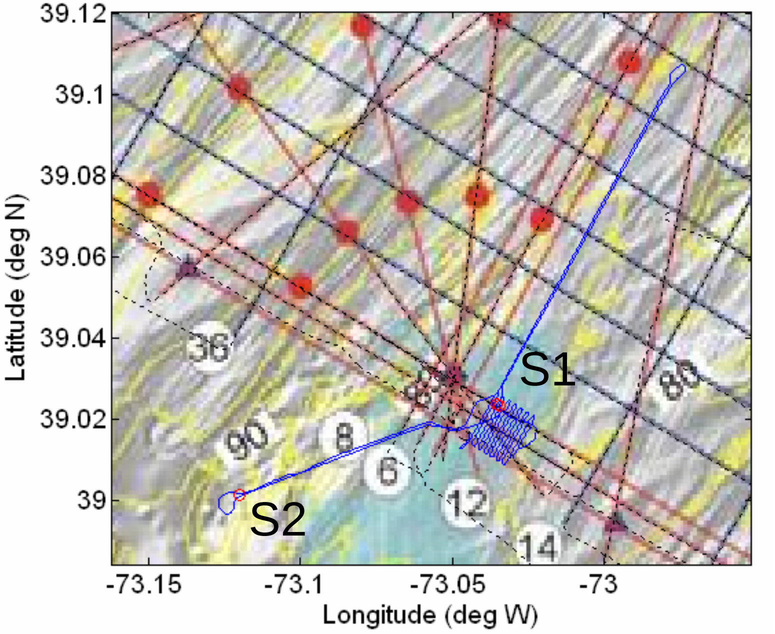


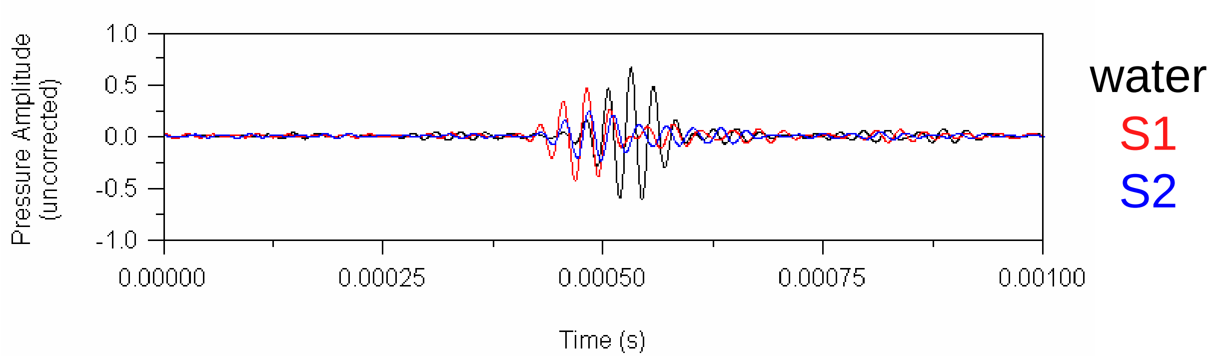
GeoProbe Measurements

NRL GeoProbe



GeoProbe Sites

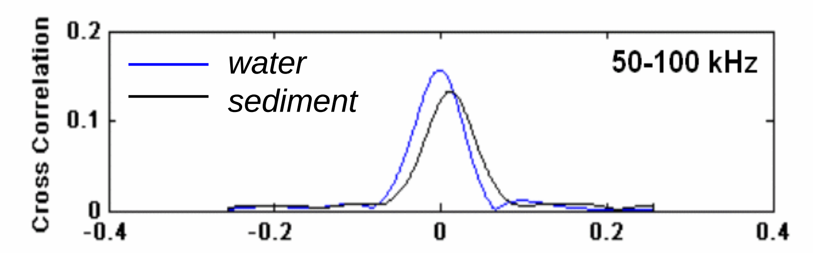




Group Speed, Phase Speed, and Attenuation Measurements

GROUP SPEED BY INTER-RECEIVER CORRELATION TIMING METHOD

Cross-correlations between two receivers (d1=45 cm and d2=75 cm)



Time (ms)

PHASE SPEED AND ATTENUATION BY SPECTRAL RATIO METHOD

Phase Delay:

$$\Delta\phi(\omega) = \tan^{-1}\{\mathrm{Im}[P_1(\omega)/P_2(\omega)]/\mathrm{Re}[P_1(\omega)/P_2(\omega)]\}$$

