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AMPLITUDE FLUCTUATIONS OF HIGH FREQUENCY UNDERWATER ACOUSTIC SIGNALS IN THE MARGINAL ICE ZONE

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INTRODUCTION

The Marginal Ice Zone (MIZ) is the region of partial ice cover between solid polar pack ice and ice-free waters. This is a dynamic area which might be very narrow in the presence of strong winds blowing onto the pack or several tens of kilometers wide when winds are blowing toward open water. Also, the MIZ generally advances as new ice is formed in the fall and winter and retreats in the spring and summer. Naturally, the oceanography of this transition region is quite complex, including volume inhomogeneities which would be expected to produce both long term and short term fluctuations in propagating acoustic signals. In order to determine the severity of high frequency signal fading in the MIZ, some data collected for a different purpose have been analyzed for amplitude fluctuations.

THE EXPERIMENT

The 5ms pulses examined in this paper were collected in the Fram Strait MIZ by the Woods Hole Oceanographic Institute as part of the Sensor Tracking System for multilab geophysical and acoustic experiments conducted in June 1984 [1]. Five sources were suspended from separate ice floes at a depth of sixty meters. Signals received on 11 hydrophones, also suspended sixty meters below the ice, were examined, along with signals from two hydrophones at a 12m depth. Sources and receivers were up to 6km apart. During data collection, the MIZ was highly dispersed and dynamic. Measurements were taken approximately 20km from open water in roughly 50% ice cover. Sensors drifted at rates as high as 1/4 knot [2]. A typical example of the relative source and receiver positions is shown in Figure 1.

High frequency sources at 8, 9, 10, and 11kHz each emitted a pulse approximately every 15 seconds, while a 13kHz source had a 7.5 second repetition interval. These were used to determine sensor locations via triangulation to an accuracy of 1m rms for ranges up to 5km. Signals from each source and receiver were telemetered to a central location where they were recorded on analog tape. Time delays and relative positions were calculated and displayed in real time.

