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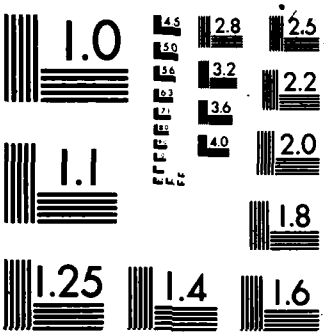

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Sensitivity of High Frequency Surface-Generated Noise to Sonar and Environmental Parameters

A Paper Presented at the Oceans '83 Conference, San Francisco, CA, 30 August 1983

E. R. Robinson
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Preface

This document was prepared under NUSC Project No. Y34581, *ADCAP Modeling*, Principal Investigator, F. E. Aidala, Jr. (Code 3661) and NUSC Project No. A65065, *NISSM III*, Principal Investigator, E. R. Robinson (Code 3342).

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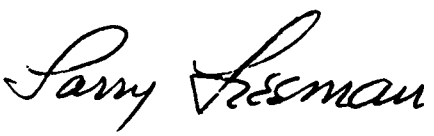

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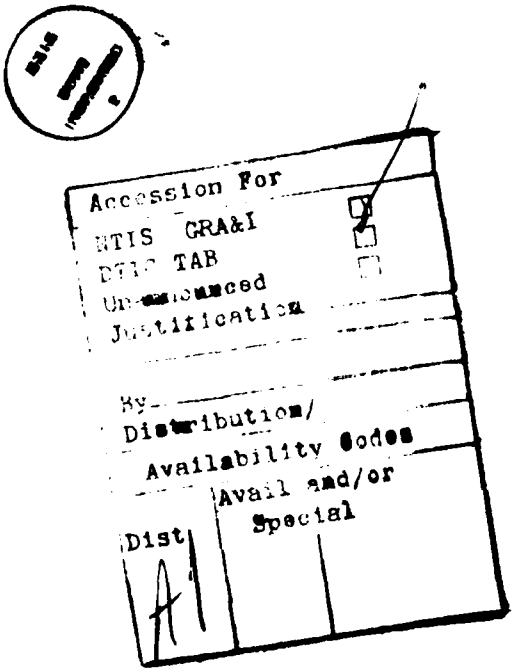
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document investigates the sensitivity of high frequency (6 to 60 kHz) surface-generated ambient noise to sonar and environmental parameters. A simulation model for the vertical directionality and depth dependence of noise originating at the ocean surface is developed. The use of the model is demonstrated when sonar beam elevation angle, receiver depth, water depth, and sound speed profile are varied at a relatively high frequency (23.5 kHz). Results show a high level of sensitivity to these parameters. In deep water,

20. (Cont'd)

it is predicted that volume absorption is the dominant contributor to the anisotropic character of the noise field. In shallow water, it is shown that the received noise levels are limited primarily by two environmental parameters of the ocean: (1) sound speed profile and (2) bottom porosity.



SENSITIVITY OF HIGH FREQUENCY SURFACE-GENERATED NOISE TO SONAR AND ENVIRONMENTAL PARAMETERS

INTRODUCTION

Currently, many sonar systems use Knudsen curves[1] to predict ambient noise levels because these curves allow for variations in wind speed and shipping density at a fixed acoustic frequency. However, this method does not provide the capability of investigating the effects on noise due to changes in other sonar and environmental parameters, such as sonar beam elevation angle, receiver depth, water depth, bottom porosity, and sound speed profile (SSP). For example, changes in either sonar beam directionality or SSP do not result in changes to predicted ambient noise levels when the Knudsen model is used.

This paper will investigate the sensitivity of high frequency (> 6 kHz) surface-generated sea noise to sonar and environmental parameters. A procedure that simulates the effect of noise originating at the ocean surface has been developed and incorporated in the Generic Sonar Model (GSM).[2] The noise levels predicted by this model include the effects of directionality and multipath propagation in realistic ocean environments.

The model is demonstrated when typical sonar parameters in several environments, including deep and shallow water, are varied. The results indicate that the received ambient noise is highly sensitive to variations in these parameters.

MODEL DESCRIPTION

Ambient noise in the ocean has many sources, including surface agitation, shipping, thermal effects, and sea life. However, because noise produced by surface agitation is dominant in the frequencies of interest (6 to 60 kHz), the model assumes that all noise originates at the sea surface. Originally developed by McConnell[3] at the Applied Physics Laboratory of the University of Washington, the model was used in conjunction with the NISSM II computer program.[4] The current version, incorporated in the GSM, allows a wide choice of supporting submodels for the computation of eigenrays, bottom reflection coefficients, and volume absorption.