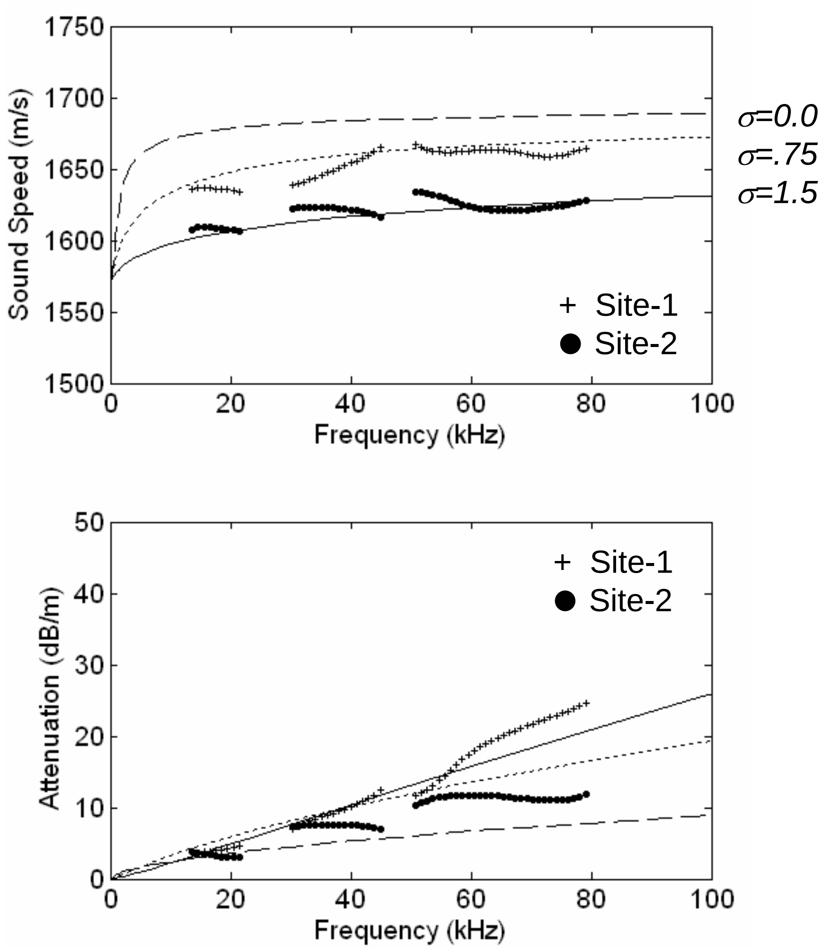
Phase Speed:

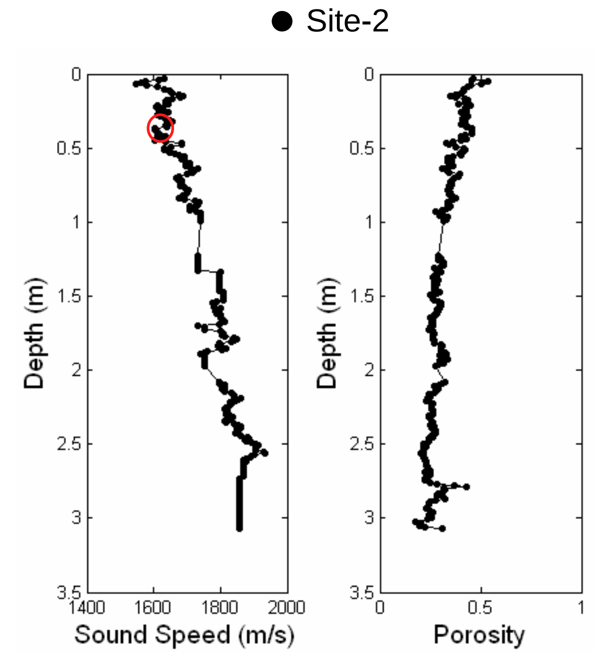
$$c_p = c_0\left(1 - \frac{c_0\Delta\phi}{\omega(d_2 - d_1)}\right)^{-1}$$

Attenuation (dB/m):

$$\alpha = \frac{8.686}{2(d_2 - d_1)}\ln[S_1(\omega)/S_2(\omega)].$$

Geoprobe and Core Measurement Results

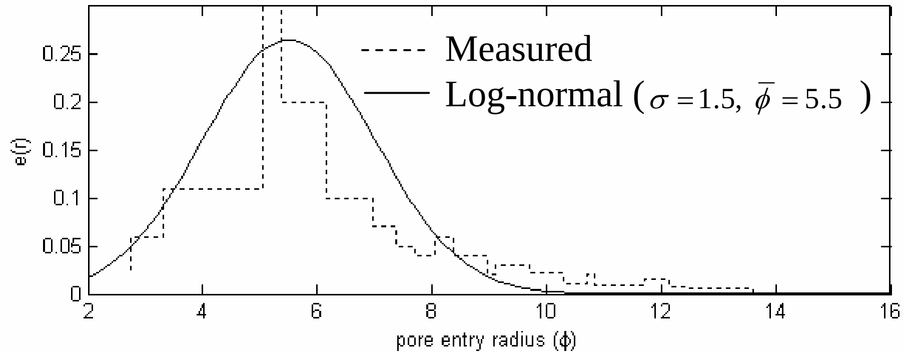


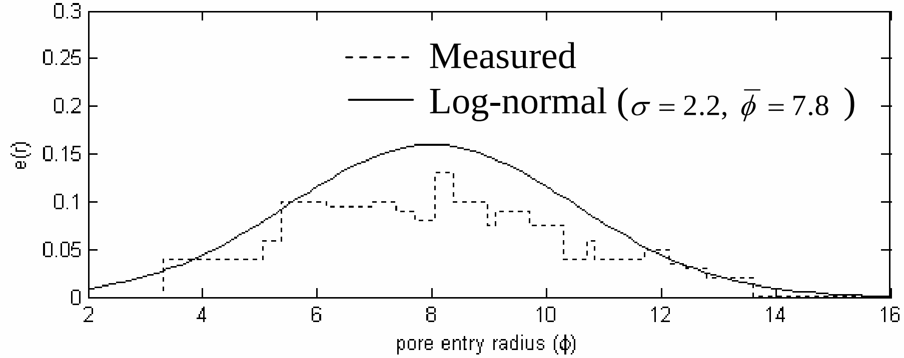


(JASA-EL, September 2008)

