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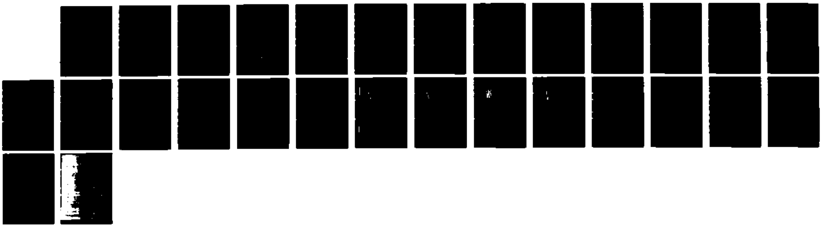

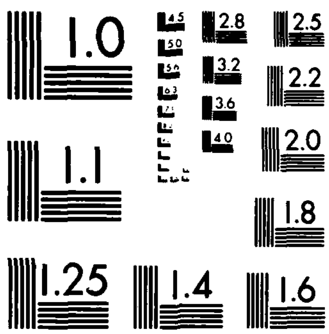
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Three-dimensional propagation loss diagrams show that effects of the North Wall on propagation loss persist at all receiver depths from sea surface to 1000 meters.

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ACOUSTIC RAY TRACING
AND
THREE-DIMENSIONAL PROPAGATION LOSS
REPRESENTATION IN THE GULF STREAM REGION

by

E. KHEDOURI

and

P. GABORSKI

SEPTEMBER 1977

U. S. NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON, D. C. 20373

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FIGURES

ABSTRACT

Acoustic ray traces and intensities for fixed and variable receiver depths were calculated for three cross sections in the Gulf Stream region using AXBT temperature profiles and historical sound velocity data. Two sections were in the Sargasso Sea and one crossed the Gulf Stream. It is shown that for shallow source and receiver depths, a 4 dB difference in intensity is found in the Sargasso Sea due to sonic layer depth differences. When sound intensities across the Gulf Stream were compared to intensities for similar situation without a front, it was found that the Gulf Stream North Wall could either increase or decrease propagation loss depending on distance of the receiver from the front; the maximum difference was 18 dB. The South Wall of the Stream had no significant effect on sound intensity.

Three-dimensional propagation loss diagrams show that effects of the North Wall on propagation loss persist at all receiver depths from sea surface to 1000 meters.

I. INTRODUCTION

Effects of oceanic fronts and eddies on acoustic sound propagation based on measured or calculated values have been documented in several publications (Gemmill, 1974; Gemmill and Khedouri, 1974; Levenson and Doblar, 1976). There is little doubt that a strong front such as the Gulf Stream has a significant effect on sound propagation. A front can either increase or decrease transmission loss depending on the distance of the source or receiver from the front, and the magnitude of transmission loss depends on factors such as bottom topography, bearing angle of sound transmission to the front and the depth of the source or receiver. Direct measurement of sound intensity across a front at various range and depth intervals is impractical. However, computer simulation and three-dimensional representation of propagation loss can be used to determine intensity variation for a given cross section as a function of range and depth.

The objective of this paper is to show theoretical sound paths and propagation loss values for three cross sections in the Gulf Stream region using methods which are adaptable to operational use. Figure 1 shows the location of the cross sections and the surface thermal structure of the area. Sections A and B are in Sargasso water and section C crosses the Gulf Stream. The data for this report consist of airborne expendable bathythermograph (AXBT) temperature profiles taken during February 1976, combined with deep historical sound velocity data.

II. METHOD

In frontal regions where horizontal temperature gradients exist along a given cross section, a multiple profile model (range dependent environment) must be used for ray tracing and propagation loss calculations in order to reflect the sound velocity changes along the cross section. NRL GRASS model (Cornyn, 1973) was used for all the acoustic calculations in this report. This is a multiple profile and variable bottom depth experimental model used primarily for research purposes. The model was significantly modified by the authors to make it more suitable for operational use.

The NRL version of GRASS requires either sound velocity vs depth, or salinity and temperature vs depth as input. The program automatically extrapolates sound velocity profiles to the ocean floor. This extrapolation can result in erroneous sound velocity values when the bottom is considerably deeper than the deepest available data point and consequently, in deep waters, relatively deep sound velocity data are required. This type of data, however, is not readily available operationally. One of the modifications made to GRASS was to combine it with the ICAPS merge program (Hanssen and Tucker, 1975). This program merges temperatures from AXBT traces or similar near-surface temperature data, with mean seasonal temperature and salinity data from historical files for a given geographic area (5 degree square), to create sound velocity profiles from sea surface to the ocean floor. This modification made it possible to use AXBTs or similar readily available temperature data as input to the program. A variation of the above technique is to merge the AXBT temperatures with historical temperatures and salinities for a particular water mass (Fisher, 1976). This method uses the near-surface temperature characteristics to select the proper water mass. The method gives superior results in frontal regions because oceanic fronts are not constrained by fixed geographical boundaries. The water mass concept was used in this report for determining sound velocity profiles from AXBT temperature profiles.

Another modification made to GRASS was the use of three-dimensional plots to display propagation loss vs range vs receiver depth. This modification allows the propagation loss at all receiver depths (1-1000 m) to be displayed in one diagram which shows the changes in propagation loss as receiver depth is varied.

III. SOUND VELOCITY PROFILES, RAY TRACES AND PROPAGATION LOSS

Sound velocity profiles used for ray tracing and propagation loss curves for sections A, B, and C are shown in figures 2, 3 and 4 respectively. Profiles used for sections A and B are in Sargasso Water. Profiles used for Section C are in Slope, Gulf Stream, and Sargasso waters.

Ray traces and transmission loss curves for sections A and B are shown in figures 5 and 6. In both cases a 290 Hz source at 137 m depth was used with an 88 m deep receiver. Comparison of ray traces shows that in section A most of the transmission is through bottom bounce and deep sound channel, whereas in section B, considerable amount of transmission is through the near-surface duct. Inspection of the sound velocity profiles used in these sections (figures 2 and 3) reveals that the only difference is in the near-surface sound velocity and in the sonic layer depth (SLD). In section A, the SLD was 240 m at the source and 105 m at the receiver, whereas in section B, the SLD was 200 m both at the source and the receiver, resulting in well defined surface ducting. This surface duct transmission resulted in 4 dB higher sound level at 50 nmi(92.6 km) range.

Ray traces for section C, crossing the Stream from Slope to Sargasso Water, with a source at 137 m depth are shown in figure 7. Sound velocity profiles used for this section (figure 4) show that in addition to near-surface sound velocity diffences, the depth of the deep sound channel axis (DSC) deepens from 700 m in Slope Water to about 1200 m in the Gulf Stream and 1400 m in the Sargasso Sea. In addition, sound velocity in the upper layer of the sound channel is higher in the Stream and Sargasso than in the Slope Water. Deepening of the sound channel and the increasing sound velocity across the Stream are reflected in the ray traces, where it can be seen that after the rays cross the North Wall of the stream, they are channeled downward into the deep sound channel. Similar results were shown by Gemmill (1974).

