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Infrasonic and Low-Frequency Ambient-Noise Measurements Off Newfoundland

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NAVAL UNDERWATER SYSTEMS CENTER

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ADMINISTRATIVE INFORMATION

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ABSTRACT

Intrasonic and low-frequency ambient-noise signals were measured using three bottom-mounted omnidirectional hydrophones located on the Grand Banks off Newfoundland. Ambient-noise signals from two hydrophones at depths of approximately 600 fm and one at approximately 2300 fm were recorded on magnetic tape continuously for 8 days from 20 to 28 July 1972. The average value of ambient noise in 25 contiguous 1/3-octave bands, at frequencies ranging from 1 to 250 Hz, was measured for consecutive 10-s intervals. Hourly averages were then computed by grouping the 10-s averages into hourly intervals. Autocorrelations of ambient-noise level and wind speed, as well as crosscorrelations of ambient-noise level with wind speed, are presented. The measured ambient-noise spectra in the 4- to 250-Hz range are produced, predominantly, by large ships local to or near the listening area, whereas in the 1- to 4-Hz range a strong wind-speed dependence is observed.

It is suspected that the high values of standard deviation (as a function of frequency) were caused by the proximity of the few ships in the area to the hydrophones. The correlation coefficient of wind speed to sea noise is variable and directly dependent on the wind-speed distribution and the amount and location of shipping during the measurement period.

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INTRODUCTION

Ambient noise in the sea is a composite of many noise sources. The major contributors affecting ambient noise are biological sources, rain, shipping, and the interaction between the atmosphere and the sea surface that is commonly referred to as wind-speed-dependent noise. In a comprehensive survey conducted by Wenz,[1] many sources of ambient sea noise have been identified. The two major ones dominating the spectra in the 1-Hz to 20-kHz frequency range in most ocean areas are wind and shipping. Within this range there is:

a. A wind-dependent component in the 1- to 100-Hz band whose probable source is turbulent pressure fluctuations.

b. A mid-frequency component most apparent in the 10-Hz to 1-kHz band whose probable source is ocean traffic.

c. A high-frequency wind-dependent component extending over the 50-Hz to 20-kHz band that results, primarily, from surface agitation.

Since 1945, various investigators have conducted studies in many ocean areas to examine the effect of wind- and shipping-dependent noise on the total ambient-noise spectrum. Most of their measurements, however, were limited to frequencies above 100 Hz. More recent investigations have included frequencies as low as 10 Hz, and Perrone[2] has shown that surface influences (wind speed) in the Bermuda area can be significant for ambient-noise signals below 20 Hz.

The data to be discussed in this report are in the 1- to 250-Hz range. The average value of ambient noise in 25 contiguous 1/3-octave bands, at frequencies ranging from 1 to 250 Hz, was measured for consecutive 10-s intervals from data recorded continuously for 8 days between 20 and 28 July 1972. A strong wind-speed dependence was observed for frequencies below 4 Hz, whereas a nonwind-speed dependence was observed above 4 Hz.

ACOUSTIC- AND WIND-SPEED-SENSOR LOCATIONS

Acoustic measurements were made at three sensor locations using bottom-mounted omnidirectional hydrophones on the slope of the Grand Banks off Newfoundland. Two of the hydrophones were located in approximately 600 fm of water and the third was located in approximately 2300 fm. Wind-speed data were obtained by USNS HAYES (T-AGOR-16) from a location in the middle of the Labrador Basin (see figure 1).

DATA RECORDING

Figure 2 shows a block diagram of the ambient-noise measurement system used to continuously record broadband ambient-noise signals on magnetic tape for 8 days. The recorder was operated at a tape speed of 1-7/8 in./s, permitting 6 h of data to be recorded on each reel. Wind-speed data were recorded once each hour.

In order to identify the sources of the ambient-noise signals being recorded (i.e., whether they were caused by shipping, other man-made noises, biological effects, etc.), the incoming broadband signals were continuously monitored, both visually and aurally. Also, the signals were passed through a 1-Hz bandwidth filter, centered at 5 Hz, and a 50-Hz bandwidth filter, centered at 200 Hz; their output signal was displayed on a two-channel, hot-wire paper recorder. The resultant records were monitored and annotated online and served as guides when the data were later reduced.

The recording system was calibrated by inserting a broadband white-noise signal at the RF detector output in place of the hydrophone signal. The calibration signal had a 0- to 500-Hz bandwidth and an overall level of -10 dB//1V.

DATA PROCESSING

The data from each hydrophone were processed through an A/D conversion system[3] at eight times the normal record speed through contiguous 1/3-octave filters ranging from 8 Hz to 2 kHz. These results were subsequently scaled down to the true frequency of 1 to 250 Hz. The average level of the ambient-noise signal for each 1/3-octave band was computed for consecutive 10-s intervals for the entire data time series. Hourly averages were then computed by grouping the 10-s averages into hourly intervals. All data presented in this report are based on hourly averages except the standard deviation curve, which was computed directly from the 10-s interval averages.

As noted earlier, the predominant noise source was established to be large fishing vessels working in the general areas of the hydrophones; therefore, any records exhibiting high levels resulting from overload of the system were discarded. All other data were compared and grouped with the wind-speed measurements made by HAYES. Before grouping, however, appropriate fixed time shifts for each location (determined by using crosscorrelation techniques) were incorporated into the acoustic data time series to compensate for the geographical separation between each acoustic sensor and the wind-speed sensor.

RESULTS

WIND AND SHIPPING DEPENDENCE

The variations with time of the ambient-noise level received on hydrophone A for selected frequency bands and the corresponding variation of wind speed are presented in figure 3. The wind-speed fluctuations during the 8-day measurement period are denoted by the dashed line. The ambient-noise curves, denoted by the solid lines, show the temporal characteristics of the ambient-noise signals that are influenced by wind speed (between 1 and 4 Hz), as well as those bands (4 and 250 Hz) that are the boundaries where ship noise predominates.

