

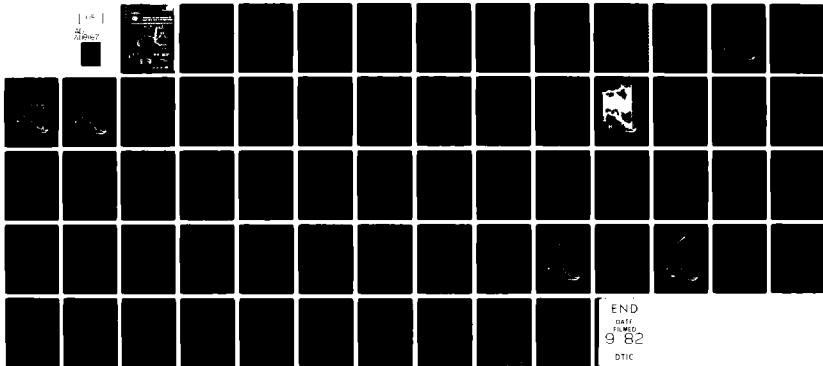
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NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY NSTL S--ETC F/6 8/10  
ENVIRONMENTAL DATA BASE DEVELOPMENT AND ACOUSTIC MODEL SURVEY D--ETC(U)  
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ABSTRACT

A numerical model and data base study was undertaken by the Acoustic Simulation Branch, Numerical Modeling Division, Naval Ocean Research and Development Activity. The study, under the sponsorship of the Surveillance Environmental Acoustic Support Project, was designed to install an environmental data base for the South Atlantic Ocean and for use in conducting a limited scope acoustic transmission loss and ambient noise model study.

The data base framework has been installed and tested. The model study has been conducted and several tentative conclusions have been reached regarding the acoustic nature of the South Atlantic. The limited adequacy of the current data base to provide accurate predictions of the acoustic sensitivity of the region is discussed. Recommendations for data base and model improvements are provided with an eye toward modeling support of future exercise planning in the region.

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#### ACKNOWLEDGEMENTS

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## INTRODUCTION

This report is a summary of an acoustic numerical model and data base study undertaken by the Acoustic Simulation Branch (NORDA Code 321), Numerical Modeling Division, for the Surveillance Environmental Acoustic Support Project of the Ocean Programs Management Office. The objectives of the study are:

- To install and test an environmental data base for the South Atlantic Ocean capable of providing properly formatted input data to a number of acoustic propagation and ambient noise models.
- To exercise the data base along several great circle paths to assess its suitability for acoustic sensitivity studies.
- To conduct a limited scope model study to determine the sensitivity of propagation loss and ambient noise to source depth, receiver depth, frequency, and track location.
- To draw some preliminary conclusions based on the modeling exercise as to the environmental acoustic characteristics and sensitivities of the region, as well as the adequacy of the data base for further, more detailed studies.
- To provide recommendations for improvements to be made in the data base, deficiencies in the environmental data and their possible correction, and further studies to be undertaken once the improvements are made and data base deficiencies corrected to the extent allowable by data availability.

The report is organized to address each of these objectives. Section I describes the great circle path tracks selected for the study. Selection criteria and a key to the track identifiers are discussed. Section II describes the data base currently installed on the CYBER 170/720 computer at NORDA. Sound speed provinces, together with their selection criteria, are defined. The source of other model inputs contained in the data base are discussed. These inputs include bathymetry, wave height, shipping, and bottom loss. Graphic representations of the environmental inputs along each great circle path track are provided. Comparisons of the archival data with recently obtained sound speed profiles for the western portion of the region are presented.

Section III includes a description of the acoustic models used in the study, together with a summary of the source depth, receiver depth, frequency and geographic sensitivities of propagation loss. Omnidirectional ambient noise predictions are provided, with some discussion of geographic and frequency sensitivities. Directional noise estimates are presented for two eastern South Atlantic sites. These estimates provide insight into the effects of the locally concentrated shipping and widespread bathymetric blockage on the azimuthal dependence of the noise field. Some indication of the directional and environmental effects on signal-to-noise ratio is shown through plots of beam noise plus transmission loss versus range for a selected track and source/receiver geometry.

Section IV provides a summary of the findings, together with a discussion of the significant data base deficiencies and recommendations for further data base development and acoustic simulation studies.

### I. TRACK SELECTION

The track selections for the study were made primarily to exercise the model input data base extensively. Secondary consideration was given to the determination of propagation loss sensitivities in areas of potential operational interest.

Table 1 contains a description of the location of each track exercised in the study. The key to the track identifier is given at the bottom of the table. All tracks were run for the South Atlantic summer; hence, they all carry an F (for February, the middle month of the season) as the first letter in the identifier. For the propagation loss study, a common set of input depths and frequencies were used. These are provided at the bottom of the table.

Gross environmental features, including the presence of the Mid-Atlantic Ridge, together with certain other major bathymetric features, allow the South Atlantic to be divided into basins that may be acoustically isolated. Several tracks were chosen to test the effects of the ridge structure on propagation. Figure 1 gives the orientation of each track with respect to gross bathymetric features and sound speed provinces. A discussion of each track, together with its criteria for being chosen, is presented below.

<u>Track</u>	<u>Criteria</u>
FA 1	- To exercise provinces 1 and 2 while crossing the Mid-Atlantic Ridge with its expected bottom limited conditions.
FB 1	- To test the sensitivity of propagation from Ascension Island, across the ridge to the African coast.
FC 1	- To test the nature of propagation from the African Coast to the Ridge. These results may give some indication of the degree to which shipping noise might propagate across the Guinea Basin.
FD 1	- To test propagation from the Angola Basin through a break in the Walvis Ridge to the African coast.
FE 1	- To test propagation in the area demonstrating the greatest potential for bottom-limited propagation due to a deep critical depth indication on the profile for province 5. The starting point for the track may be shielded from South American coastal shipping due to bathymetric blockage to the northwest.
FF 1	- To test propagation from the Angola Basin across the Walvis Ridge.
FH 1	- To test propagation from a deep water position in the Angola Basin across the Walvis Ridge to the Cape Basin.
FH 2	- To test propagation from a bottom-limited position on the flanks of the Walvis Ridge to the Cape Basin. The position would probably be shielded by bathymetry to the west and the northwest.
FI 1	- To exercise several provinces along a highly range-dependent track exhibiting large changes of sound speed and bathymetry.

For the most part, the criteria set in the track selection phase were met. Some locations were not properly chosen to optimize the effect desired to be shown by a particular track. It was not possible to display the bathymetry on an area-wide basis for this study; thus, any bathymetric selection criteria were met by chance. The use of bathymetric charts, potentially quite different from the bathymetry in the model data base, makes exact predetermination of track bathymetry impossible. An example of this is shown in track FD 1. This track missed the gap in the Walvis Ridge; thus, the "window" effect expected by blockage over all but those directions containing the bathymetry gap was not adequately demonstrated.

## II. ENVIRONMENT

For the purpose of this study, the South Atlantic was divided into nine sound speed profile (SSP) areas as shown in Figure 1. In determining the boundaries of these areas, two factors were considered: (1) Gross topographical features, such as

Table 1  
South Atlantic Study

Track Identifier	Province	Latitude	Longitude	Bearing (*T)	Range (nm)
FA 1	1	6.01S	31.01W	90°	1400
FB 1	2	7.50S	14.01W	65°	1200
FC 1	3	4.01S	7.50E	270°	1000
FD 1	4	9.01S	1.01E	150°	1000
FE 1	5	26.01S	34.01W	50°	1000
FF 1	6	22.01S	2.01E	90°	1000
FH 1	8	30.01S	3.50W	135°	1000
FH 2	8	30.01S	3.50E	135°	1000
FI 1	9	42.01S	35.01W	45°	1800

**Key:**

FG 1 = Track Identifier

F = Feb (South Atlantic Summer)

G = Province letter A=1, B=2, C=3, etc. (for origin province)

1 = First Track in province

**For all tracks:**

Receiver Depth (ft):

500

Source Depth (ft):

20, 60, 300,  
Channel Axis,  
Bottom Depth - 50 ft.

Frequency (Hz):

25, 50, 300

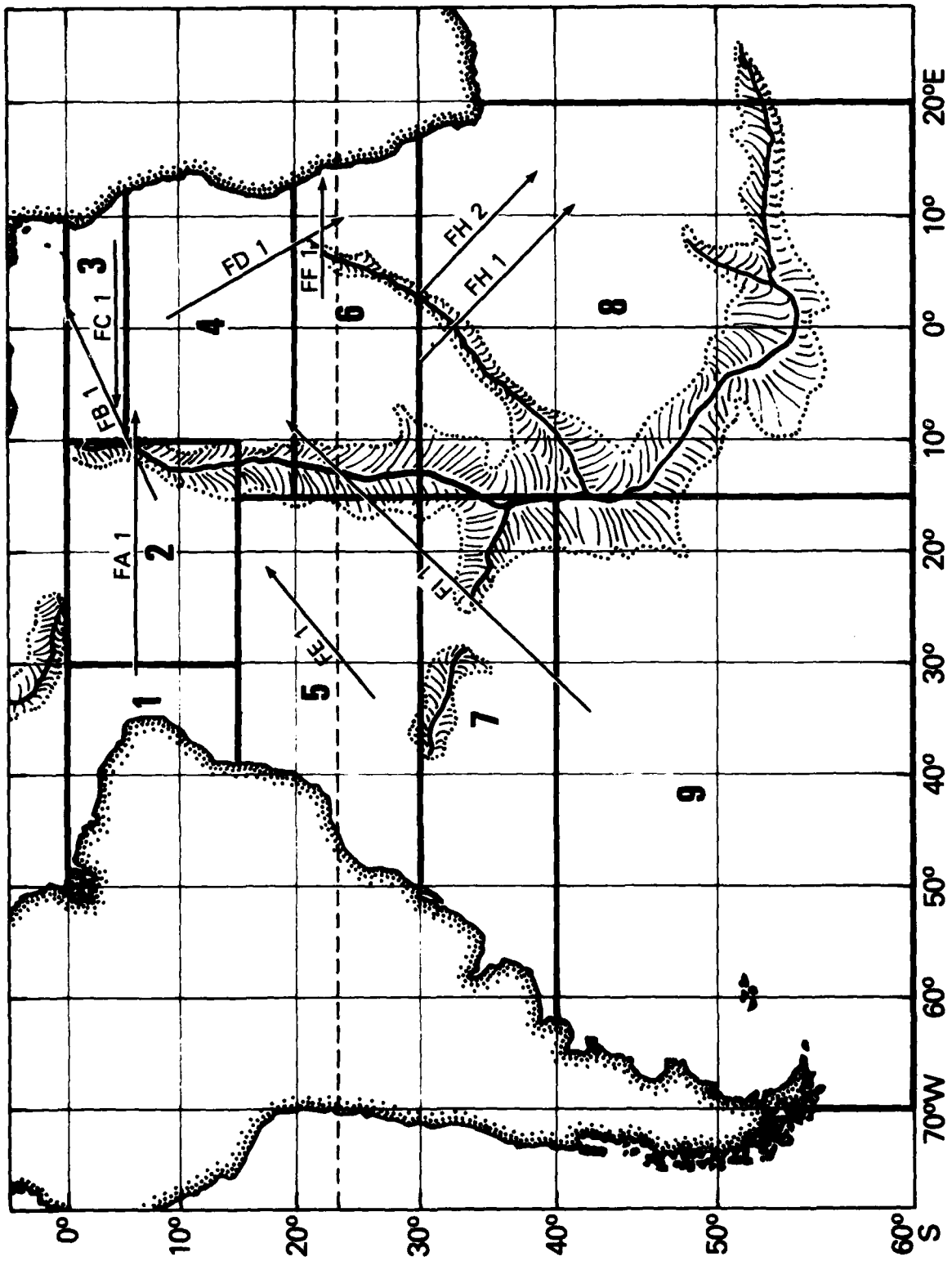


Figure 1

the Mid-Atlantic Ridge and basins, identify acoustically isolated areas; and (2) Oceanographic features, such as temperature and convergence zone (areas where cold polar water masses mix with warmer equatorial water masses), that identify boundaries of areas with similar SSPs. A detailed discussion of factor 2 is given below.

#### A. SOUND SPEED PROFILES

Selection of a representative SSP for a given area may be biased due to the magnitude of the sound speed profile data voids that currently exist in the South Atlantic. Figure 2 is a map of the data-void areas for the January/February/March season.

The extent to which each of the nine areas is bottom limited is shown in parentheses (percent) in Figure 3. These were calculated by using a typical SSP for each area along with bathymetric charts. It can be seen that several areas are highly bottom limited, while others are only slightly bottom limited. In general, the highly bottom limited areas are found west of the Mid-Atlantic Ridge, while those which are less so are found among areas east of the Ridge. There are exceptions such as Area 3, an eastern area which is highly bottom limited, and Area 9, which is a western area and is only slightly bottom limited. The western areas are highly bottom limited for several reasons. With the exception of Area 1, these regions include a wide shallow shelf off the coast of South America and the western flanks of the Mid-Atlantic Ridge. In addition, the deep sound speeds of these areas are reduced over those normally expected by an influx of cold, deep-water masses. This, coupled with high surface sound speeds, results in deeper critical depths and thus a greater degree of bottom limiting. In Area 1, the high degree of bottom limiting is principally due to the deep critical depths and not shallow water, since the coastal shelf is not very wide in this area.

In contrast, the critical depth of Area 9 is shallow, due to low surface sound speed. This is illustrated by Table 2, which was obtained from salinity and temperature vs. depth for Areas 1 and 9 (Figs. 4, 5, 6, & 7).

Table 2  
Salinity and temperature vs. depth

	Area	T(°C)	S(ppt)	Sound Speed (m/s)
Surface	1	27.5	36.00	1541.10
	9	12.5	34.40	1497.80
Deep Water (4000 m)	1	2.1	35.04	1526.21
	9	0.6	34.70	1519.15

Since sound speed depends upon both temperature and salinity, the Table 2 shows that the surface sound speeds of Area 1 are expected to be considerably greater than those of Area 9, while the deep water sound speeds of these areas will not show appreciable difference. Thus, critical depths for Area 1 will be greater than those of Area 9.

As previously mentioned, Area 3 is an eastern area that is highly bottom limited. In this area, as in Area 1, the high surface sound speed is due mainly to the warm surface water typical of these latitudes during the summer and is primarily responsible for the deep critical depth. Thus, even though the area consists of relatively deep water, it is highly bottom limited. The SSP of Area 4 is similar to