The model equation used to calculate the received ambient noise level is given by

$$P_r = A \iint_{\text{surface}} N(\theta_s)a(R)h(R)b_r(\gamma)RdRd\phi \ ,$$

where

P_r = received noise power intensity, in micropascals^2/hertz,

A = scale factor that is a function of frequency and wind speed, in micropascals^2/hertz/steradian,

N = surface radiation pattern,

θ_s = surface grazing angle,

b_r = receiver beam pattern,

R = horizontal range between sonar and surface element,

ϕ = azimuthal angle relative to beam axis,

a = absorption loss to surface element,

h = spreading loss to surface element, and

γ = angle off beam axis.

The scaling function, A, refers to the noise level at the surface of the ocean.[3] With increasing range, this level is attenuated because of the propagation loss terms. The surface radiators, represented by the function $N(\theta_s)$, are assumed to be distributed uniformly along the ocean surface. The absorption loss, a, and spreading loss, h, are computed by means of eigenray routines selected from the GSM.[2]

Figure 1 schematically describes the noise model. Although the ray paths linking the surface radiators and receiver are depicted as straight lines, the simulation model accounts for the effects of refraction. Therefore, in realistic cases, the rays would undergo some bending.

RESULTS

The results of this investigation show predictions based on the ambient noise model in both deep and shallow-water oceans. Within a particular ocean, the effect on the noise level is examined when the following parameters are varied: beam elevation angle, receiver depth, bottom porosity, and salinity. The predictions are based on a frequency of 23.5 kHz. The beam has a width of 18 degrees and is assumed to be symmetric. A 13 knot wind speed was selected because that speed represents the average of the world oceans. A $\sin^2\theta$ function represents patterns of the surface radiators because that function fits measured data closely at the high frequencies. Note that this dipole function is a very important contributor to the anisotropic characteristic of the noise field.

Figure 2 presents predictions of received noise level versus sonar beam elevation angle for ocean depths of 200, 650, and 2000 m. The receiver is fixed at 100 m. A bottom porosity of 0.4 (sand) is assumed. To eliminate

the influence of refraction, the ocean sound speed is constant with depth. It can be seen that the noise field below the horizontal is significantly smaller than the field above the horizontal for the deeper oceans. This decrease in noise for the downward looking beams reflects the dominant role that volume absorption plays at these high frequencies. That is, the bottom reflection loss is small in comparison with the absorption effect because a sandy bottom is a good reflector of sound, particularly at the lower grazing angles. However, the results in shallow water are significantly different than those in deep water. This difference, which can be attributed to the relatively unattenuated noise arriving along the bottom bounce paths, illustrates the importance of multipaths in shallow water noise predictions. As shown in figure 2, the curve of the noise levels predicted by the Knudsen model is independent of the parameters considered here.

Figures 3 and 4 contain the SSP's that illustrate the importance of this parameter in deep water noise predictions. The profile shown in figure 3 is characterized by a deep surface duct (layer depth of 251 m). In contrast, figure 4 shows the second profile with a relatively shallow layer (49 m) followed by a steep thermocline region.

Figures 5 and 6 show the effects of variations in receiver depth on noise level when the deep water profiles shown in figures 3 and 4, respectively, are used. Because of the high losses due to volume attenuation, it is expected that the ambient noise level will decrease with increasing receiver depth, as shown in figure 5. Note that the variation in level is independent of beam elevation angle, except for the steeper upward-looking angles of the 30-m receiver, where the curve is higher because of the greater returns from the $\sin^2\theta$ radiation pattern.

Figure 6 contains results for an ocean with the same depth (6000 m), but with a relatively shallow layer (49 m). The lower noise levels for the 200-m curve (compared with the deep layer case) illustrate the effect of the layer (and accompanying steep thermocline) on refraction and, thus, on received noise. It should be noted that for the shallow layer result, the 200-m receiver is below the layer and, therefore, suffers from the strong downward refraction of the thermocline, whereas, in the previous result, the 200-m receiver was within the layer. In comparison, figure 7 shows the results for an isovelocity ocean.

In figure 8, the importance of bottom porosity as a factor of noise reception in shallow water oceans (200 m) is shown. The received noise versus beam elevation angle is compared for bottom porosities of 0.4, 0.6 and 0.9. The receiver is at 100 m and the ocean sound speed is constant with depth. Because bottom loss is a parameter used to scale propagation loss, it is not surprising that the noise curves for the more porous bottoms fall off measurably when the sonar beam is directed downward, as shown here. Thus, in shallow water where absorption is not an influential factor, the contribution from bottom bounce paths can significantly affect the noise field.

Figure 9 indicates that the effect of variable salinity is not large for the steeper surface-directed beams; the difference between curves based on salinity extremes of 21 and 45 parts per thousand does not exceed 2 dB. When the beam is depressed downward, however, a 4 dB variation in the noise

level occurs. This difference illustrates the importance of salinity for predictions made in shallow water where salinity content can vary significantly.