Wind speed varied from 0 to 40 knots between 20 and 28 July, resulting in a mean wind speed of 17 knots. Its effects in the 1- to 4-Hz range indicate a striking, and relatively strong, wind-speed dependence that decreases with increasing frequency until, above 4 Hz, little or no such dependence is evident. Ship noise predominated between 4 and 250 Hz, masking any surface influence in this portion of the spectrum. The degree of ship-noise influence on the total spectrum is demonstrated by the two major peaks occurring at approximately 1330 and 1630 hours on 26 July. This ship-noise signal is evident over the entire frequency range between 1 and 250 Hz during a time when the wind speed was relatively high (approximately 35 knots) — probably the result of a fishing vessel changing locations. Transient shipping peaks of lesser magnitude are evident at other times during the measurement period.

AMBIENT-NOISE SPECTRA

The data for each hydrophone location are grouped according to wind speed in figures 4 through 6, and the mean spectrum level is plotted versus frequency for each of nine wind-speed groups. In figures 4 and 5 there is a clear distinction between those portions of the spectrum that are predominantly wind-speed dependent and those that are not. (Note that the dependence shown in figure 4 is greater than that in figure 5.) In figure 6, no wind-speed dependence is observed at the low frequencies, since ship noise predominated at this location, as indicated by the 10-dB higher noise level received for the 1- to 2-Hz range. These results show that, although the spectrum levels are dependent on location, their shapes (except in the 5- to 60-Hz range at location A) are quite similar. For all locations, the spectrum curves for the 2- to 5-Hz range are observed to rapidly fall off at a rate of 20 dB/octave. The ambient-noise spectra are essentially flat in the 5- to 60-Hz range, except in figure 4, which shows a positive slope of 6 dB/octave. Above 60 Hz the spectra for all locations are observed to decrease at a rate of 8 to 10 dB/octave.

Variability in the ambient-noise spectrum levels and shapes, as a function of area, is seen more clearly in figure 7, where the mean ambient-noise level for the entire data time series, independent of wind speed, is plotted as a function of frequency. The differences in the absolute levels of the spectra and the variations in their shapes are probably caused by different shipping distributions at the three locations.

The standard deviation of the ambient-noise signal is plotted as a function of frequency in figure 8 for each hydrophone location. In general, the shapes of the three curves are quite similar. Fluctuations in the noise signal below 2 Hz vary from 4 to 7 dB, and above 2 Hz they vary from 2.5 to 5 dB. The high fluctuation observed in the ambient-noise signal below 2 Hz for location A is the result of the variation of the ambient-noise level with wind speed. The overall results show that fluctuations in the ambient-noise signals for these areas are, on the average, 2 to 3 dB higher than in the Bermuda area.[2] It is suspected that the higher values of standard deviation (as a function of frequency) were caused by the proximity of the few ships in the area to the hydrophones.

CROSSCORRELATION AND AUTOCORRELATION

In order to provide some quantitative measure of the dependence of the total ambient-noise spectrum upon fluctuations in wind speed, the ambient-noise time series in each of the filter bands were crosscorrelated with the wind-speed time series. In figure 9, the resulting crosscorrelation coefficients are plotted as a function of frequency for hydrophone A. In order to compensate for the geographical separation between the acoustic and wind-speed sensor locations, a fixed 6-h time shift was incorporated into the acoustic data time series to obtain maximum correlation. The coefficients are highest at 1 Hz and decrease with increasing frequency, except at 5 and 31.5 Hz where they increase as a result of a slight wind dependence (see figure 4). The shape of the crosscorrelation curve shown in figure 9 depends on the distribution of wind speed and the shipping activities prevailing during a measurement period.

The autocorrelation function of the wind-speed time series is plotted in figure 10, where two similarly derived curves, based on results published for the Bermuda area[2] and the Ionian Basin,[4] are included for comparison. The figure shows that the autocorrelation function for wind speed is independent of area and that complete decorrelation occurs at a time shift of approximately 31 h. In figures 11 through 13 autocorrelation coefficients are plotted for each hydrophone location as a function of frequency for four time shifts of 2, 4, 8, and 12 h. The correlation functions shown in the figures are quite similar in shape, although the correlation coefficients are somewhat different for each geographical location. In figures 11 and 12 the correlation coefficients obtained for the four time shifts for frequencies below 2 Hz are essentially identical. Thus, these results demonstrate that the spectra shown in figures 4 and 5 for ambient-noise signals below 2 Hz are primarily wind dependent. Above 4 Hz, the ambient-noise signal is primarily ship-noise generated. For this portion of the spectrum, the correlation coefficients are observed to decorrelate at a much faster rate than the wind-generated portions of the spectrum; complete decorrelation is observed in approximately 10 h. In the 2- to 4-Hz range, independent of time shifts, the correlation coefficients are observed to decrease rapidly with increasing frequency. This rapid decrease in the correlation coefficients with increasing frequency is the result of the transition of the noise signal from predominantly wind-generated to predominantly nonwind-generated noise.

Figure 13 shows that, for frequencies below 2 Hz at time shifts of 2 and 4 h, some wind characteristics that are not obvious in the spectrum curves shown in figure 6 are observed; this is indicated by the high value of correlation. However, as a result of the lower correlation values obtained for the 8- and 12-h time shifts, it is felt that, for this location, the spectrum is produced, predominantly, by shipping. Consequently, a more rapid decrease in the correlation function is shown for this location as compared with the much slower decrease in the correlation function for the other two locations. Above 2 Hz the correlation coefficients shown in figure 13 are characteristic of shipping noise.

In figure 14, the time shift corresponding to the crossing of the autocorrelation function through zero is plotted as a function of frequency for each hydrophone location. The wind-dependent, nonwind-dependent, and transitional regions of the ambient-noise spectra are shown. For locations A and B, the wind-dependent area below 2 Hz, the nonwind-dependent area above 4 Hz, and the transitional regions from 2 to 4 Hz are clearly identified. For the wind-generated noise below 2 Hz, the zero crossings of the autocorrelation function are observed to be in good agreement with the zero crossing for the wind correlation function. Decorrelation occurs at approximately 30 to 35 h. For the nonwind-generated noise above 4 Hz, a much steeper slope to the correlation function is observed. Complete decorrelation for ship-generated noise, independent of frequency, occurs at a time shift of approximately 9 h, indicating that, in these bands, the bandwidth of the noise variation is significantly greater than in other bands where the signal is wind generated. This behavior is consistent with the hypothesis that noise signals generated by shipping vary more rapidly than wind-dependent noise.