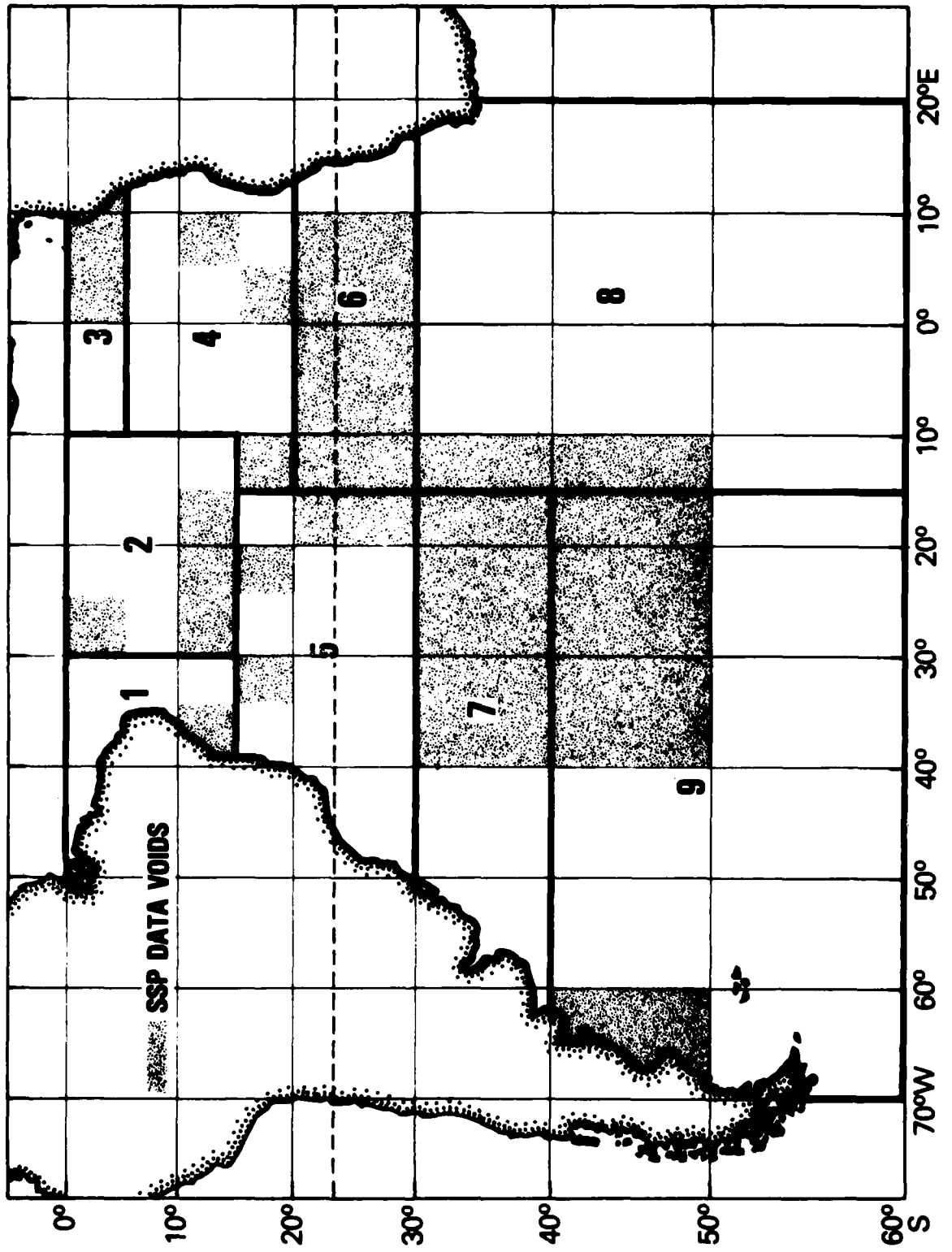


Figure 2

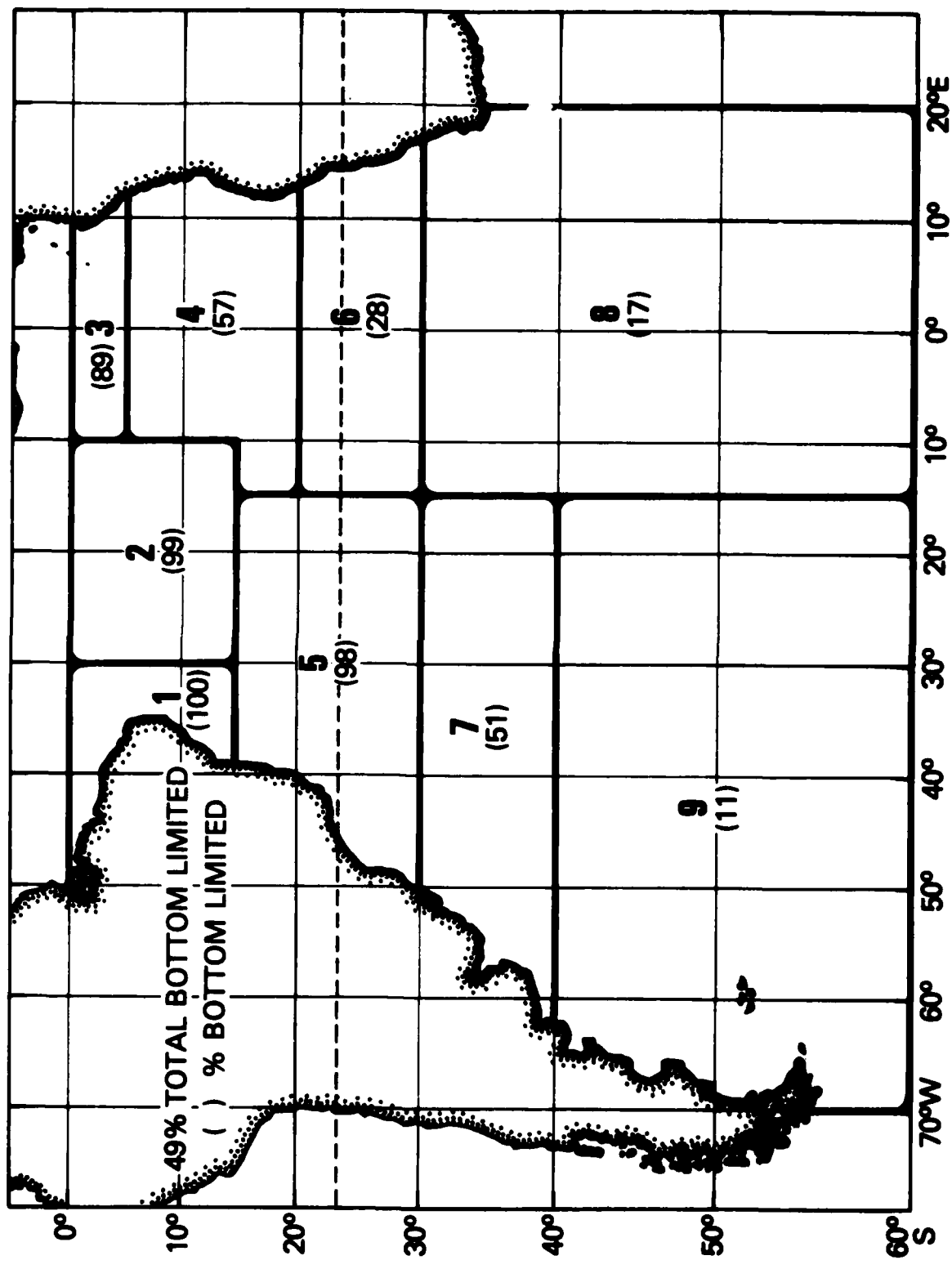


Figure 3

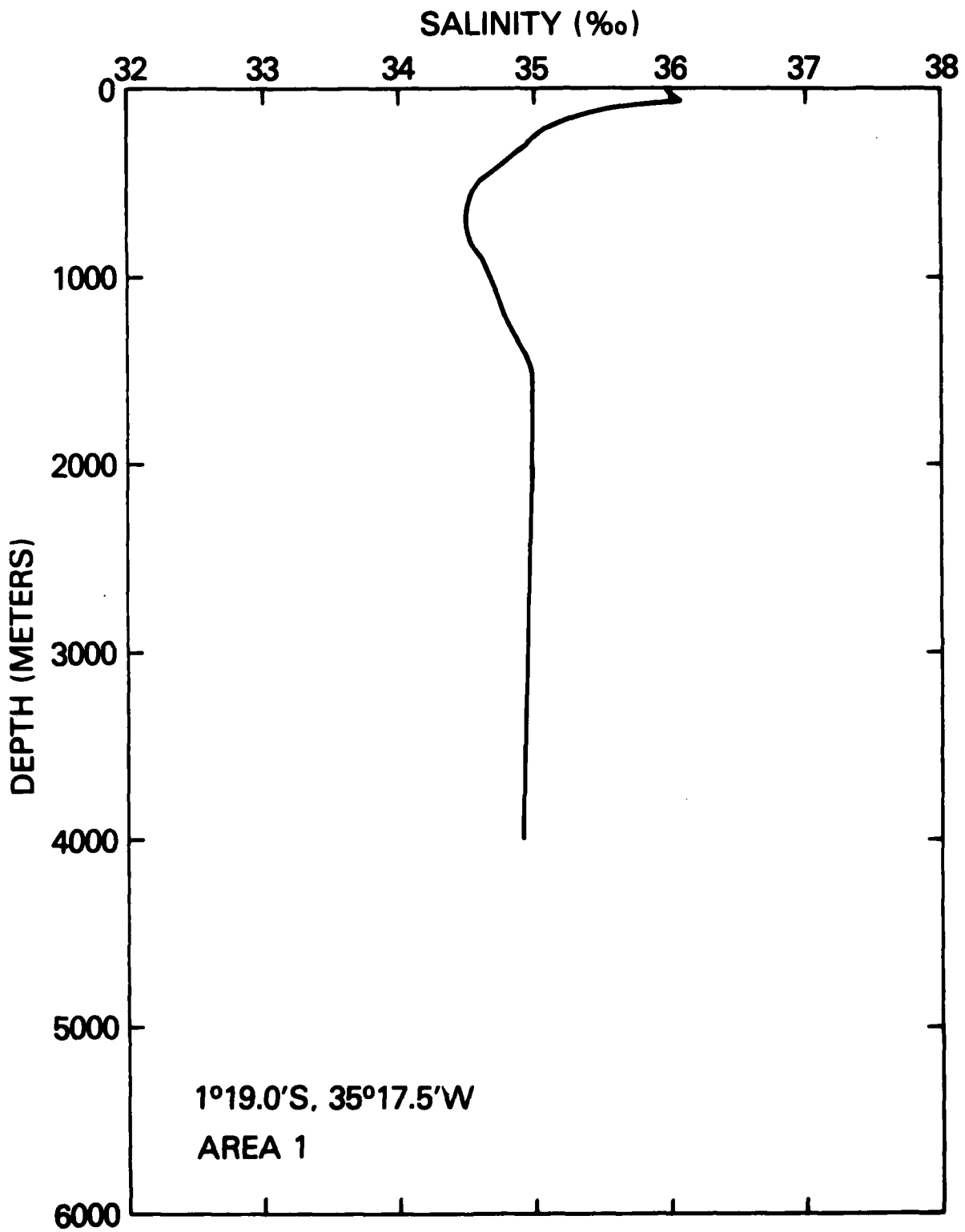


Figure 4

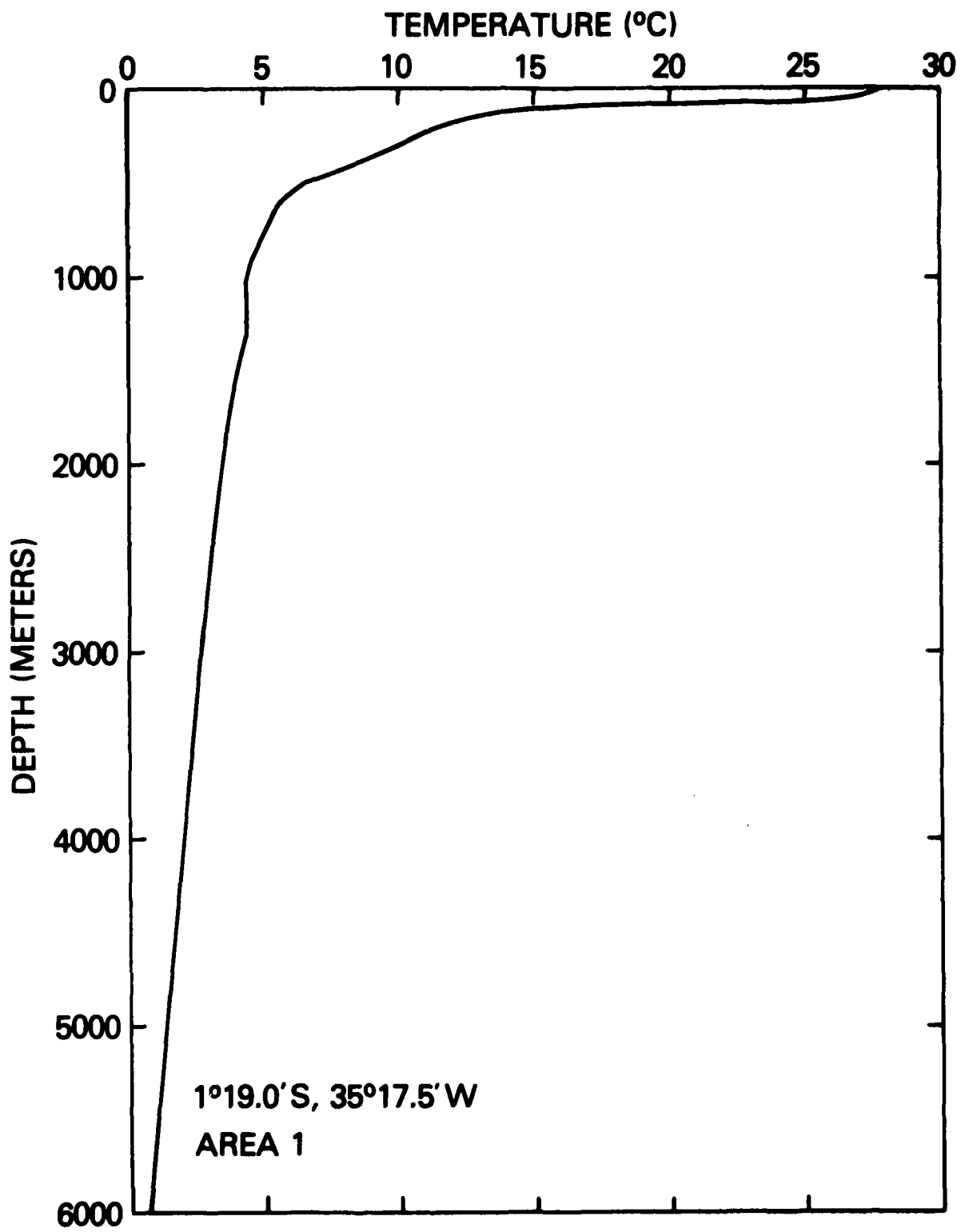


Figure 5

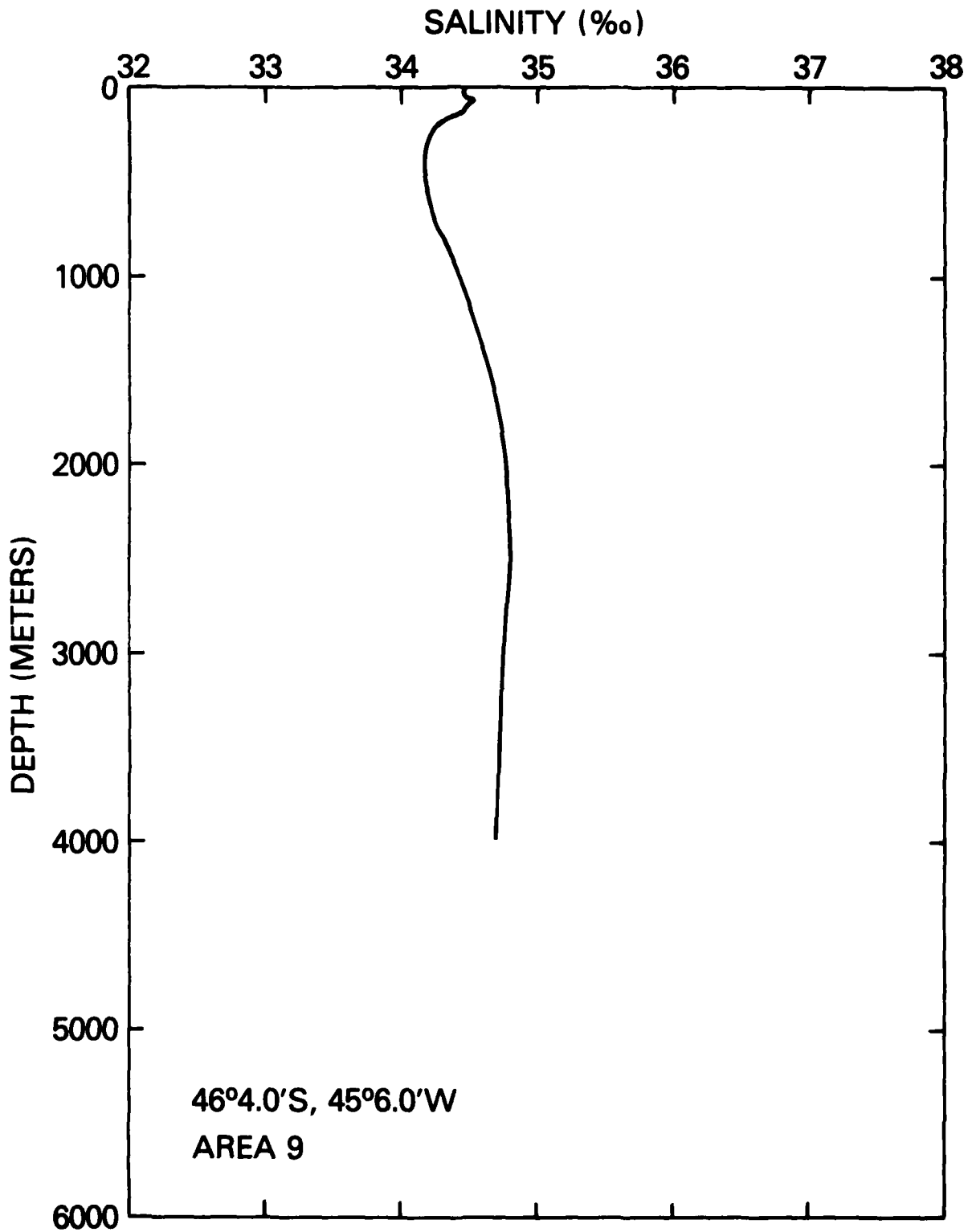


Figure 6

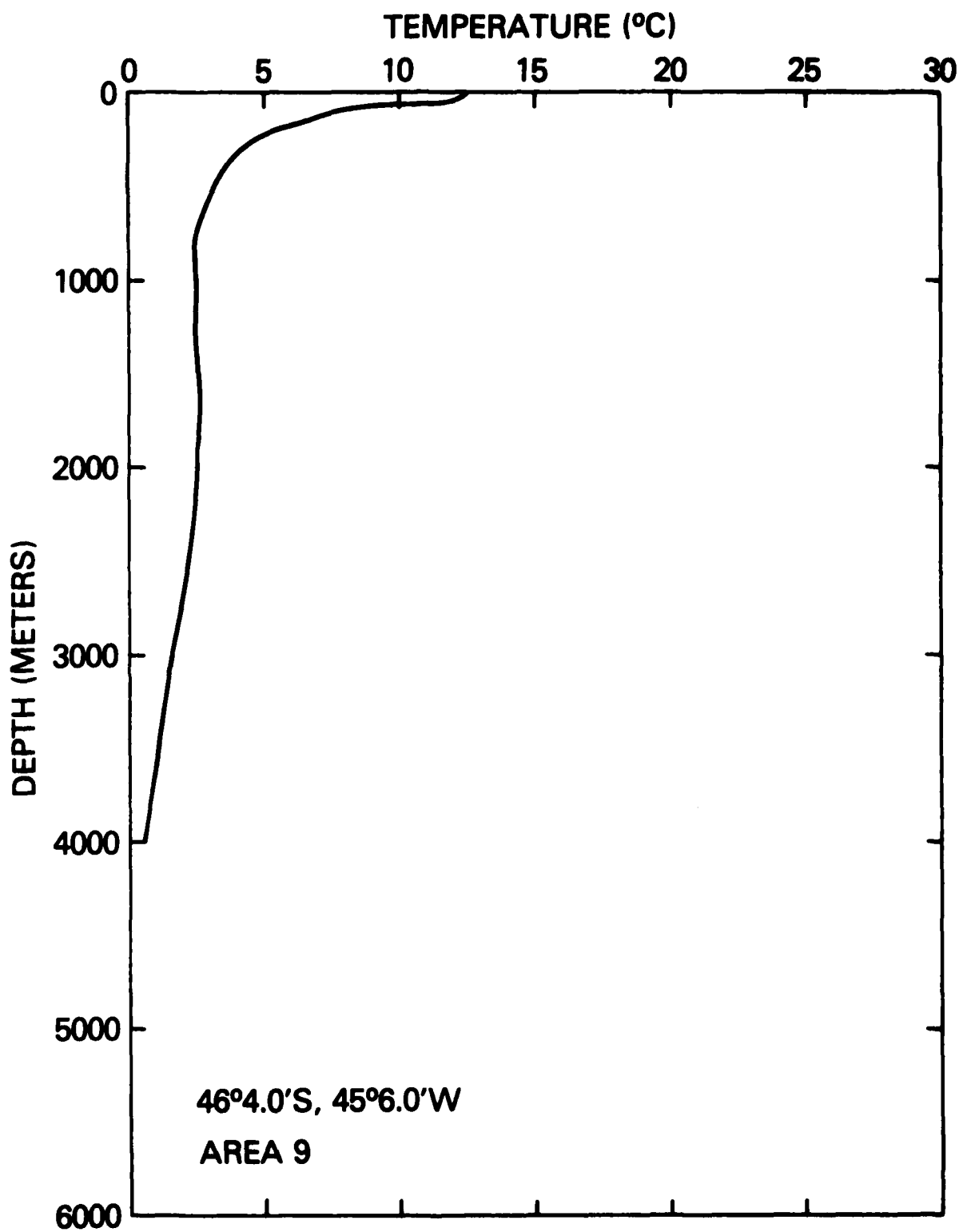


Figure 7

that of Area 3, but the basin is deeper, resulting in less bottom limiting than Area 3. The critical depths for Areas 6 and 8 are relatively shallow due to low surface sound speeds. This, coupled with deep basins, results in relatively small bottom limited regions in these areas.

#### B. BOTTOM LOSS

The bottom loss curves used in the South Atlantic for transmission loss and ambient noise calculations were taken from the BEARING STAKE exercise. In this exercise, low-frequency bottom loss curves were measured for six geologically different bottom types. Of these six types, three have geological features similar to those in the South Atlantic. For example, bottom class (BC)6 in BEARING STAKE corresponds to a rough, highly scattering ridge structure. Thus, the Mid-Atlantic Ridge and other ridge structures in the South Atlantic were assigned BC=6. In contrast, highly absorbing, thickly sedimented basins were assigned BC=4 in BEARING STAKE. On the basis of geological similarity, basins in the South Atlantic were assigned BC=4. The regions consisting of a combination of ridges and shallow sediments were assigned BC=5 in the BEARING STAKE exercise. In the South Atlantic this bottom class was assigned to regions which include the broad flanks of the ridge, consisting of rough subbottom surfaces partially covered with sediment and the shelves. See Figures 8, 9, and 10 for representative bottom loss curves used in this study. A map of the assigned geographical distribution of bottom classes is shown in Figure 11.

#### C. TRACK ENVIRONMENT

The actual great circle path environments for each track consisting of sound speed profiles by province, 1° resolution Smith-Menard<sup>1</sup> bathymetry, and BEARING STAKE bottom classes are shown in Figures 12 through 20. Included in these figures are (1) the bathymetry along the track, (2) the BEARING STAKE bottom classes over the appropriate ranges, and (3) the sound speed profiles. It should be noted that for tracks which intersect two or more SSP provinces, the SSP that is labeled "1" corresponds to the profile of the province which contains the starting point of the track. The SSP labeled "2" corresponds to that of the next province which the track intersects and so on.

For comparison purposes sound speed profiles derived from historical salinity and expendable bathythermographs (XBTs) for points in Areas 5 and 7 are included in Figures 21 and 22. These profiles were calculated using the Mackenzie<sup>2</sup> equation for three stations in each of these areas from data taken during a January 1981 cruise. They are shown along with the "typical" archival SSP for that area used in this study. Also included with these plots are the values of the surface sound speed (SFC/SS), surface layer depth (SLD), channel axis depth (DC), and critical depth (CRIT) for each curve. It can be seen that these measured profiles show fair agreement with the profiles used on this study. It should be noted that there are differences in the channel axis depth and the critical depth. For example, in Area 7 the measured profiles yield critical depths which vary from 4500 m to 5610 m, whereas the typical SSP for that area yields a critical depth of 4450 m.

#### D. DEEP SOUND SPEED GRADIENTS

During the process of selecting representative sound speed profiles for nine areas within the South Atlantic Ocean, a noticeable increase in the sound speed gradient was detected in the western South Atlantic profiles between 4000 and 6000 meters (Table 3). In contrast to the North Atlantic, the deep water mass of the