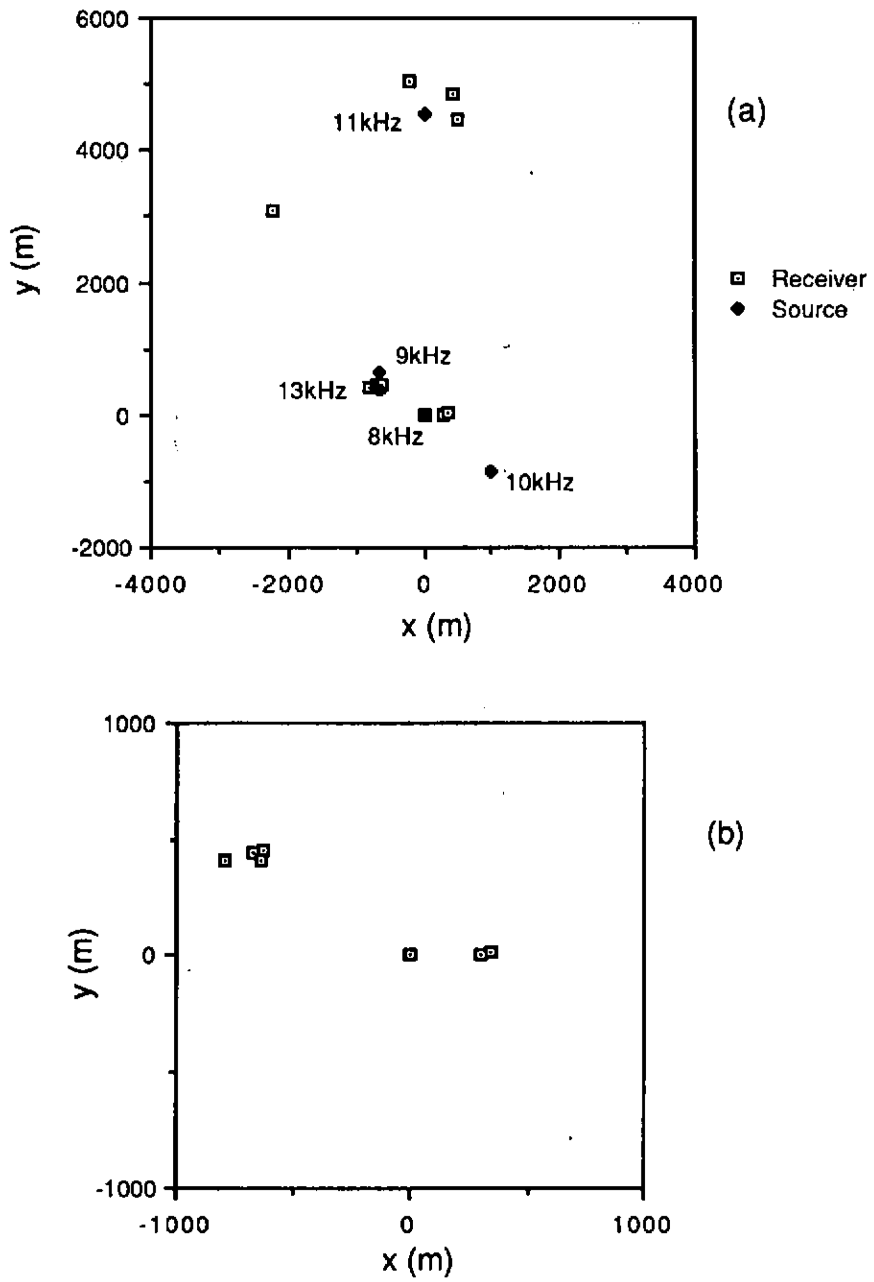

FIGURE 1
Relative positions of sources and receivers for 10 min. series beginning 3:11:30 June 18,1984. The origin and the positive y direction are defined by the locations of the 8 kHz source and the 11 kHz source, respectively. The solid square in (a) indicates the co-location of a source and a receiver at the origin. Only receiver locations are shown in (b), which is an enlargement of the field near the origin.

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For the present purposes, each channel of data was bandpass filtered and quadrature sampled. A bandwidth of 1.5 kHz was used in most cases to reduce interference from signals at adjacent frequencies and to eliminate low frequency background noise.

OBSERVATIONS

Data from two different time intervals on 18 June 1984 were analyzed in detail. One set started at 9:38:30 and lasted until 10:00. The other was a ten minute time series beginning at 3:11:30. The position of the tending ship was 8°50'E and 80°25'N. Figure 2 shows examples of the mid-morning data set and Figure 3 of the early morning, ten minute, set. Figures 2a, 2c, and 3a have low coefficients of variation while Figures 2b and 3b have high coefficients of variation. The coefficient of variation is the standard deviation of the pressure amplitude divided by its mean.

Some of these examples show gradual small fluctuations of 3 dB per minute or less as in Figure 2a. The time series in Figure 3b shows occasional fluctuations of 6dB or more between pulses. There were also cases where large rapid fluctuations occurred during the entire time series as in Figure 2b. Figure 2d shows a fairly well behaved set of data with one sharp dip.

DISCUSSION

Cursory examination of the data yields no obvious trends. In fact, large random fluctuations in amplitude can occur even at very short ranges, while one long range sample at a range of 3127m shows relatively little fluctuation with a coefficient of variation of .237. Since it was not anticipated that these data would be analyzed for signal fluctuation, the continuous monitoring of microscale sound speed fluctuations required for sophisticated model comparisons was not done. Nevertheless, the results may be compared with the relatively simple Born approximation [3] for propagation of a finite wave through an isotropic inhomogeneous random medium. This theory predicts that the coefficient of variation increases linearly with $k^2 R$, where k is the wave number and R is the range. The data comply reasonably well with this prediction for $k^2 R$ less than $3 \times 10^6 m^{-1}$, as seen in Figure 4. At that point, saturation occurs and the coefficient of variation no longer increases. The analysis reported by Wenzel [4] can be used to infer the variance of the sound speed from the value of $k^2 R$ at saturation. For the present case, the inferred sound speed variance (normalized with respect to the mean sound speed squared) is on the order of 10^{-7}.