For frequencies that are a composite of the two noise sources (those in the transitional region between 2 and 4 Hz), the zero crossings of the correlation function will occur at a time shift that depends on the relative level of the signal received from the individual noise sources, i.e., between 9 and 30 h. Figure 14 shows that this condition exists in the 2- to 4-Hz range for hydrophones A and B and in the 1- to 4-Hz range for hydrophone C. Above 4 Hz, zero crossings for hydrophone C occur with a time shift of approximately 8 h, which is typical of ship-generated noise.

SUMMARY AND CONCLUSIONS

Infrasonic and low-frequency ambient-noise signals were recorded continuously for 8 days between 20 and 28 July 1972 using three omnidirectional hydrophones at locations on the Grand Banks off Newfoundland. The data were processed through 25 contiguous 1/3-octave bands of frequencies ranging from 1 to 250 Hz. In the 1- to 4-Hz range, a strong wind-speed dependence is observed. Above 4 Hz the ambient-noise spectra are predominantly noise produced by the large fishing vessels that use the area extensively. The correlation coefficient of ambient noise with wind speed depends on the distribution of wind speed and the type and amount of shipping activity prevailing during a measurement period. The zero crossings of the autocorrelation function for wind-dependent noise occur at approximately 31 h, which is identical to the zero crossing of the wind autocorrelation function. The zero crossings for shipping noise occur at a time shift of from 8 to 10 h, which is consistent with the hypothesis that noise signals generated by shipping vary more rapidly than wind-dependent noise. The zero crossings of the correlation function for the transitional regions occur at a time shift that depends on the relative level of the noise signal received from the individual sources.

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3. D. A. Quigley, Scientific Analog Data Processing at the Naval Underwater Systems Center, New London Laboratory, NUSC Technical Document 4557, 30 May 1973 (UNCLASSIFIED).

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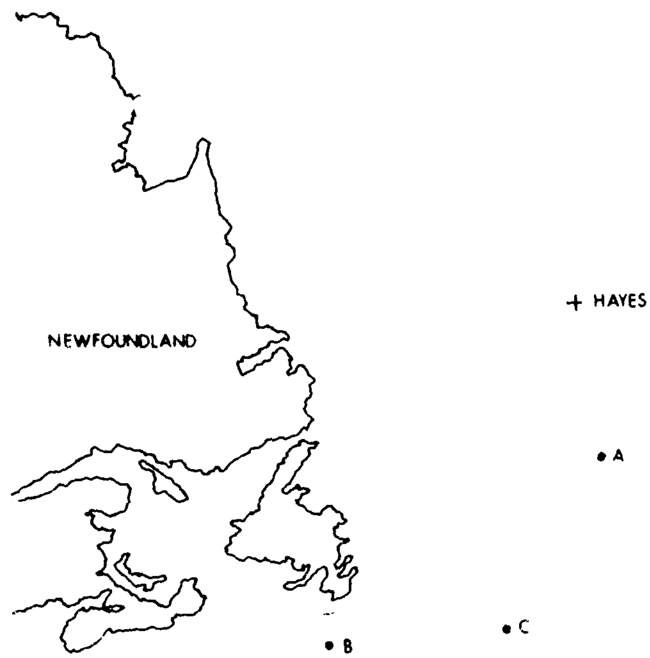