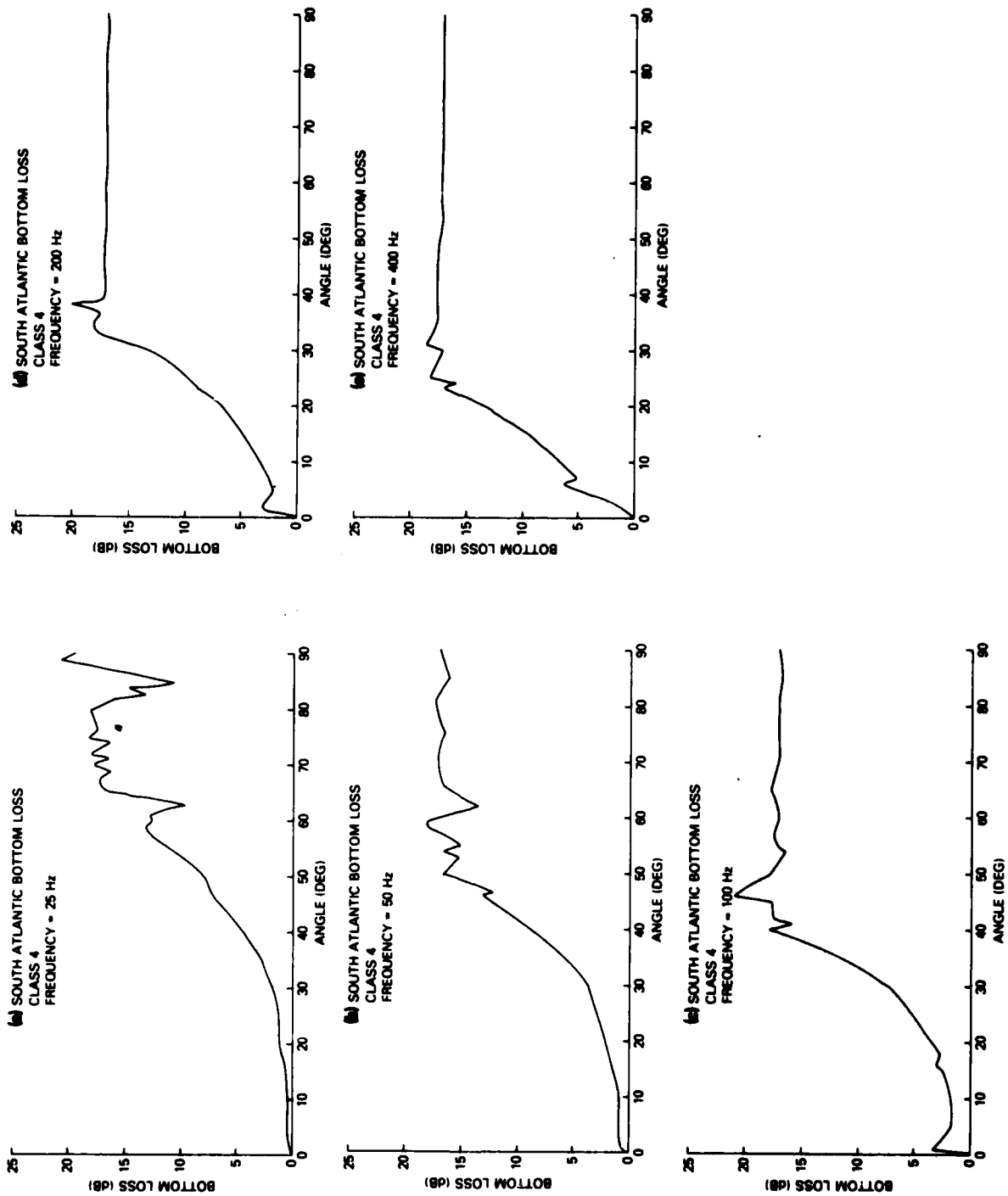


Figure 8

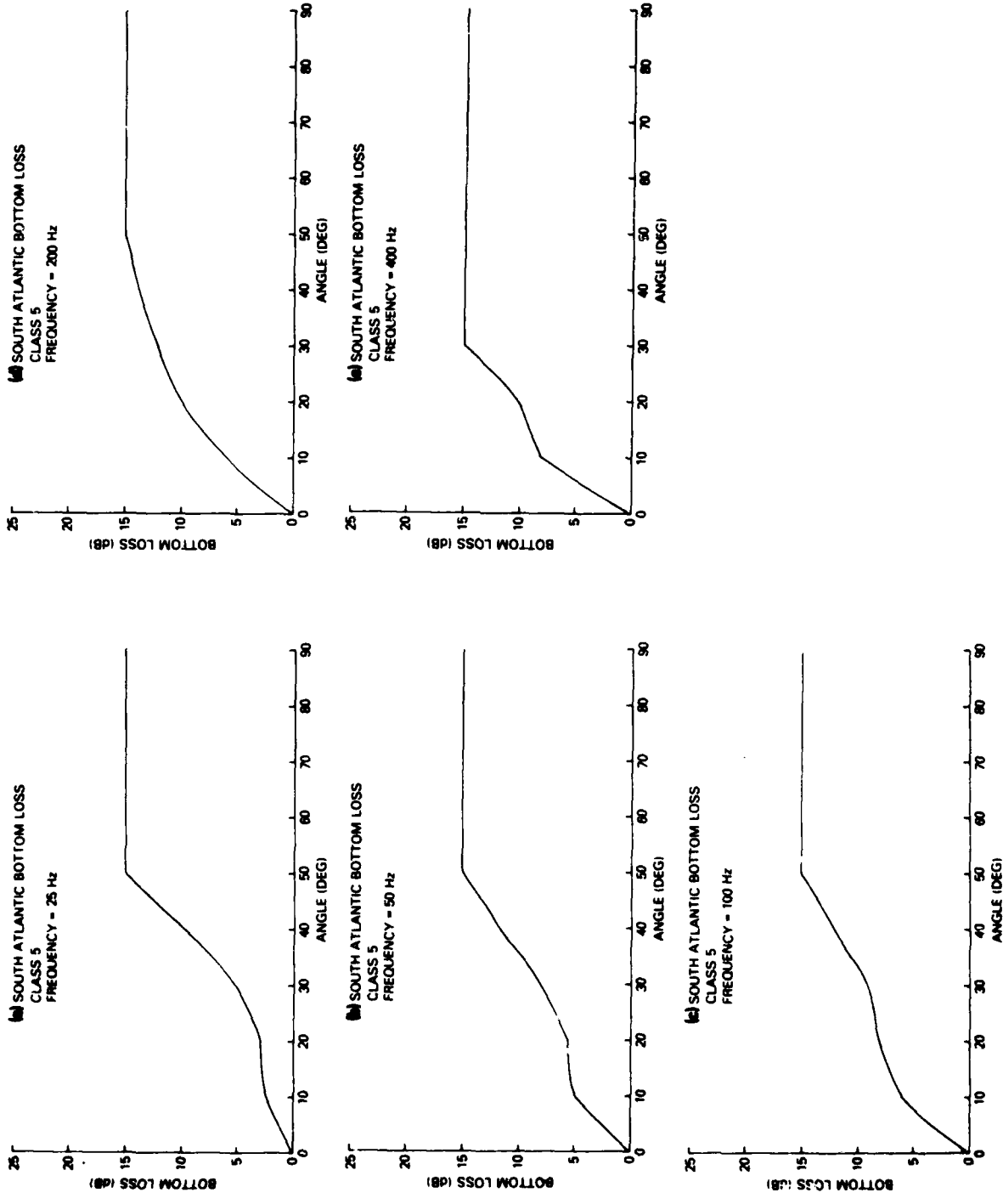


Figure 9

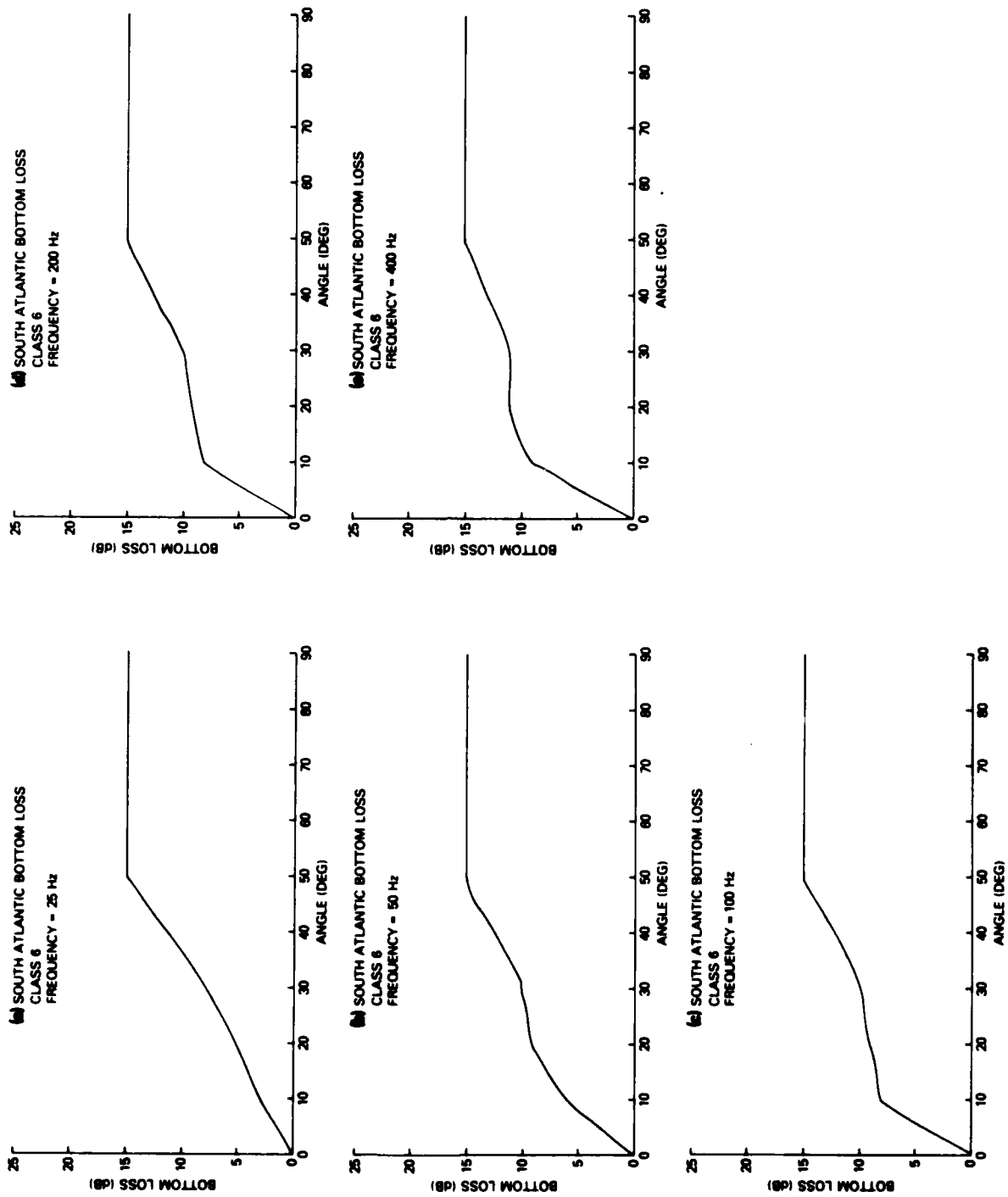


Figure 10

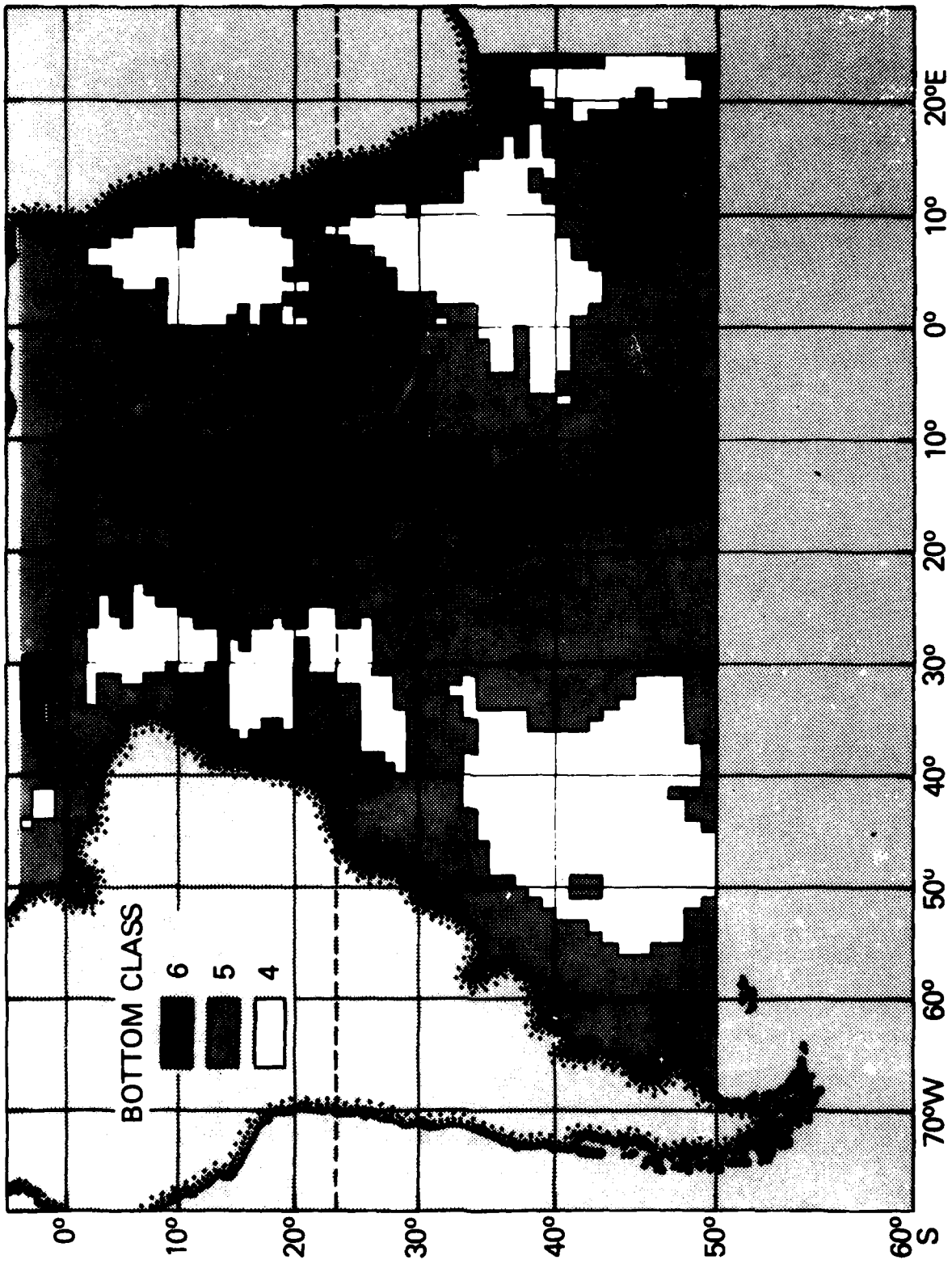


Figure 11

### SOUTH ATLANTIC TRACK FA 1

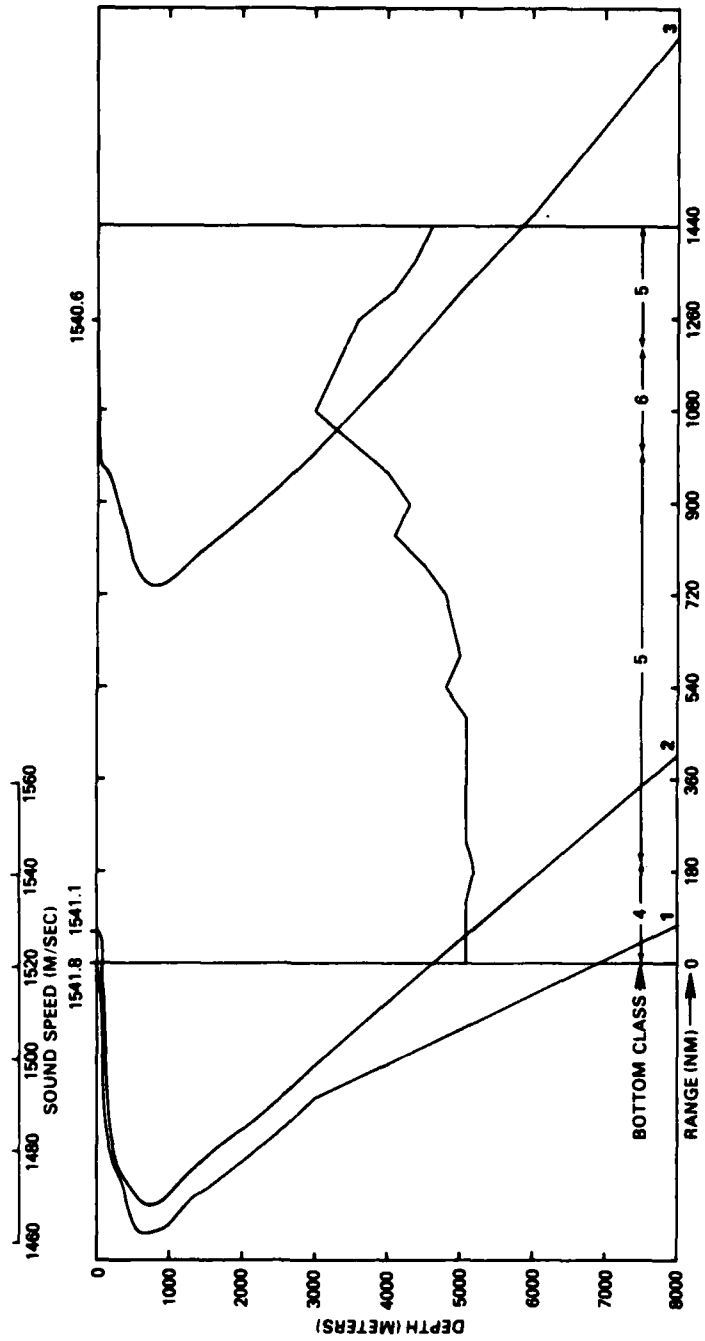


Figure 12

# SOUTH ATLANTIC TRACK FB 1

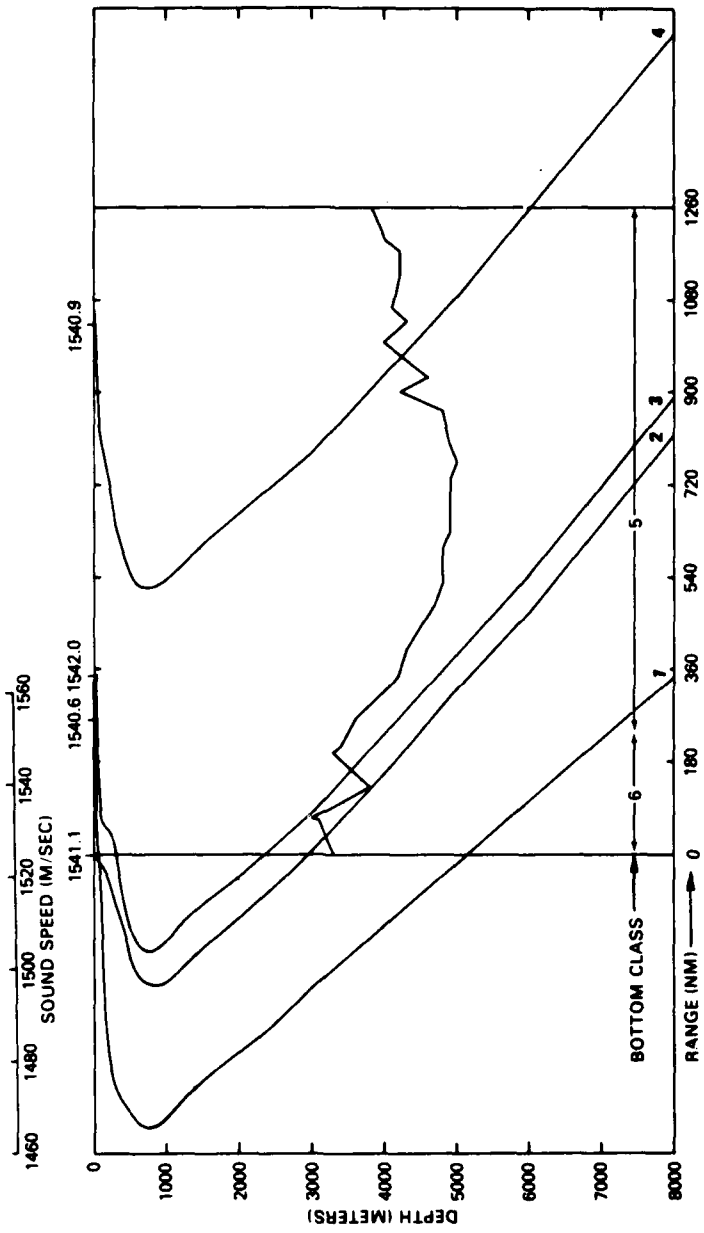


Figure 13

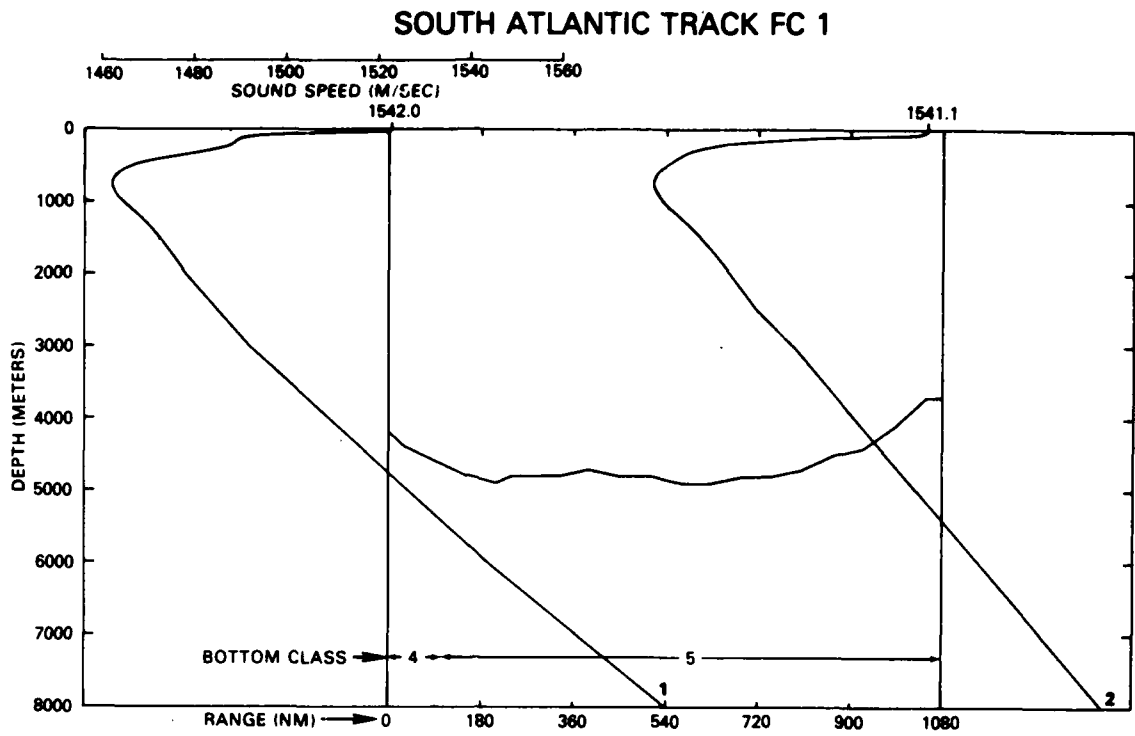


Figure 14

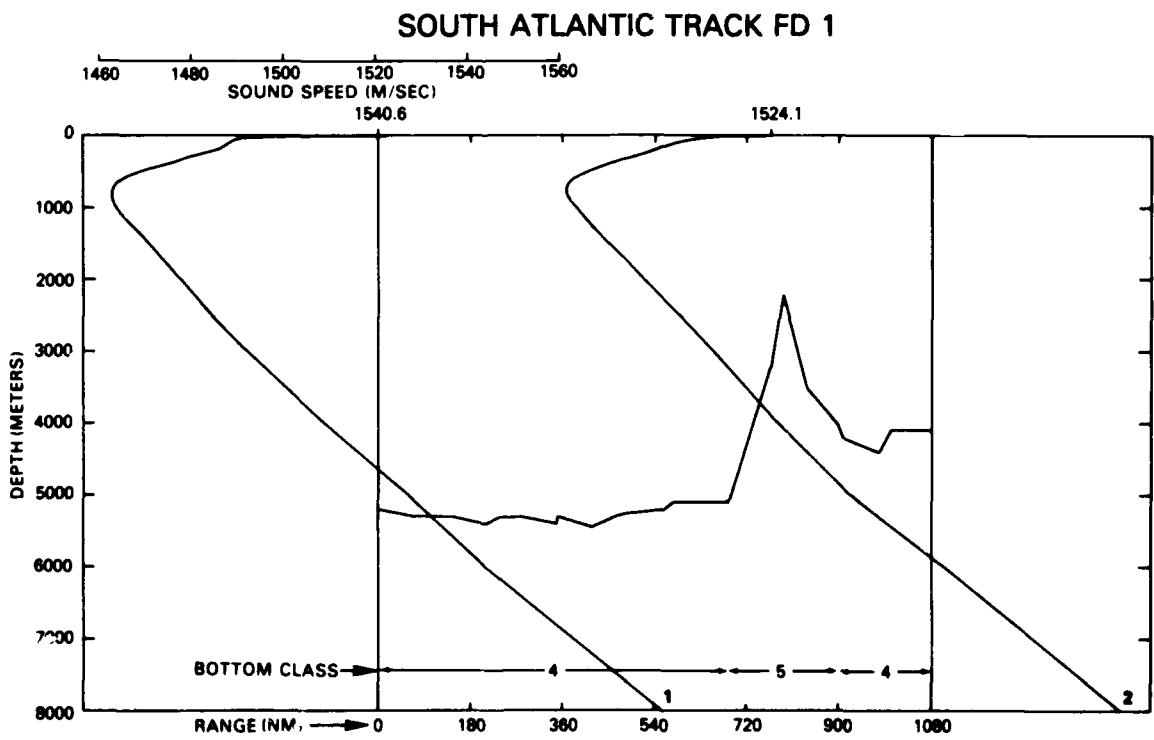


Figure 15

### SOUTH ATLANTIC TRACK FE 1

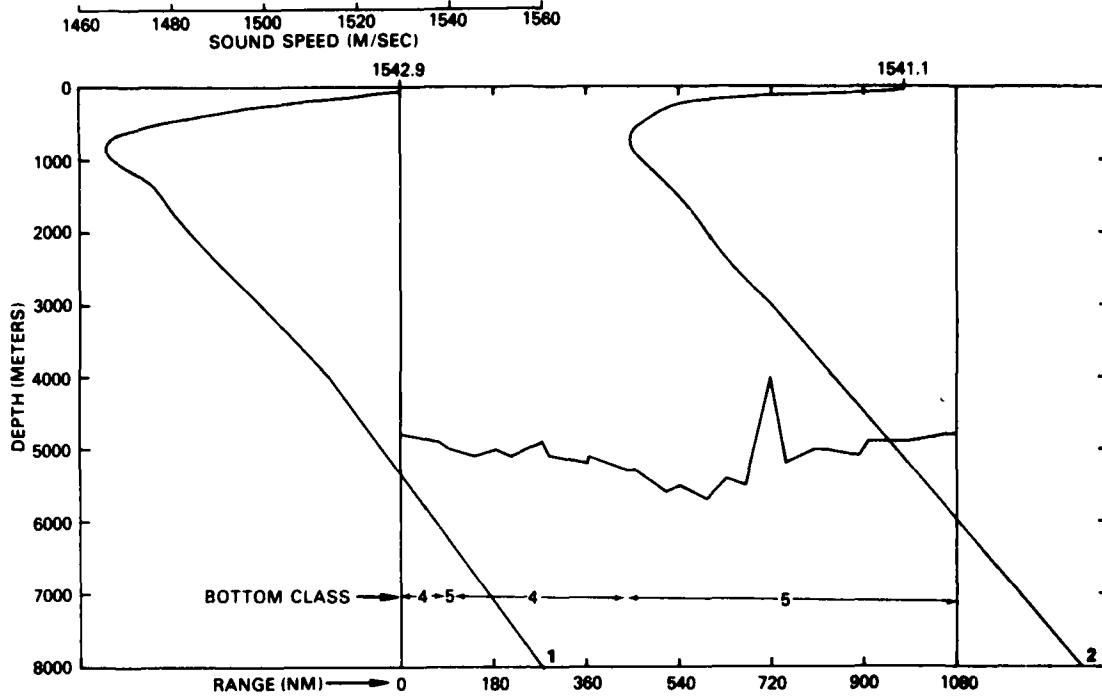


Figure 16

### SOUTH ATLANTIC TRACK FF 1

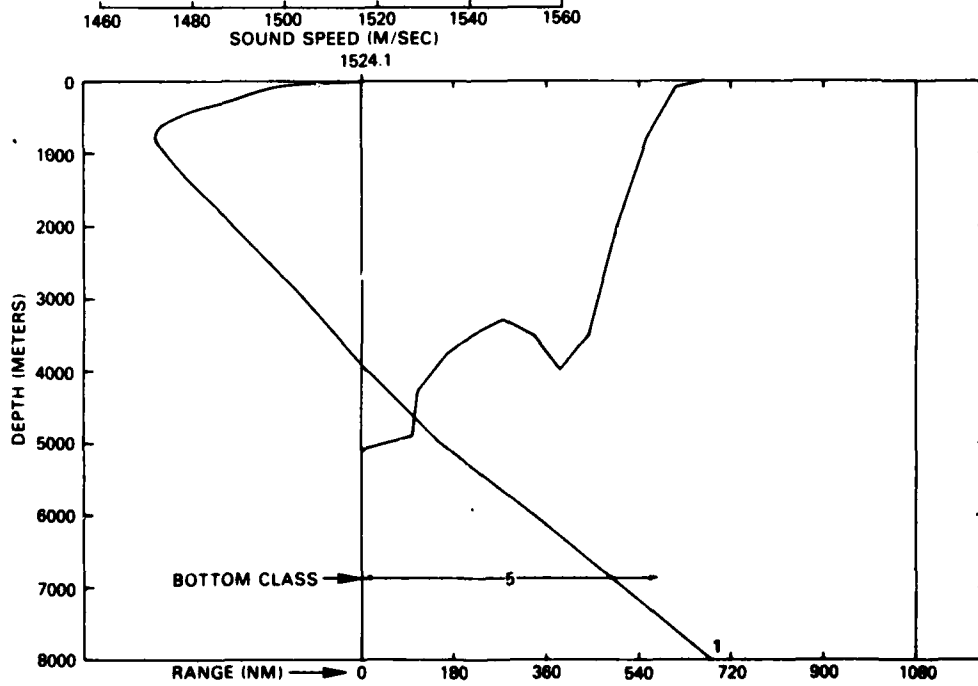


Figure 17

### SOUTH ATLANTIC TRACK FH 1

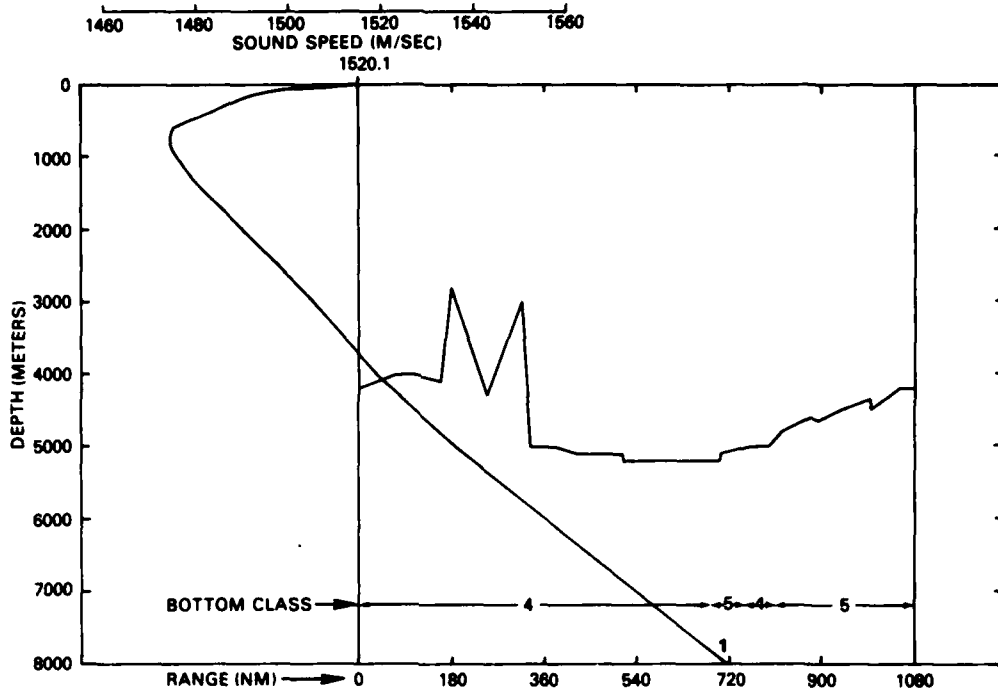


Figure 18

### SOUTH ATLANTIC TRACK FH 2

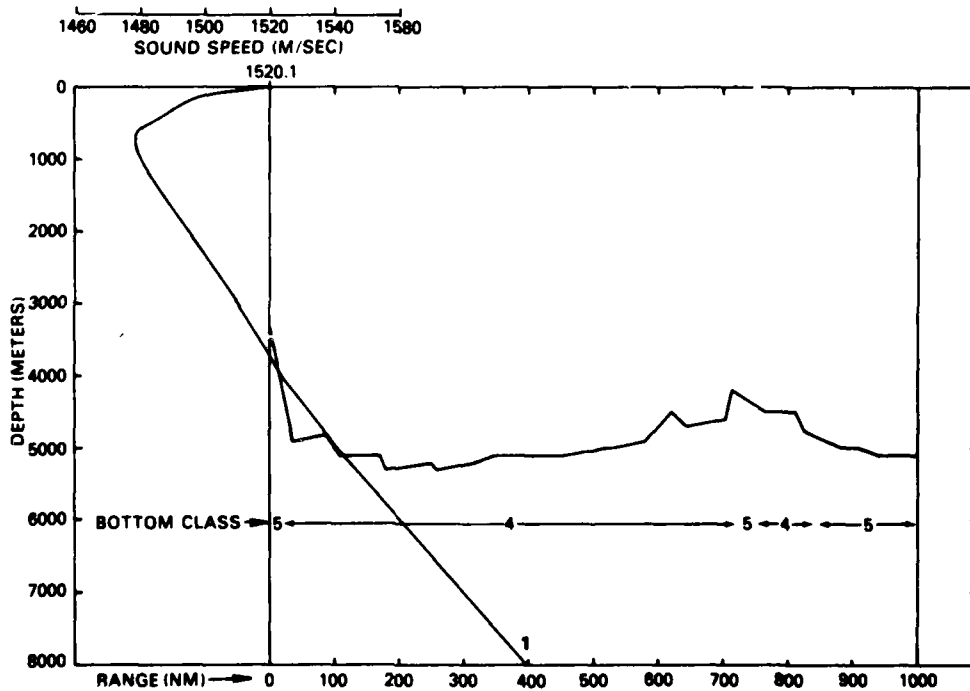


Figure 19

SOUTH ATLANTIC TRACK FI 1

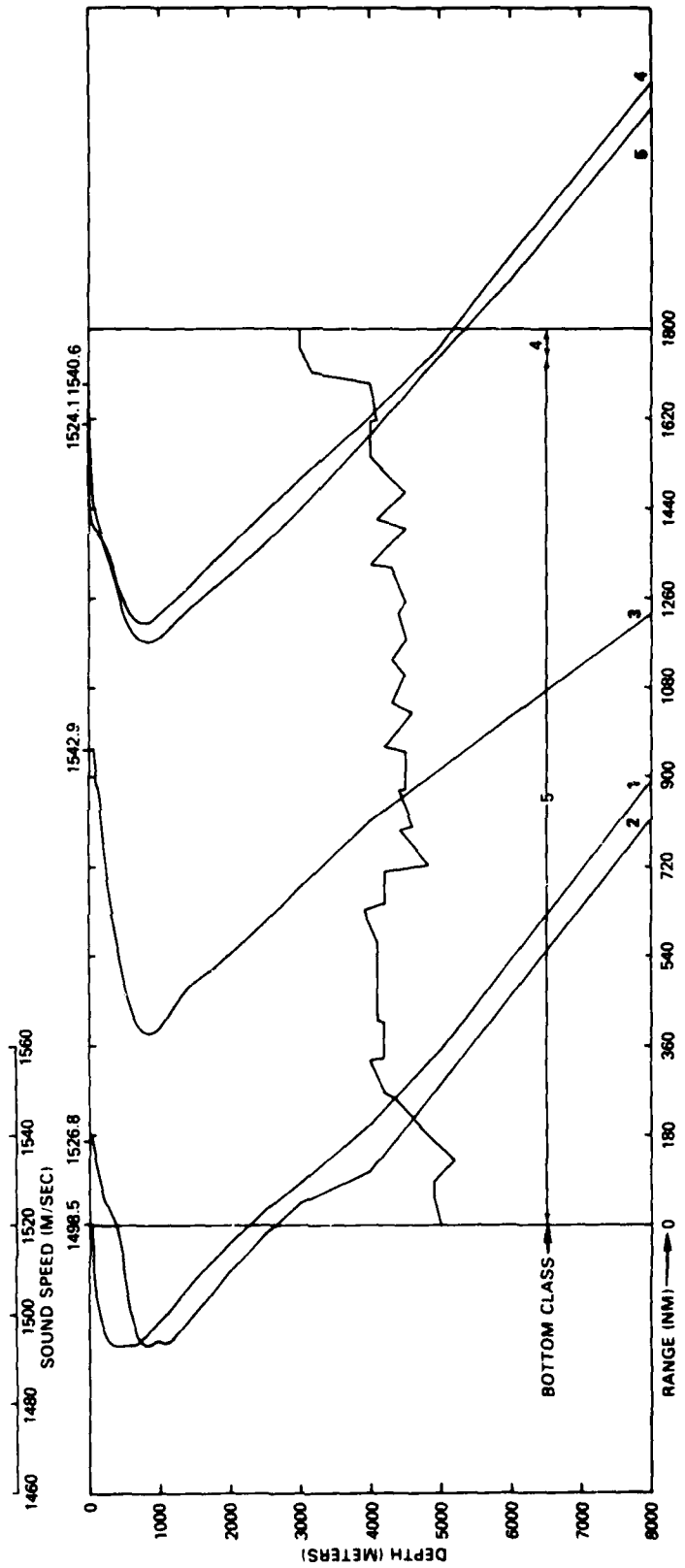


Figure 20

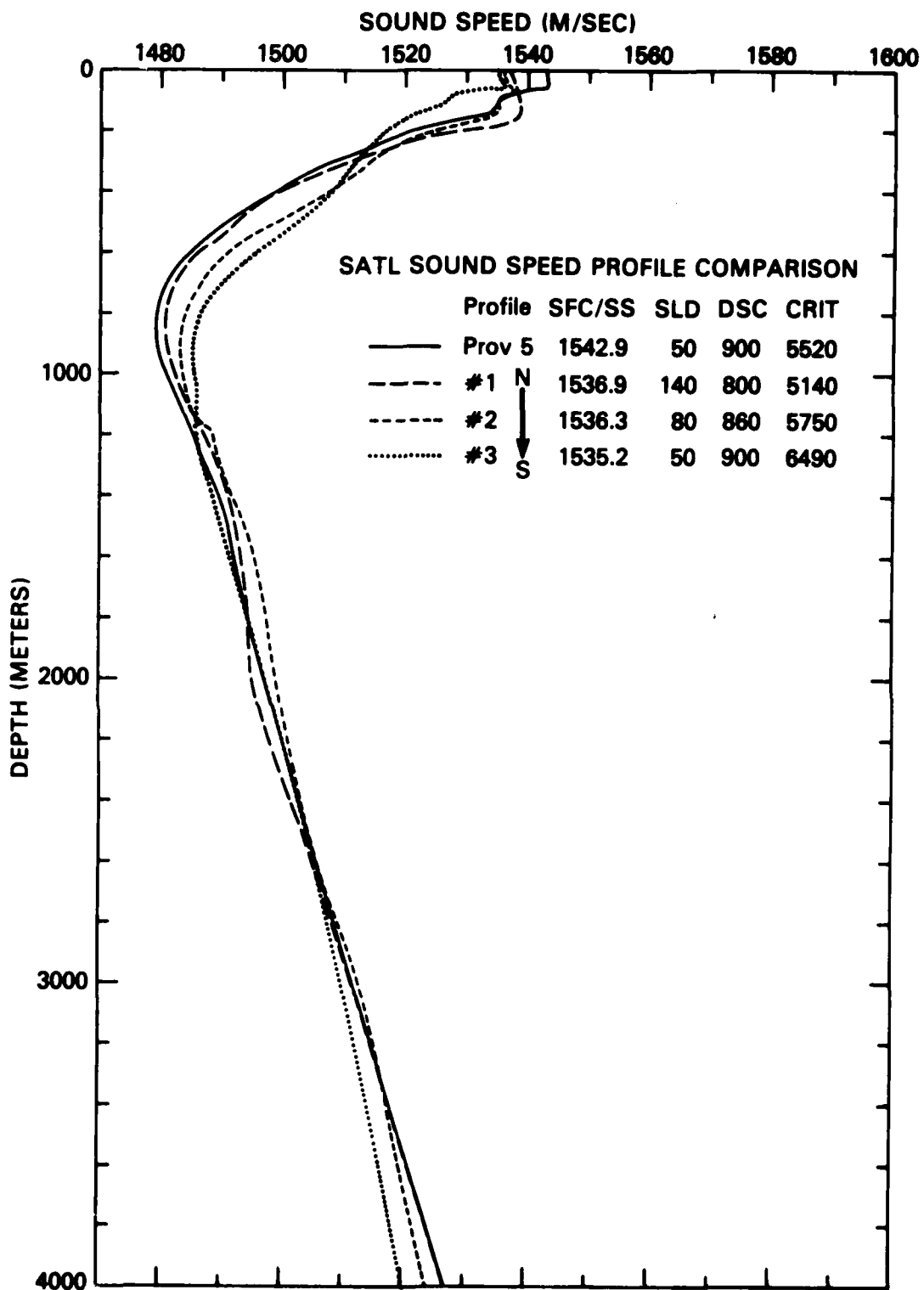


Figure 21

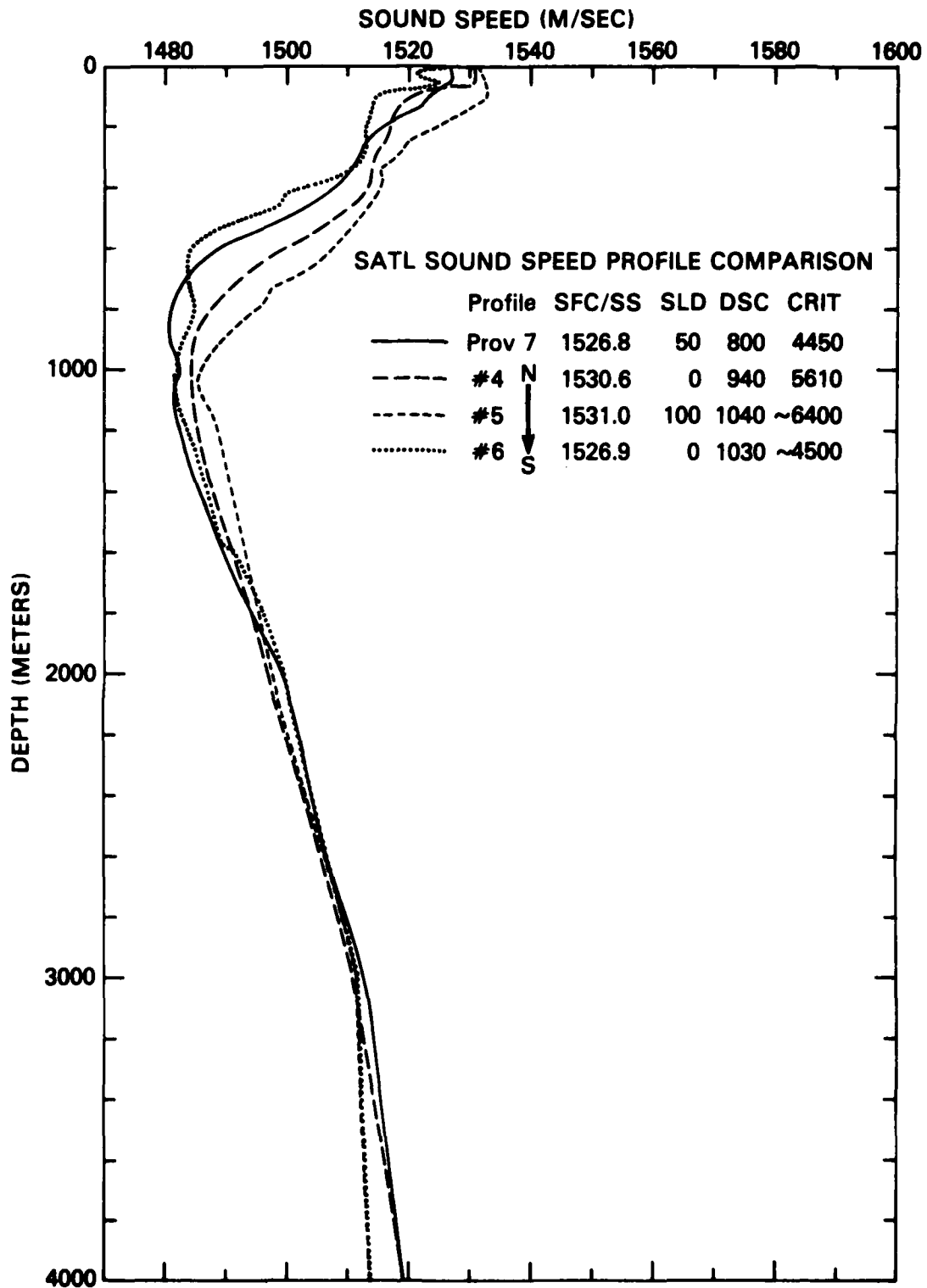


Figure 22

South Atlantic (especially the western basins) is of polar origin. These very cold, low-salinity waters were expected to produce a deep sound speed gradient decrease instead of the observed increase. As a result the deep sound speeds in three western Atlantic regions, (Area 1, Area 2, and Area 5) were modified by continuing the gradient that existed above the gradient discontinuity. Table 3 presents the original sound speeds and the modified sound speed representative of the Northern Hemisphere Winter (January, February, and March) for those depths at which modifications were made. Resulting critical depth changes in these regions were: Area 1 from 5174 meters to 7137 meters, Area 2 from 5160 meters to 5250 meters, and Area 5 from 5283 meters to 5478 meters.

Table 3

Comparison between deep-archival sound speeds with modified sound speeds in three Western South Atlantic Ocean regions (Bars indicate no modifications were made)

DEPTH (M)	ORIGINAL ARCHIVAL SOUND SPEED (m/sec)	MODIFIED SOUND SPEED (m/sec)		
		AREA 1	Area 2	Area 3
4000	1526.6	1519.6	-----	-----
5000	1538.4	1526.3	-----	1537.9
6000	1558.4	1533.6	1551.2	1549.0
7000	1579.0	1540.9	1564.4	1560.3
8000	1599.0	1548.2	1577.6	1571.6
9000	1619.0	1555.5	1590.8	1582.9
10000	1638.0	1562.8	1604.0	1594.2

Because pressure effects on the speed of sound usually dominate temperature and salinity effects at depth, the modifications made to the original archival deep sound speeds may have been excessive, especially in Area 1. It was, therefore, decided to compare the deep archival sound speeds which are of unknown origin, with sound speeds derived from the deeper portions of all Nansen casts made in the study areas.