Figure 10 compares the received noise levels for two shallow water oceans: (1) an isovelocity ocean and (2) the Gulf of Maine (figure 11). The noise curve corresponding to the Gulf of Maine profile clearly shows the sensitivity of received noise to refraction. Note that if a steeper set of angles (i.e., $|\theta| > 30^{\circ}$) had been included, the noise curves for the Gulf of Maine would have increased or decreased (depending on the amount of bottom loss suffered), because the steeper angle would have overcome the effects of refraction. Figure 12, which shows the ray diagram for the Gulf of Maine based on a 91-m receiver, illustrates the highly shadowed surface.

CONCLUSIONS

The selected frequency of 23.5 kHz for this study results in noise level predictions that are highly sensitive to ocean depth. In deep water oceans, a large decrease in the noise signal below the horizontal occurs. This loss is due to the dominance of volume absorption caused by the longer ray paths required to link the receiver and noise source between the ocean bottom and the surface. Specifically, the following observations were made:

- When receiver depth is fixed, the noise level falls off sharply below the horizontal.
- When receiver depth for a fixed sonar beam angle is varied, the noise level decreases with increasing receiver depth.
- When water depth is varied, the noise level is not affected if beam angle and receiver depth are held constant.

In shallow water oceans, for a fixed wind speed, it is predicted that the received noise levels are limited predominantly by two environmental parameters: SSP and bottom porosity. Changes in the SSP can affect the directionality of noise. Most striking is the case of an extreme surface-shadowed environment, where only the steepest ray paths reach the surface. The ocean bottom can be an excellent reflector of sound and, thus, noise. However, increasing bottom porosity yields a decrease in received noise levels at angles below the horizontal.

Based on the results of this study, it is expected that this noise model will play a significant role in system performance predictions, particularly at the higher sonar frequencies.

