Shallow-water reverberation: Geoacoustic inversion

Ji-Xun Zhou
School of Mechanical Engineering, Georgia Institute of Technology
Atlanta, GA 30332-0405
phone: (404) 894-6793 fax: (404) 894-7790 email: jixun.zhou@me.gatech.edu

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LONG-TERM GOALS

The long-term goals of this work are: to develop a practical model for predicting reverberation level (RL), echo-reverberation ratio and reverberation vertical coherence (RVC) in shallow water; to characterize seabottom geoacoustic parameters (sound speed and attenuation) and scattering function from high quality reverberation data in a frequency range of 100-2000Hz.

OBJECTIVES

The scientific objectives of this effort include: (1) To set up a high quality data base on RL and RVC as a function of frequency and reverberation time from at-sea measurements, including Yellow Sea ’96 and the Asian Sea International Experiment (ASIAEX). (2) To develop shallow water reverberation models for RL and VRC, using seabottom scattering models with a physical basis. (3) To simultaneously invert bottom geoacoustic parameters and scattering function from reverberation data.

APPROACH

This year we focus on geoacoustic inversion from reverberation. SW reverberation from a single shot provides a continuous spatial sampling of the surrounding sound field up to several tens of kilometers. It involves bottom controlled two-way sound propagation and bottom scattering process, which brings back rich information on seabottom geoacoustic parameters. SW reverberation can thus be used as the basis for a quick and inexpensive method for geoacoustic inversion. Moreover, the optimal array processing techniques in shallow water require the knowledge of the spatial correlation of reverberation. Assuming a seabottom scattering model is separable and reciprocal, $M_b(\theta,\phi) = M(\theta)M(\phi)$, we have an expression for SW reverberation vertical coherence as follows:

$$\rho(\Delta z, r, z; z_0) = \{\sum_n \overline{|\Phi_n(z)|^2}\,\overline{|\Phi_n(z_h)|^2} \cos[k(z)\Delta z \sin\theta_n(z)] M[\theta_n(z)] \exp(-2\beta_n r)/k_n\}$$
$$\times\{\sum_n \overline{|\Phi_n(z)|^2}\,\overline{|\Phi_n(z_h)|^2} M[\theta_n(z)] \exp(-2\beta_n r)/k_n\}^{-1}$$

Here ρ is the normalized vertical correlation coefficient of reverberation. Δz is a separation between a pair of hydrophone. k_n and β_n are the horizontal wave number and attenuation factor of the nth mode respectively. $Sin\theta_n(z) = [1 - k_n^2/k^2(z)]^{1/2}$. $\overline{|\Phi_n(z)|^2}$ is the slow depth-varying distribution function of mode energy. This model was originally expressed by the average angular spectrum of sound

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14. ABSTRACT

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propagation from ray-mode analogies. It has been converted back to a more familiar summation of normal-modes which is suitable for numerical computation with normal-mode codes. This model is used to compare with the experimental RVC data, obtained from the ASIAEX in the East China Sea, and to invert bottom sound speed and attenuation. Initially, for simplicity we assume that the bottom is homogeneous half-space fluid medium, and that the bottom scattering obeys the modified Lambert's law, $M(\theta_n,\phi_n)=\mu Sin\theta_n \, Sin\phi_m / V(\theta_n)V(\phi_m)$. Future work will use bottom scattering models with a more physical basis and consider possible layered structure of the bottom.

RESULTS

We have developed a model for reverberation vertical coherence in shallow water. The average reverberation vertical coherence as a function of time and frequency has been obtained from the ASIAEX, conducted on June 3, 20001 in the East China Sea. Measured reverberation cross-correlation coefficients as a function of time and frequency are in good agreement with theoretical predictions.