Propagation loss curves in figure 7 show the intensities for a 290 Hz source at 137 m and a receiver depth of 88 m. The solid line shows the intensities from the eight profiles used in the ray trace, and the dashed line shows the intensities using only the first Slope Water profile. The difference between the two curves, therefore, represents the difference caused by the fronts. When the North Wall is crossed, the sound rays become out of phase and the convergence zones which are typical for a single water mass are destroyed. The resultant effect on intensities is seen by the significant difference between the two curves when the North Wall is crossed. The maximum difference of 11 dB occurs at 90 nmi (166.7 km) range.

Figure 8 shows the ray traces and propagation loss curves for Sargasso to Slope transmission across the Stream using sound velocity profiles shown in figure 4. Ray traces were calculated for a 137 m source depth. When the South Wall of the Stream is crossed the surface bounce propagation is terminated. This is because the SLD is considerably shallower in the Stream than it is in Sargasso Sea as shown in the sound velocity profiles. When sound travels across the North Wall, convergence zones become reinforced with significant effect on propagation loss values. Propagation loss curves in figure 8 were calculated for a 290 Hz source at 137 m and a receiver depth of 88 m. The solid line represents the propagation loss calculated from the eight profiles used in the ray traces and the dashed line shows the loss for identical conditions using the first Sargasso profile. The difference between the curves, therefore, is caused by the fronts. It can be seen that the South Wall of the Stream has only a minimal effect (4 dB) on propagation; the North Wall of the Stream, however, has a very significant effect which is caused by reinforcement of convergence zones. For example, at 130 nmi (241 km) range, transmission is decreased by 14 dB, but at 135 nmi range, transmission is improved by 8 dB because of the front.

IV. 3-D PROPAGATION LOSS REPRESENTATION

Three-dimensional propagation loss diagrams serve primarily as visual aids to show the variation of intensity at several receiver depths. Exact values of propagation loss, for any receiver depth and range, however, can also be determined from the diagrams.

The following example, using figure 9, will illustrate how to read the propagation loss value at any point. To determine the propagation loss value at 40 nmi (74 km) range and 200 meter receiver depth, the following procedure can be used:

1) Find the propagation loss vs depth line at 40 nmi range (see arrow in figure 9).

2) Find the propagation loss vs range line at receiver depth of 200 m.

3) Find the intersection of the two lines.

4) Draw a line from this intersection parallel to the range axis and equal in length to 40 nmi on the range axis scale. The resulting propagation loss value of -88 dB can be read on the propagation loss plane. In cases of

complex sound velocity structure, parts of the propagation loss surface may be hidden and it may not be possible to read some points from the diagrams. In these cases, a new viewpoint can be selected to display hidden regions of interest.

The 3-D propagation loss diagrams for sections A and B are shown in figures 9 and 10 respectively. The two diagrams are similar except for the near-surface values, caused by the near-surface sound duct as described in Section III. In both cross sections, which are in the Sargasso Sea, there is a significant decrease in propagation loss between the su·ˉace receiver and a receiver at 25 m; below 25 m propagation loss vs depth is arly constant. (The abrupt change at 25 m has no physical significance; it caused by computational procedures where receiver depth was incrementι . 25 m intervals.

The 3-D plots of propagation loss across the Stream for section C, from Slope to Sargasso and from Sargasso to Slope, are shown in figures 11 and 12 respectively. When sound travels from cold Slope Water to warmer Gulf Stream and Sargasso Water the convergence zones become weaker as sound is deflected into the deep sound channel (see the ray traces in figure 7). The effects of weaker convergence zones are reflected in the 3-D plot of propagation loss in figure 11, and it can be seen that the effects of the front persist at all receiver depths from sea surface to 1000 m. When sound travels from Sargasso to Slope Water, the convergence zones are reinforced as can be seen in the ray trace in figure 8 and the resultant 3-D propagation loss plot in figure 12. Effects of the front are again evident at all receiver depths.

Note that reciprocity of sound pressure level exists because the ocean system is linear with respect to the pressure levels encountered in acoustic surveillance. Therefore, identical propagation loss curves would be obtained if the source and receiver locations were interchanged. In the case of 3-D diagrams, this means that identical propagation loss surfaces would be obtained for variable source levels and a single receiver depth as for single source depth and variable receiver depth. The 3-D diagrams in figures 9 to 12, therefore, can also be used for receiver depth of 137 m and variable source levels from 1-1000 m. In order for reciprocity to strictly hold, all possible rays must be used in intensity calculations. In the above figures an envelope of rays from +20° to -20° from the horizontal at 1° increments was used, and rays were terminated after 5 bottom bounces and 10 surface bounces. This has little effect on propagation loss values and reciprority, but provides considerably clearer ray diagrams.

V. CONCLUSIONS

1) For shallow source and receiver depths, there was a 4 dB difference in intensity at 50 nmi (92.6 km) range between the two cross sections in the Sargasso Sea. The difference was attributed to a deeper SLD in one of the sound velocity profiles which resulted in rays being trapped in the surface duct.

2) When sound is propagated from Slope Water across the Gulf Stream into Sargasso Sea, recurrent convergence zones which are typical for a single water mass are destroyed. When sound is propagated from the Sargasso Sea, across the Stream, into the Slope Water, the convergence zones are reinforced. This has a significant effect on propagation loss values.

3) When propagation loss for shallow source and receiver depths calculated for a single Slope Water profile is compared to propagation loss values calculated from multiple profiles across the Gulf Stream under similar conditions, a maximum of 11 dB difference occurs. When propagation loss is calculated from a single Sargasso Sea profile and compared with propagation loss values using multiple profiles across the Gulf Stream, a maximum difference

of 18 dB results. In both cases the difference is caused by the Gulf Stream North Wall.

4) The effects of the North Wall on propagation loss are evident at all receiver depths from sea surface to 1000 meters.