Measured Pore-size Distribution

(New Jersey Shelf Sediments)

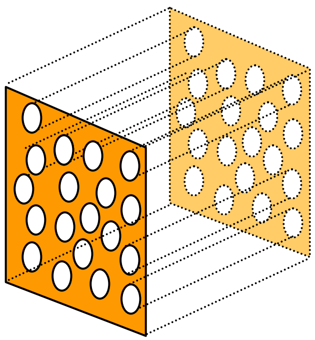




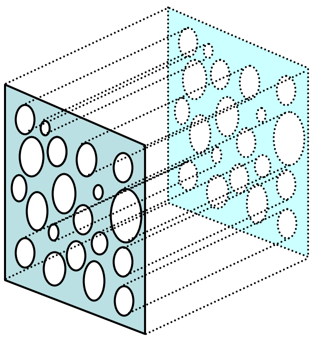
(Univ. of Miami Report, 1987)

Extended Biot Theory

UNIFORM PORE SIZE



DISTRIBUTED PORE SIZE
(Log-normal pore-size distribution)



The ratio of the total friction force to the average fluid velocity

$$\frac{2\pi r\,\tau(\omega)}{U(\omega)} = \frac{2\pi\eta\kappa K(\kappa)}{1+2iK(\kappa)/\kappa}.$$

$$G(\omega) = \frac{\langle T(\omega)\rangle}{\langle U(\omega)\rangle} = \frac{2\beta\eta r^{-2}\kappa K(\kappa)}{1+2iK(\kappa)/\kappa},$$

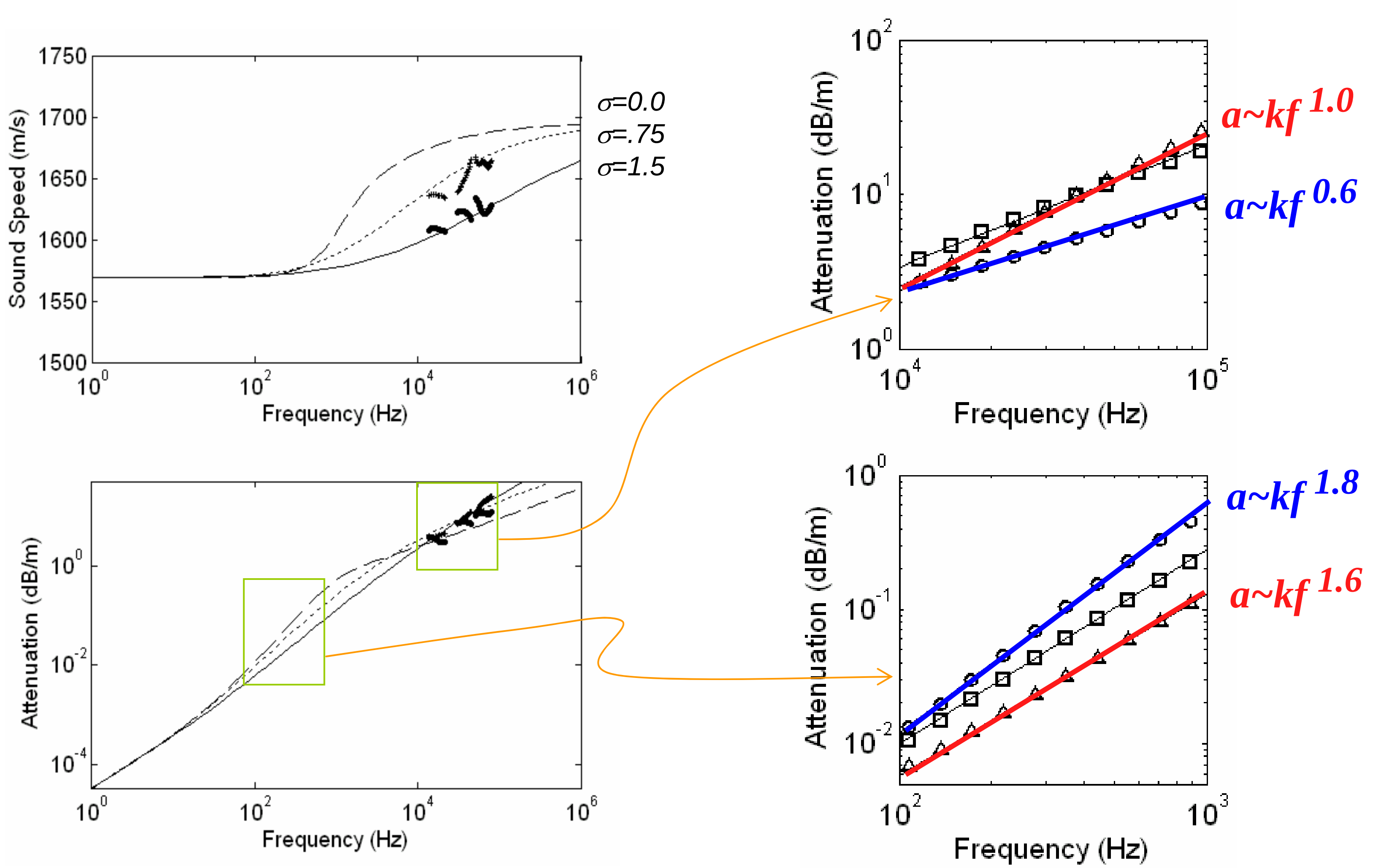
Viscosity correction factor (Oscillatory flow/laminar flow)

$$F(\omega) = \frac{\tau(\omega)/U(\omega)}{\tau(0)/U(0)} = \frac{\kappa K(\kappa)}{4[1+2iK(\kappa)/\kappa]}.$$