Because sound speed gradients sometimes have more acoustical significance than absolute sound speed values, the deep archival profiles were converted to sound speed gradients. These were compared with the average deep sound speed gradients calculated from all deep (>1000 meter) hydrocasts in each of the nine representative areas within the South Atlantic Ocean. Table 4 presents these average gradients between 2000 and 7000 meters in 1000 meter increments. Also included for comparison are the archival gradients for each depth range.

Results for the western South Atlantic, the eastern South Atlantic north of the Walvis Ridge, and the eastern South Atlantic south of the Walvis Ridge are separated since relatively cold, fresh, Antarctic water prefers the western basin. Cold waters also migrate north in the eastern South Atlantic, but their progression is blocked by the Walvis Ridge.

The deep archival sound speed gradients are in close agreement ( $\pm 1.0$  m/sec/1000 m), with the mean sound speed gradients in a majority of the cases for which deep hydrocast data were available. In only two instances, Area 8 between 2000 and 3000 meters and Area 9 between 3000 and 4000 meters, did the deep archival sound

Table 4

Comparison between average and archival deep sound speed gradients in nine selected areas of the South Atlantic Ocean. The number of gradients used to calculate the average gradient is given in parentheses. Sound speed gradients are given as sound speed differences in m/sec over 1000 meter increments.

Depth range (m x 10 <sup>3</sup> )	2-3	3-4	4-5	5-6	6-7
<b>AREA</b>	<b>WESTERN SOUTH ATLANTIC</b>				
1 AVG	14.0 (80)	14.1 (48)	13.5 (21)	18.5 (3)	19.0 (3)
ARCHIVAL	14.4	13.5	13.3	20.1	20.5
2 AVG	13.7 (25)	14.5 (9)	--	--	--
ARCHIVAL	14.4	13.5	13.3	20.1	20.5
5 AVG	14.6 (80)	12.9 (52)	13.1 (14)	--	--
ARCHIVAL	14.4	13.5	13.3	20.1	20.5
7 AVG	15.5 (30)	10.8 (7)	11.8 (2)	--	--
ARCHIVAL	14.4	13.5	13.3	20.1	20.5
9 AVG	13.3 (33)	13.3 (28)	15.4 (7)	--	--
ARCHIVAL	13.3	11.6	16.3	21.5	20.0
<b>EASTERN SOUTH ATLANTIC NORTH OF THE WALVIS RIDGE</b>					
3 AVG	13.7 (15)	16.2 (14)	17.0 (1)	--	--
ARCHIVAL	13.4	16.9	17.9	16.2	19.0
4 AVG	13.8 (56)	16.5 (37)	18.0 (9)	--	--
ARCHIVAL	13.4	16.9	17.9	16.2	19.0
<b>EASTERN SOUTH ATLANTIC SOUTH OF THE WALVIS RIDGE</b>					
6 AVG	14.7 (10)	13.3 (5)	--	--	--
ARCHIVAL	13.7	14.1	15.5	20.0	19.0
8 AVG	15.2 (121)	13.6 (67)	15.7 (2)	--	--
ARCHIVAL	13.5	16.5	16.3	19.4	20.0

speed gradients differ from the calculated mean sound speed gradients by more than 1.0 m/sec/1000 m, and also lie outside one standard deviation of the mean gradient.