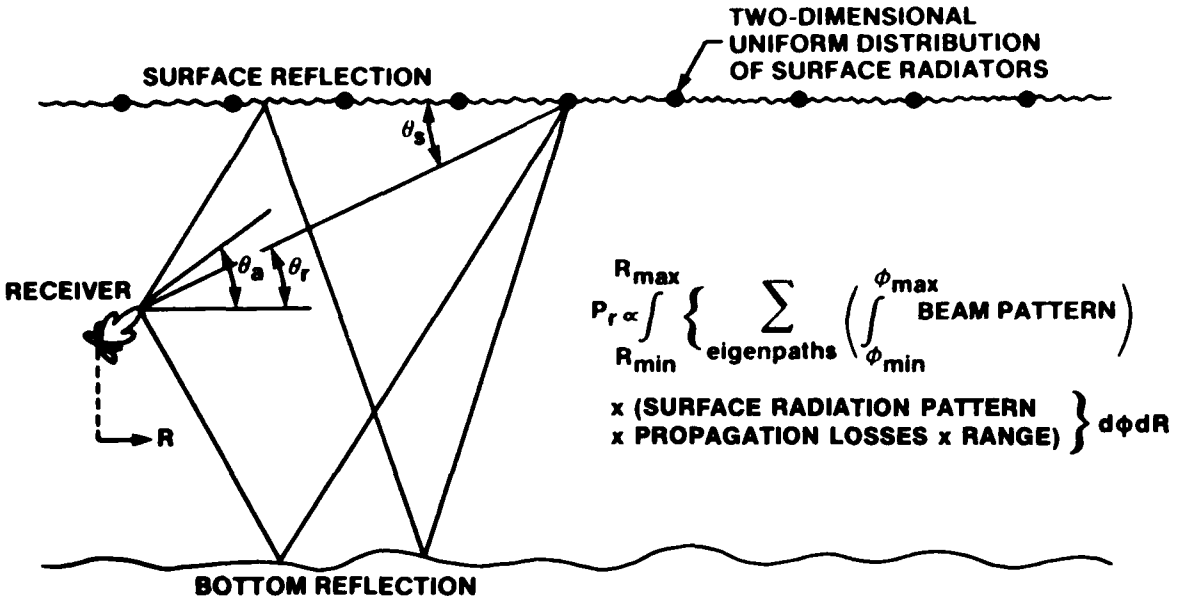


Figure 1. Ocean Model for Surface-Generated Ambient Noise Predictions

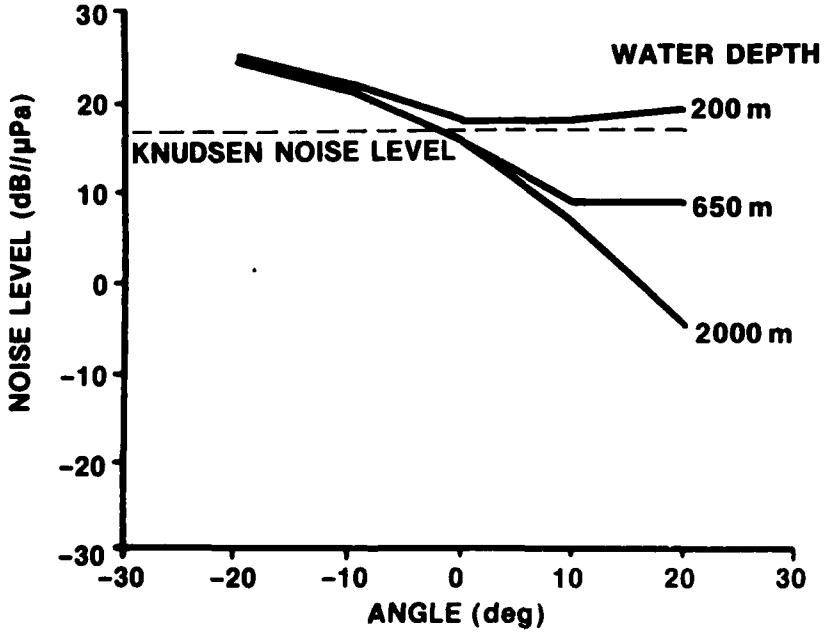


Figure 2. Ambient Noise vs. Beam Elevation Angle, With Receiver Depth of 100 m and Water Depths of 200, 650, and 2000 m

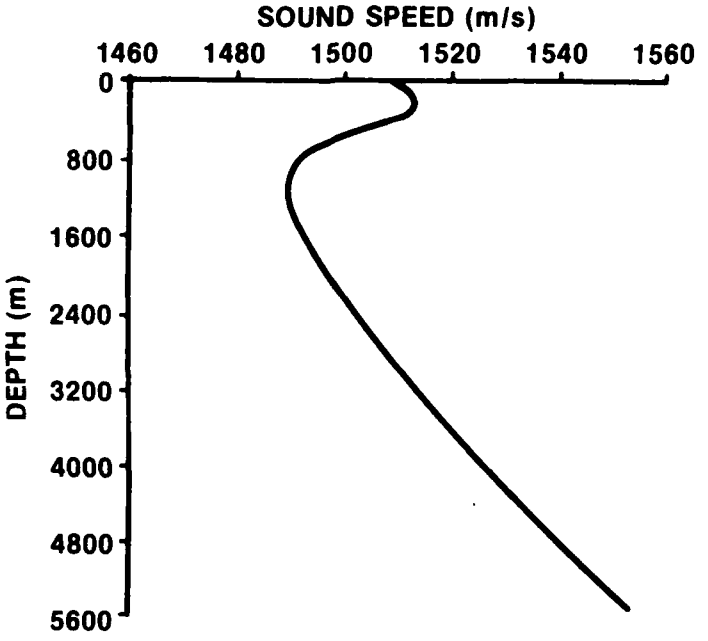


Figure 3. Ocean Sound Speed vs. Depth, With Layer Depth of 251 m and Water Depth of 6000 m

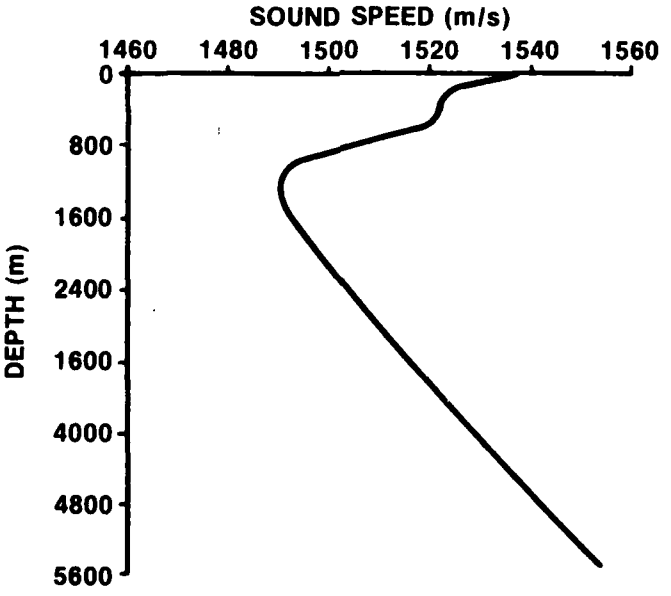


Figure 4. Ocean Sound Speed vs. Depth, With Layer Depth of 49 m and Water Depth of 6000 m