Figure 1. Acoustic- and Wind-Speed-Sensor Locations

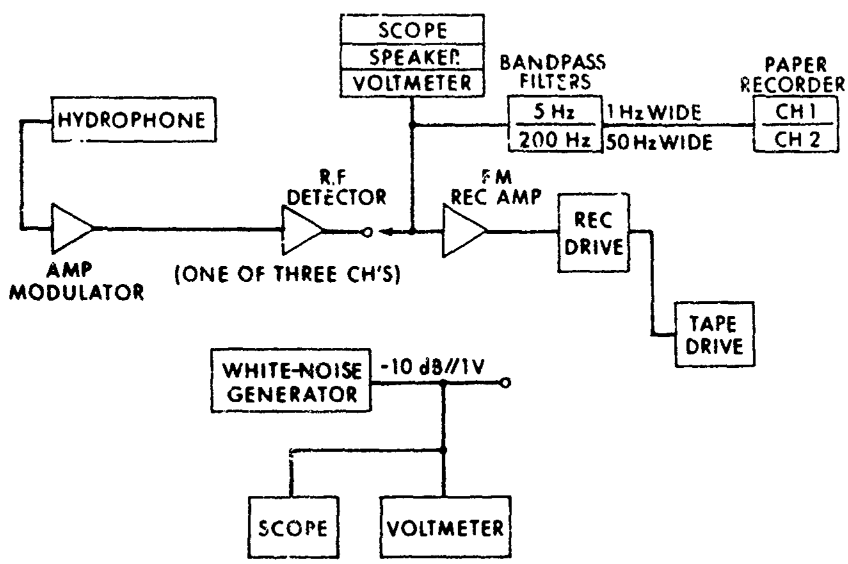

Figure 2. Ambient-Noise Measurement System

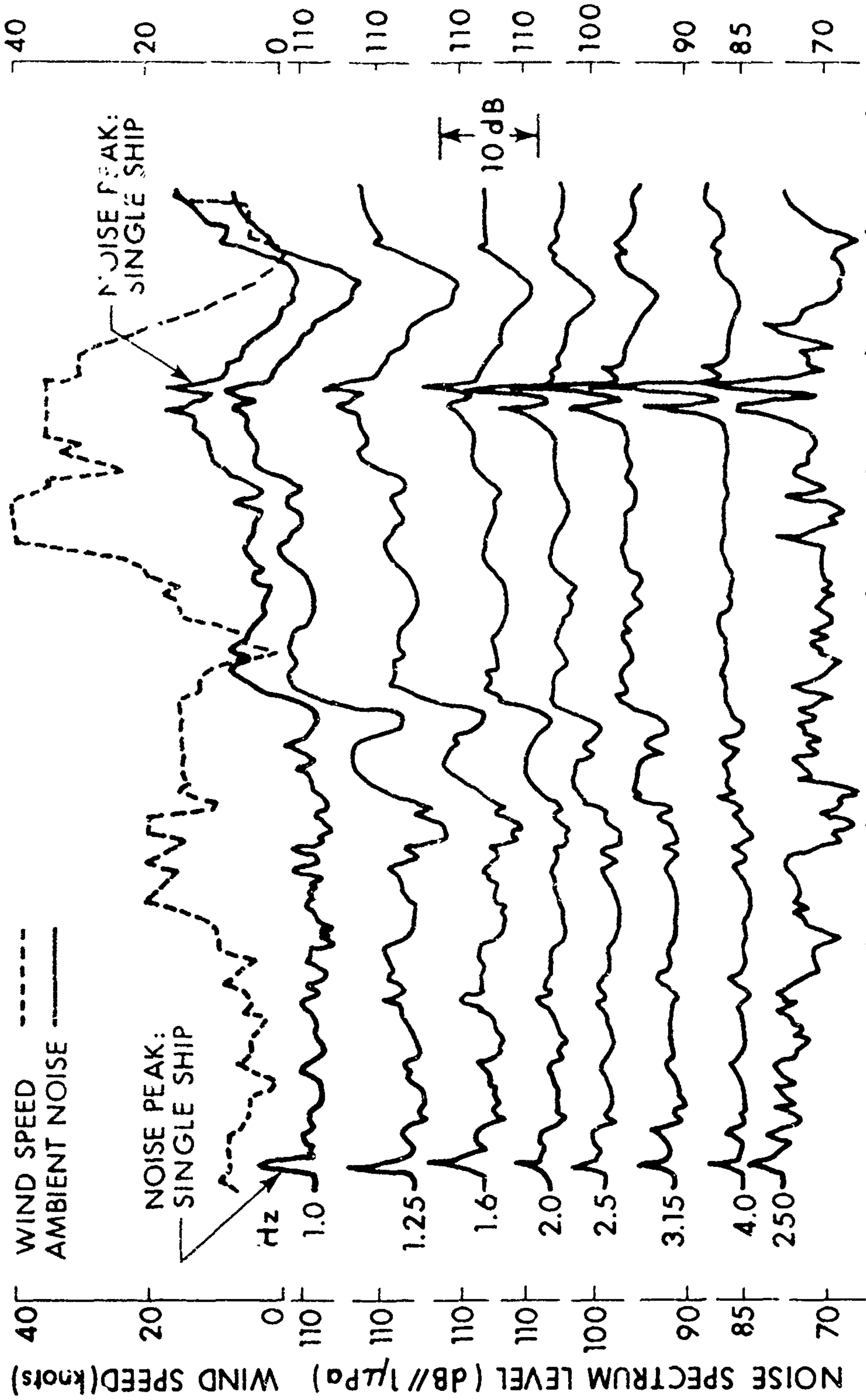

Figure 3. Comparison of Ambient Noise and Wind Speed

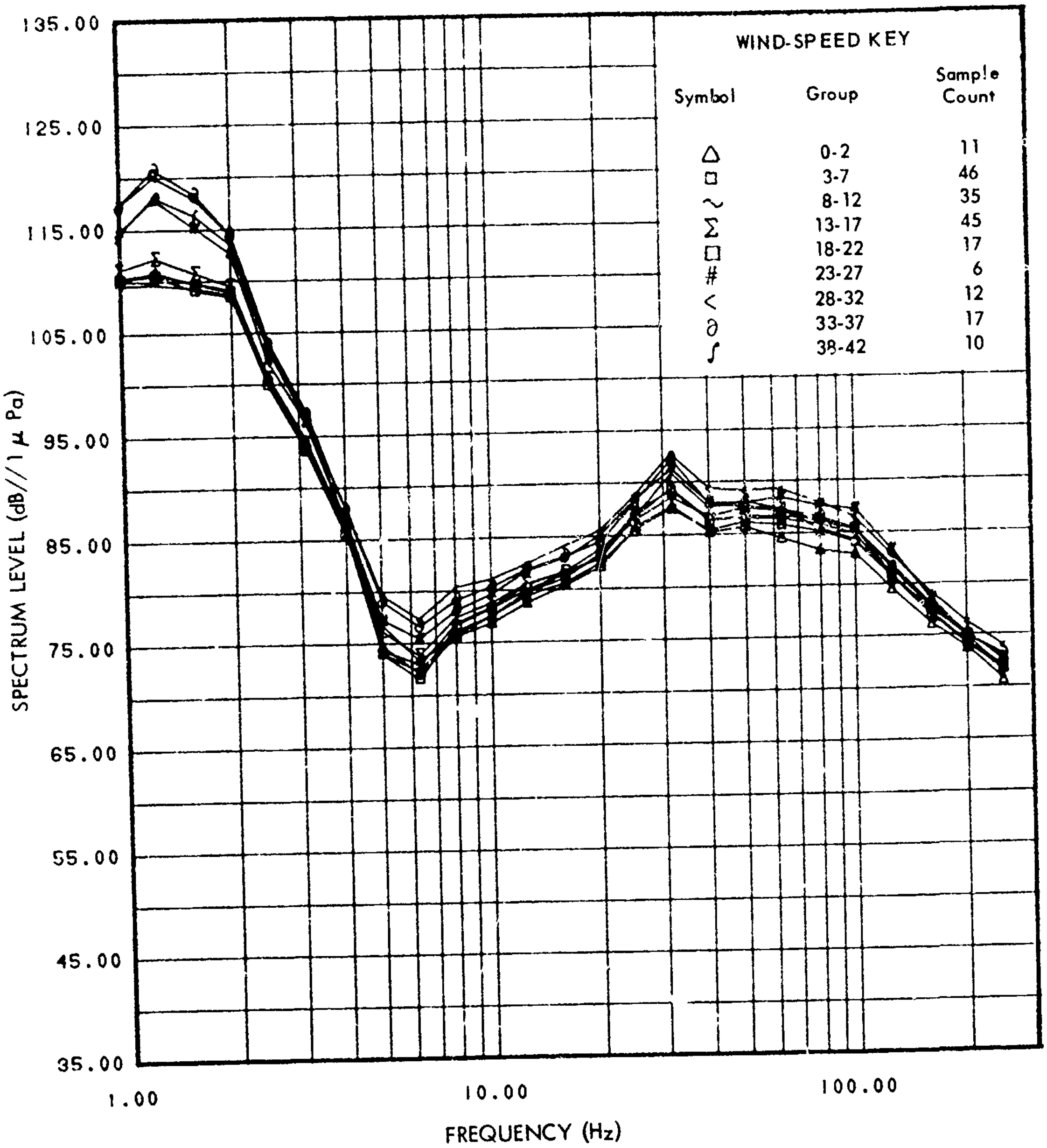

Figure 4. Ambient-Noise Spectrum versus Wind-Speed Group (Hydrophone A)