For Area 8 between 2000 and 3000 meters and Area 9 between 3000 and 4000 meters, the standard deviation of the calculated sound speed gradient was 1.1 m/sec/1000 m. The average calculated gradient exceeded the archival gradient by 1.7 m/sec/1000 m. When the standard deviation of the absolute values of the speed of sound at 3000 meter depth is considered (Table 5), then the 1.7 m/sec/1000 m gradient differences do not appear severe.

For Area 8 between 3000 and 4000 meters, the archival sound speed gradient exceeded the average by 2.9 m/sec/1000 m. The standard deviation of the gradient in this case is 0.88 m/sec/1000 m. From Table 5 it appears that the gradient differences for Area 8 at 2000 to 3000 meters and 3000 to 4000 meters are a result of the 3000 meter archival sound speed.

From Table 5 in which absolute sound speed values are compared, it is evident that Area 7, Area 8, and Area 9 have larger sound speed variations and larger differences between the archival sound speeds and the calculated average sound speeds than the other areas considered. These variations are probably a result of the Subtropical Convergence and the Antarctic Convergence across which large variations may occur.

It is recommended that the gross South Atlantic sound speed profiles retain the deep archival sound speeds with the exception of Area 8, and that the deep archival sound in Area 8 at 3000 meters be changed to the calculated average value of 1509.2 m/sec.

It is believed that a finer grid South Atlantic sound speed profile data file (which is currently being developed) will reduce the amount of variation in all areas and will provide a more accurate estimate of the deep sound speed gradients.

With the change in deep sound speed gradient in Areas 1, 2, and 5, it became necessary to determine the effect of this change on bottom limiting and transmission loss. It was found, however, that this effect was small and, in fact, the percentage of bottom limiting of each of the affected provinces was reduced by less than two percent, i.e.,

bottom limited

Area 1	99
Area 2	98
Area 5	96

Since the areas are generally heavily bottom limited to begin with, these changes will have only minor effects on the present analysis.

### III. MODELS AND RESULTS

#### A. MODELS

The introduction of BEARING STAKE bottom classes as descriptors of the South Atlantic bottom limited the number of models that were appropriate to use with the data base. In order to use a model to simulate transmission loss and ambient noise

Table 5

Comparison between archival and calculated sound speeds  
in specific areas of the South Atlantic Ocean

	Depth (m)	Archival Sound Speed (m/sec)	Mean Sound Speed (m/sec)	Standard Deviation (m/sec)	Number of Points
Area 1	1000	1483.2	1483.7	0.763	72
	2000	1497.2	1497.5	0.405	80
	3000	1511.6	1511.5	0.253	80
	4000	1525.1	1525.7	1.130	48
	5000	1538.4	1538.4	0.667	21
	6000	1558.5	1558.5	0.058	3
	*7000	1579.0	1577.4	0.058	3
Area 2	*1000	1483.2	1484.3	0.418	23
	2000	1497.2	1498.0	0.364	25
	3000	1511.6	1511.7	0.160	25
	4000	1525.1	1526.1	0.475	9
Area 5	*1000	1483.2	1481.1	0.734	75
	2000	1497.2	1496.9	0.787	79
	3000	1511.6	1511.8	0.455	79
	4000	1525.1	1524.7	1.358	52
	5000	1538.4	1537.9	0.458	14
Area 7	**1000	1483.2	1480.4	1.475	31
	2000	1497.2	1496.2	1.237	31
	3000	1511.6	1511.6	1.392	29
	**4000	1525.1	1521.3	2.427	7
	**5000	1538.4	1536.2	0.636	2
Area 6	1000	1481.4	1480.6	0.978	11
	2000	1495.1	1495.9	0.397	10
	3000	1510.4	1510.8	0.264	10
	4000	1524.5	1524.1	0.518	5
Area 3	*1000	1483.1	1484.4	0.119	13
	*2000	1496.5	1497.7	0.156	15
	3000	1511.0	1511.44	0.135	15
	4000	1527.9	1527.7	0.198	14
	*5000	1545.8	1544.5	0.000	1
Area 4	1000	1483.1	1483.0	0.817	48
	2000	1496.5	1497.0	0.298	53
	3000	1511.0	1511.3	0.37	56
	4000	1527.9	1527.8	0.352	37
	5000	1545.8	1545.7	0.107	7

Table 5 (Cont.)

	Depth (m)	Archival Sound Speed (m/sec)	Mean Sound Speed (m/sec)	Standard Deviation (m/sec)	Number of Points
Area 8	**1000	1488.0	1480.3	3.328	58
	2000	1493.3	1494.0	1.244	123
	**3000	1506.8	1509.2	2.075	121
	4000	1523.3	1523.7	1.186	67
	5000	1539.9	1539.9	0.141	2
Area 9	**1000	1479.7	1476.6	0.677	25
	**2000	1495.3	1493.2	1.677	32
	**3000	1508.6	1506.6	2.238	33
	4000	1520.2	1519.7	1.696	28
	5000	1536.5	1536.6	1.291	7

Note: \* = Differences greater than 1 m/sec but less than 2 m/sec.  
 \*\* = Differences greater or equal to 2 m/sec.

in the South Atlantic, the existing FNOC bottom curves had to be excised from some models and replaced with the appropriate BEARING STAKE bottom loss curves. Toward this end, special editions of ASTRAL<sup>3</sup> (for transmission loss) and FANM (for ambient noise) had BEARING STAKE bottom loss descriptions included.

ASTRAL was used to provide transmission loss predictions. ASTRAL is a range-dependent model that propagates mode-like envelopes to produce range-averaged (over convergence zone spacing) transmission loss.

FANM (Fast Ambient Noise Model) is a range dependent model. It was used to produce omnidirectional ambient noise predictions. However, FANM may also be used to predict vertical and horizontal directional noise. FANM operated from the South Atlantic data base along with the weighted ship counts obtained from HITS<sup>4</sup> (Historical Temporal Shipping) data base.

In order to simulate a range-dependent environment, FANM is provided with a preprocessor, FANIN. FANIN will not extract ship densities from the data base for use by FANM when the water depth reaches a user-specified critical depth and/or minimum depth.

CNOISE<sup>5</sup> is a collection of three models that were used to generate horizontal directional noise simulations for this study. The transmission loss used by CNOISE was generated by ASTRAL. CNOISE operated from the same shipping data base as FANM.

For transmission loss the following inputs were used:

Receiver depth (ft)	500, Channel Axis, BOTTOM DEPTH - 50
Source depth (ft)	20, 60, 300
Frequency (Hz)	25, 50, 300

For receiver depths, the channel axis depth was calculated from the first profile in the track. In a similar manner for the bottom-minus-50 ft receiver depth, the first bathymetry data point was used after subtracting 50 ft.

## B. MODELING RESULTS

### 1. Parameter Dependence

The large quantity of data generated by the transmission loss runs has been reduced to a summary of the "general" trends of parameter dependence as shown in Table 6. This synopsis of all the transmission loss information was generated for each track. To produce this table, "standard" values for each of the three parameters (source depth, receiver depth, frequency) had to be established. The criteria for setting the standard values was to study all the transmission loss plots produced for a particular track and then to determine which value of each parameter gave the best transmission in the South Atlantic; thus 25 Hz and 300 ft were chosen for the standard frequency and source depth, respectively. Since little or no effect was found by changing the receiver depth, 500 ft was chosen as the standard.

#### a. Receiver Depth Dependence:

A weak (0 to 5 dB) receiver depth dependence was demonstrated in the transmission loss. Two exceptions to the general trend are tracks FB 1 and FI 1. Along these two tracks, the deep receiver (bottom-50) was shielded behind an up-slope, which effectively stopped all transmission. This phenomenon will be discussed in more detail in Section 2.

Table 6  
Parameter dependence of transmission loss variability by track

<u>Track</u>	<u>Receiver Depth Dependence</u>	<u>Source Depth Dependence</u>	<u>Frequency Dependence</u>
FA01	W	S	M
FB01	W	S	M
FC01	W	S	M
FD01	W	S	W
FE01	W	S	M
FF01	W	S	W
FH01	W	S	M
FH02	W	S	W
FI01	W	S	M

W = WEAK DEPENDENCE (0-5 dB)  
M = MODERATE DEPENDENCE (10-15 dB)  
S = STRONG DEPENDENCE (20-25 dB)

b. Source Depth Dependence:

Strong (20-25 dB) source depth dependence was demonstrated among all the tracks because of two reasons: (1) at low frequencies, surface image interference (SII) played the dominant role; (2) at high frequencies, bottom interaction accounted for most of the source depth related differences among transmission loss results.

c. Frequency Dependence:

The frequency dependence was weak to moderate (10-15 dB). This dependence was principally due to volume absorption and bottom interaction (except in cases where SII was present). It is important to note that the cases of weak frequency dependence occurred for tracks FD1, FF1, and FH2. These tracks are, in general, not bottom limited. Thus, frequency dependent bottom interaction effects are less pronounced in these transmission loss curves.

2. Examples of Parameter Dependence

In order to demonstrate the type of dependencies that have been predicted for the South Atlantic, two tracks, FB1 and FH2, have been chosen and will be discussed at length.

a. Province 2 Track 1 (FB1):

The receiver depth dependence shown in Figure 23 demonstrates a very weak receiver depth dependence, except for the deep, 11,400 ft (bottom-50 ft) receiver which exceeds 130 dB at 170 nautical miles. A look at the plot of the environment along track FB 1 (see Fig. 13) shows that a receiver located 50 feet off the bottom would be positioned behind an upslope (Mid-Atlantic Ridge). One would naturally expect that there would be some loss in transmission due to blockage. However, what is disturbing about the behavior shown in the transmission loss is that there is no recovery beyond the ridge.

In order to investigate this problem, the Parabolic Equation (PE) model<sup>6</sup> was used with this environment to predict the transmission loss behavior. This model uses a critical angle representation of the bottom instead of the bottom loss curves used in ASTRAL. The critical angle bottom in PE depicts the bottom as a perfect reflector for all energy arriving at less than a user-supplied grazing angle. At angles greater than the critical angle, all energy is absorbed. Thus, a critical angle of 0 degrees infers that all bottom interacting energy is absorbed and a critical angle of 19 degrees allows the return of energy striking the bottom at grazing angles less than 19 degrees. The PE results shown in Figures 24 a-c (19° critical angle) and 25 a-c, (0° critical angle) predict recovery in most cases. By comparison, Figure 26 shows the corresponding ASTRAL TL plots. All three source depths (20, 60 and 300 ft) show no recovery and, in fact, exceed 130 dB loss before 100 nautical miles is reached.

The strong source depth dependence for track FB 1 is shown in Figure 27. In this case the driving factor is Surface Image Interference (SII), as demonstrated by the nearly parallel transmission loss curves.

The frequency dependence for track FB 1 is illustrated in Figure 28. The most striking feature of this set of curves is the large transmission loss experienced by the 300 Hz curve in the 100 to 250 nautical mile range interval. This strong frequency dependence can be explained by examining the type 6 bottom loss

ASTRAL TRACK FB 1

FREQUENCY	SOURCE	RECEIVER
25 Hz	300 FT	500 FT
25 Hz	300 FT	2460.60 FT
25 Hz	300 FT	11400.10 FT

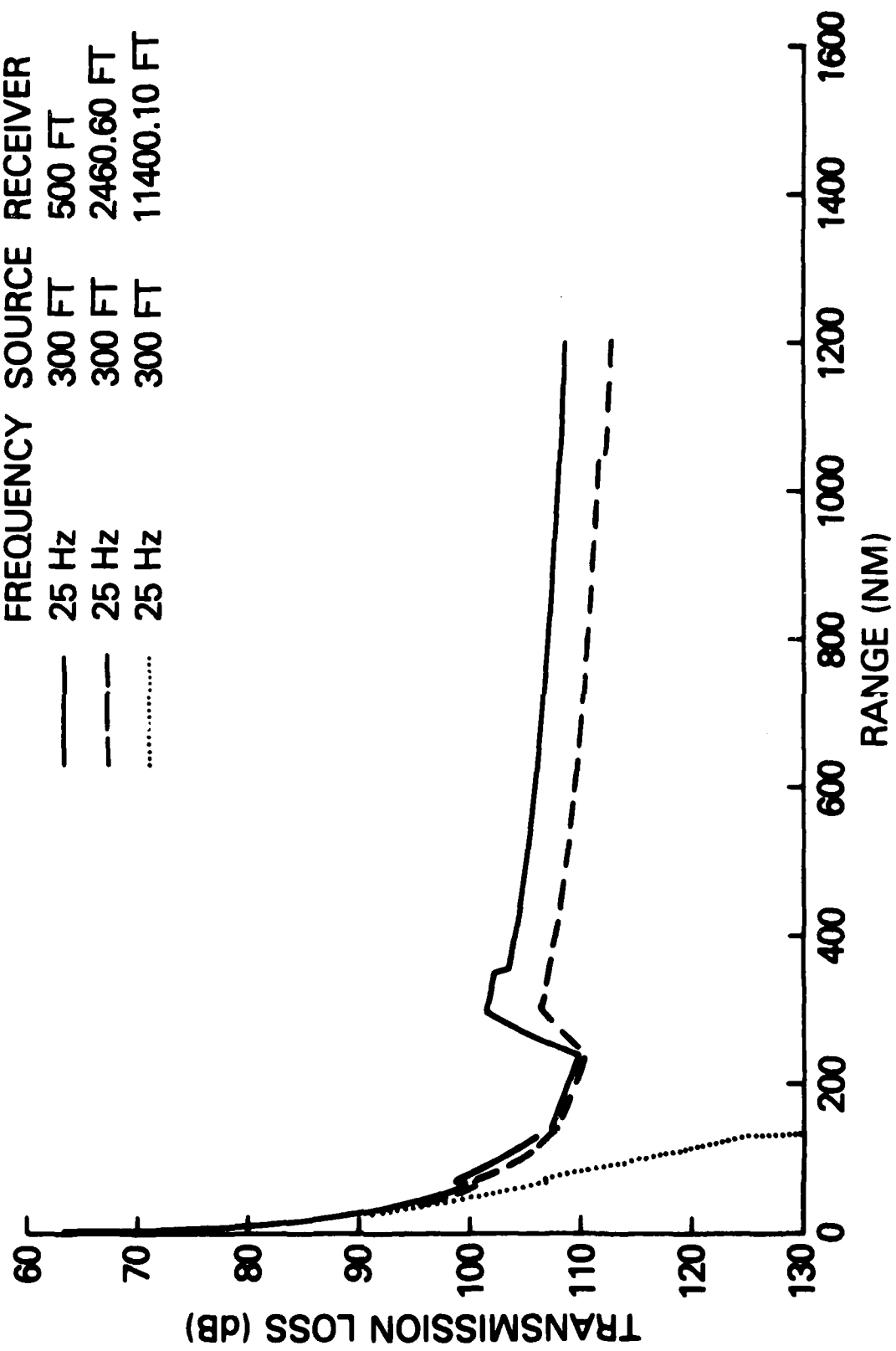


Figure 23

(a) PE 5 NM AVG. CRITICAL ANGLE=19°

FREQUENCY SOURCE RECEIVER  
50 Hz 20 FT 11400 FT

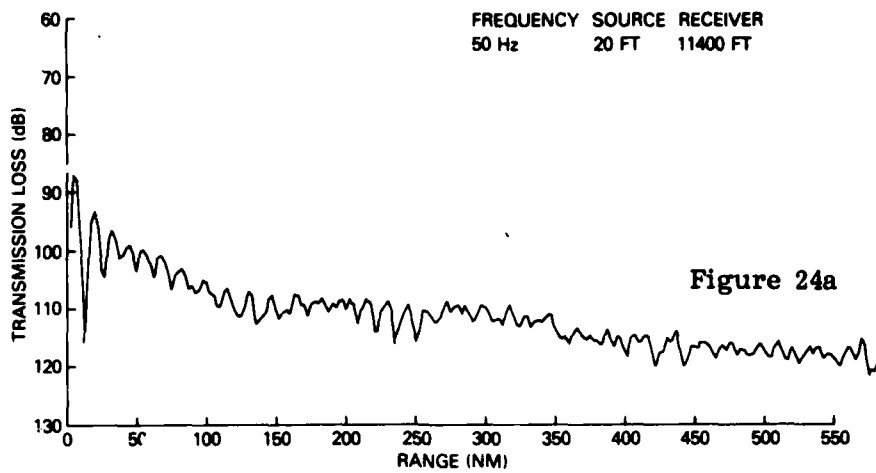


Figure 24a

(b) PE 5 NM AVG. CRITICAL ANGLE=19°

FREQUENCY SOURCE RECEIVER  
50 Hz 60 FT 11400 FT

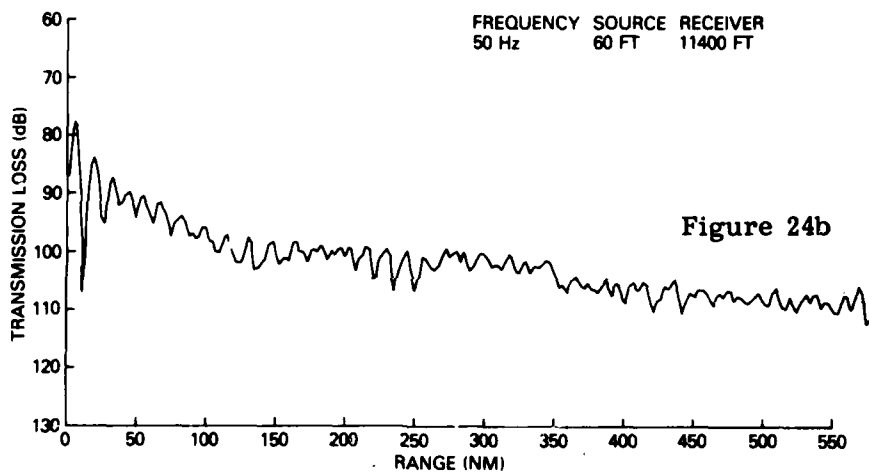


Figure 24b

(c) PE 5 NM AVG. CRITICAL ANGLE=19°

FREQUENCY SOURCE RECEIVER  
50 Hz 300 FT 11400 FT

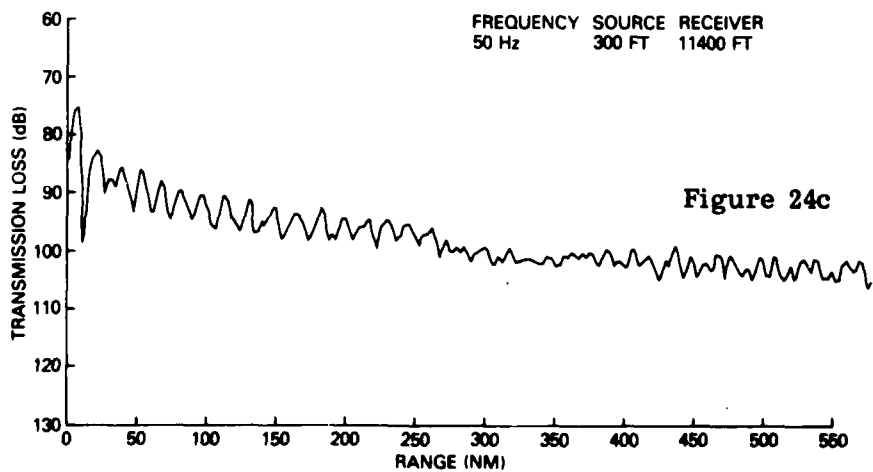
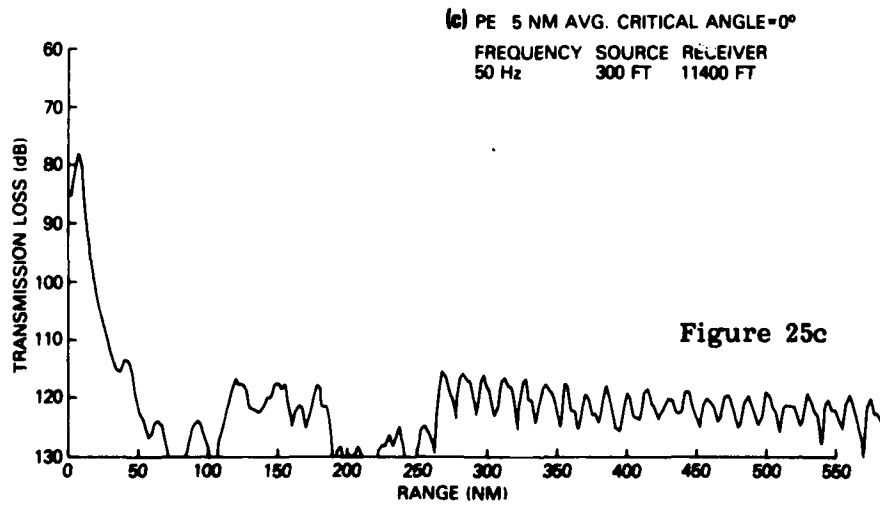
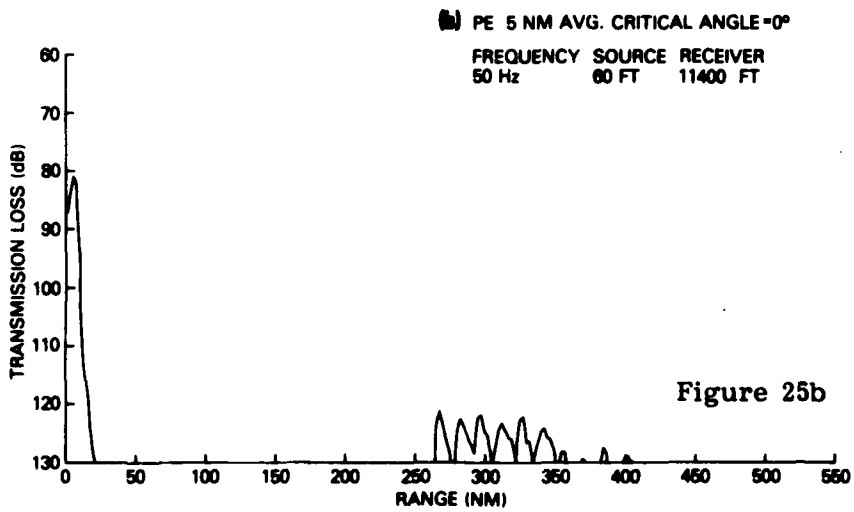
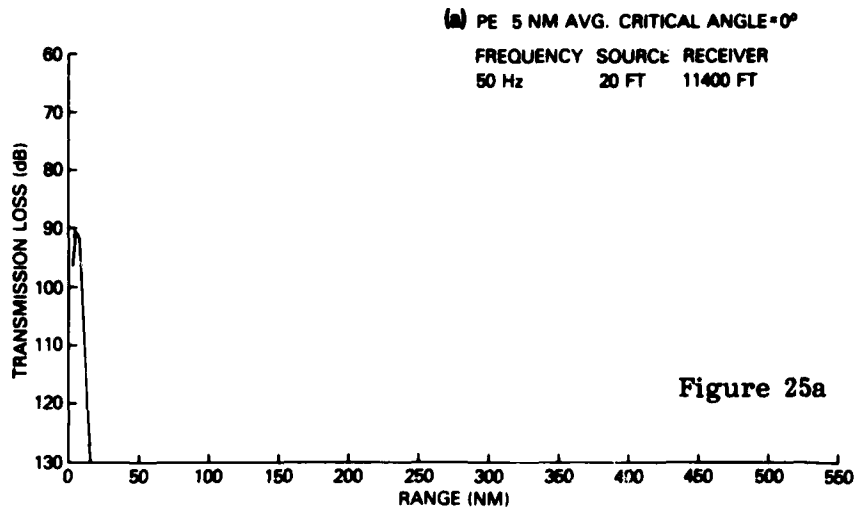