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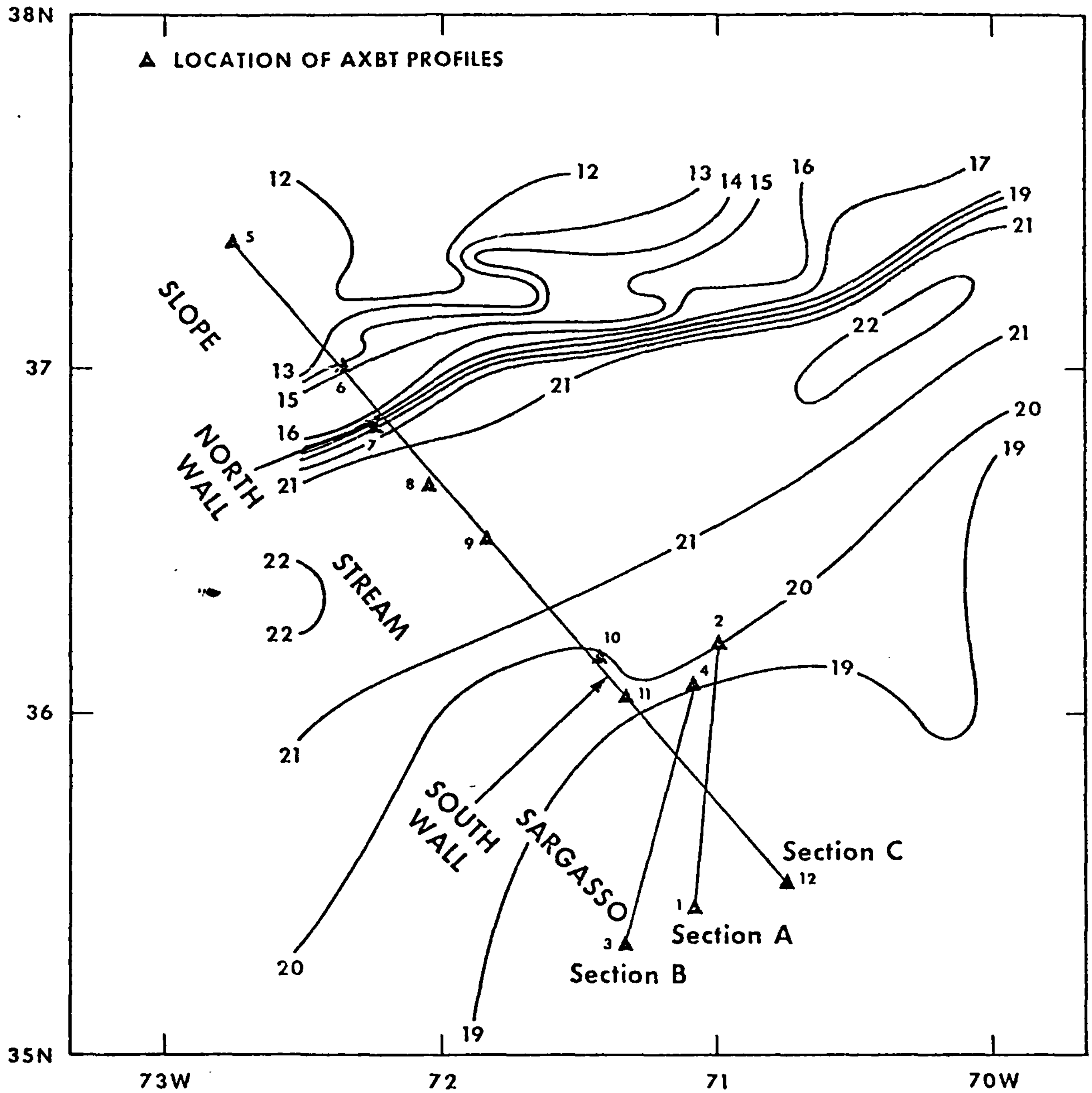


Figure 1 - Surface Thermal Structure and Location of AXBT Profiles (14 February 1976)

