

The effect of ship noise on the horizontal correlation of ambient noise

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I. INTRODUCTION

The spatial correlation of the noise field is always a very important topic in ocean acoustics [1-5]. The noise data were measured by a horizontal line array during a three days experiment conducted in the Yellow Sea in June 2005. It is found that the horizontal correlation of the measured noise near a sea route at low frequencies has an obvious difference with that predicted by the classical ambient noise model. The analysis indicates that the discrete ships may have an important effect on the horizontal correlation of the noise field near a sea route.

II. THEORY

For the case when the noise sources are randomly distributed near the ocean surface and the noise sources are uncorrelated, the normal mode representation of the cross-spectral density of ocean sound from surface noise sources at two separated hydrophones can be expressed as

$$C_{\omega}(R, z_1, z_2) = \frac{i\pi q^2}{\rho^2 k^2} \sum_m \sum_n \Psi_m(z_s) \Psi_m(z_1) \Psi_n(z_s) \Psi_n(z_2) f_{mn} \times [H_0^{(1)}(k_{mn} R) + H_0^{(2)}(k_{mn}^* R)] \quad (1)$$

where $f_{mn} = 1/(k_{mn}^2 - (k_{mn}^*)^2)$, $\Psi_m(z)$ is the eigenfunction of the m th normal mode, k_{mn} is the eigenvalue of the m th mode, $H_0^{(1)}$ and $H_0^{(2)}$ are the Hankel functions, R is the distant separation between two hydrophones, z is the source depth, z_1 and z_2 are the receiver depths, q is the surface source strength.

When the hydrophones are located near a sea route, the measured sound field is often the combination of the surface noise sources and the nearby discrete ships. It can be derived that the cross-spectral density of the ocean sound from both the random surface noise sources and a ship located at the point (\mathbf{r}, z) can be written as

$$C_{\omega}(r_1, r_2, z_1, z_2) = \int \langle S(\mathbf{r}') S(\mathbf{r}'') \rangle g(\mathbf{r}_1, \mathbf{r}', z_1, z_1') g(\mathbf{r}_2, \mathbf{r}'', z_2, z_2'') d^2 \mathbf{r}' d^2 \mathbf{r}'' \\ + |S_1(\mathbf{r})|^2 \sum_m \sum_n \Psi_m(z) \Psi_m(z_1) \Psi_n^*(z) \Psi_n^*(z_2) e^{-j(k_m R_1 - k_n R_2)} \quad (2)$$

where S_1 is the source level of the ship, R_1 is the range between the ship and the first hydrophone, and R_2 is the range between the ship and the second hydrophone. In this paper, Eq. (1) is called the classical noise model and Eq. (2) is called the combinational model.

III. EXPERIMENTS

In June 2005, three days of ambient noise measurements were conducted in the Yellow Sea. The water depth was 31 m. A horizontal line array consisting of 48 hydrophones at 2 m separation was deployed on the bottom. Noise signals were recorded with a sample frequency of 4.0 kHz for each channel.

The received time series at two hydrophones denoted by $x_1(t, \Delta T_i)$, $x_2(t, \Delta T_i)$ were divided into portions of 8192 samples (roughly $\Delta T_i = 2s$, $i = 1, 2, \dots, n$) and transformed into the frequency domain denoted by $X_1(f, \Delta T_i)$, $X_2(f, \Delta T_i)$ with a standard fast Fourier transform (FFT). The horizontal correlation coefficient of the noise between two receivers is averaged over n time segments according to the following equation:

$$C_{12} = \frac{1}{n} \sum_{i=1}^n \frac{X_1(f, \Delta T_i) X_2^*(f, \Delta T_i)}{\sqrt{X_1(f, \Delta T_i) X_1^*(f, \Delta T_i)} \sqrt{X_2(f, \Delta T_i) X_2^*(f, \Delta T_i)}}. \quad (3)$$

Experimental horizontal correlation as a function of hydrophone separation at frequency of 100 Hz is shown in Fig. 1 with circles. The numerical prediction by the classical noise model (Eq. (1)) is plotted in Fig. 1 as the solid curve. It is shown that the prediction from the classical noise model is largely diverse from the measured data. The geoacoustic parameters used in the numerical prediction are inverted by Li [6]. Numerical simulations also show that the uncertainties of ocean environment parameters are not the cause of differences between the experimental results and the numerical prediction.

The beamforming result of the same data indicates that there is a ship at bearing of 42° . Therefore the combinational model is used to explain the measured data. The source level of the ship and the range between the ship and the receiver are unknown. Those two parameters are adjusted to fit the measurements best. The numerical prediction from the combinational model (Eq. (2)) is shown as the dashed curve in Fig. 1. Comparing the measured data and the numerical calculations in Fig. 1, one can conclude that the combinational model can explain the measured horizontal correlation well. Nearby discrete ships might have large effects on the horizontal correlation of the noise.

IV. CONCLUSION

The noise measurements over three days during an experiment conducted in the Yellow Sea in June, 2005 were analyzed. Obvious difference between the experimental horizontal correlation and the classical noise model at low frequencies was observed and explained by the existence of nearby discrete ships.

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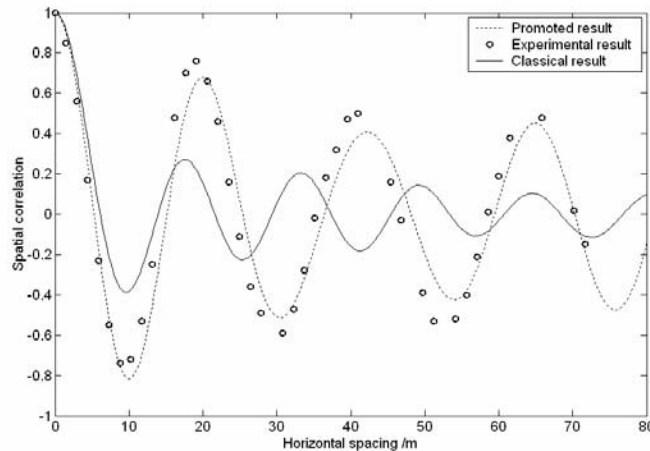


Fig. 1. The comparison of the experimental horizontal correlation with the numerical results