Figure 24c



ASTRAL TRACK FB 1

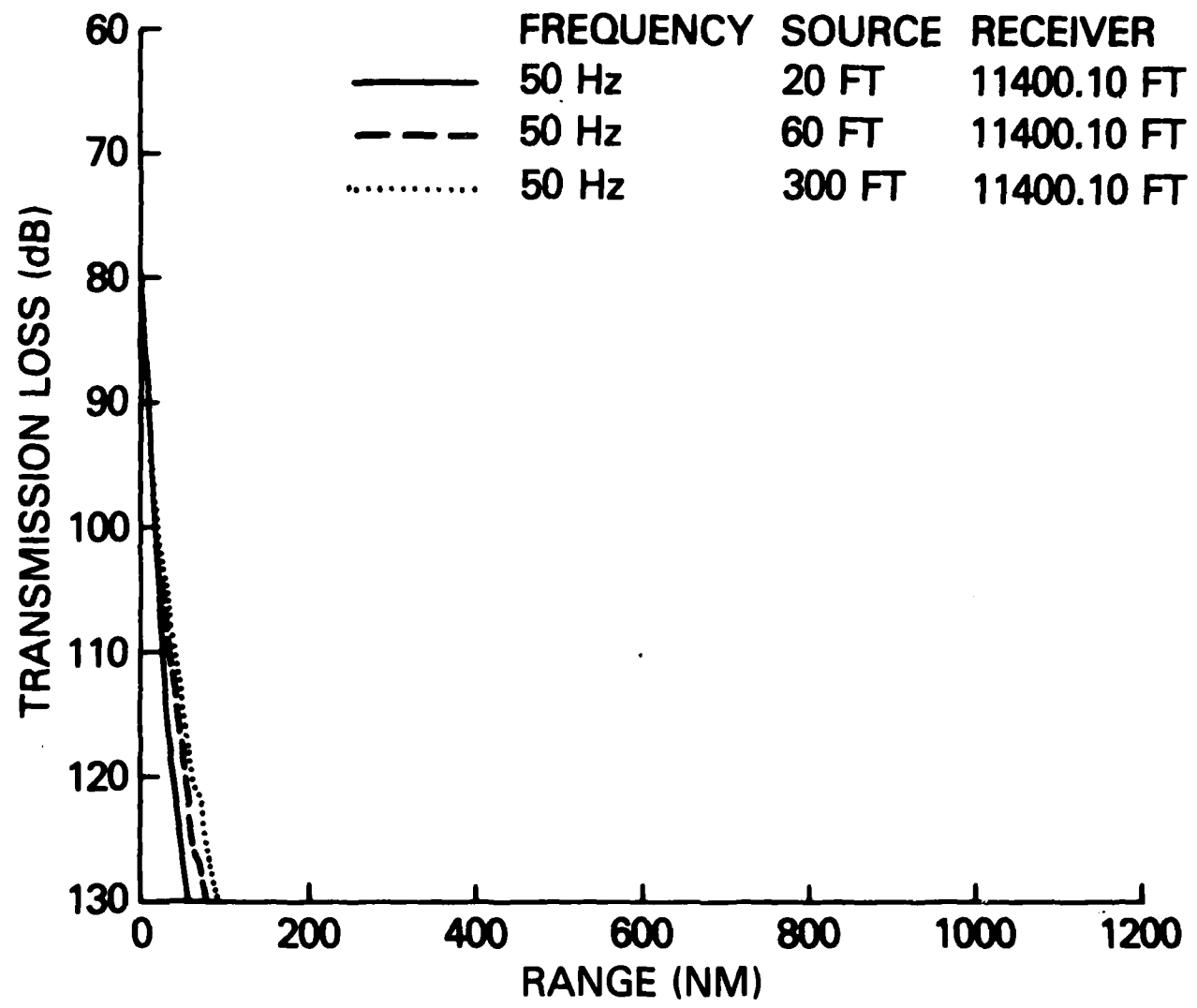


Figure 26

# ASTRAL TRACK FB 1

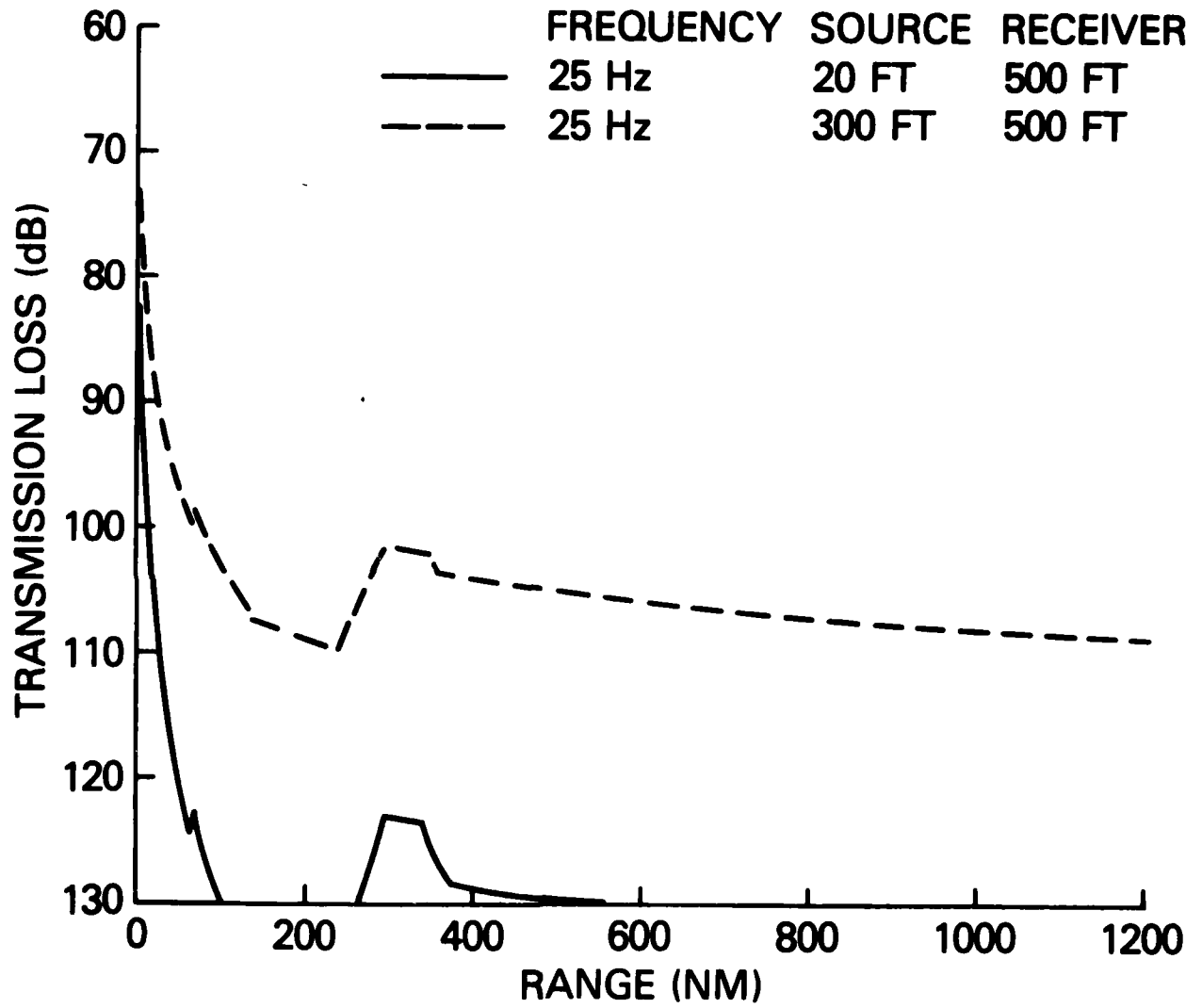


Figure 27

ASTRAL TRACK FB 1

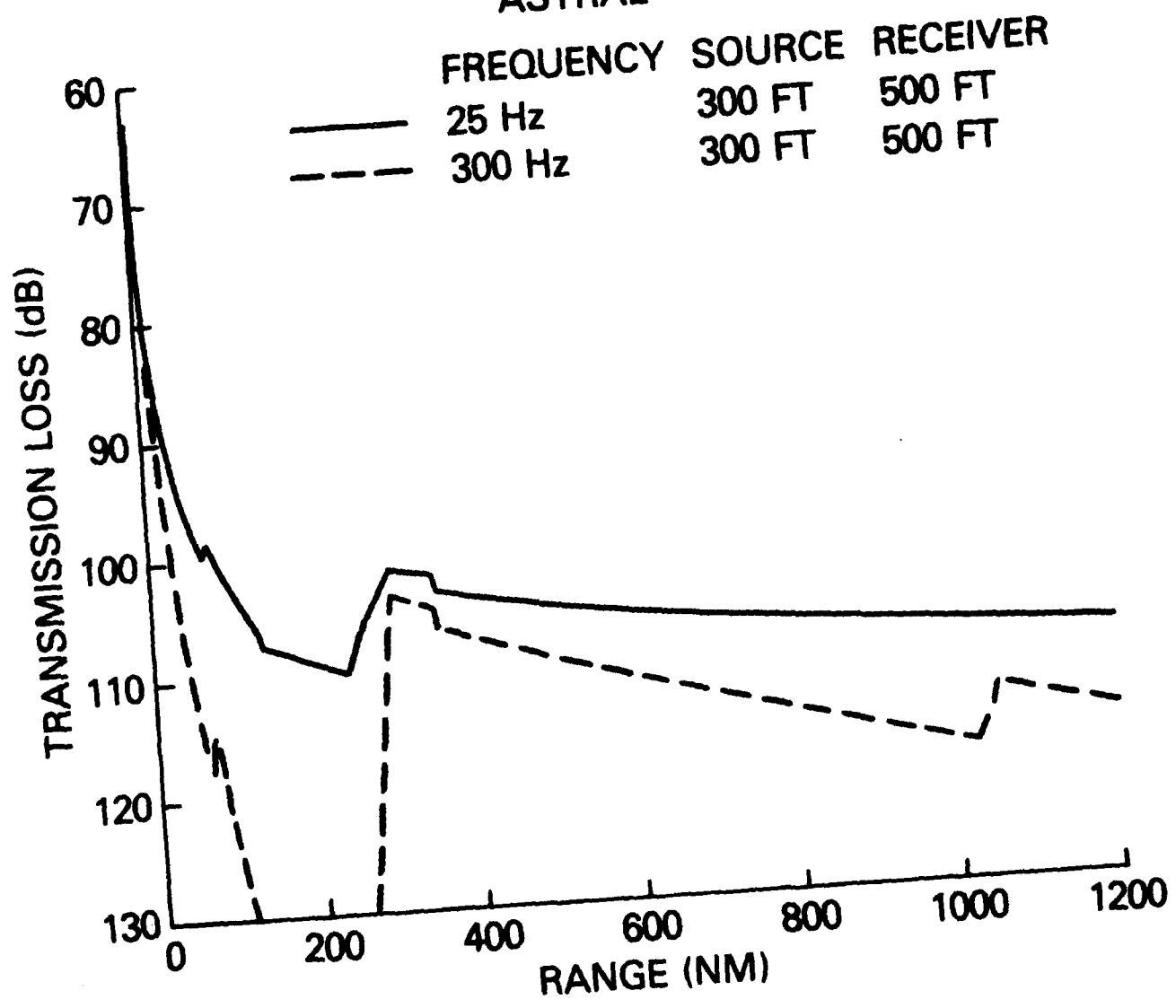


Figure 28

curves for high and low frequencies (see Figs. 10 a-e). Since 3 to 5 dB greater loss per bounce is experienced by high frequencies (in excess of 300 Hz) and there is more bottom interaction crossing the ridge, the greater transmission loss experienced by the 300 Hz source is expected. The slight range-dependent spreading between the 25 and 300 Hz curves at large ranges is due primarily to differences in volume absorption at the two frequencies.

b. Province 8 track 02 (FH 2)

The plot of the environment for this track (see Fig. 19) shows that shallow sources for this environment are bottom limited only at the very beginning, thus bottom interaction effects are less pronounced.

The receiver depth dependence shown in Figure 29 is not significant, whereas the source depth dependence shown in Figure 30 is quite pronounced. Again, SII is responsible for this strong dependence. The frequency dependence shown in Figure 31 is a good illustration of the range-dependent effect of attenuation due to volume absorption.

C. AMBIENT NOISE

1. Omnidirectional Noise

FANM was used to calculate the omnidirectional ambient noise estimates. The starting latitude and longitude of each of the transmission loss tracks was chosen as the position for a 500 ft deep receiver. For the noise prediction, FANM was used in a manner to maximize the calculated noise at a frequency of 50 Hz by maximizing the ship count in all directions. (This will produce an upper limit noise estimate). Figure 32 shows the location used for each FANM simulation, along with the appropriate noise value. For bottom-limited positions, a bottom-limited value is listed after the omninoise value. The data shows, as expected, that less noise can be expected for bottom limited stations. Table 7 gives the omnidirectional noise predicted by FANM for a 500 ft receiver depth and a range of frequencies for all the stations. A bottom-limited site gives lower values for noise over the range of frequencies, as compared to a corresponding non-bottom-limited site (e.g., FH 1, FH 2).

Table 7  
FANM omnidirectional ambient noise  
RD = 500 ft

LAT. - LON. LOCATION	(TRACK)	FREQUENCY (Hz)					
		25	50	100	200	300	500
AREA 1	(FA1)	77.4	74.9	67.1	61.0	60.0	61.1
AREA 2	(FB1)	66.6	64.9	58.8	55.1	55.2	57.1
AREA 3	(FC1)	66.4	61.9	54.9	52.8	54.2	56.8
AREA 4	(FD1)	81.5	81.0	74.2	66.8	61.8	57.9
AREA 5	(FE1)	71.9	69.6	62.3	58.8	59.3	61.1
AREA 6	(FF1)	86.5	86.2	79.8	72.9	68.5	64.9
AREA 8-1	(FH1)	82.1	81.9	75.3	67.6	63.7	63.3
AREA 8-2	(FH2)	75.5	71.6	64.9	61.8	61.9	63.1
AREA 9	(FI1)	78.3	78.0	71.8	66.3	64.6	64.2