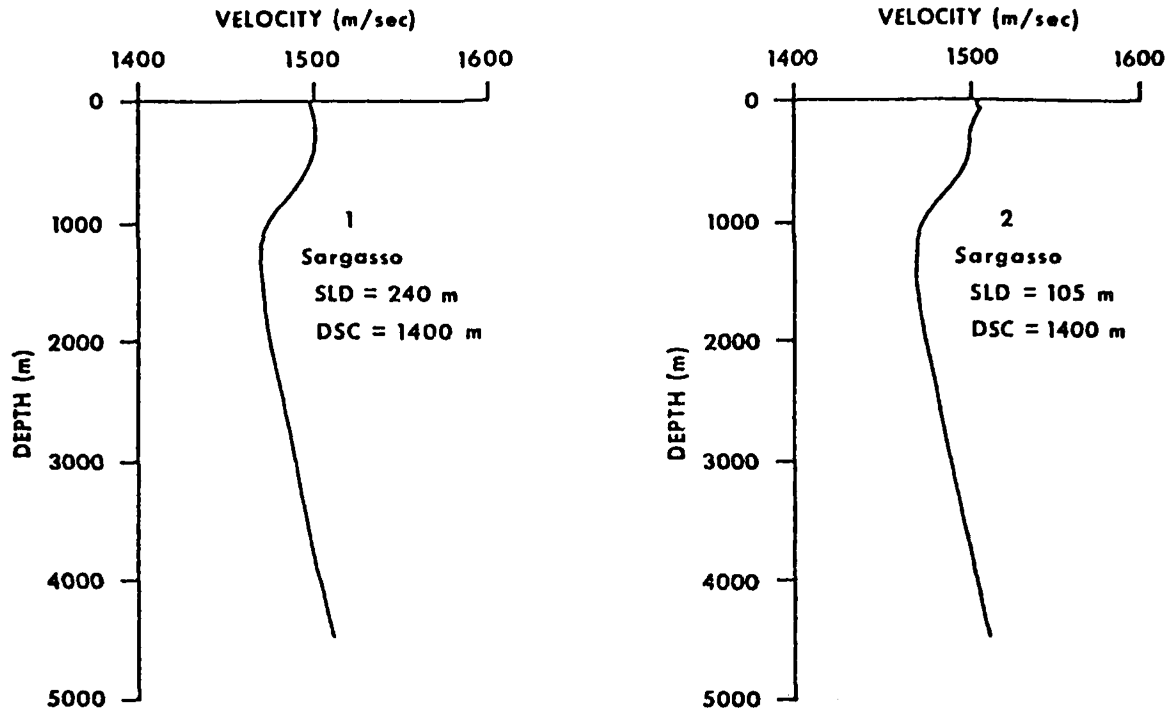


Figure 2 - Sound Velocity Profiles for Section A

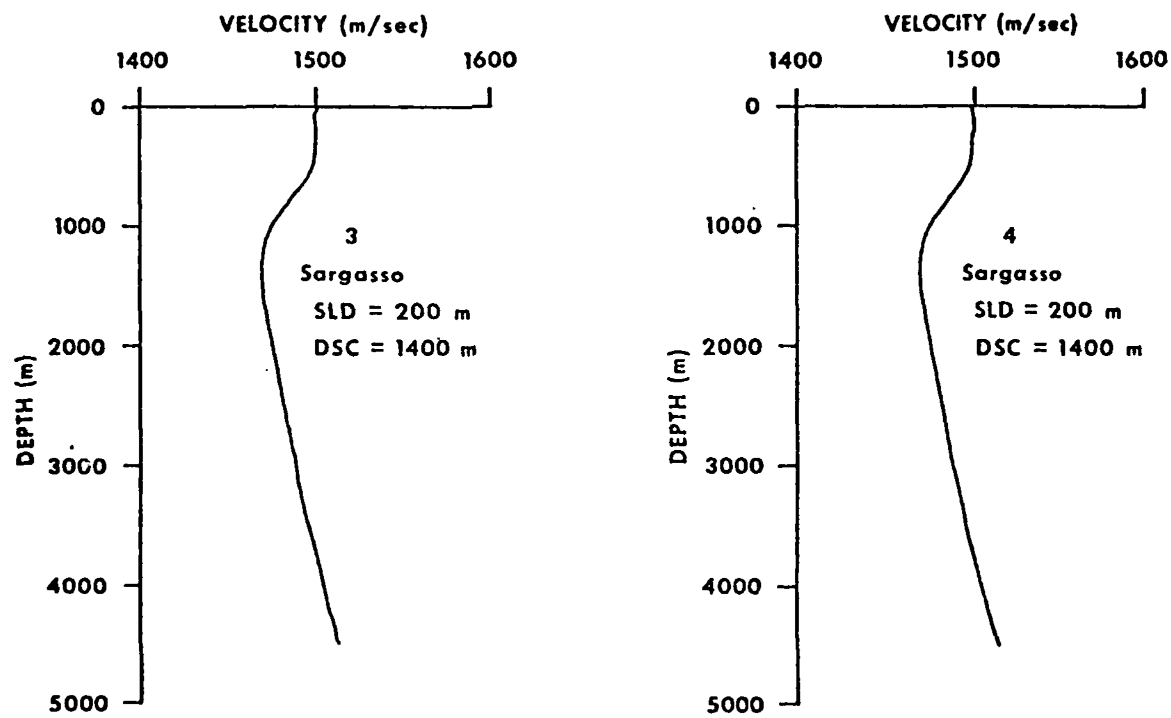


Figure 3 - Sound Velocity Profiles for Section B

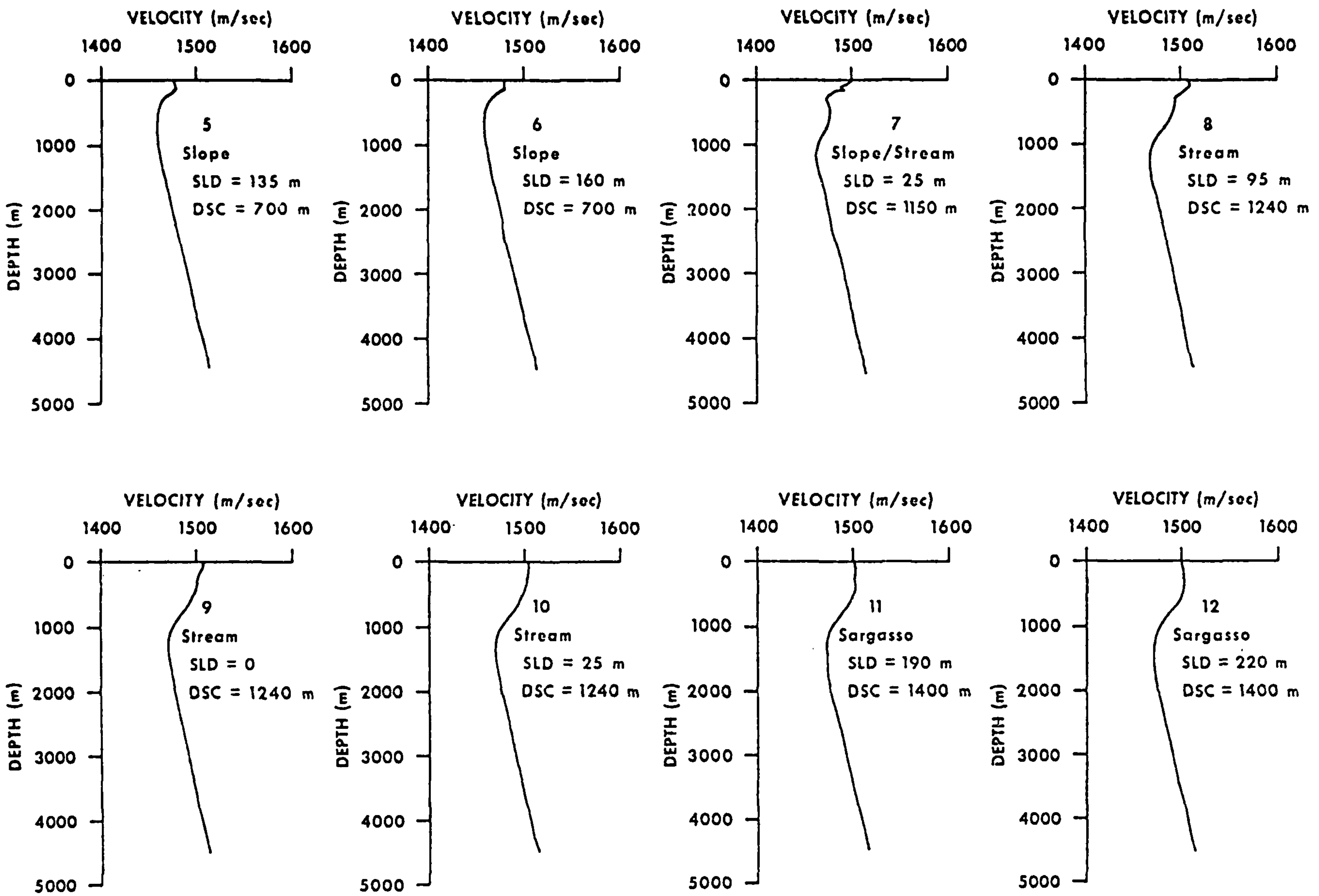
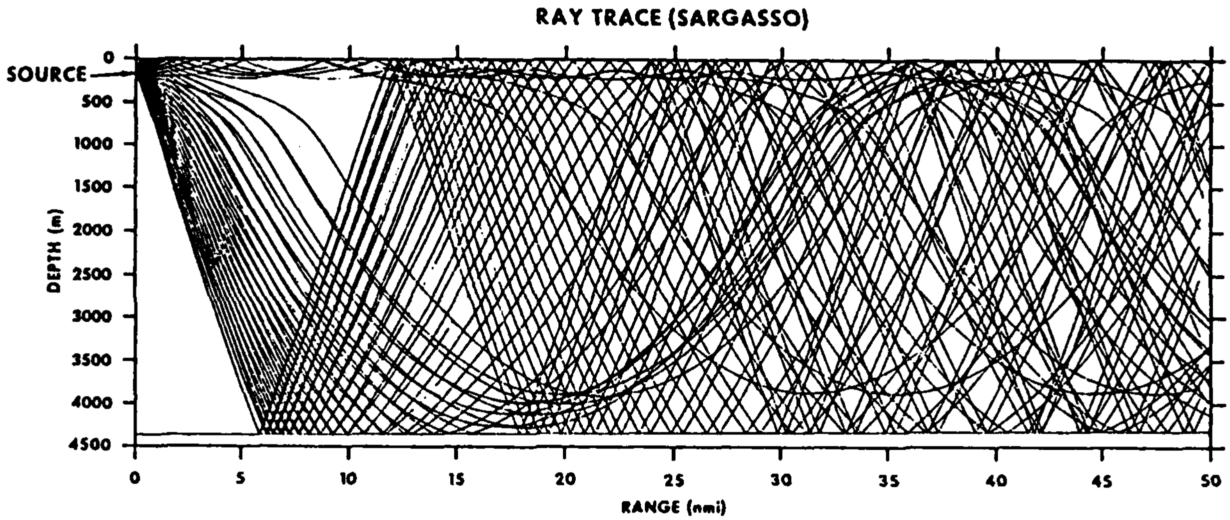