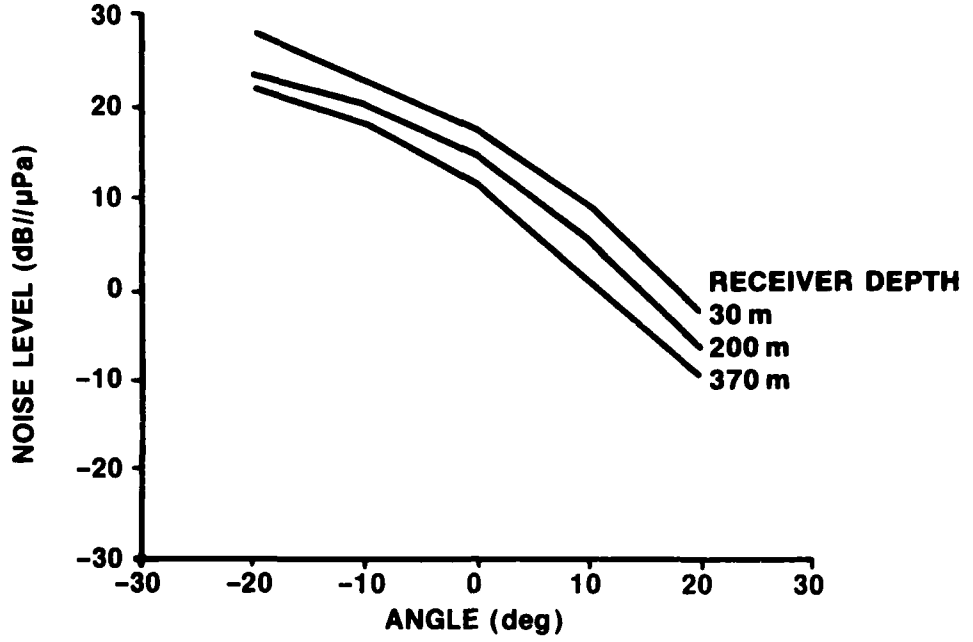


Figure 5. Ambient Noise vs. Beam Elevation Angle, With Receiver Depths of 30, 200, and 370 m for Deep Layer Case

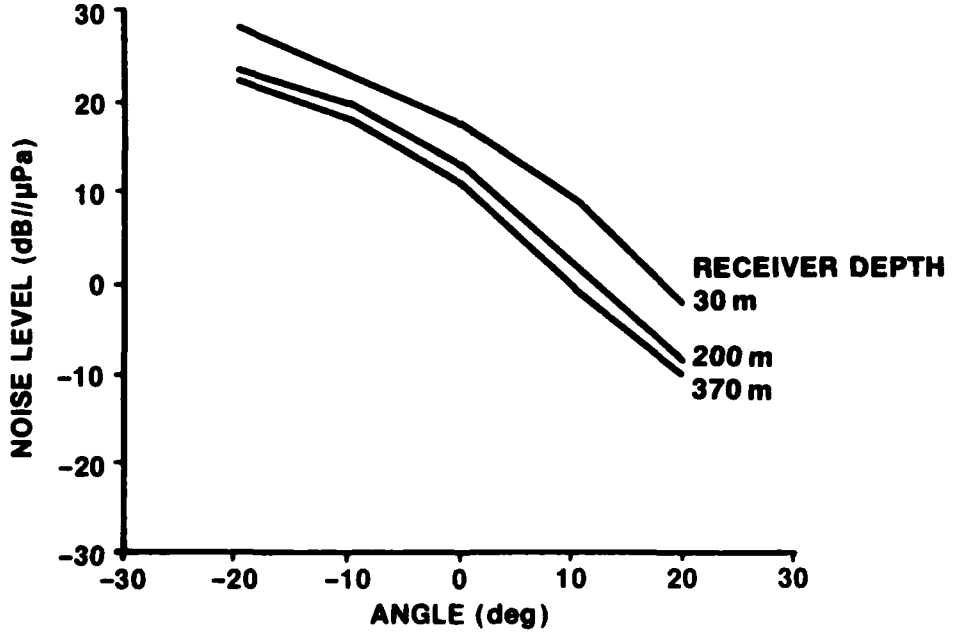


Figure 6. Ambient Noise vs. Beam Elevation Angle, With Receiver Depths of 30, 200, and 370 m for Shallow Layer Case