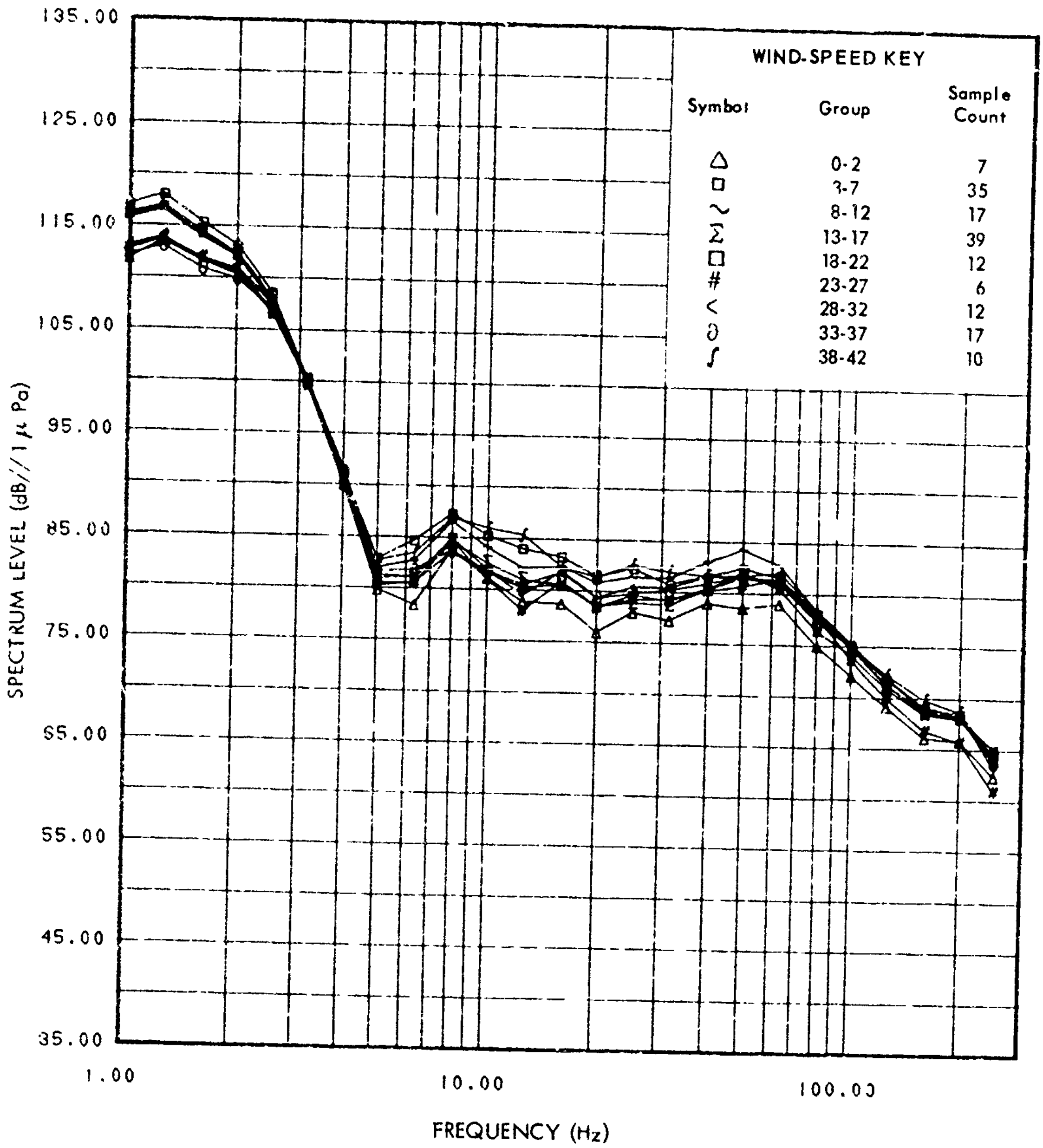

Figure 5. Ambient-Noise Spectrum versus Wind-Speed Group (Hydrophone B)