Figure 4 - Sound Velocity Profiles for Section C



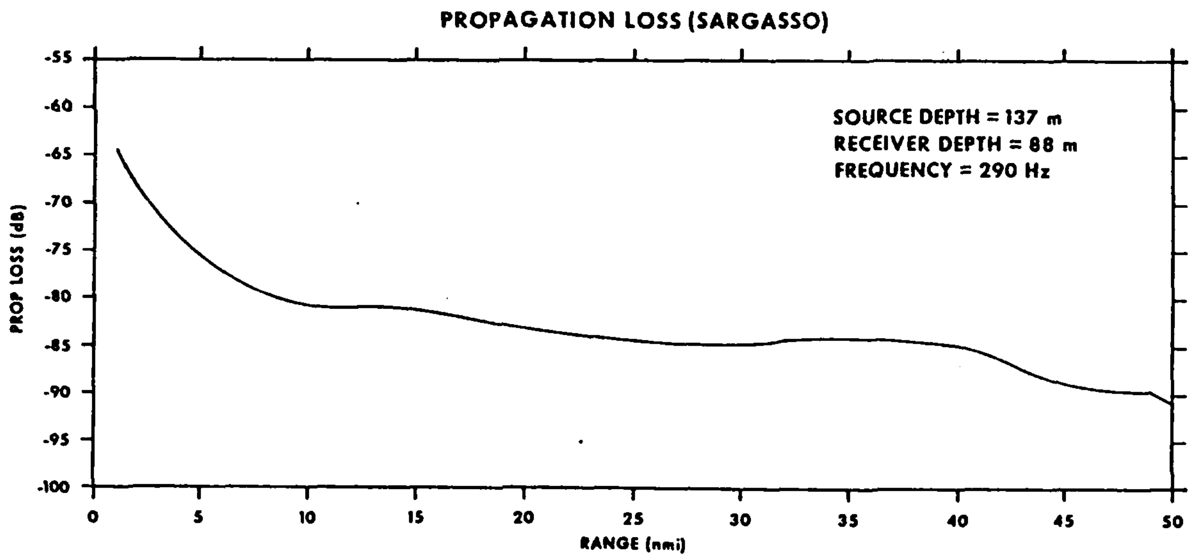


Figure 5 - Ray Trace and Propagation Loss for Section A

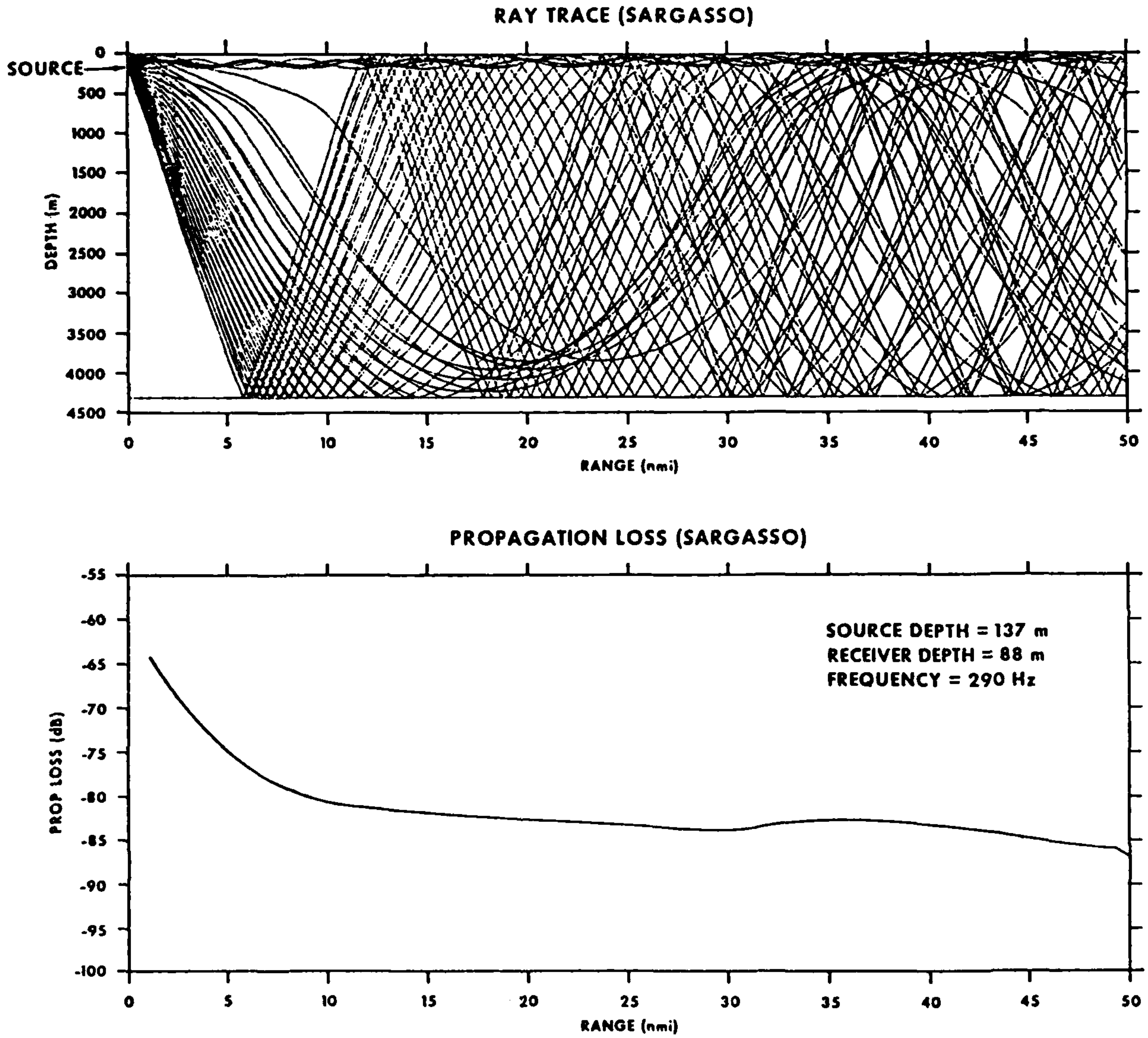


Figure 6 - Ray Trace and Propagation Loss for Section B