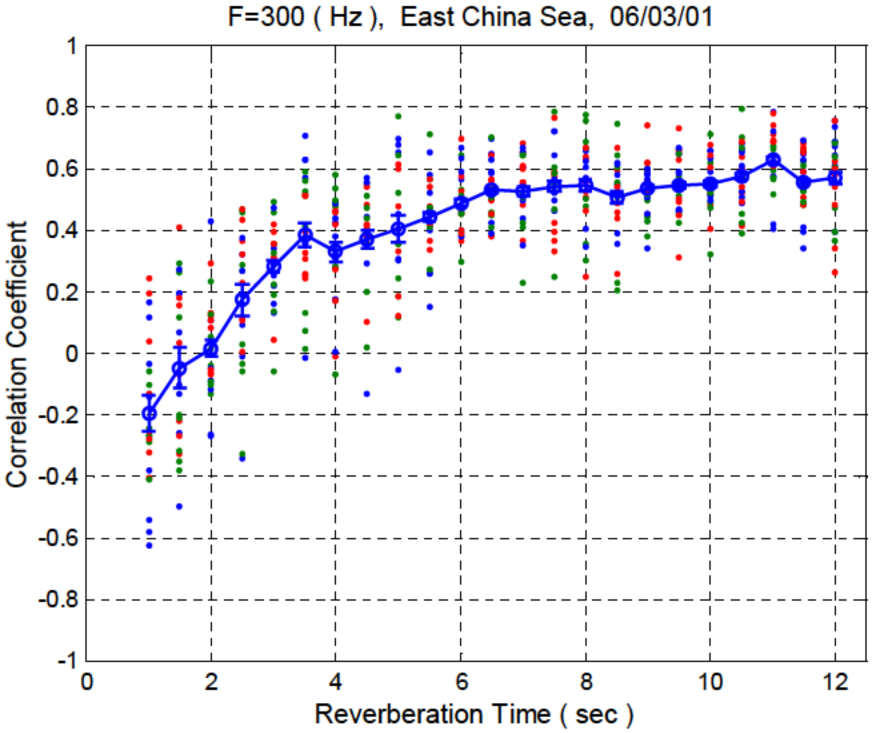

Figure 1. Statistic characteristics of SW reverberation vertical coherence

The RVC is a statistical characteristic of the sound field. It requires an ensemble average. As a typical example of our data, Figure 1 shows 24 RVC realizations, their average value and the standard deviations at 300 Hz for a hydrophone separation of 4m. The RVC curves differ a lot from one realization to another. However, the RVC standard deviations (STD) are very small.

From the best match between the measurements and predictions of RVC (using the least squares method), sound speed and attenuation in sediments at the ASIAEX site have been inverted in a frequency range of 100-1300 Hz. As examples, Figure 2 shows the match details for 300 Hz.