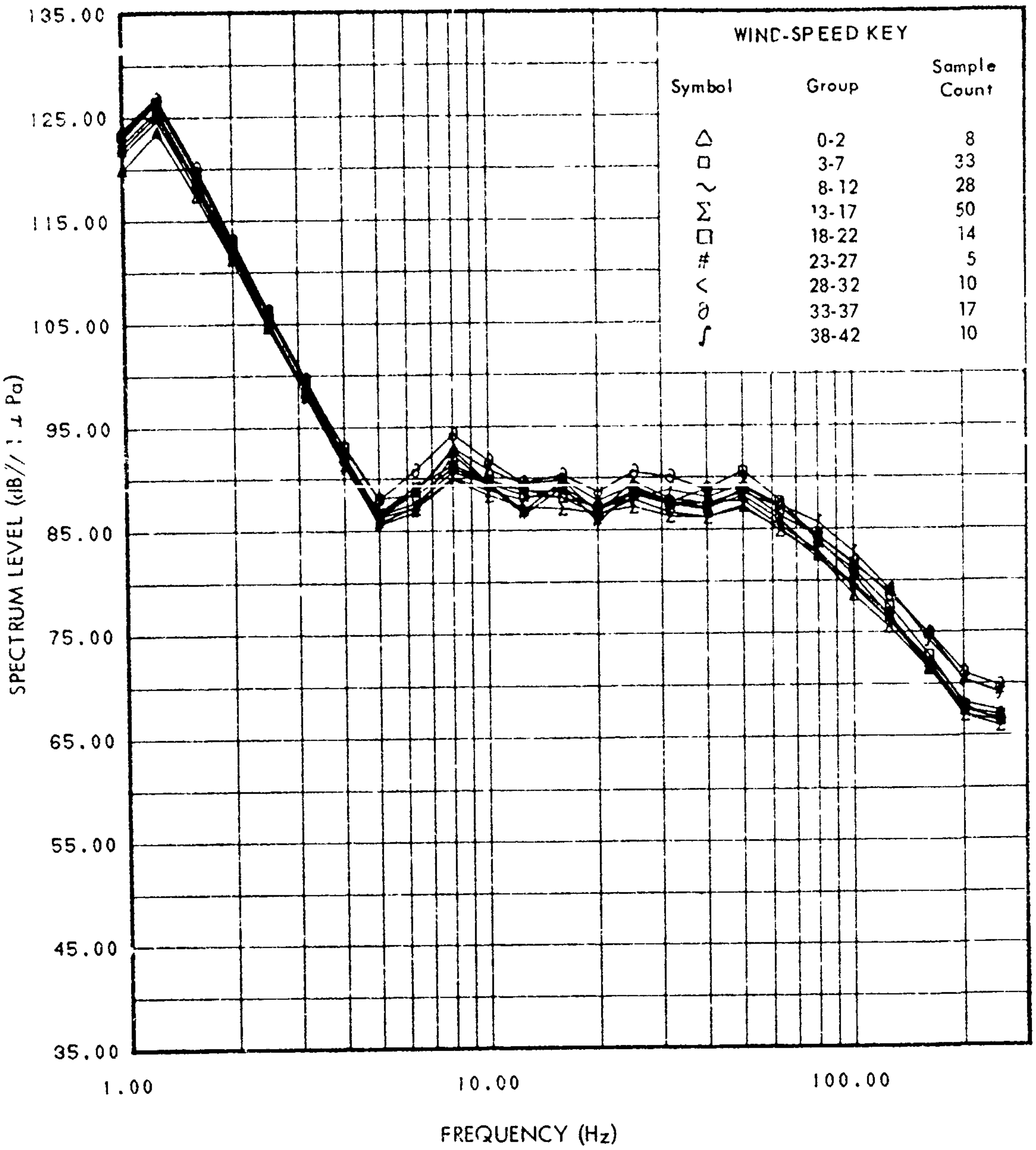

Figure 6. Ambient-Noise Spectrum versus Wind-Speed Group (Hydrophone C)

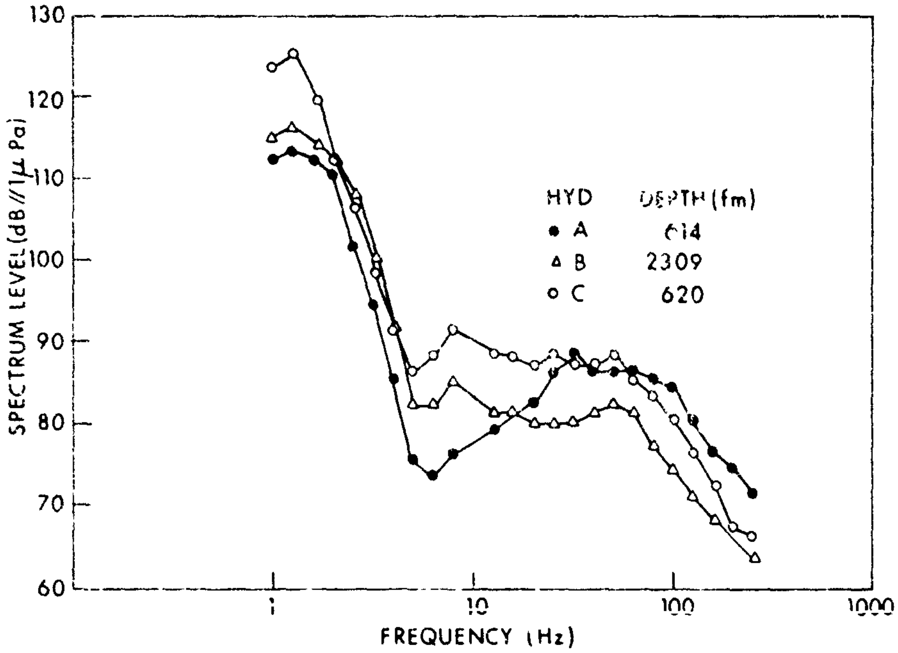

Figure 7. Average Ambient-Noise Spectra Independent of Wind Speed (Hydrophones A, B, and C)

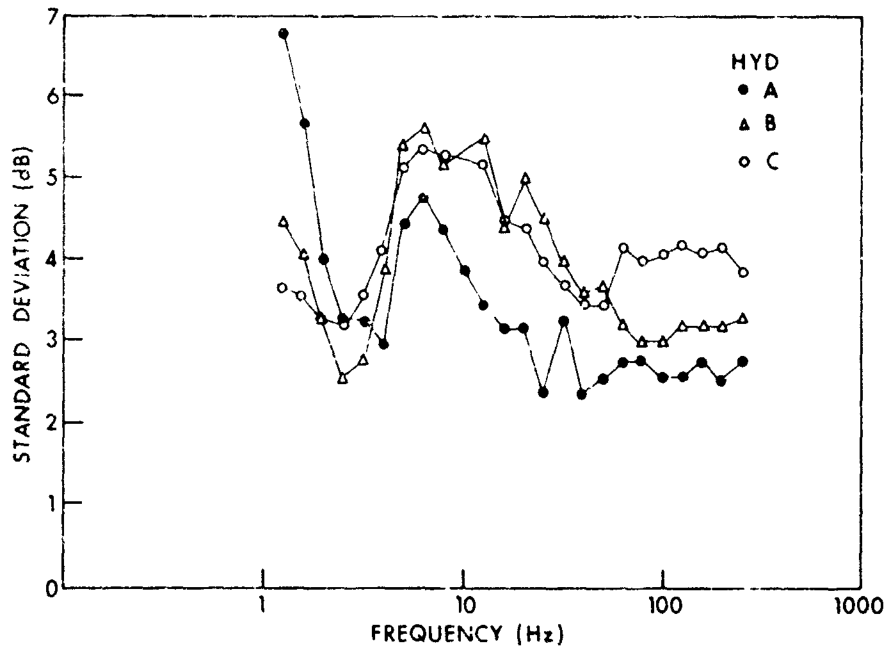

Figure 8. Standard Deviation of Ambient Noise (Hydrophones A, B, and C)