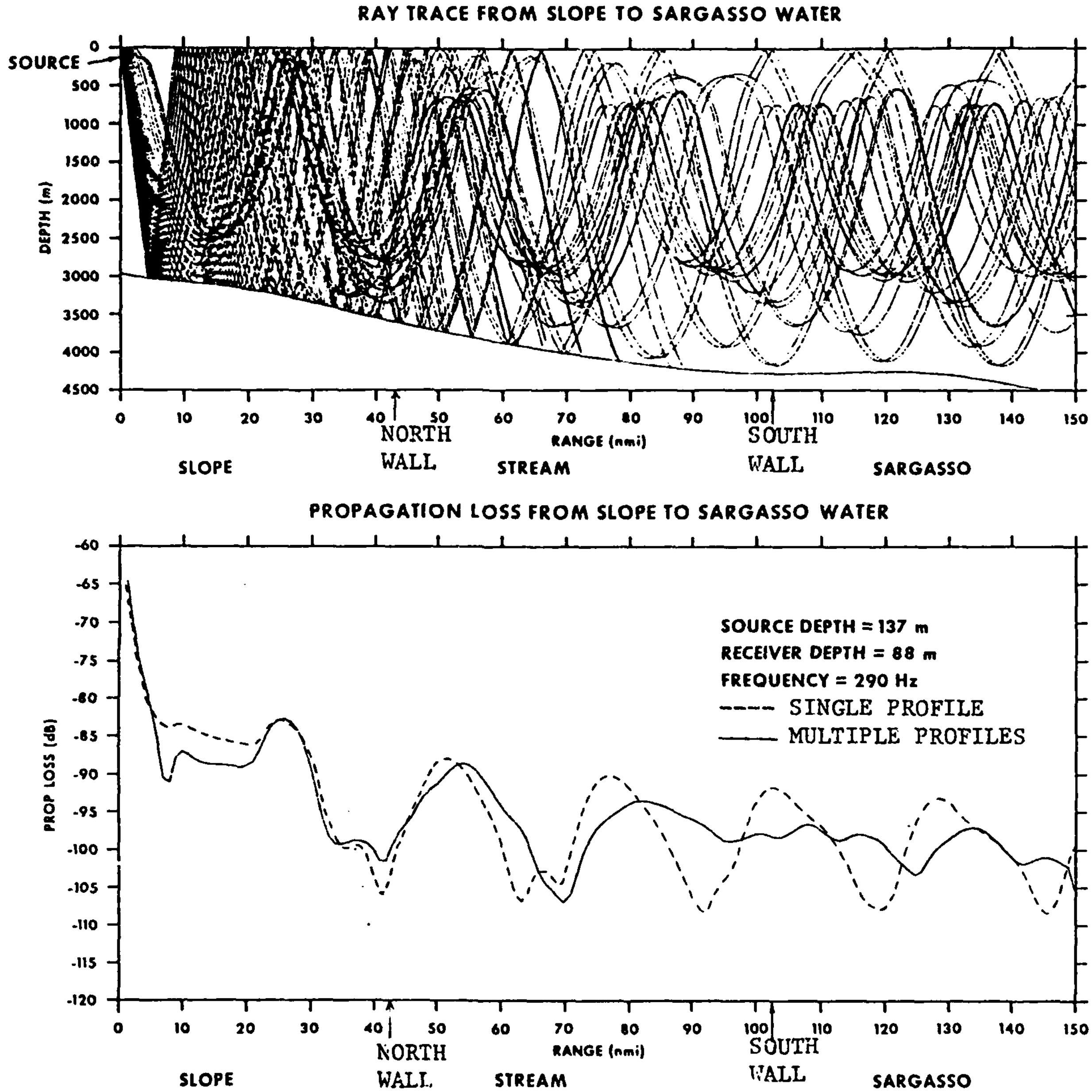


Figure 7 - Ray Trace and Propagation Loss for Section C. Slope to Sargasso Water

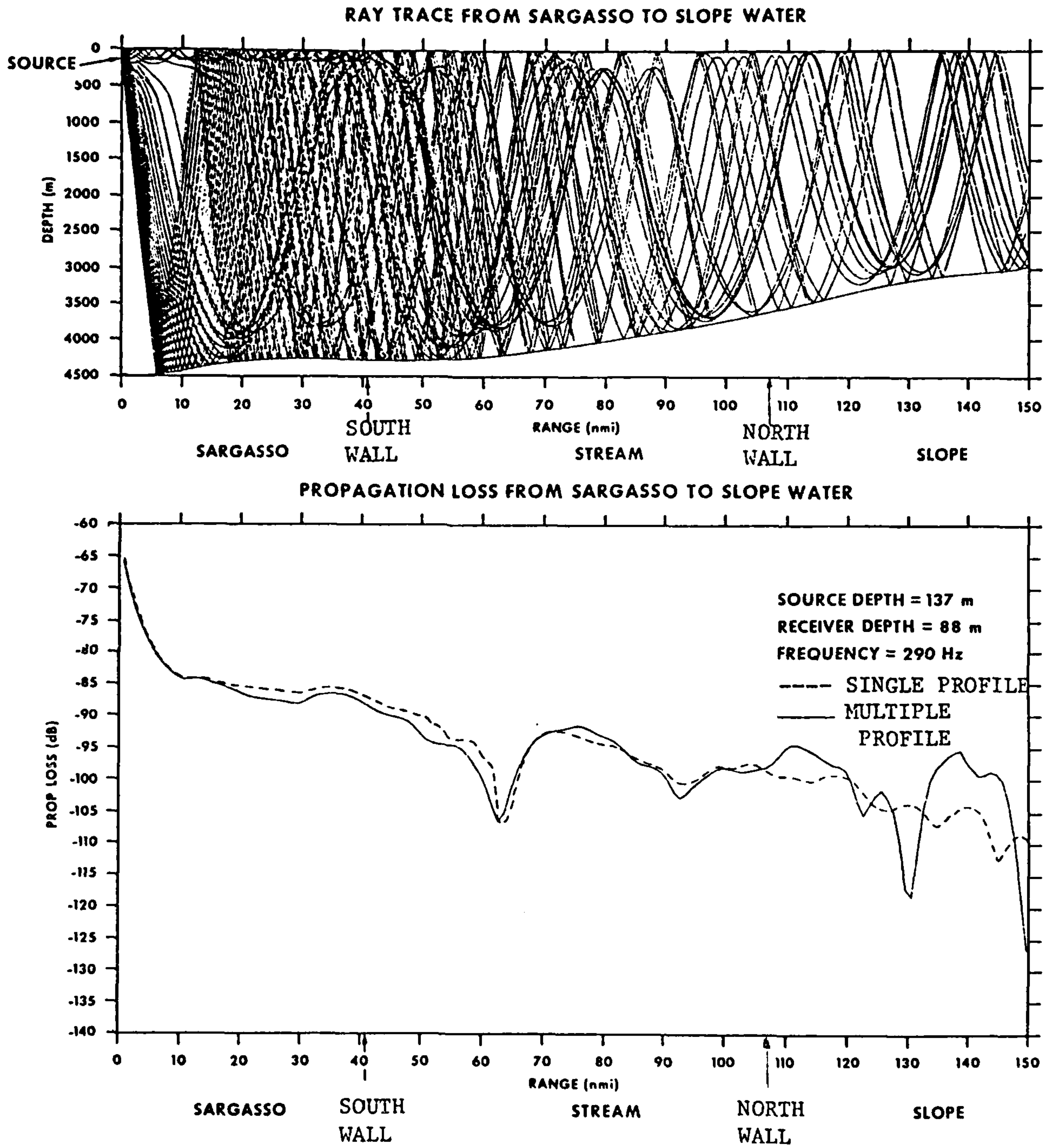


Figure 8 - Ray Trace and Propagation Loss for Section C. Sargasso to Slope Water