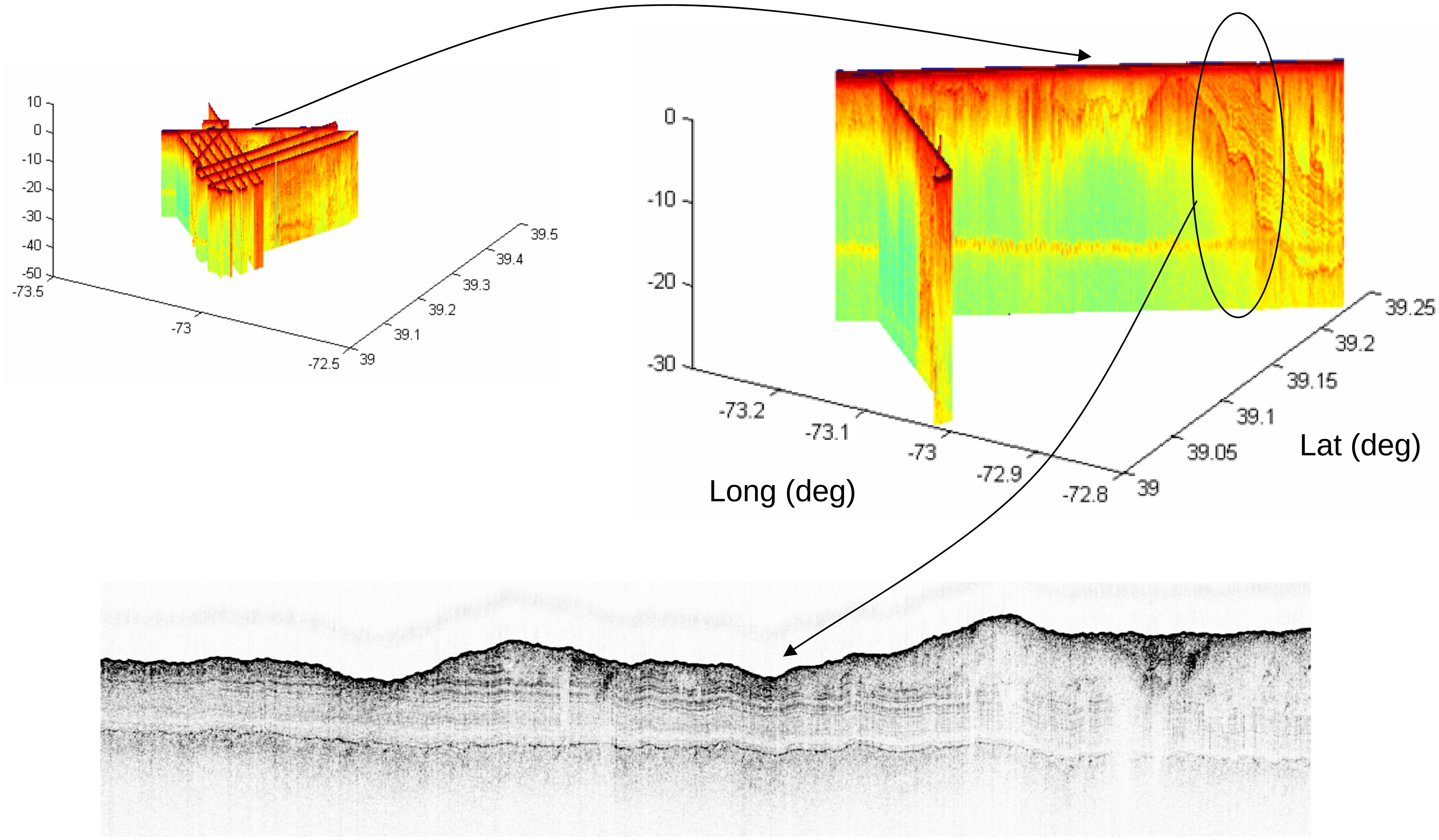
$$F_b(\omega) = \frac{G(\omega)}{G(0)} = \frac{k_s}{\beta}\,\frac{2\int_0^\infty r^{-2}\kappa K(\kappa)e(r)\,dr}{\int_0^\infty [1+2iK(\kappa)/\kappa]e(r)\,dr}.$$

(Yamamoto&Turgut, JASA 1988)

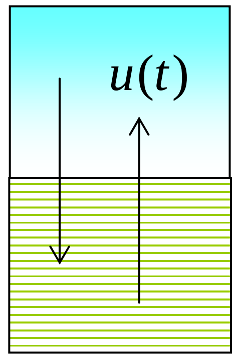
Frequency-Dependency of Attenuation and Sound-Speed Dispersion