ASTRAL TRACK FH 02

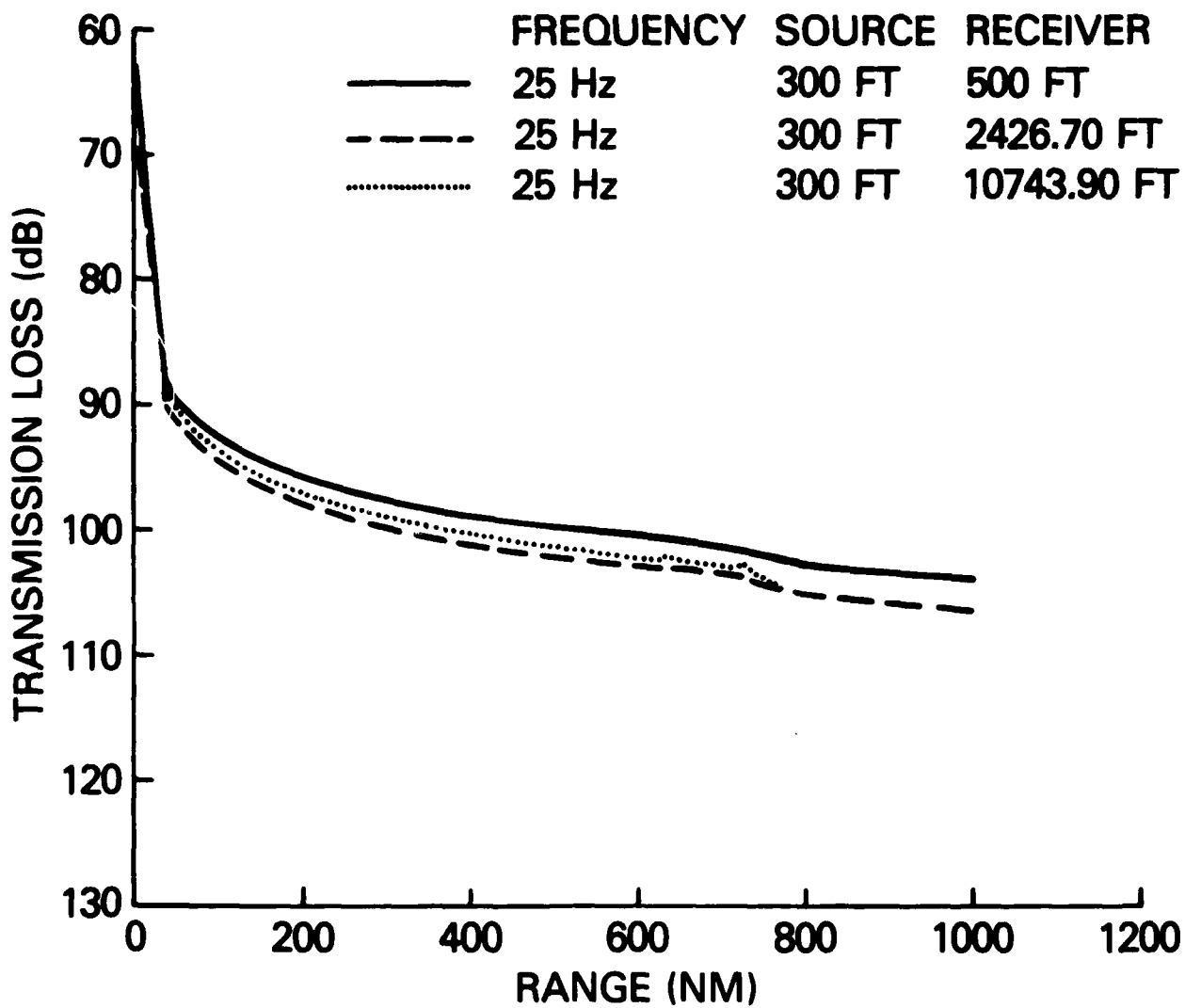


Figure 29

ASTRAL TRACK FH 02

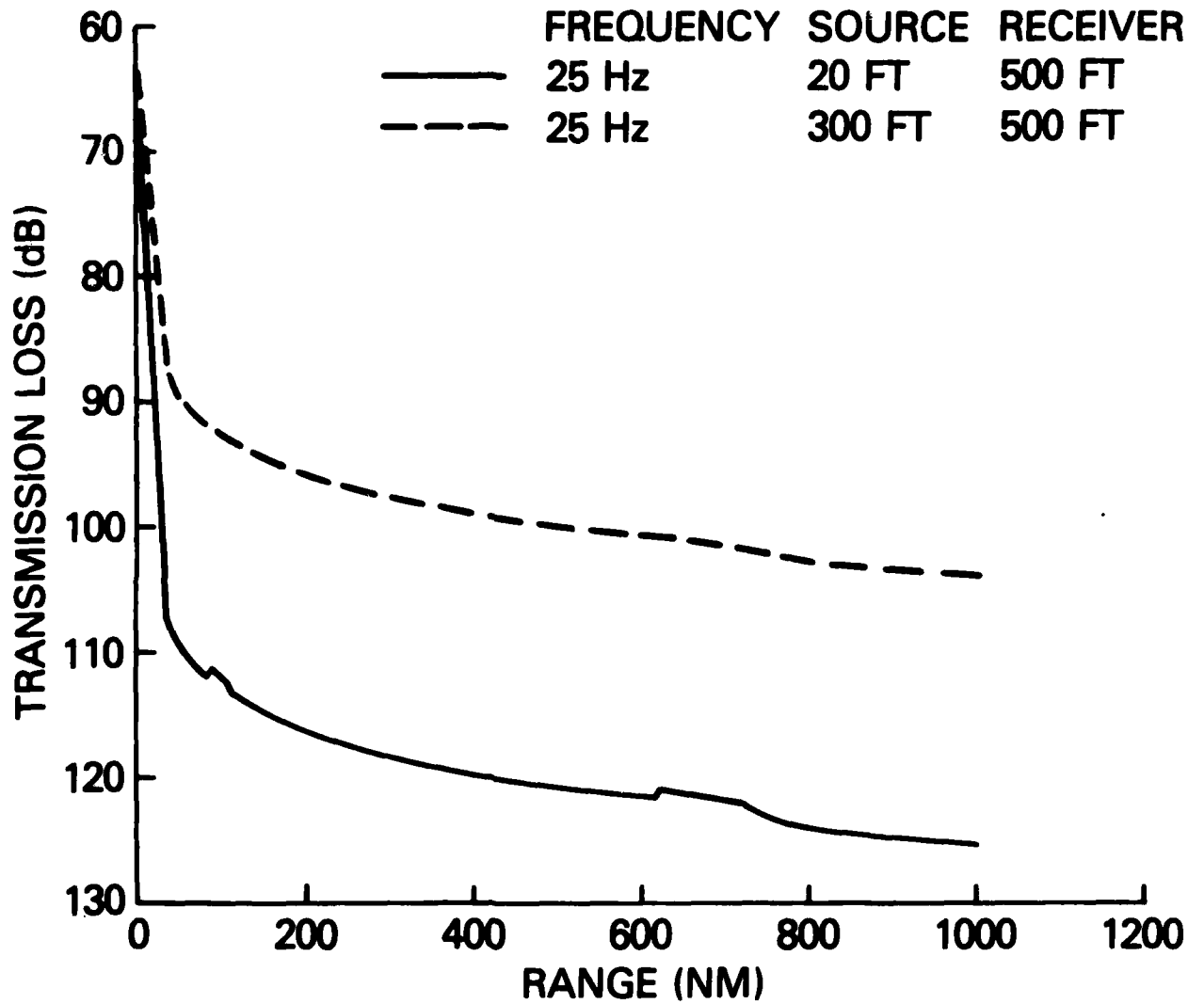


Figure 30

ASTRAL TRACK FH 02

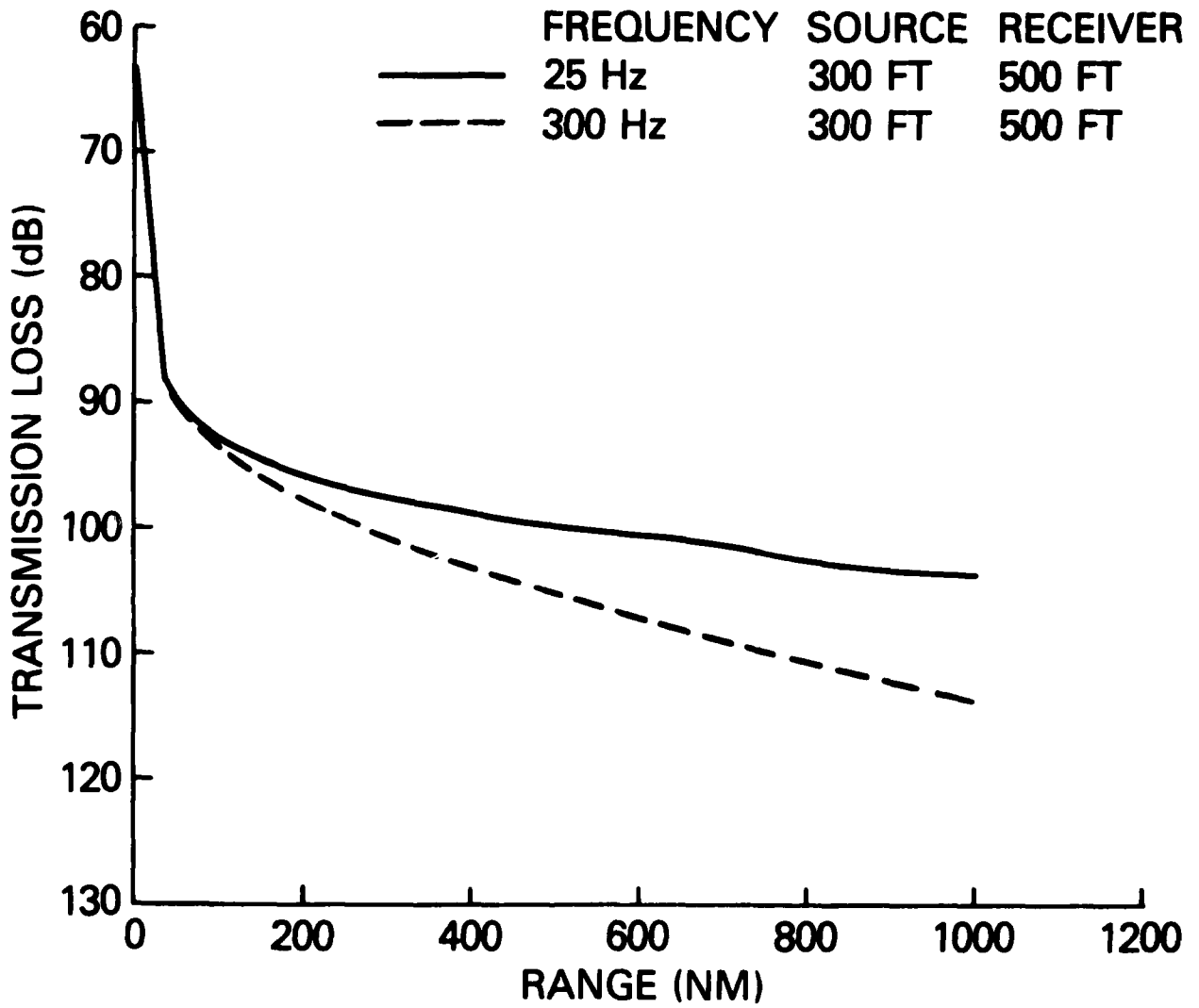


Figure 31

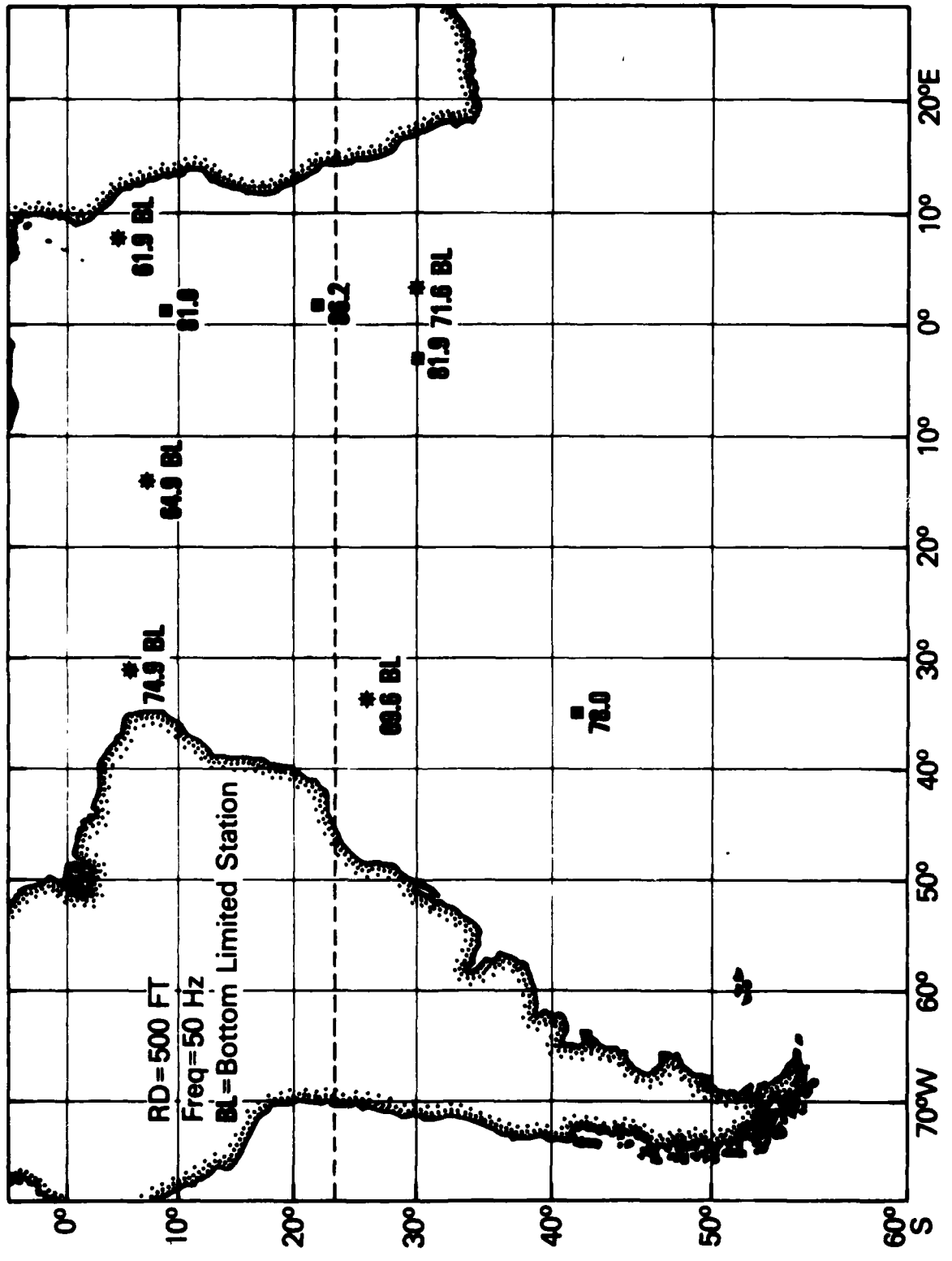


Figure 32

When one compares the FANM prediction to either measured or calculated noise values in other parts of the world (see Table 8), the South Atlantic is relatively quiet.

Table 8  
OMNI noise for selected ocean areas

EASTERN GULF OF MEXICO

F (Hz)	Omni Level (dB/ $\mu$ Pa, Hz)	Source
25	86-88	FANM
67	80-82	FANM
149	71-73	FANM
50	86	Measured

WESTERN GULF OF MEXICO

F (Hz)	Omni Level (dB/ $\mu$ Pa, Hz)	Source
25	80	FANM
67	74	FANM
149	66	FANM

MEDITERRANEAN (IONIAN)

F (Hz)	Omni Level (dB/ $\mu$ Pa, Hz)	Source
25	83-90	Measured
50	87-92	Measured
200	72-76	Measured
500	65-66	Measured
50	88-89	FANM
300	58-70	FANM

2. Horizontal Directional Ambient Noise

Only two sites were chosen for predictions of the horizontal noise directionality. These sites were the starting point of track FH 2 (Site 1) and 400 nautical miles along FB 2 (Site 2); the receiver was to the east of the Mid-Atlantic Ridge.

The locations of the two sites for which directional noise calculations were made are shown in Figure 33 in relation to the shipping information. As seen in Figure 33 the shipping in the South Atlantic is very concentrated. While using ASTRAL transmission loss radials for CNOISE in the South Atlantic, a problem became apparent. ASTRAL uses a ray-like treatment out to the first environmental change. When one uses a coarse data base structure as in the South Atlantic, this first range step size may be on the order of 60 nautical mile. A module of CNOISE then takes the supplied transmission loss and linearly interpolates it at uniform range steps (in this case 2 nautical miles). A linear interpolation at the beginning of a transmission loss curve with a large initial step may shift the values appreciably. To circumvent this, the starting point of some of the radials were shifted a small amount (approximately two minutes of latitude) so that ASTRAL would encounter a new environment within two nautical miles along the environmental tracks. This problem points out the need for a finer resolution in the South Atlantic data base.

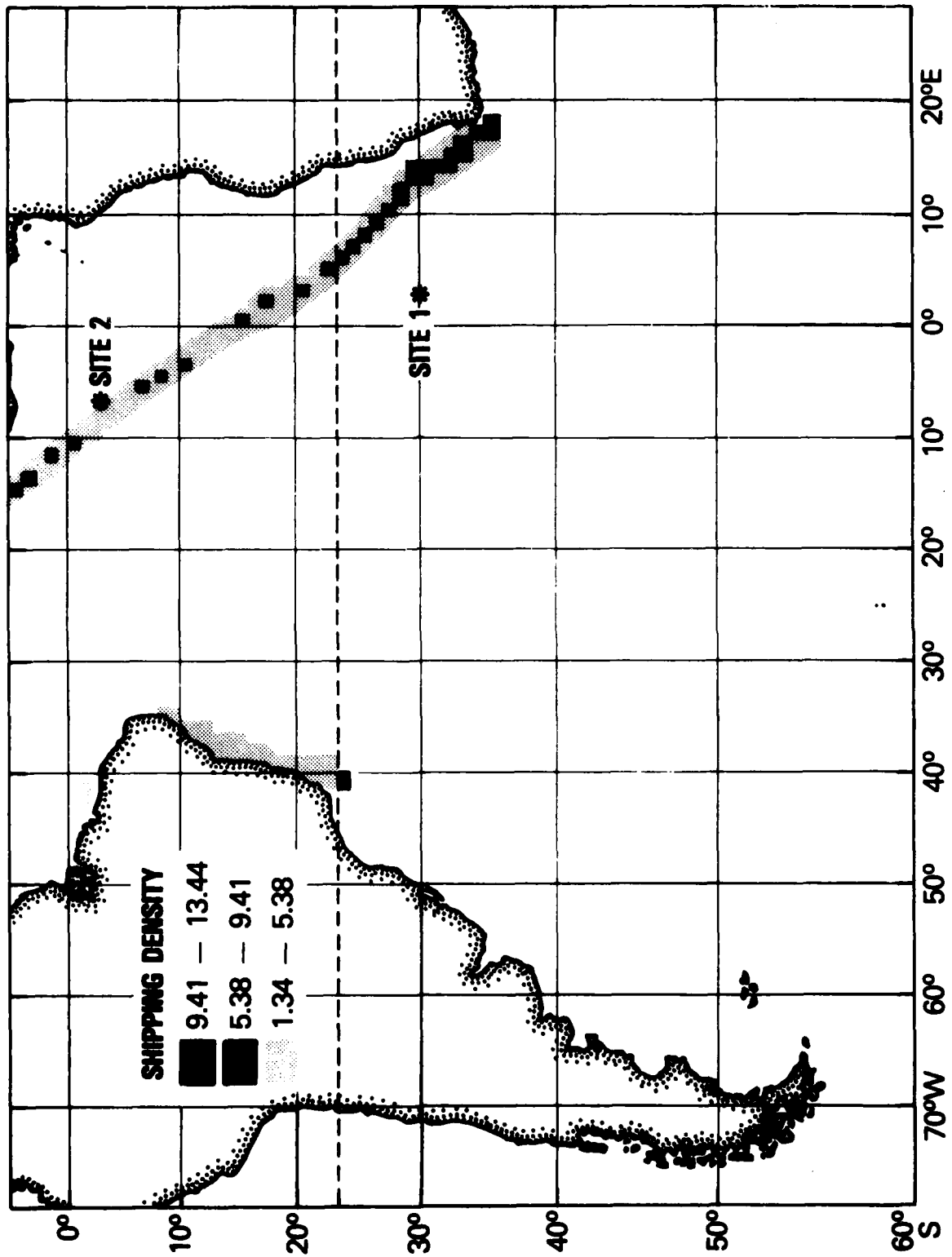


Figure 33

For Site 1, four ASTRAL runs were made in order to provide CNOISE with appropriate TL. The radials used are listed in Table 9 below.

Table 9  
Site 1 CNOISE sector coverage

<u>Radial No.</u>	<u>Bearing</u>	<u>Sector Coverage</u>
1	0°	300° - 30°
2	135°	30° - 150°
3	180°	150° - 210°
4	315°	210° - 330°

The corresponding transmission loss curves are given in Figures 34 a-d.

The horizontal directional noise rose generated by CNOISE for Site 1 is shown in Figure 35. The arrowheads on the noise roses give the direction of the TL curves used for each of the four respective sectors. The noise rose shows a strong noise component in the eastern quadrant. This is expected because of the strong noise source concentration from the shipping lane around the southern tip of Africa.

The second example of horizontal directional noise used Site 2 as the receiver location for a 500 ft receiver. ASTRAL was again used to supply the four transmission loss radials used by CNOISE. The following table lists the radials used.

Table 10  
Site 2 CNOISE sector coverage

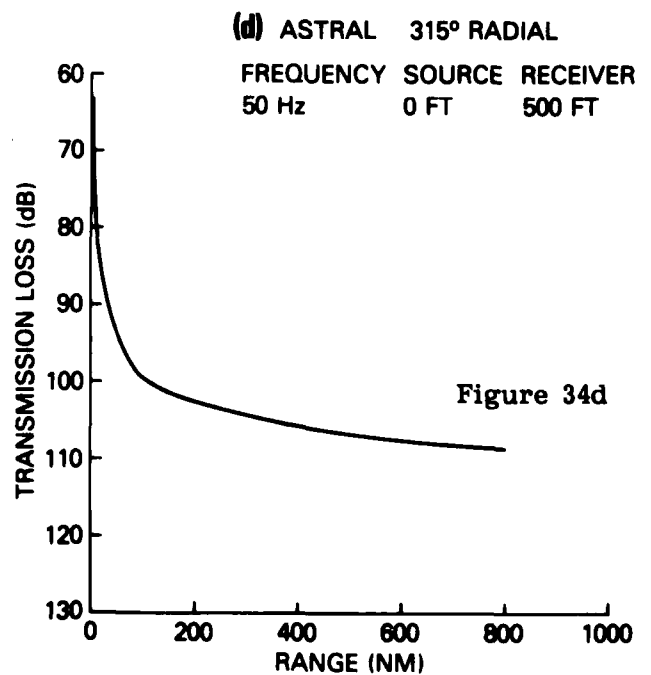
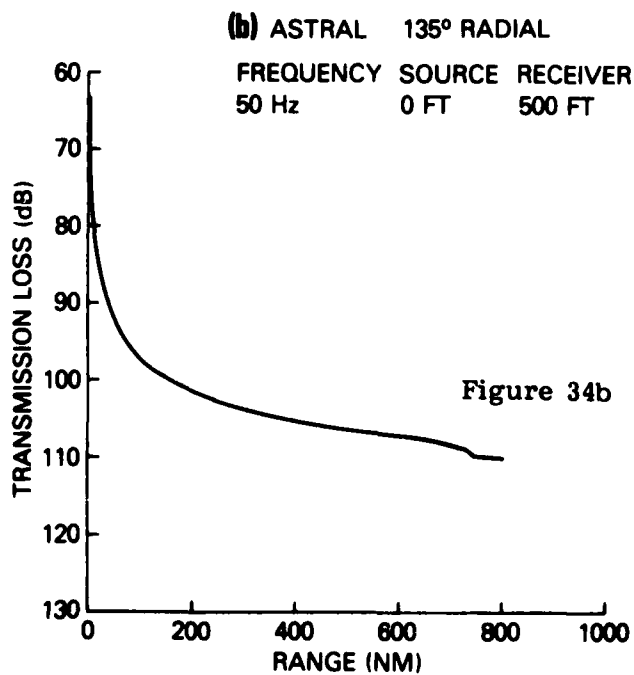
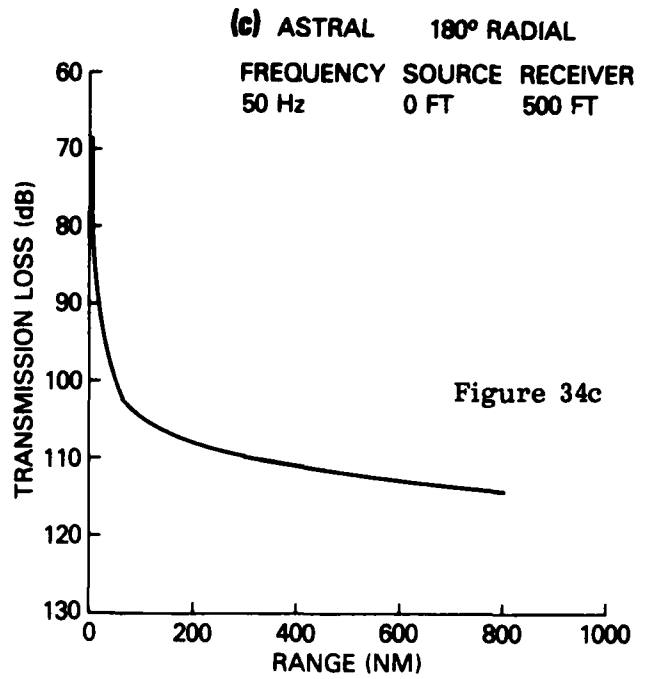
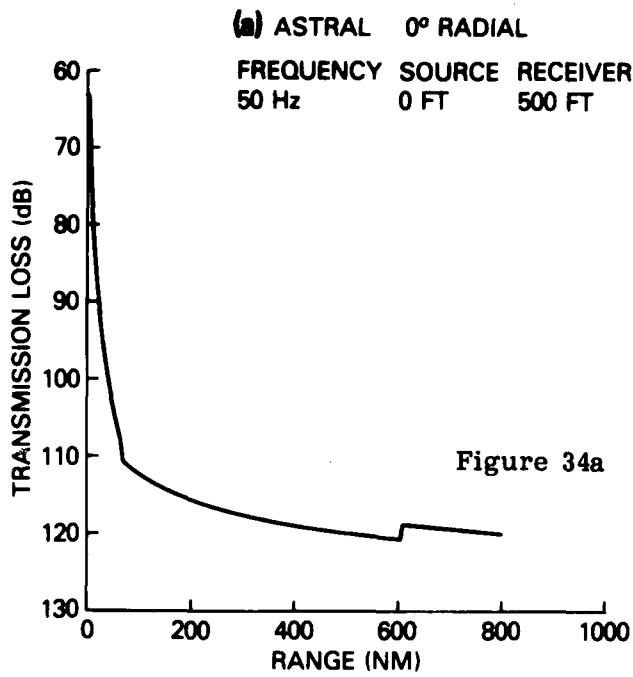
<u>Radial No.</u>	<u>Bearing</u>	<u>Angular Coverage</u>
1	0°	330° - 60°
2	90°	60° - 150°
3	180°	150° - 240°
4	270°	240° - 330°

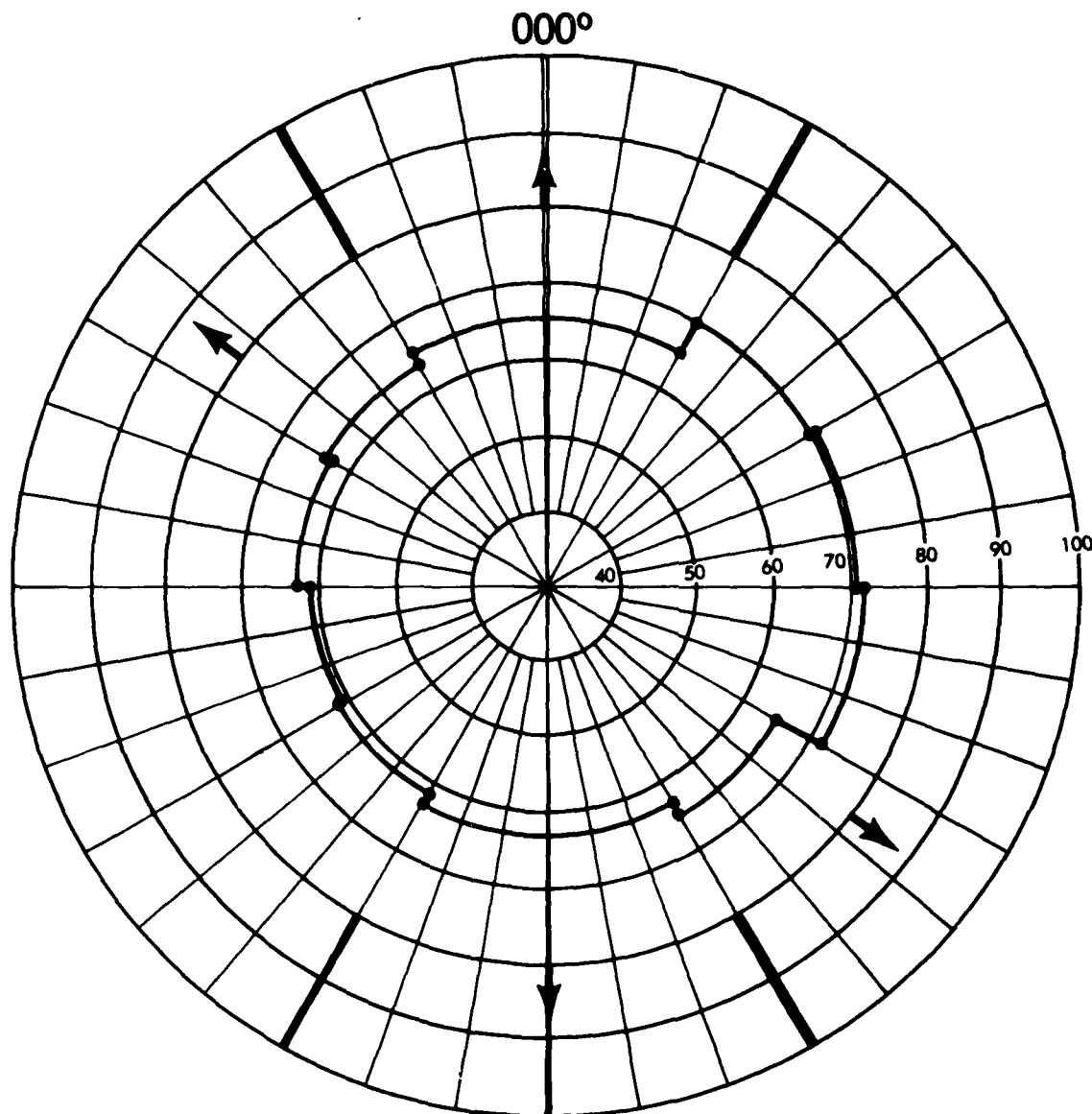
The transmission loss plots used are shown in Figures 36 a-d.