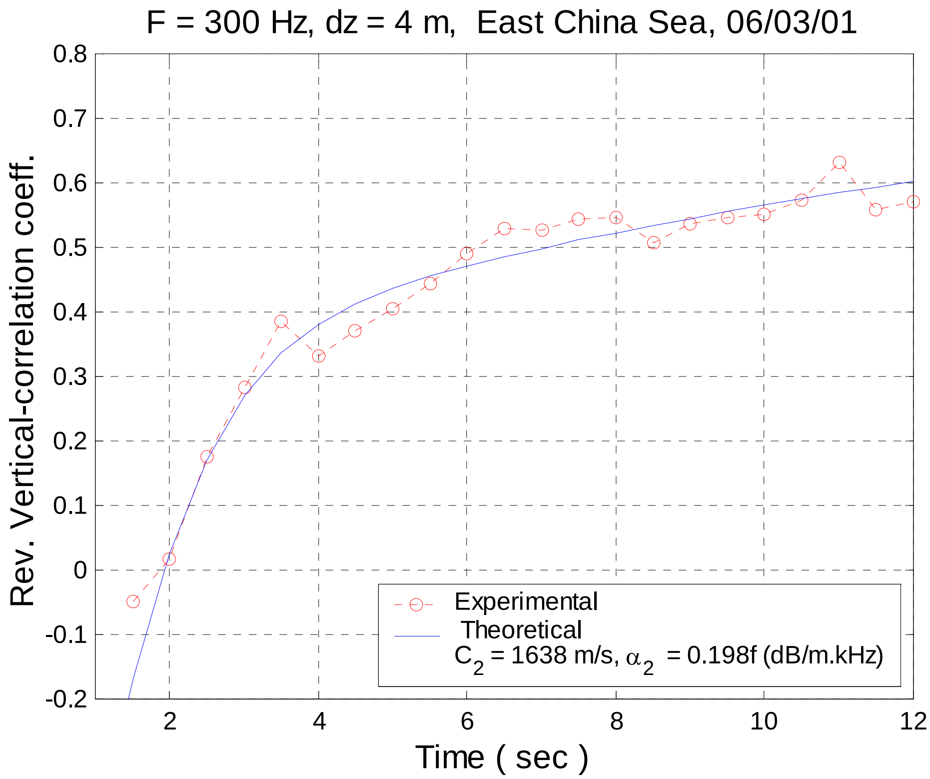

Figure 2. RVC-inverted bottom sound velocity and attenuation at 300 Hz

The theoretical RVC is numerically evaluated for bottom sound speed between 1500 and 1900 m/s at 1m/s intervals with attenuation coefficients between 0 and 0.6 dB/m.kHz at 0.001 dB/m.kHz intervals. The pair of bottom sound speed and attenuation values for which the numerical RVC curves best match the experimental RVC data is easily and uniquely determined. Figure 3 shows the RVC-inverted bottom sound velocity as a function of frequency at the ASIAEX site. The averaged velocity from 100Hz to 1300 Hz equals to 1626 m/s. It corresponds to a sound speed ratio (relative to the overlying seawater) of 1.07. It is close to the values predicted by Hamilton's empirical model for silty sand or sandy silt bottom. In general, higher the frequency, the lower the equivalent bottom sound velocity. It shows that the sound velocity in the sediments might increase with increasing the depth. Figure 4 shows the RVC-inverted bottom sound attenuation as a function of frequency at the ASIAEX site in the East China Sea. A dashed line corresponds to $\alpha_2 = 0.182 \cdot f\ (dB/m \cdot kHz)$. The bottom sound attenuation at the ASEAEX site is lower than one predicted by Hamilton's empirical model.

Both the RVC-inverted sound velocity and attenuation are also close to the values obtained by inversion from sound propagation data using different methods at the same site. The RVC-inverted bottom sound speed and attenuation are equivalent (effective) values due to two reasons: they are average values for an area, ringed by two radii of 1.52 km and 9.12km (corresponding to 2-12s reverberation); we assume that the bottom is a homogeneous half-space fluid medium.