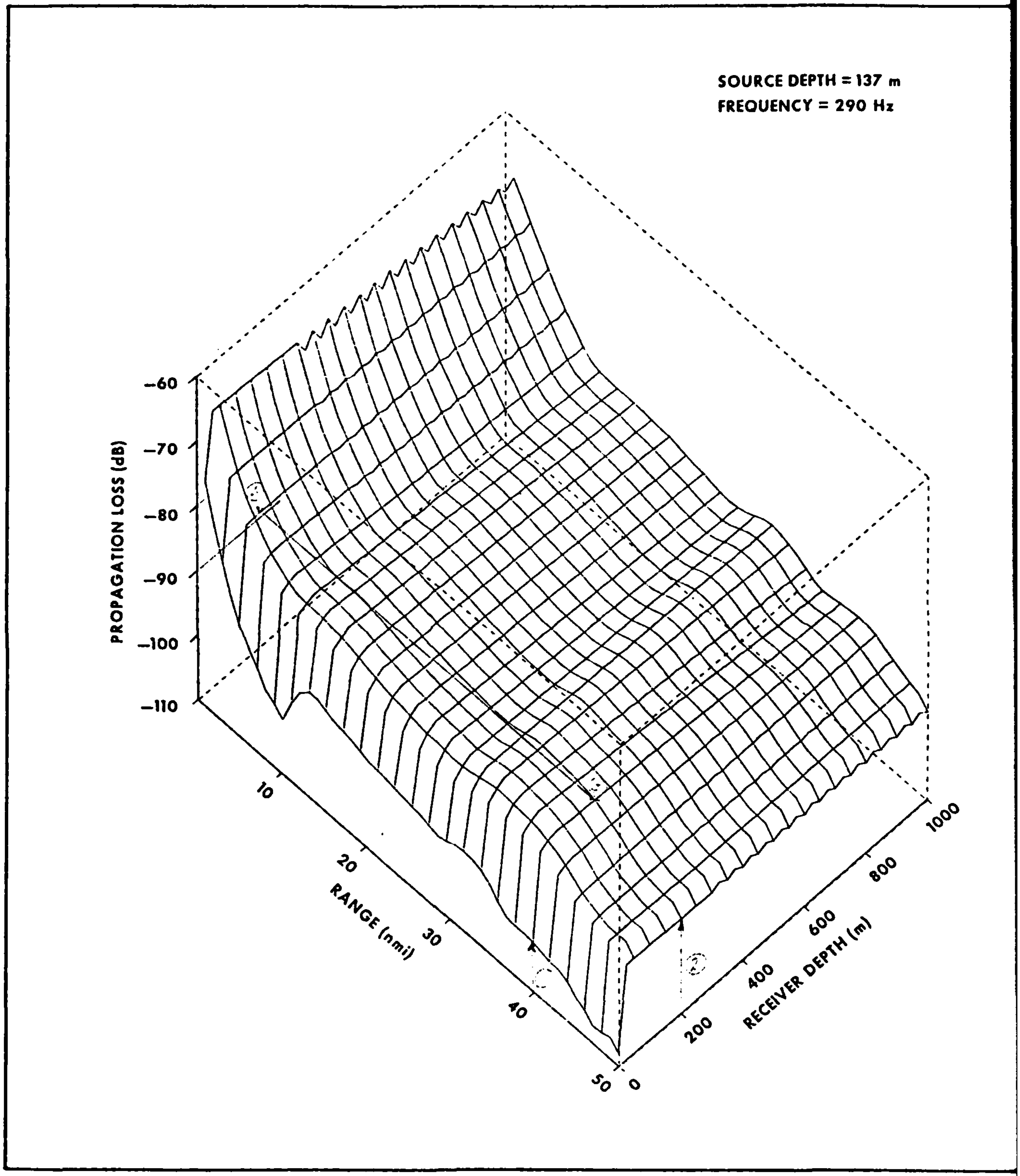


Figure 9 - 3-D Propagation Loss for Section A

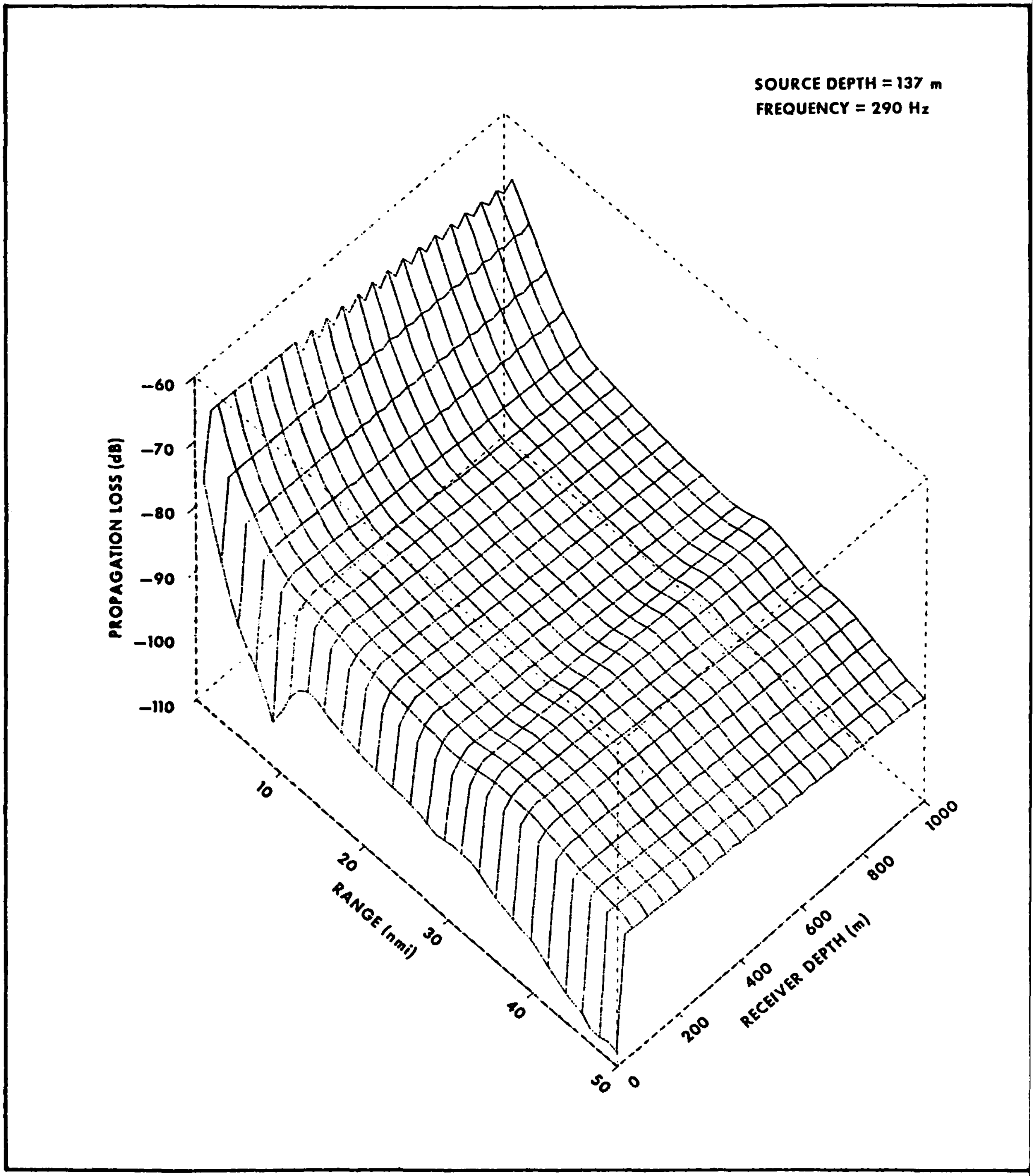


Figure 10 - 3-D Propagation Loss for Section B

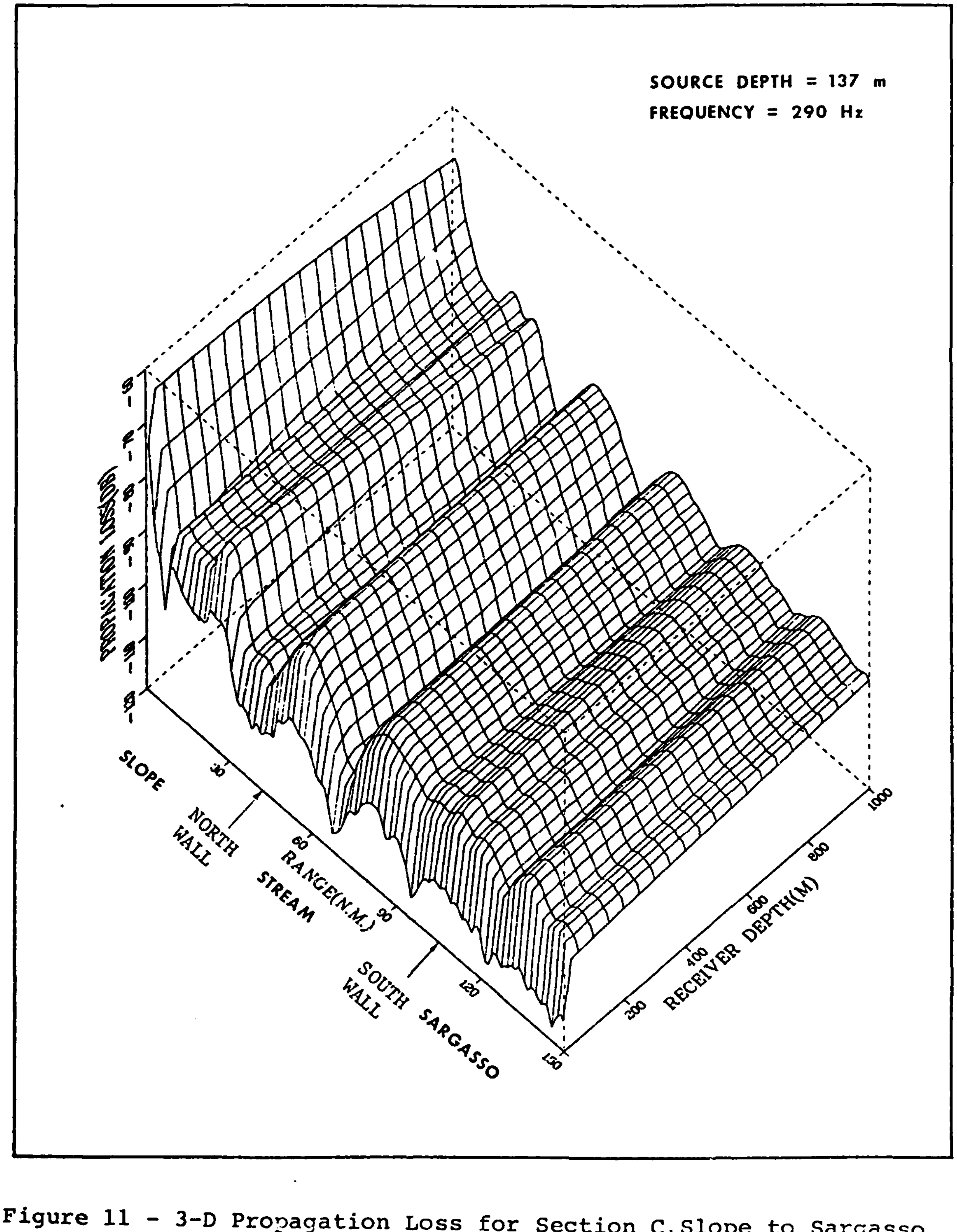