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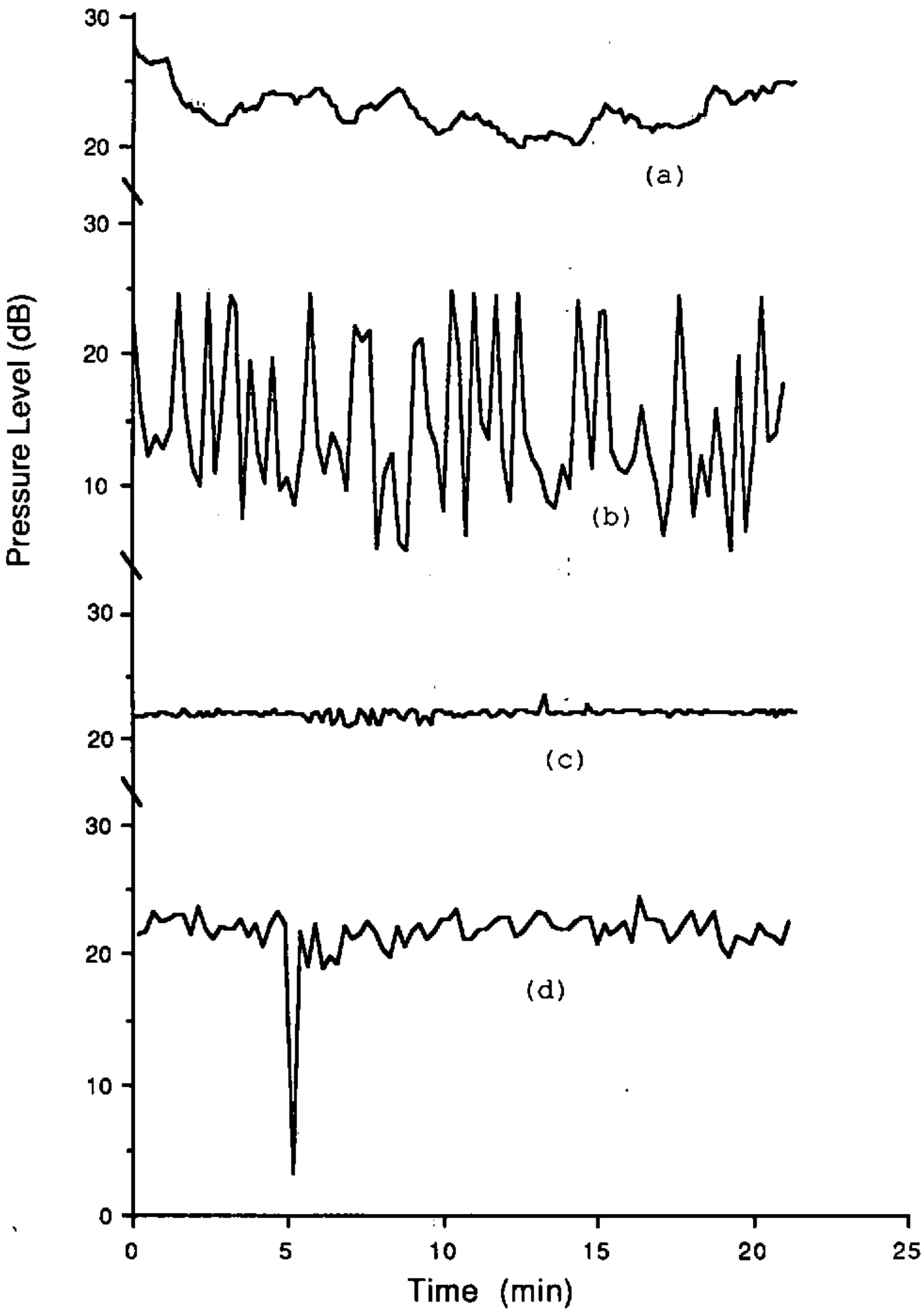

Figure 2

Pressure level in dB (arbitrary common reference) versus time for four representative signals during the 21.5 min period beginning at 9:38:30 , 18 June 1984: (a) 13kHz, 167m, 278°; (b) 8khz, 314m, 73°; (c) 13kHz, 77m, 342°; (d) 8kHz, 358m, 69°.