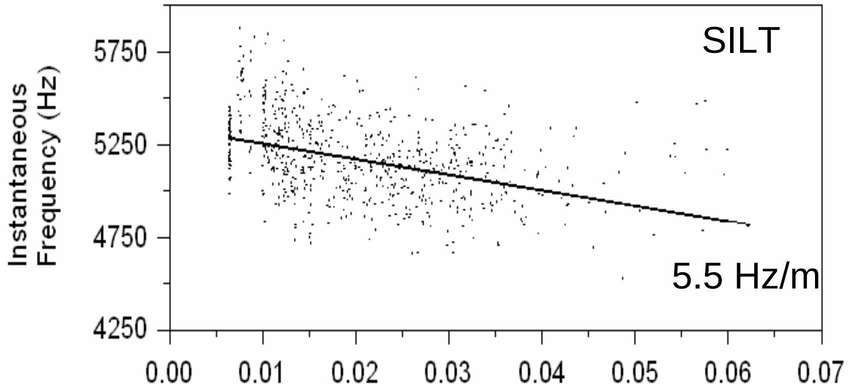


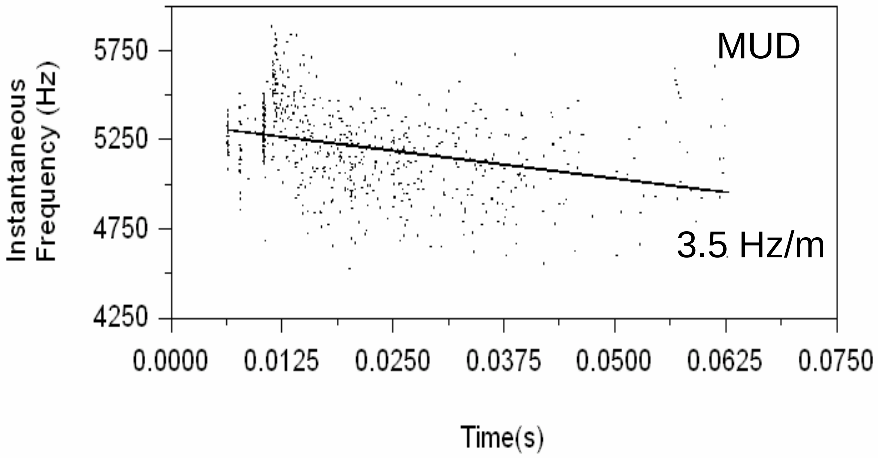
Chirp Sonar subbottom profiles



Frequency-Shift Method for Attenuation Estimation







$$u(t) = E(t)\, \mathrm{e}^{i\phi(t)}$$

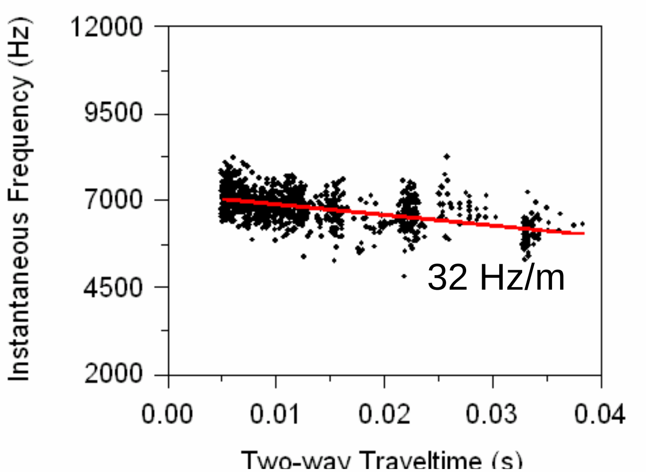
$u(t)$: Analytic signal