The resulting plot of horizontal noise at 50 Hz (see Fig. 37) shows that the bathymetric ridge to the west does produce some blockage, leading to a decrease in the calculated noise.

### 3. Transmission Loss Plus Beam Noise

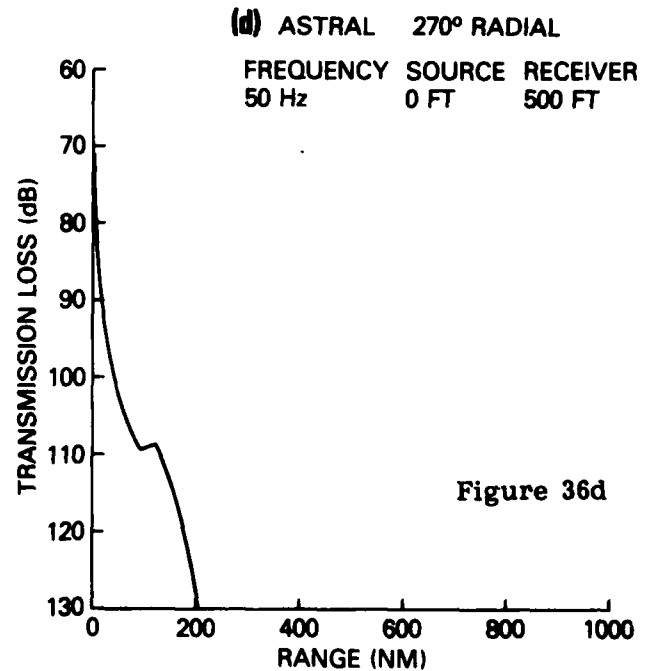
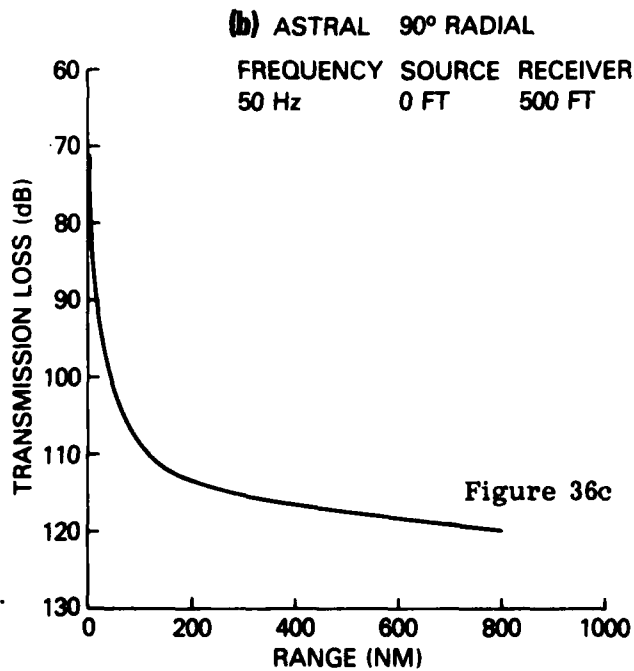
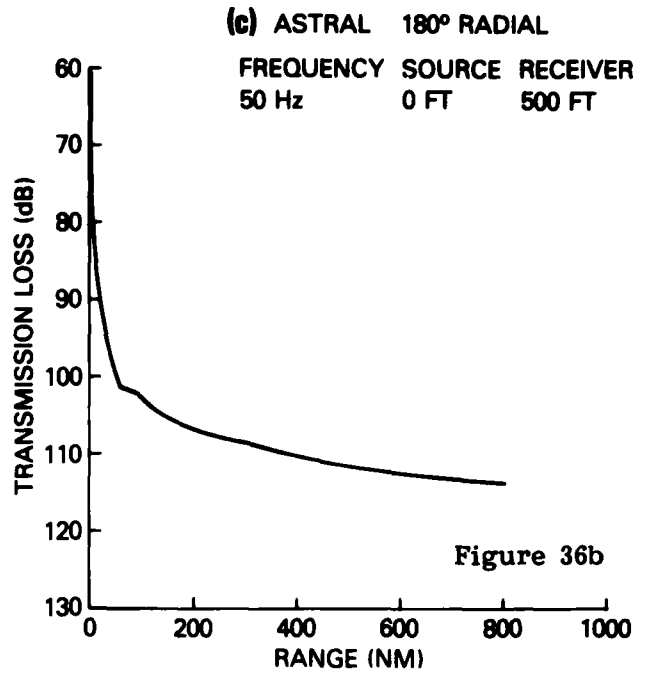
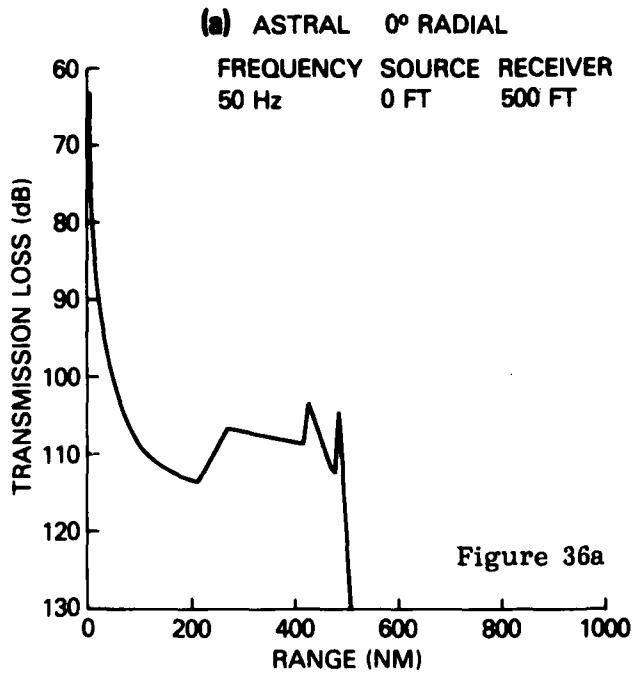
As a last calculation, the environmental terms (TL+BN) of the passive sonar equation were combined for Site 1. The beam noise (BN) was calculated for a 5° beam from the sector noise information generated in CNOISE, and the transmission loss (TL) came from ASTRAL. Radial 2 (from Table 9), which had a bearing of 135° and sector coverage of 30°-150°, was used. The results (see Figs. 38 a-c) show that the highest signal-to-noise ratio (lowest TL + BN) is for the 300 ft source. Because of the directionality demonstrated in the noise calculation, TL+BN is probably highly directional at this site.

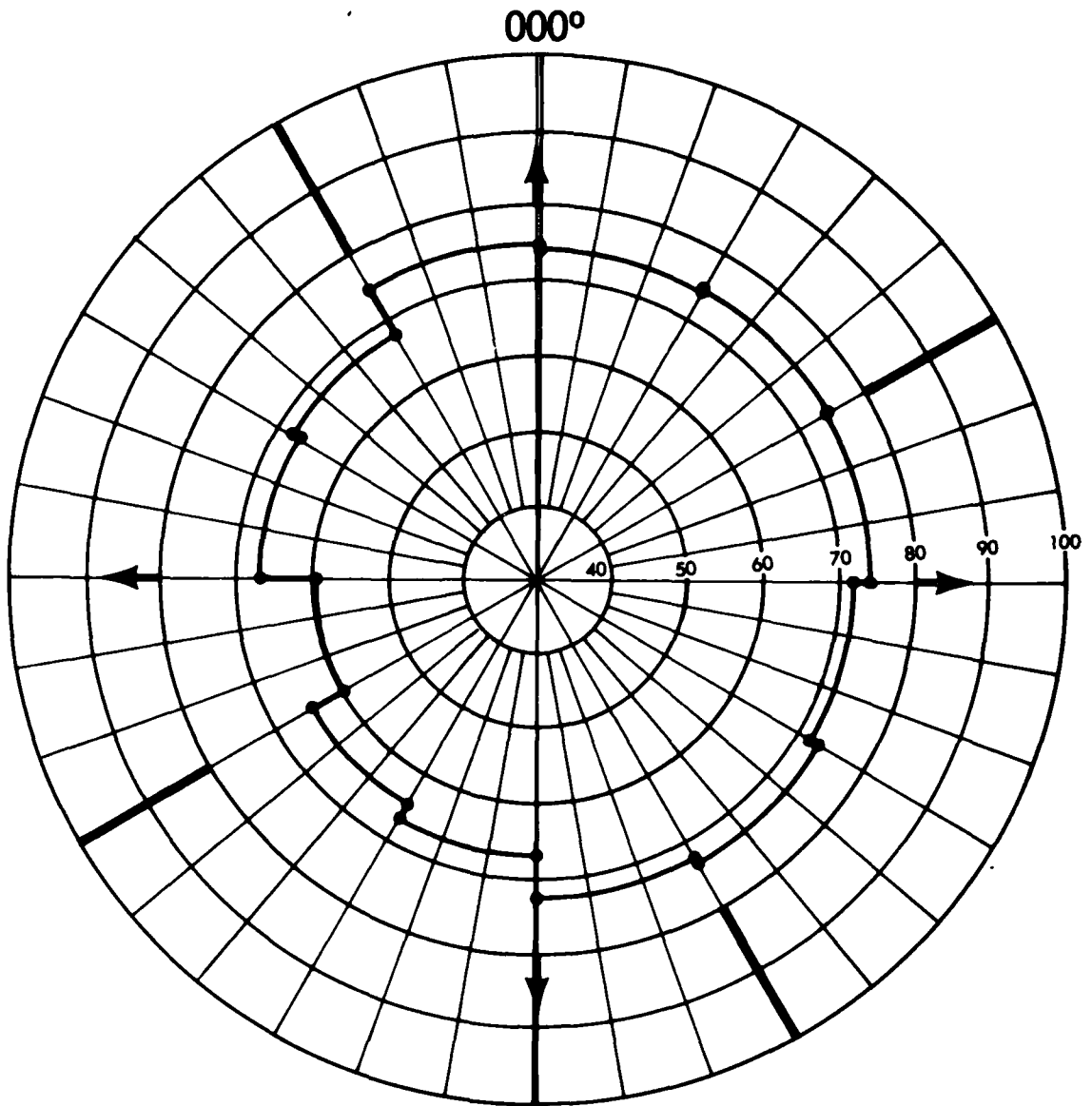




**SITE 1**  
**Horizontal Noise Directivity (dB// $\mu$ Pa, Hz)**  
**CNOISE**  
**FREQ=50 Hz**  
**R D=500 FT**

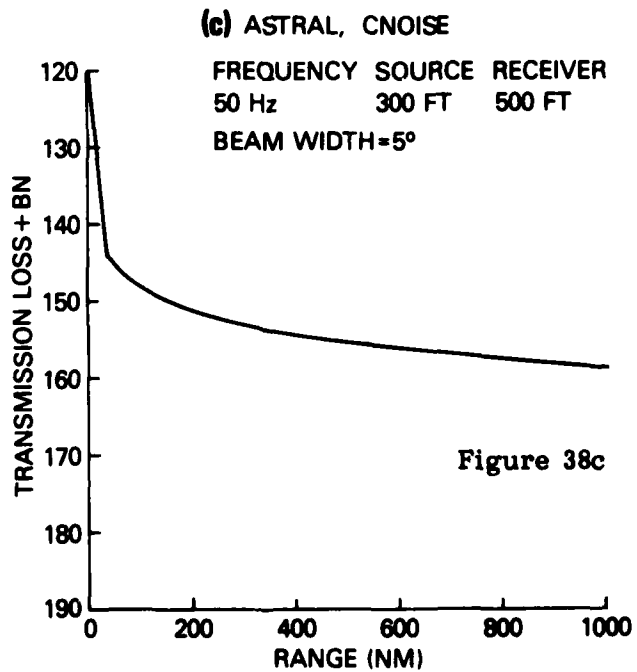
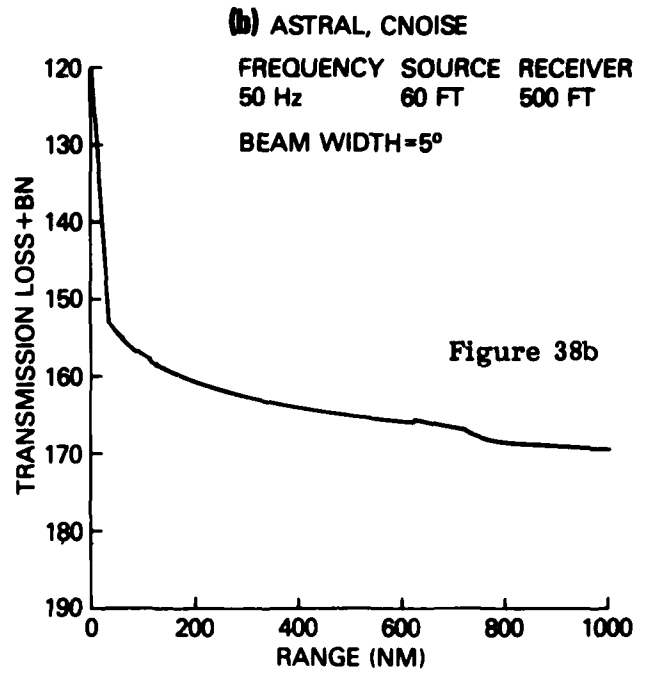
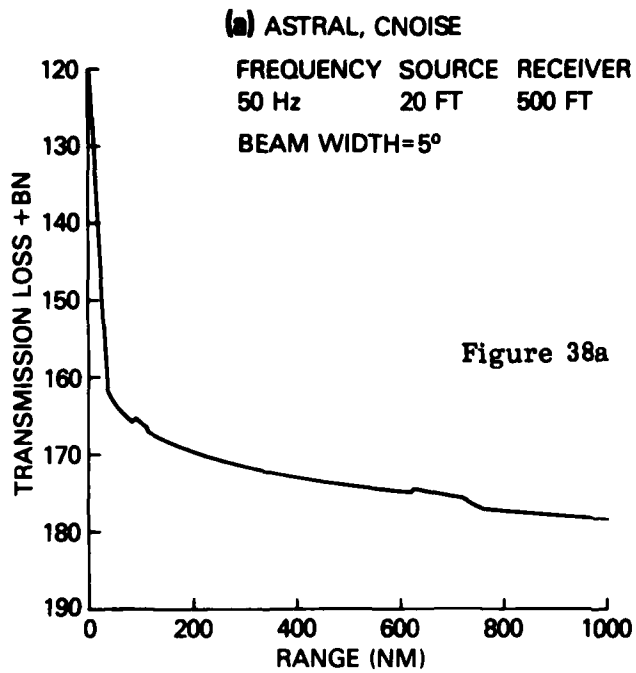
Figure 35





**SITE 2**  
**Horizontal Noise Directionality (dB// $\mu$ Pa, Hz)**  
**CNOISE**  
**FREQ=50 Hz**  
**R D=500 FT**

Figure 37



#### IV. CONCLUSIONS AND RECOMMENDATIONS

As a result of the efforts described in this report, a modeling data base skeleton is in place at NORDA. The data base consists of sound speed profiles, bathymetry, bottom loss, and shipping distribution. Data for this study was distributed on a coarse geographic grid (9 provinces for sound speed, 1° resolution for bathymetry). Sound speed and shipping distribution are available on a seasonal basis (winter, summer). The bottom loss classes are derived from the BEARING STAKE exercise. Bottom loss province assignments are based on physiographic similarities. It is felt that the data base is inadequate for detailed studies because of the coarse resolution of SSP's and bathymetry and the unknown validity of the bottom loss assignments and curves. Efforts are underway to refine the data base resolution as data availability permits and to verify the applicability of the bottom loss treatment.

##### A. CONCLUSIONS

Recognizing their obviously tentative nature, modeling conclusions that impact future planning in the South Atlantic region include:

- South Atlantic is environmentally complex.
  - Large differences are observed in critical depth from east to west across the Mid-Atlantic Ridge. This is primarily due to large differences in the deep sound speed gradients.
  - A substantial portion of the western South Atlantic north of 40°S is bottom limited during the Southern Hemisphere Summer (January-March).
- Substantial bathymetric blockage is evident.
  - Detailed characterization of the area is not possible due to the lack of a high resolution bathymetric data base.
  - Ridges divide the South Atlantic into semi-isolated basins.
- Environmental/acoustic data is scarce.
  - Little ambient noise data is available.
  - Little bottom loss data is available.
- Bottom interaction is a critical factor in propagation and noise predictions.
  - Bottom loss estimates have a significant effect on the accuracy of model predictions.
  - Little confidence may be placed on the validity of the current bottom loss data base.
- Model input sensitivities show significant bottom interaction effects.
  - Strong source depth dependence is evident due to bottom interaction at high frequency (300 Hz).
  - Weak receiver depth dependence is evident except in cases where near-by bathymetric blockage is a factor.

- Weak to moderate frequency dependence is evident due to surface image interference and bottom interaction for shallow sources and volume absorption for deep sources.
- Omnidirectional ambient noise levels should be lower than other ocean areas
  - Comparisons with previously measured and predicted ambient noise levels indicate that South Atlantic omnidirectional levels are generally lower at all frequencies.
- Significant geographic dependence of ambient noise is indicated by model predictions.
  - Primarily due to bottom limiting and geographic concentration of noise sources.
- Strong azimuthal dependence of ambient noise is indicated by model predictions.
  - Shipping is concentrated in well-defined lanes.
  - Significant bathymetric blockage occurs in some directions for some sites.
  - Most propagation paths are bottom interacting for surface noise sources.
- Mid-water low-frequency systems will probably perform acceptably.
  - Noise propagation will generally be bottom interacting.
  - Concentrated shipping leads to highly directional ambient noise.
  - Omni-directional noise levels may be lower than other ocean areas.
  - Bathymetric blockage may be used for shielding of systems from noise.
- Currently available propagation models may be inadequate for detailed studies.
  - Bottom interaction is critically important.
  - Sloping bottom topography is present over most propagation paths.
  - Thin sediment over rough basement is probably present over many propagation paths.
  - Shelf-borne shallow water noise sources are present at basin margins.

The validity of these conclusions is highly dependent upon the degree to which the model data base is representative of the actual environment.

#### B. RECOMMENDATIONS

It is recommended that efforts continue to upgrade the quality and resolution of the data base. The bathymetry grid should be improved to preclude problems observed with the use of ASTRAL and the current data base. New sound speed provinces should be selected based upon further analysis of available oceanographic data. The validity of the application of BEARING STAKE bottom classes in the South Atlantic is a critical question. Current analyses of bottom loss data taken during the January 1981 transit of the Brazil Basin may be helpful in addressing this issue. Geoacoustic modeling may also be employed to shed additional light on bottom loss validity.

These recommendations are all data quantity/quality related, and it is not expected that a satisfactory solution, affording reliable system performance predictions, will be achieved short of extensive environmental/acoustic survey efforts in the South Atlantic.

Several model-related recommendations proceed from the experiences encountered during this study. Since the South Atlantic is highly bottom limited, a detailed propagation model is needed which is capable of properly treating these conditions. PE would be the natural choice, given its proven performances under deep-water conditions. However, NORDA does not currently have a version of PE capable of handling bottom interaction propagation in an acceptable manner. It is recommended that efforts be continued to ensure that an acceptable propagation model is available for detailed studies in this or other regions where a significant degree of bottom limiting is present. In the same vein, the current version of ASTRAL is cumbersome to use when the regional bottom loss description is other than FNOC curves. A new updated modification of ASTRAL is required for each departure from FNOC descriptions. A version of ASTRAL is needed that is capable of handling different bottom descriptions in a routine fashion. A final model related recommendation concerns ambient noise calculations. In an environmentally diverse region such as the South Atlantic, noise directionality calculations require range dependent TL estimates. FANM-like estimates are unsatisfactory. The use of ASTRAL is indicated as an acceptable solution to the range dependent problem, assuming adequate resolution in the environmental data base to avoid the observed interpolation anomalies, and avoiding problems due to bathymetric blockage as discussed in Section III B-2a. The problem is one of implementation. The current version of ASTRAL at NORDA does not have multi-radial looping capabilities. Implementation of a directional ambient noise model with multi-radial looping capabilities using ASTRAL, CNOISE and NORDA data bases would be quite helpful in future modeling efforts.

While one must reiterate the tentative nature of the conclusions and recommendations presented as a result of this limited study, it is felt that they can serve as a guide to planning the role that numerical modeling will play in future exercise planning efforts in the South Atlantic region.

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The data base framework installed and tested. The model study has been conducted and several tentative conclusions have been reached regarding the acoustic nature of the South Atlantic. The limited adequacy of the current data base to provide accurate predictions of the acoustic sensitivity of the region is discussed. Recommendations for data base and model improvements are provided with an eye toward modeling support of future exercise planning in the region.

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