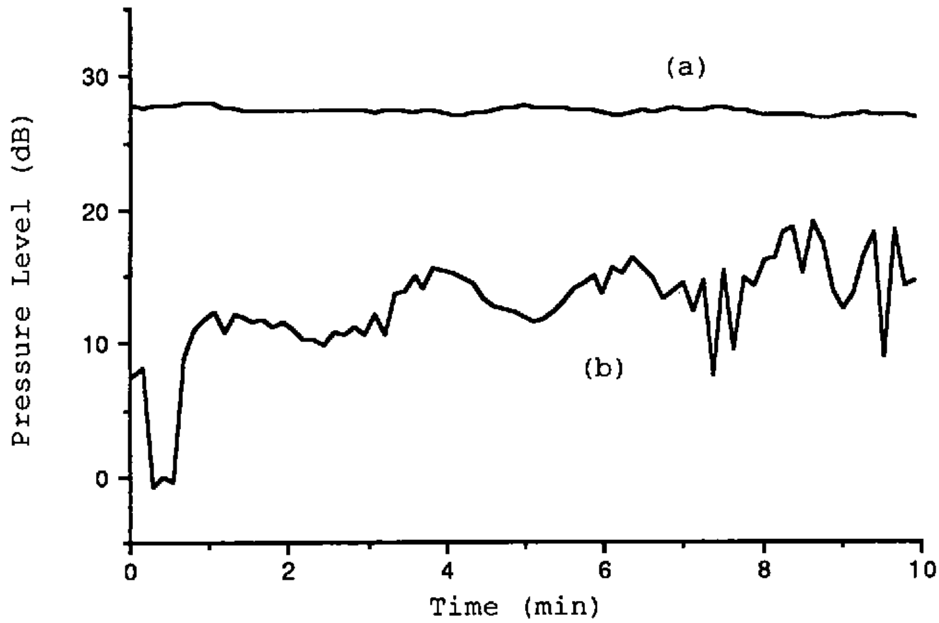

FIGURE 3
Pressure level in dB (same arbitrary reference as in Figure 2) versus time for 10 minute time series: a. 13kHz, 161m, 284°; b. 13kHz, 1004m, 111°.

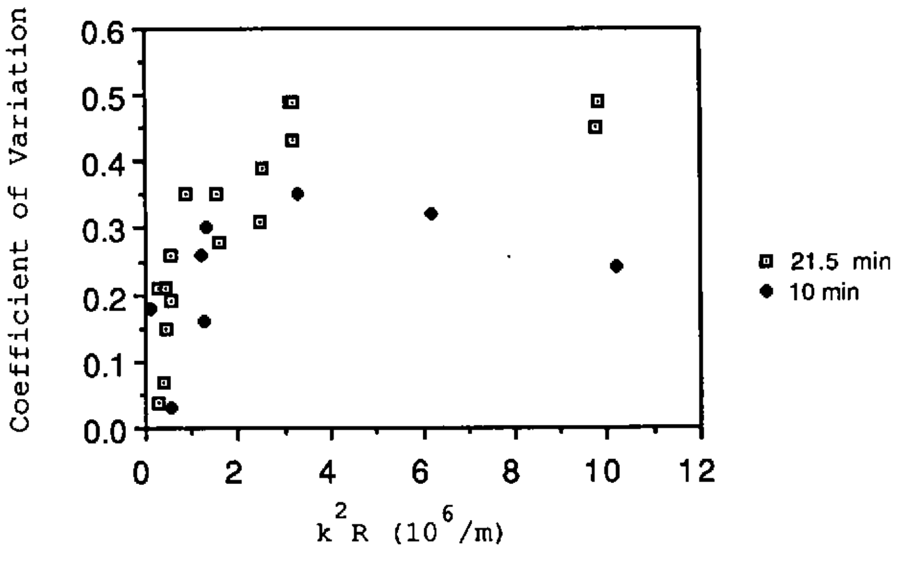

FIGURE 4
Coefficient of variation versus wave number squared times range for 8 source-receiver pairs in the 10 minute data set and 17 in the 21.5 minute data set.