Figure 11 - 3-D Propagation Loss for Section C. Slope to Sargasso Water

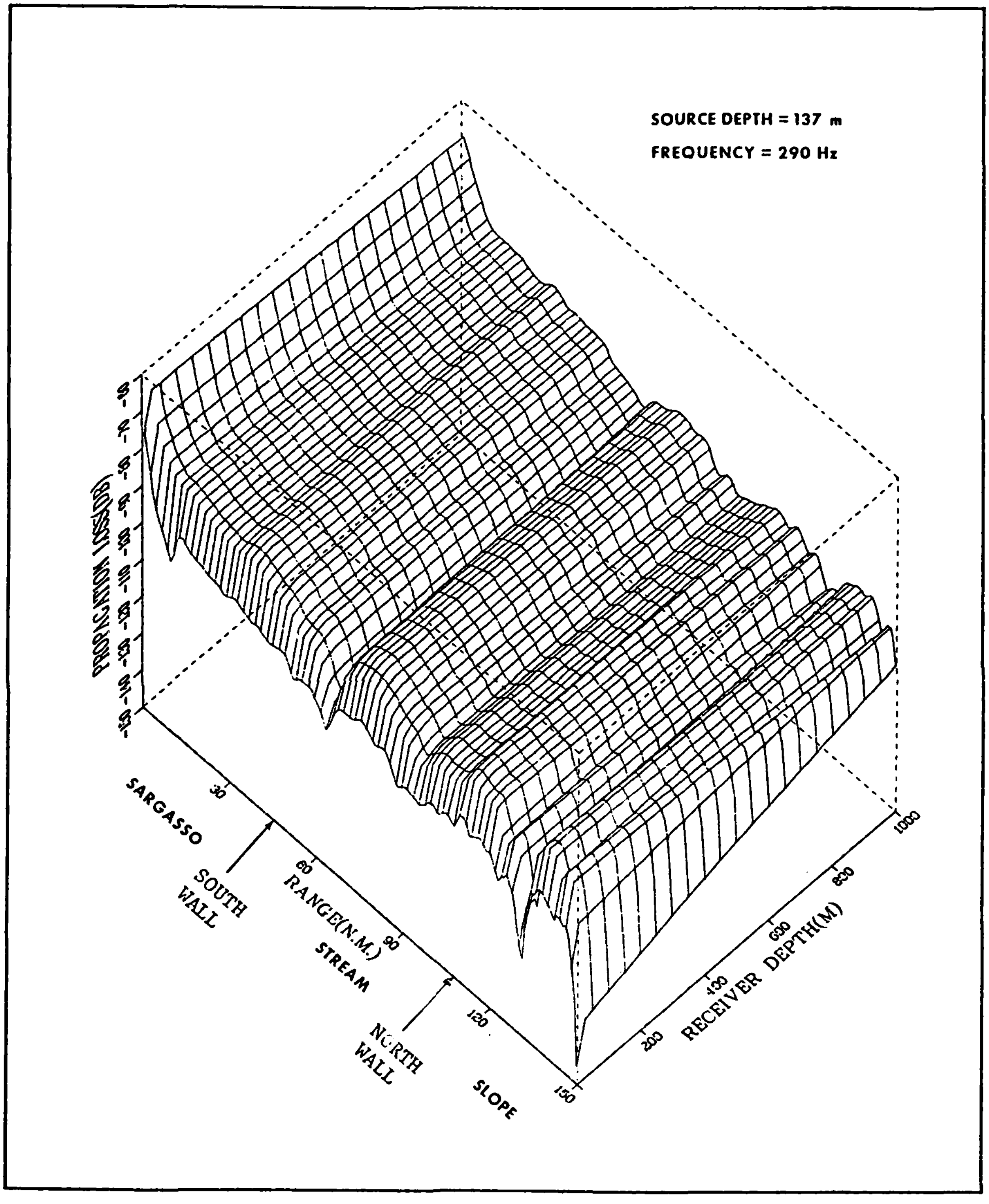


Figure 12 - 3-D Propagation Loss for Section C.Sargasso to Slope Water

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