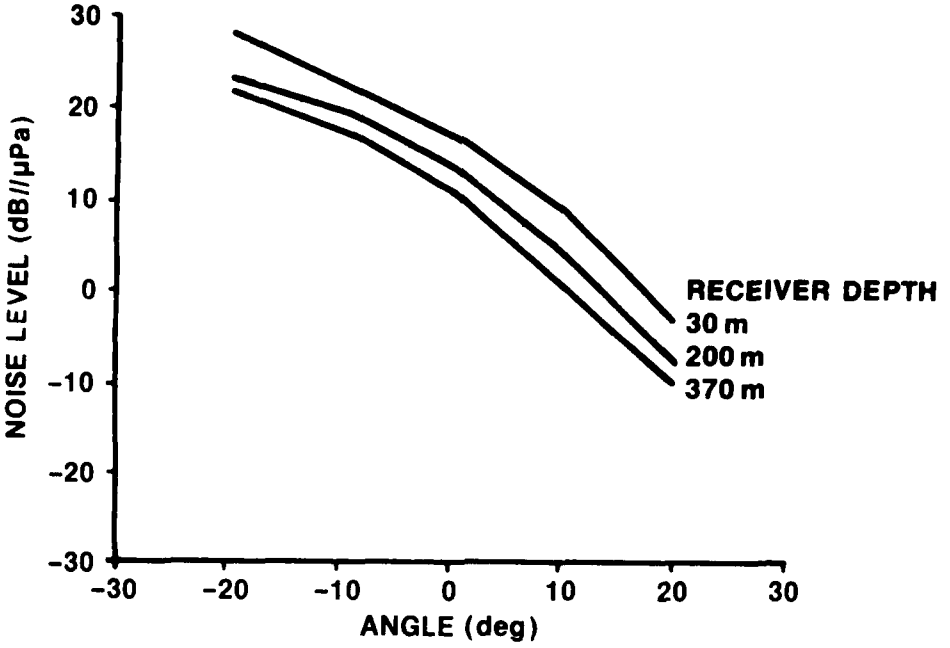


Figure 7. Ambient Noise vs. Beam Elevation Angle, With Receiver Depths of 30, 200, and 370 m for Isospeed Case

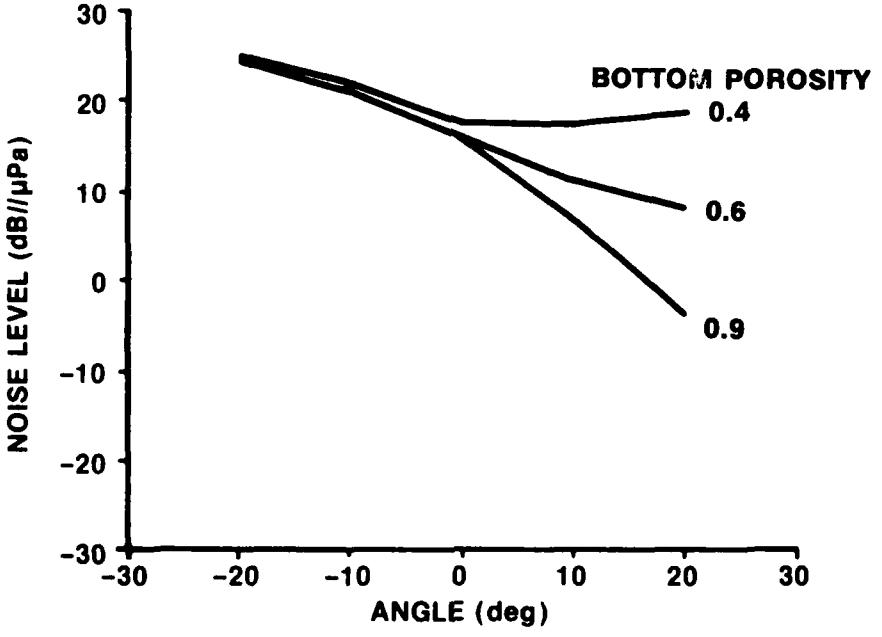


Figure 8. Ambient Noise vs. Beam Elevation Angle, With Receiver Depth of 100 m, Water Depth of 200 m, and Bottom Porosities of 0.4, 0.6, and 0.9

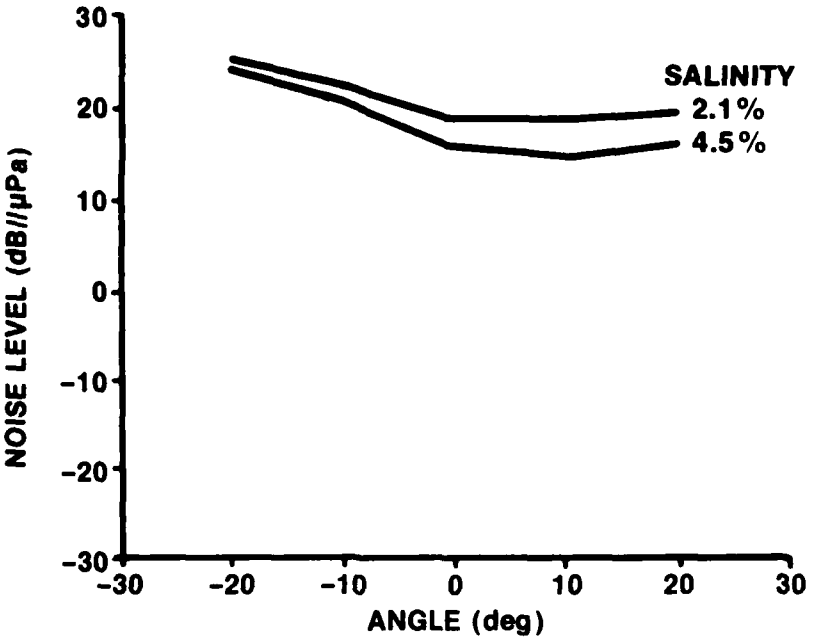


Figure 9. Ambient Noise vs. Beam Elevation Angle, With Receiver Depth of 100 m, Water Depth of 200 m, and Salinities of 2.1 and 4.5 Percent