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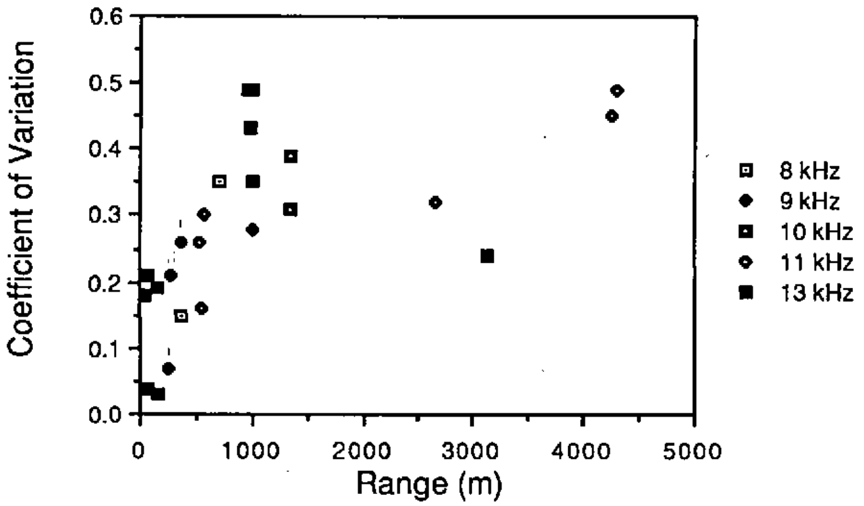

FIGURE 5
Coefficient of variation versus range with each data point identified with its associated acoustic frequency.

Each frequency showed a wide range of coefficients of variation even at like ranges (see Figure 5). Figure 6 is a duplicate of Figure 4 except that each data point is identified by the quadrant of its propagation azimuth. In the 10 minute data set, signals from between 0 and 15 degrees and 180 and 195 degrees were all extremely weak when received at all; therefore, none are plotted in Figure 6. The absence of these signals indicates the presence of highly directional oceanographic features. Even though the mean amplitude was azimuthally dependent, no such dependence was found for the coefficient of variation in those cases in which the signal to noise level permitted its calculation.

Figure 7 shows that outside the shadow zone noted above, the signal is attenuated about 6 dB per doubling of range, which is typical of spherical spreading. Signals from the 12m deep hydrophones are not included in Figure 7. The signal associated with the stray point at the 35m range also has an anomalously high coefficient of variation, 0.57.

Figure 8 shows the autocorrelation for two representative pressure histories, one from each of the data collection periods. Each data set has a time constant (the time at which the autocorrelation is equal to 1/e) of about 12 minutes.

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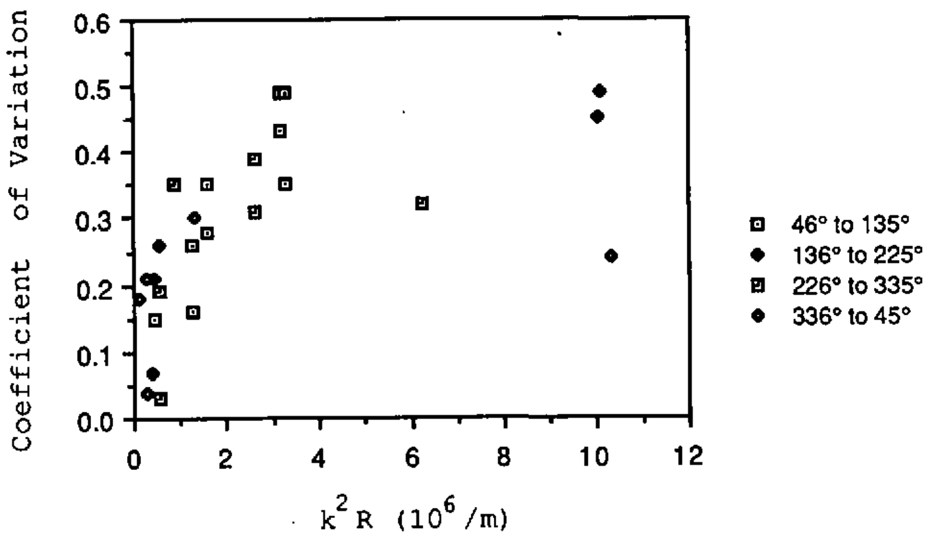

FIGURE 6
Duplication of Figure 4 with each point identified by the quadrant of its associated azimuth of propagation.