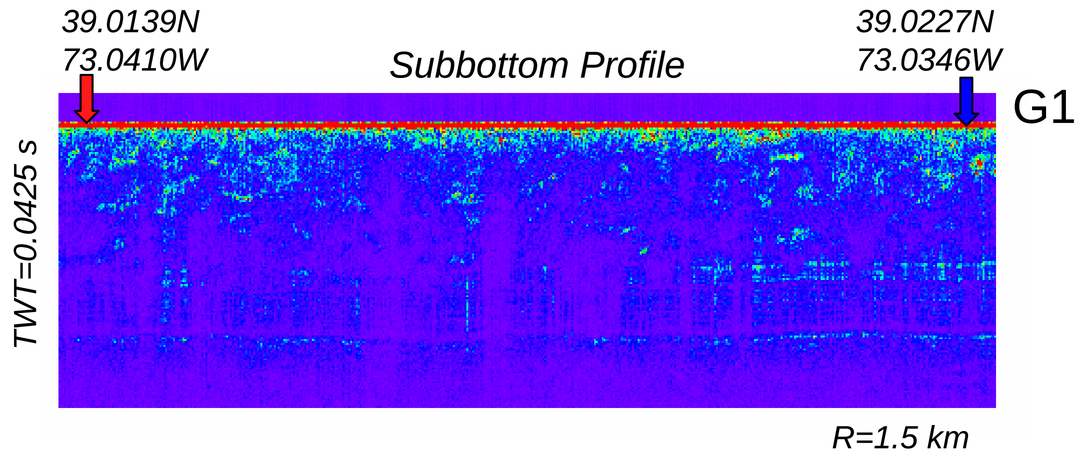
$E(t)$: Envelop function

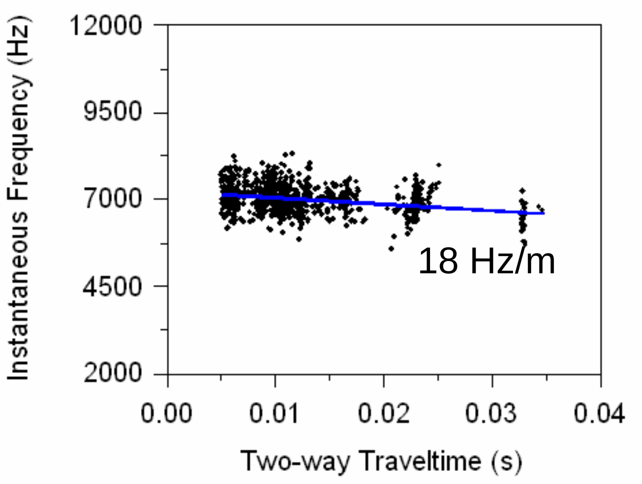
Instantaneous Frequency:

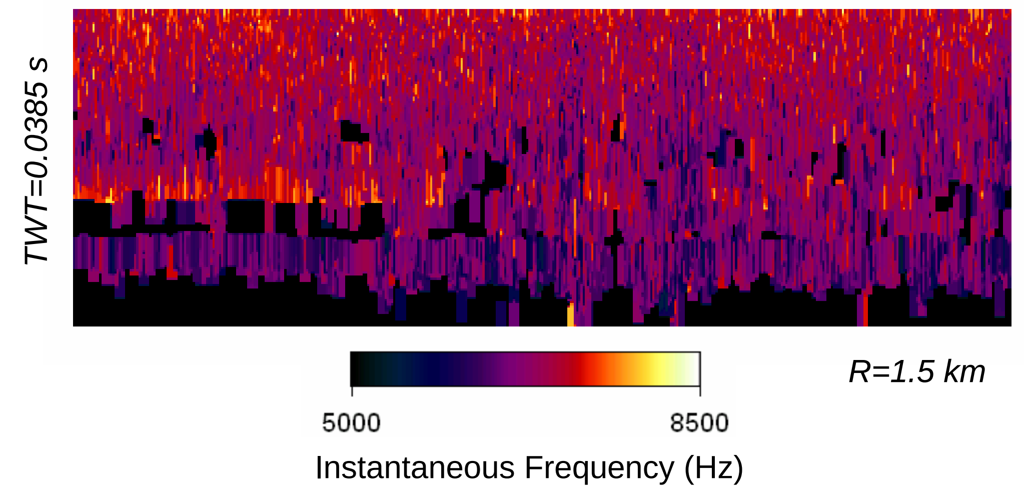
$$\omega_t = \frac{d\phi(t)}{dt} = \frac{2}{\Delta t} \mathrm{Im}\left(\frac{u_t - u_{t-\Delta t}}{u_t + u_{t-\Delta t}} \right)$$