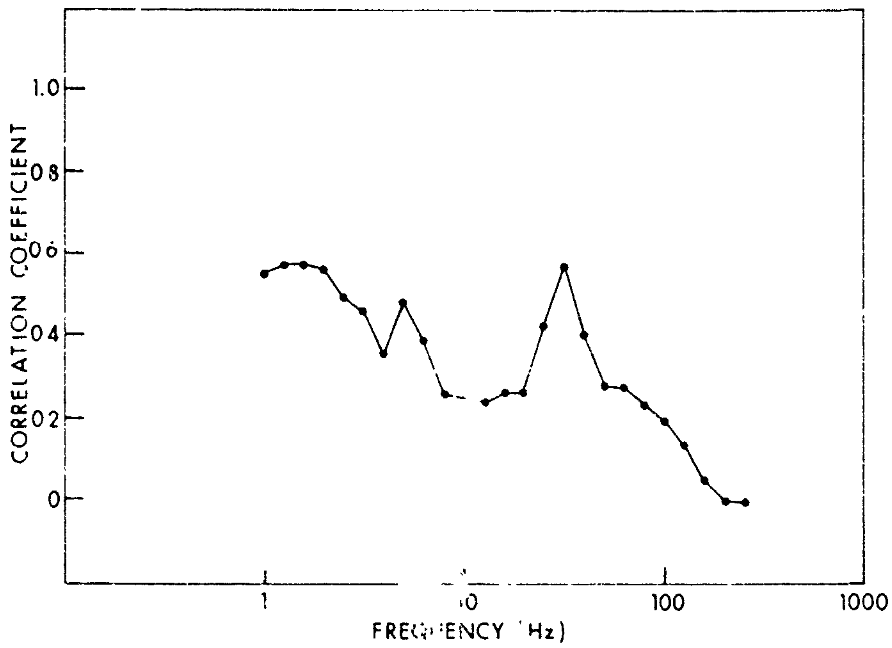

Figure 9. Crosscorrelation of Ambient Noise with Wind Speed for Hydrophone A (6-h Time Shift)

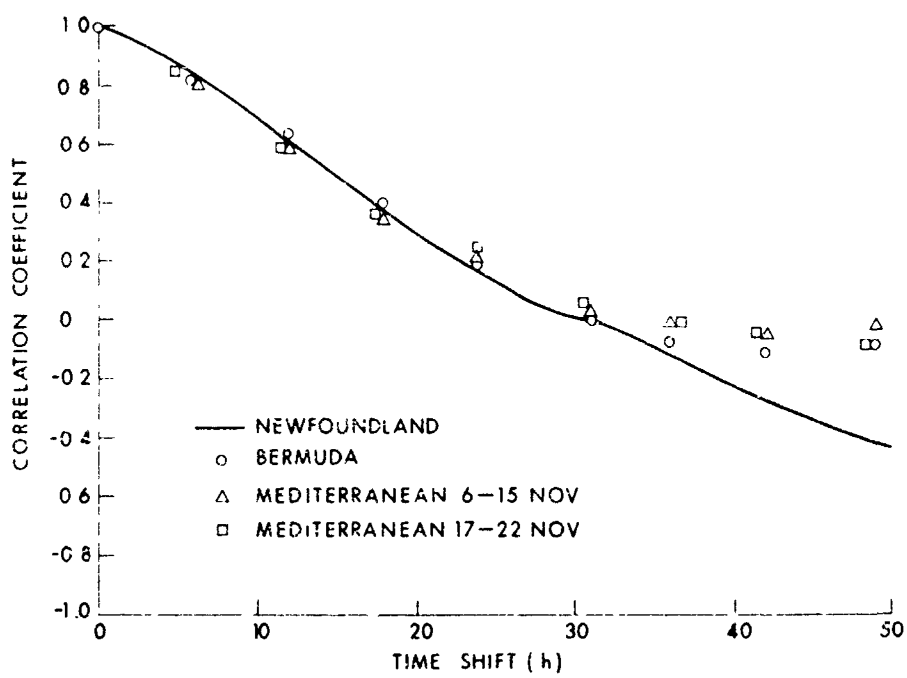

Figure 10. Autocorrelation of Wind Speed for Three Ocean Areas

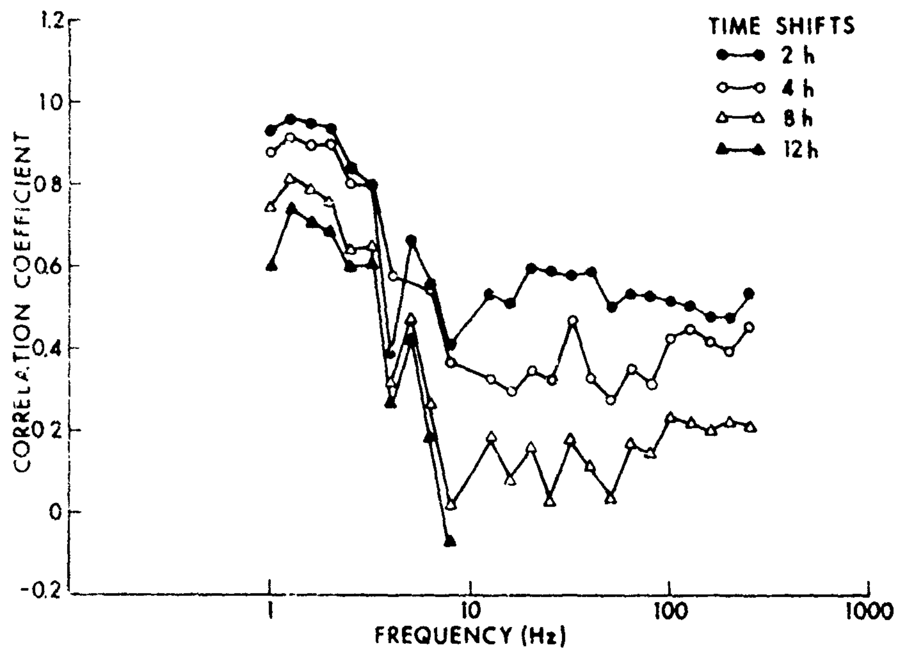

Figure 11. Autocorrelation of Ambient Noise for Four Time Shifts (Hydrophone A)