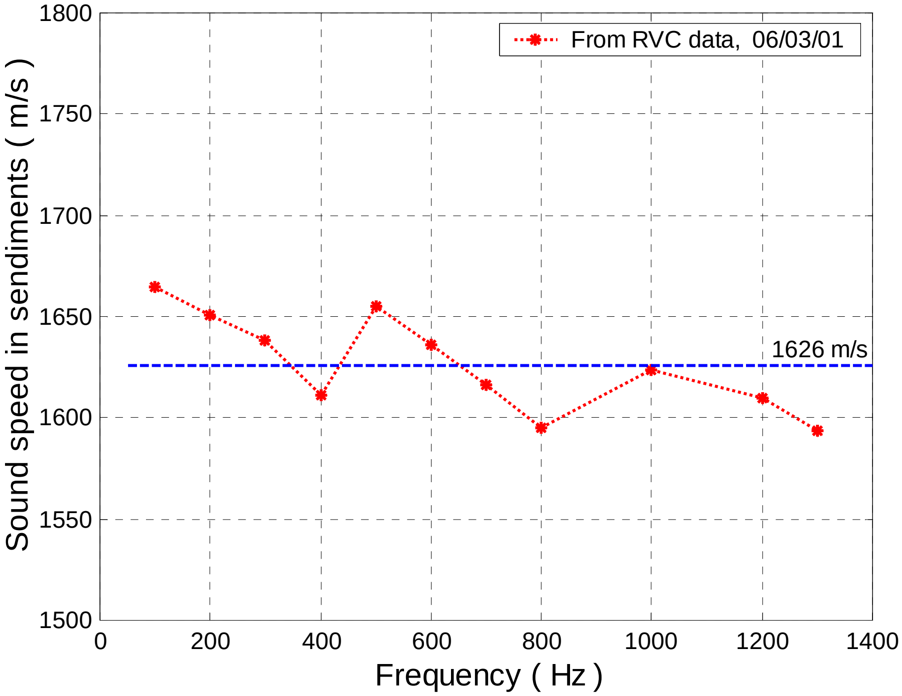

Figure 3. RVC-inverted bottom sound velocity in the East China Sea.

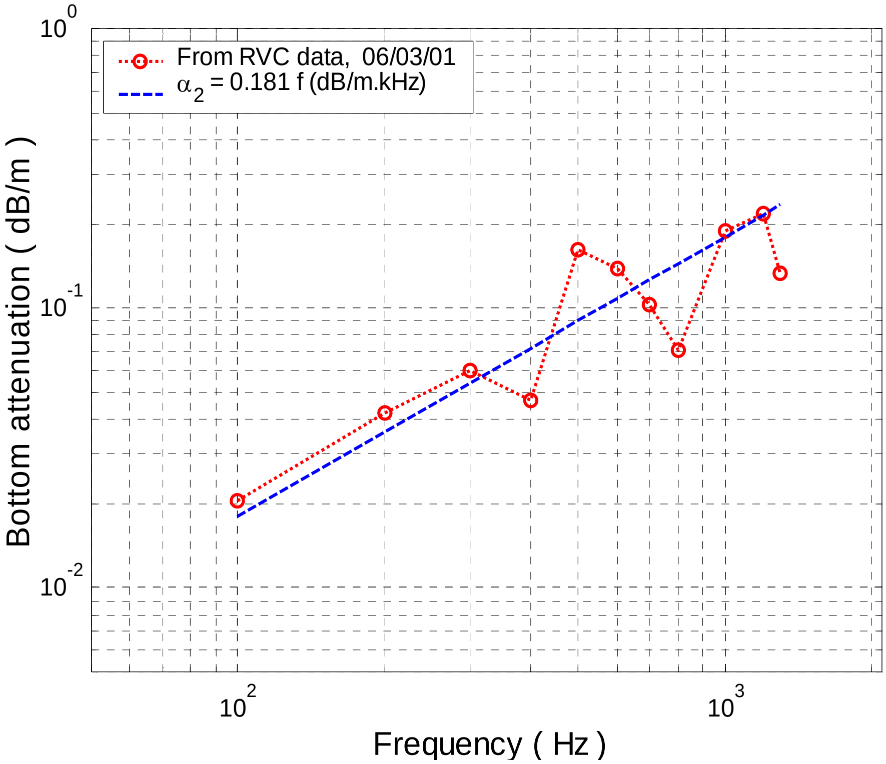

Figure 4. RVC-inverted bottom sound attenuation in the East China Sea.

IMPACT/APPLICATIONS

The theoretical model and experimental data on the reverberation vertical coherence will be useful for optimal array processing techniques in shallow water. The preliminary results also show that the reverberation vertical coherence can be a powerful characteristic for use in fast inversion of seabottom acoustic parameter in shallow water. The principle may be used as the basis of a new real-time measurement system.

PUBLICATIONS

1. J.X. Zhou and X.Z. Zhang, “Inversion of seabottom acoustic parameters from shallow-water reverberation,” WESTPAC VIII Conference proceedings, TA44, (Melbourne, Australia, 7-9 April, 2003).
2. Z.H. Peng and J.X. Zhou, “In-plan bistatic backward scattering from an inhomogeneous seabed,” WESTPAC VIII Conference proceedings, WA21 (Melbourne, Australia, 7-9 April, 2003).
3. J.X. Zhou and X.Z. Zhang et al., “Reverberation vertical coherence and seabottom geoacoustic inversion in shallow water,” [submitted to IEEE/JOE].