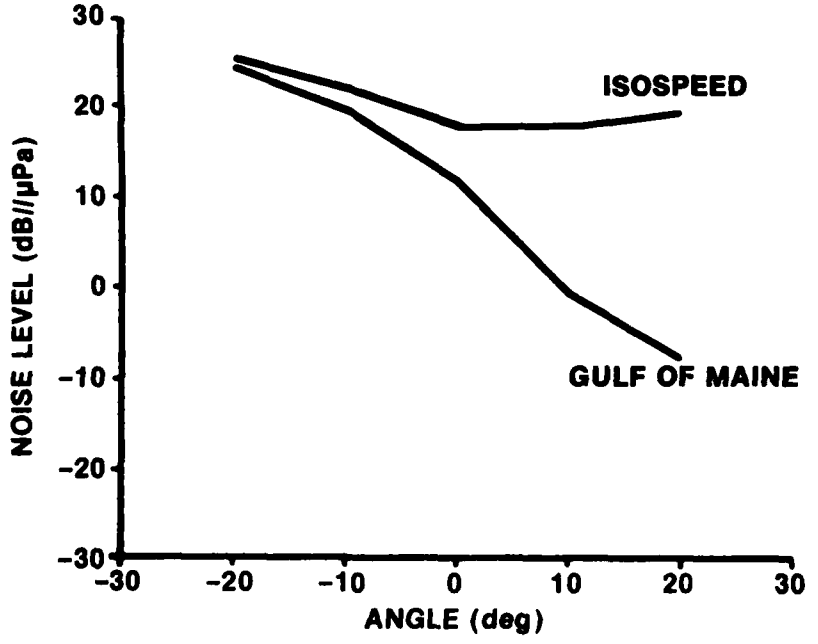


Figure 10. Ambient Noise vs. Beam Elevation Angle, With Receiver Depth of 91 m and Water Depth of 200 m, for Isospeed and Gulf of Maine Profiles