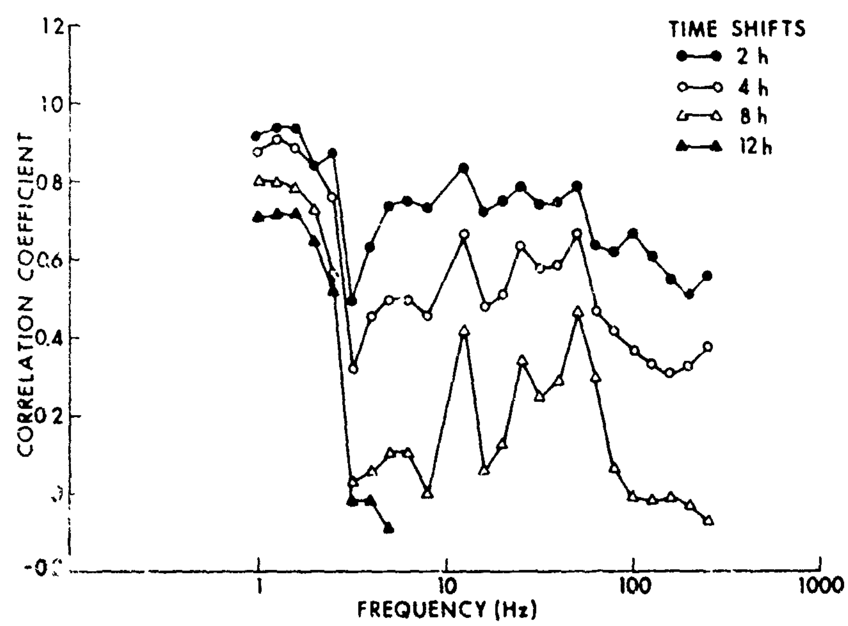

Figure 12. Autocorrelation of Ambient Noise for Four Time Shifts (Hydrophone B)

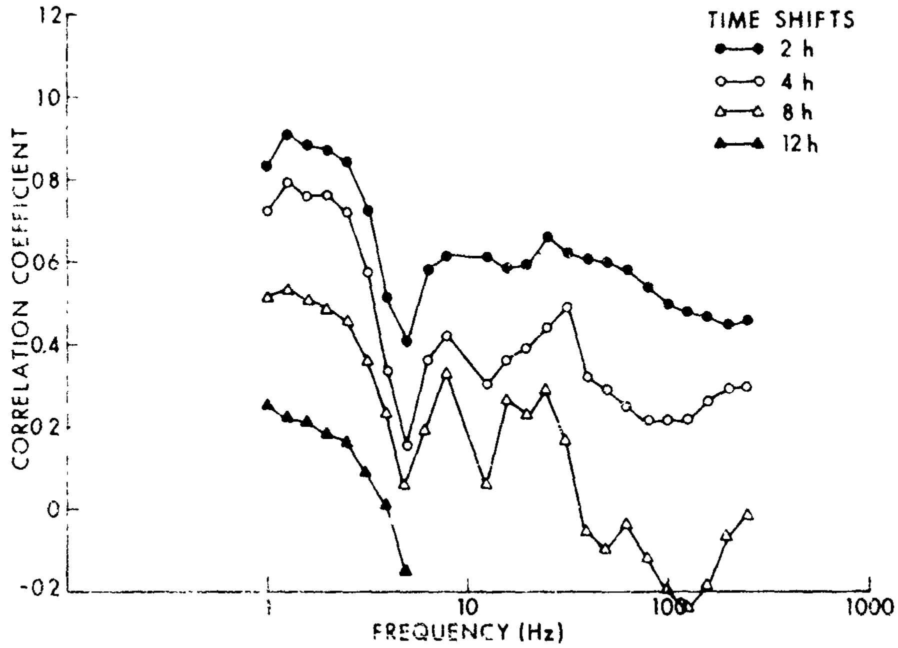

Figure 13. Autocorrelation of Ambient Noise for Four Time Shifts (Hydrophone C)

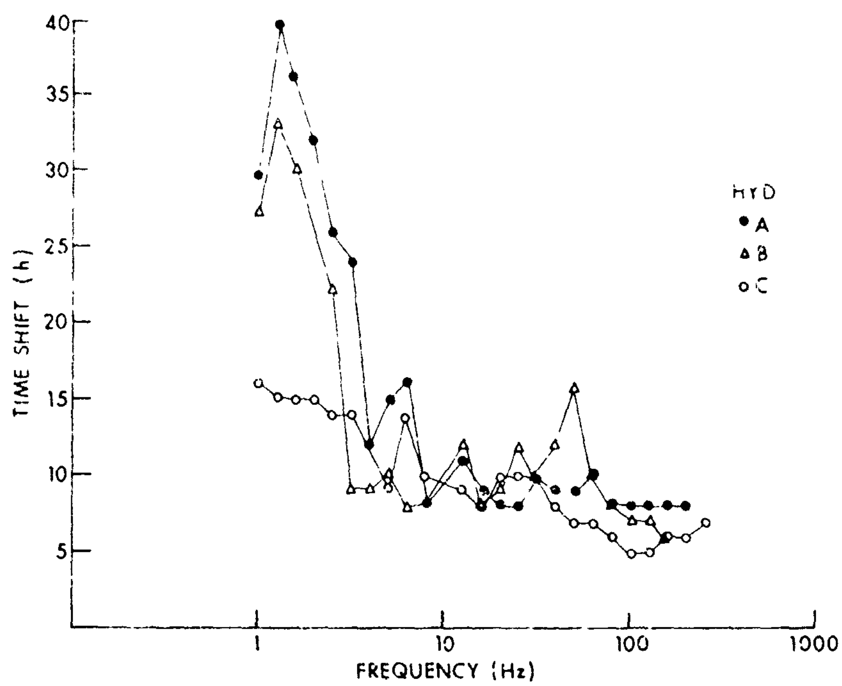

Figure 14. Autocorrelation of Ambient Noise at Zero Crossings (Hydrophones A, B, and C)

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