Frequency-Shift Method for Attenuation Estimation

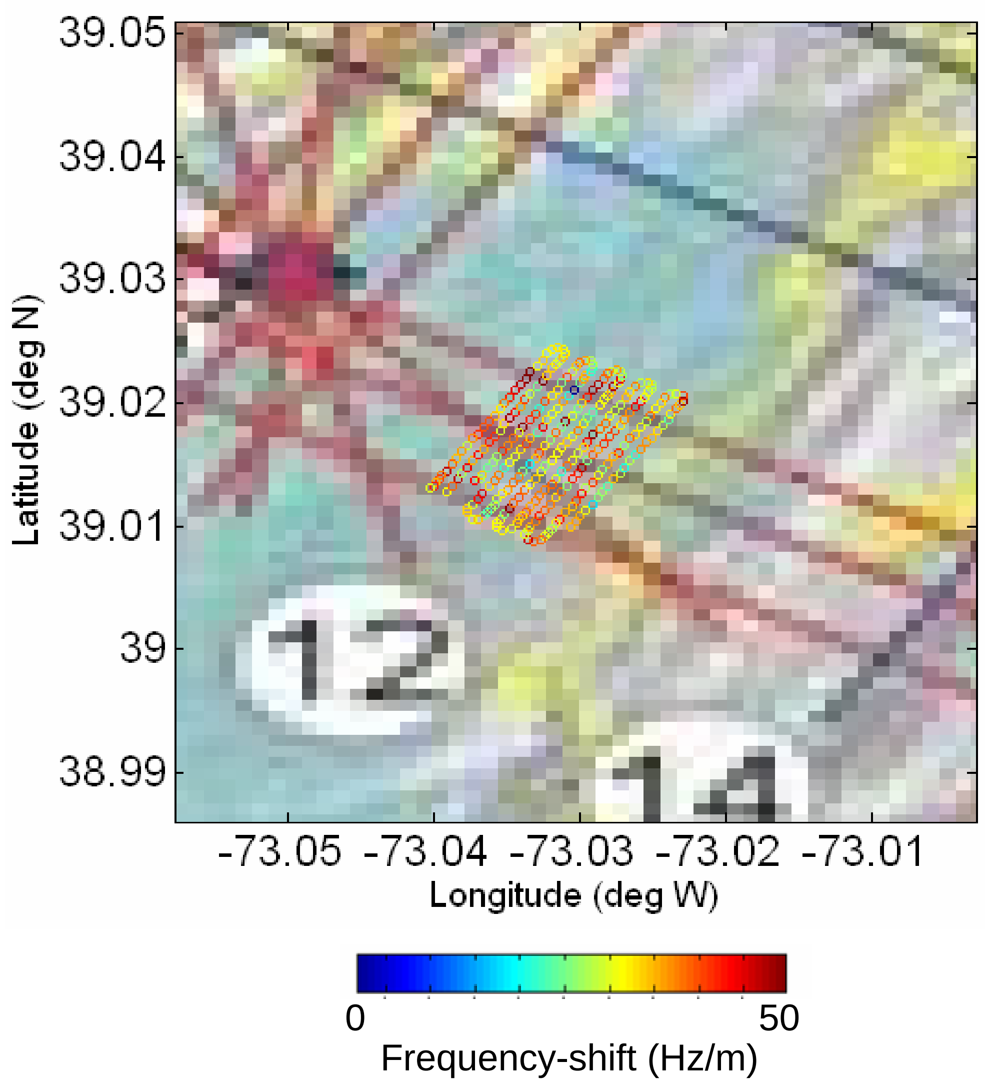




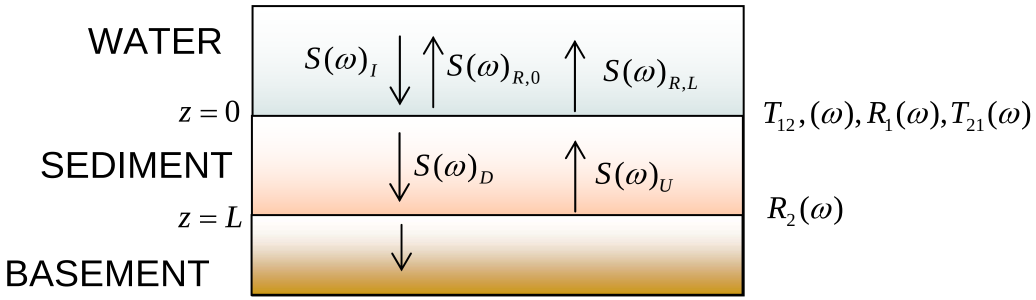




Frequency-Shift at High-Resolution Survey Area



Estimation of Attenuation Roll-off



Amplitude spectrum of sediment/basement echo:

$$S(\omega)_{R,L} = S(\omega)_I T_{12}(\omega) R_2(\omega) T_{21}(\omega) e^{-2\alpha L}$$

Amplitude spectral ratio:

$$X(\omega) = \frac{S(\omega)_{R,L}}{S(\omega)_{R,0}} = \aleph(\omega) 10^{-\frac{2aL}{20}}, \quad a\,(\mathrm{dB/m})$$

Relative attenuation:

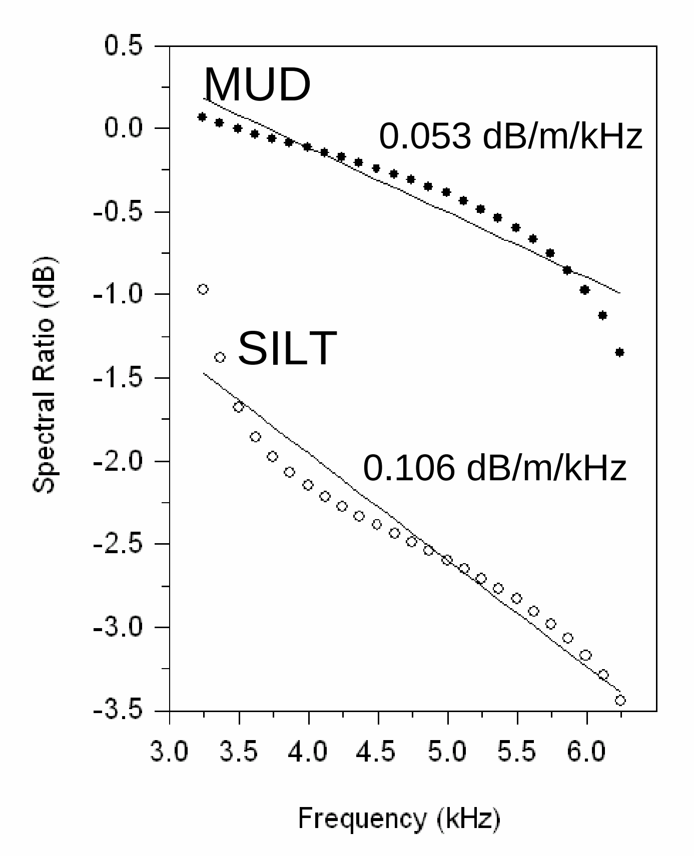
$$A(\omega) = \frac{20\log X(\omega)}{2L} = \frac{20\log \aleph(\omega)}{2L} - a$$