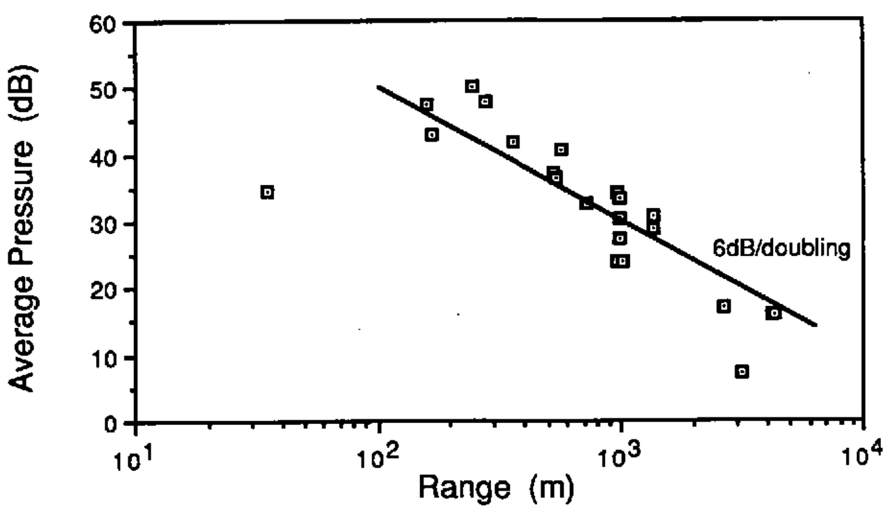

FIGURE 7
Mean signal level (arbitrary dB reference) versus range. The straight line shows the spherical spreading falloff rate of 6 dB per doubling of range.

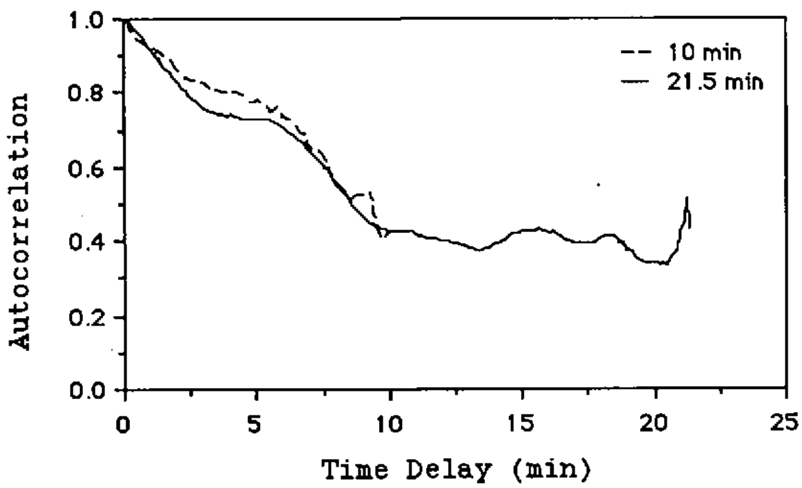

FIGURE 8

Autocorrelation for two representative signal amplitude histories: a. 10 min. series, 11kHz signal, 525m, 98°; b. 21.5 min. series, 13kHz signal, 961m, 96°.

CONCLUSIONS

Significant temporal signal fluctuations were observed for near surface propagation of high frequency acoustic signals in the MIZ. Specifically, a 10 kHz signal reached saturation in about 1500m. Thus, signals at higher frequencies would saturate at even shorter ranges. If the sources and recievers were in greater relative motion than were those in this experiment, larger fluctuations and shorter time constants would be expected.

ACKNOWLEDGEMENTS

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