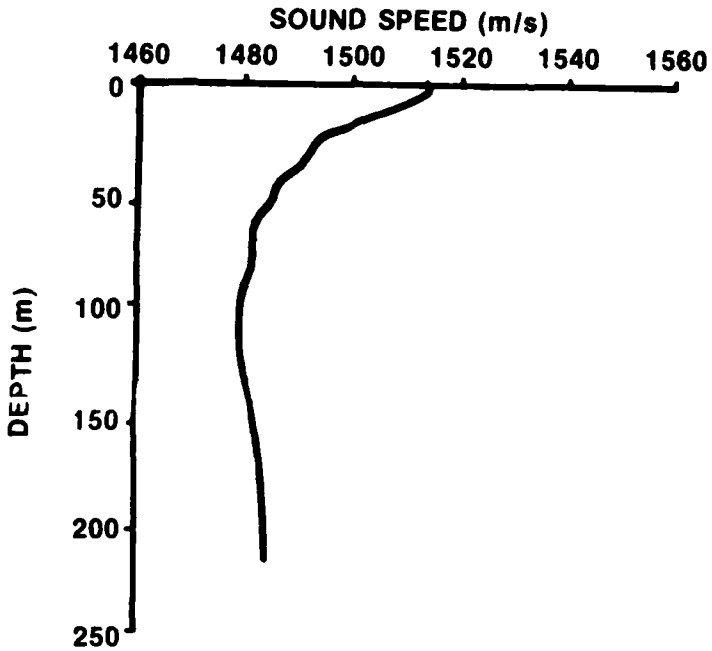


Figure 11. Ocean Sound Speed vs. Depth for Gulf of Maine Profile

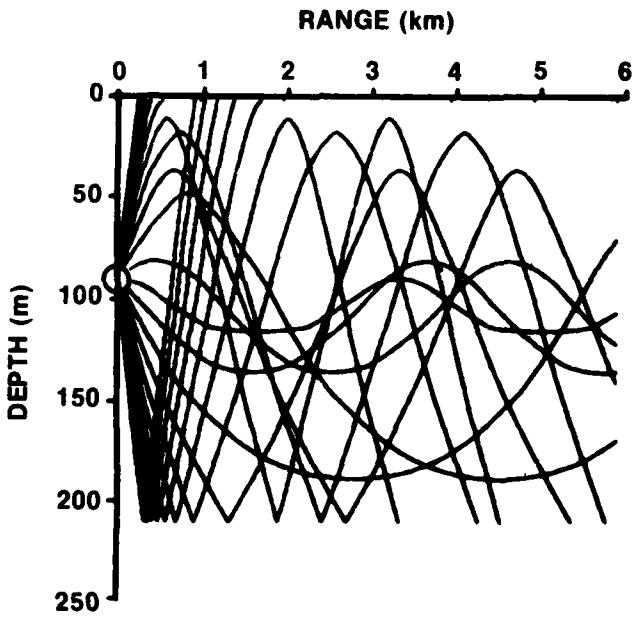


Figure 12. Ray Diagram for Gulf of Maine Profile

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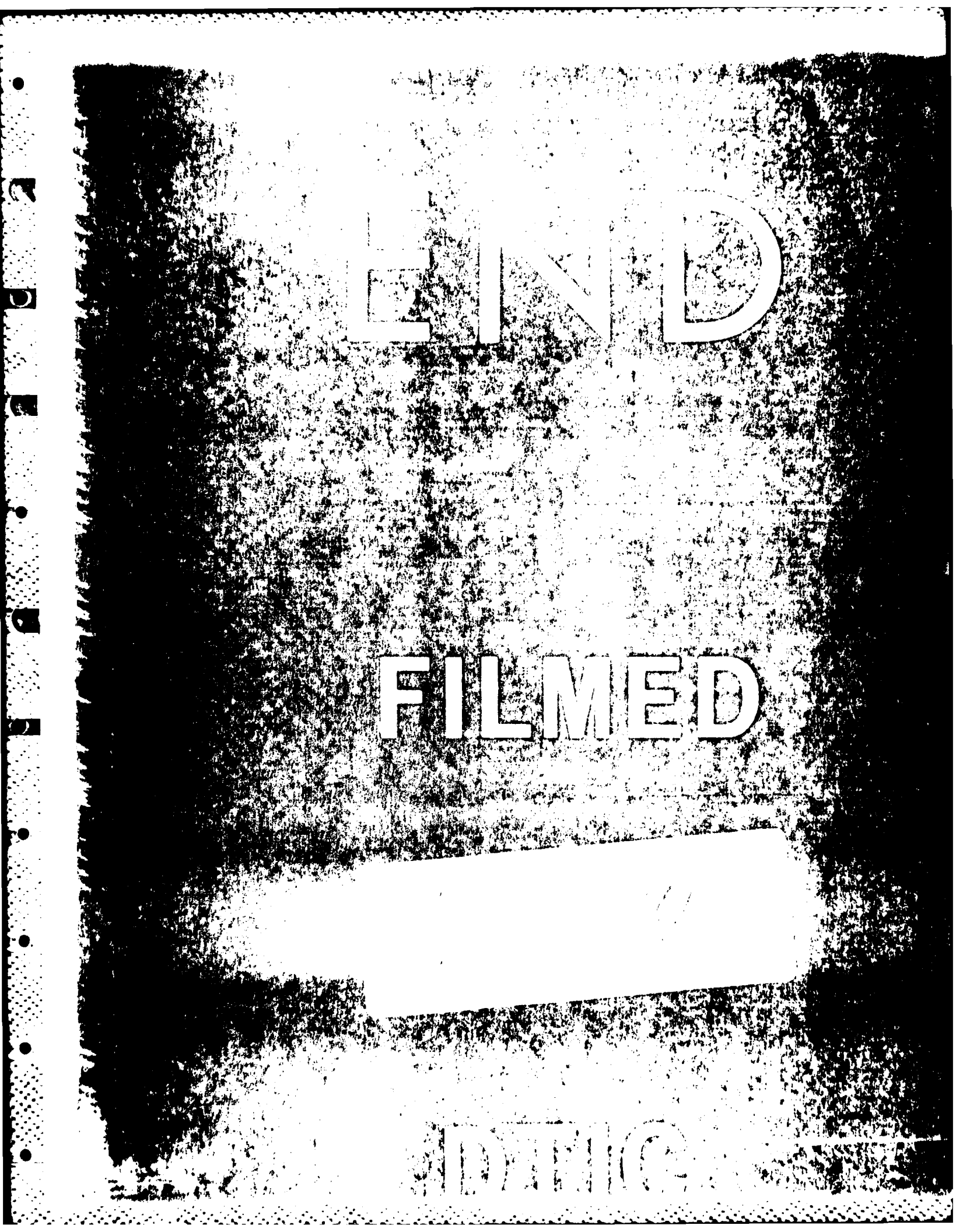
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