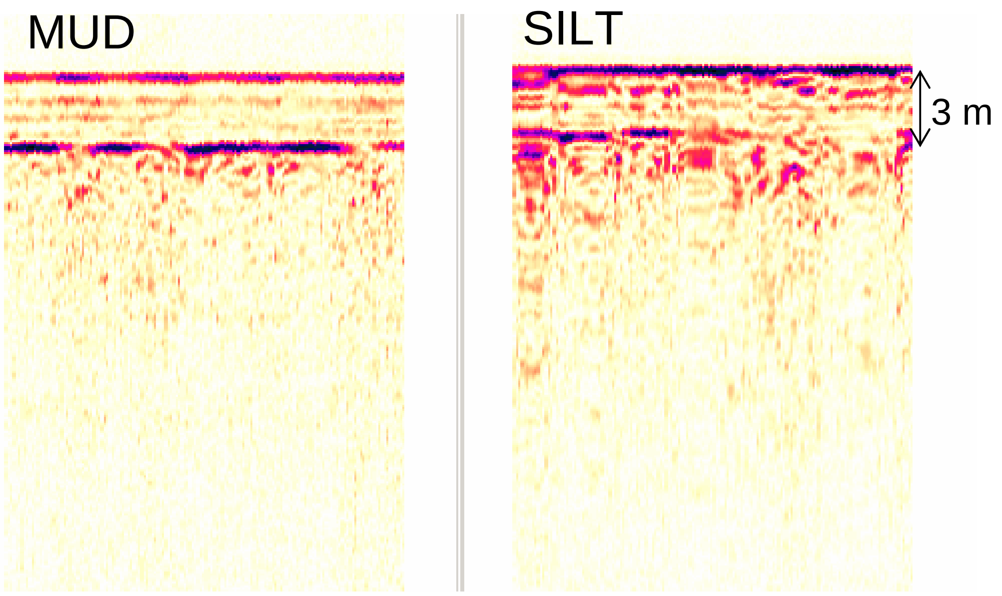
Attenuation roll-off:

$$\frac{dA(\omega)}{d\omega} \approx \frac{da}{d\omega}$$

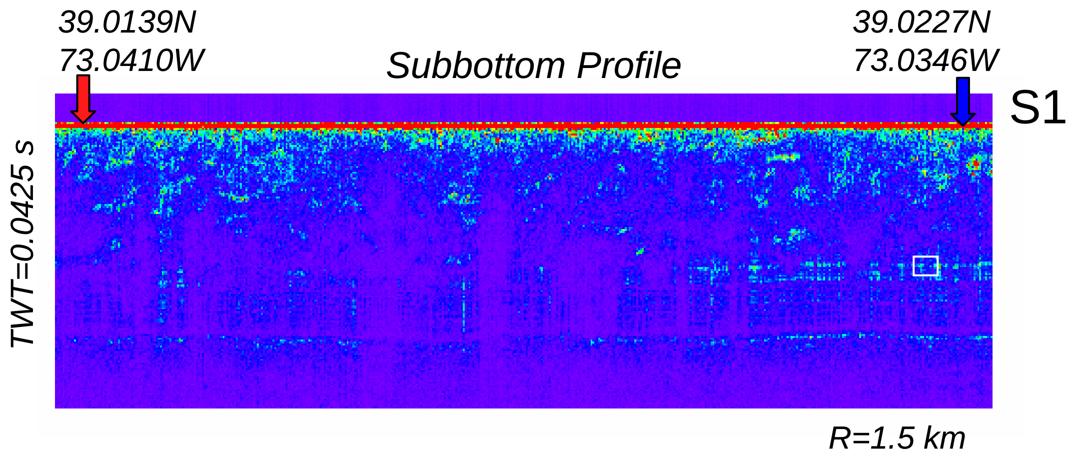
(Schock, IEEE J. Ocean. Eng, 2004)

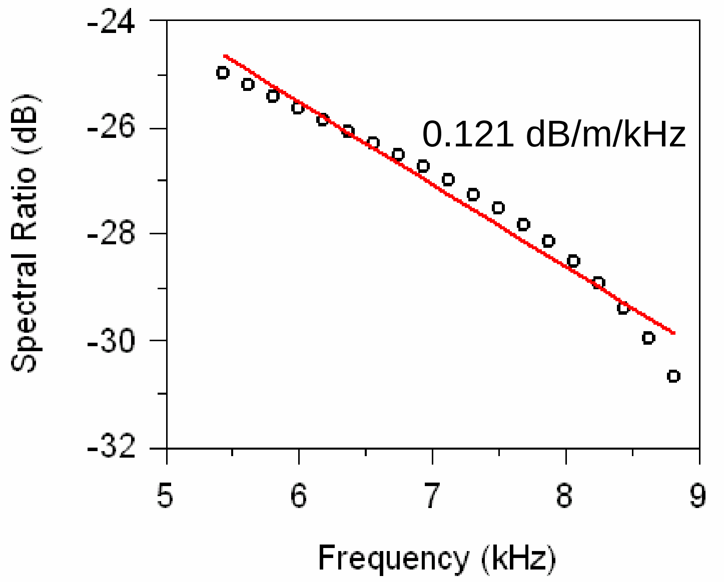
Attenuation Roll-off at Muddy and Silty Sites





Attenuation Roll-off at High-Resolution Site





Summary

- High-quality chirp sonar data were used for large-area geological assessment and high-resolution bottom characterization and attenuation estimation
- Broadband (10-80 kHz) sediment sound-speed and attenuation were measured by a GeoProbe system
- Linear frequency-dependency of attenuation and mild sound-speed dispersion were observed at 10-80 kHz frequency at two silty-sand sites
- Extended Biot theory predicts $a \sim kf^{1.7}$ at 100-1000 Hz and $a \sim kf^{1.0}$ at 10-100 kHz.