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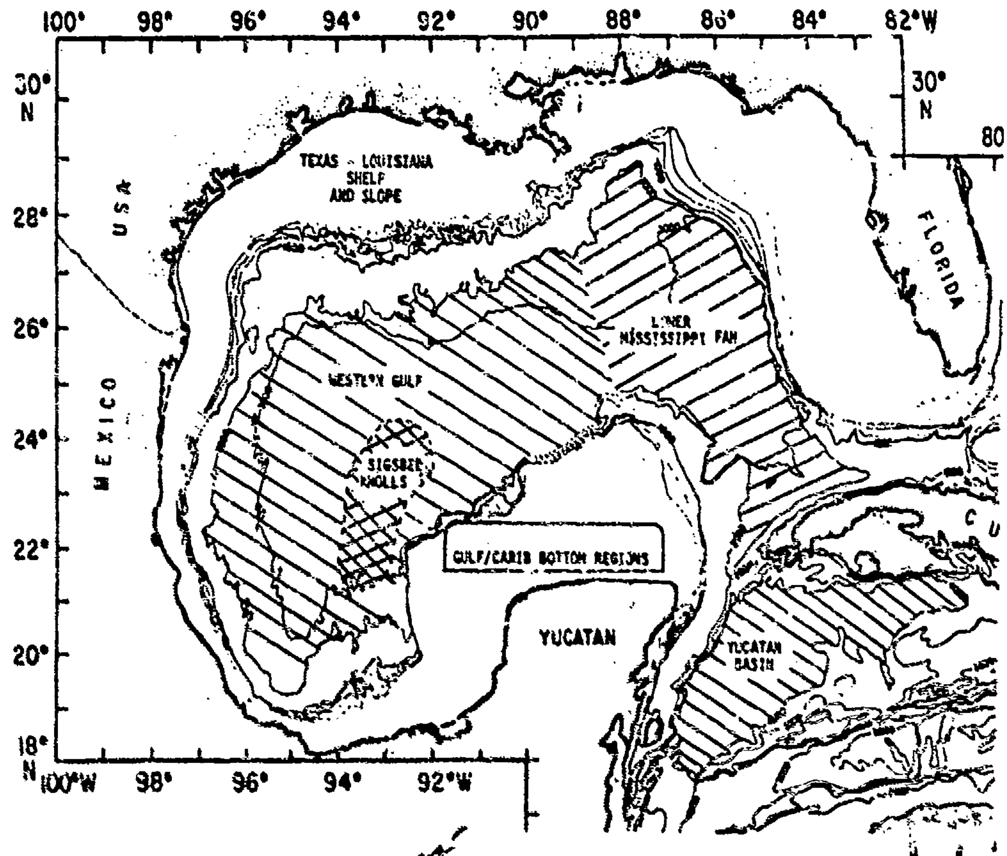
Environmental Effects on Low Frequency Transmission Loss in the Gulf of Mexico (U)



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Burlie A. Brunson
M. Mark Truxillo
Richard B. Evans

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ABSTRACT (U)

(U) Acoustic transmission loss data were acquired during Cruise 1 of the CHURCH STROKE III Exercise of July 1979. Initial comparisons of observed transmission loss data, with pre-exercise model predictions made using the ASTRAL model with historical environmental data inputs indicated a considerable degree of disagreement. A series of post-exercise model runs were undertaken to isolate the environmental factors contributing to the observed disagreement. Model runs using a range-dependent normal mode model (SNAP) were made using a geoacoustic description of the seafloor. Good agreement was attained for detailed structure comparisons. Estimates made using the model ASTRAL, together with a bottom loss description derived from the same geoacoustic description of the seafloor, matched the observed levels quite well in an average sense. Since the attenuation estimates were derived from those resulting from the BEARING STAKE Exercise, some implications as to the validity of geoacoustic parameter extrapolation are apparent. Additional implications arise with respect to the degree to which pre-exercise ambient noise estimates agree with observations made during CHURCH STROKE III.

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CONTENTS (U)

ILLUSTRATIONS (U)

I. INTRODUCTION (U)

(C) During the summer of 1979 an environmental acoustic measurement exercise known as CHURCH STROKE III was conducted in the eastern Gulf of Mexico. The exercise, sponsored by the Long Range Acoustic Propagation Project, resulted in measurements of transmission loss and ambient noise directionality being obtained at a site located near a bathymetric feature known as the Catoche Tongue (23.62°N, 86.00°W; point E of Fig. 1).

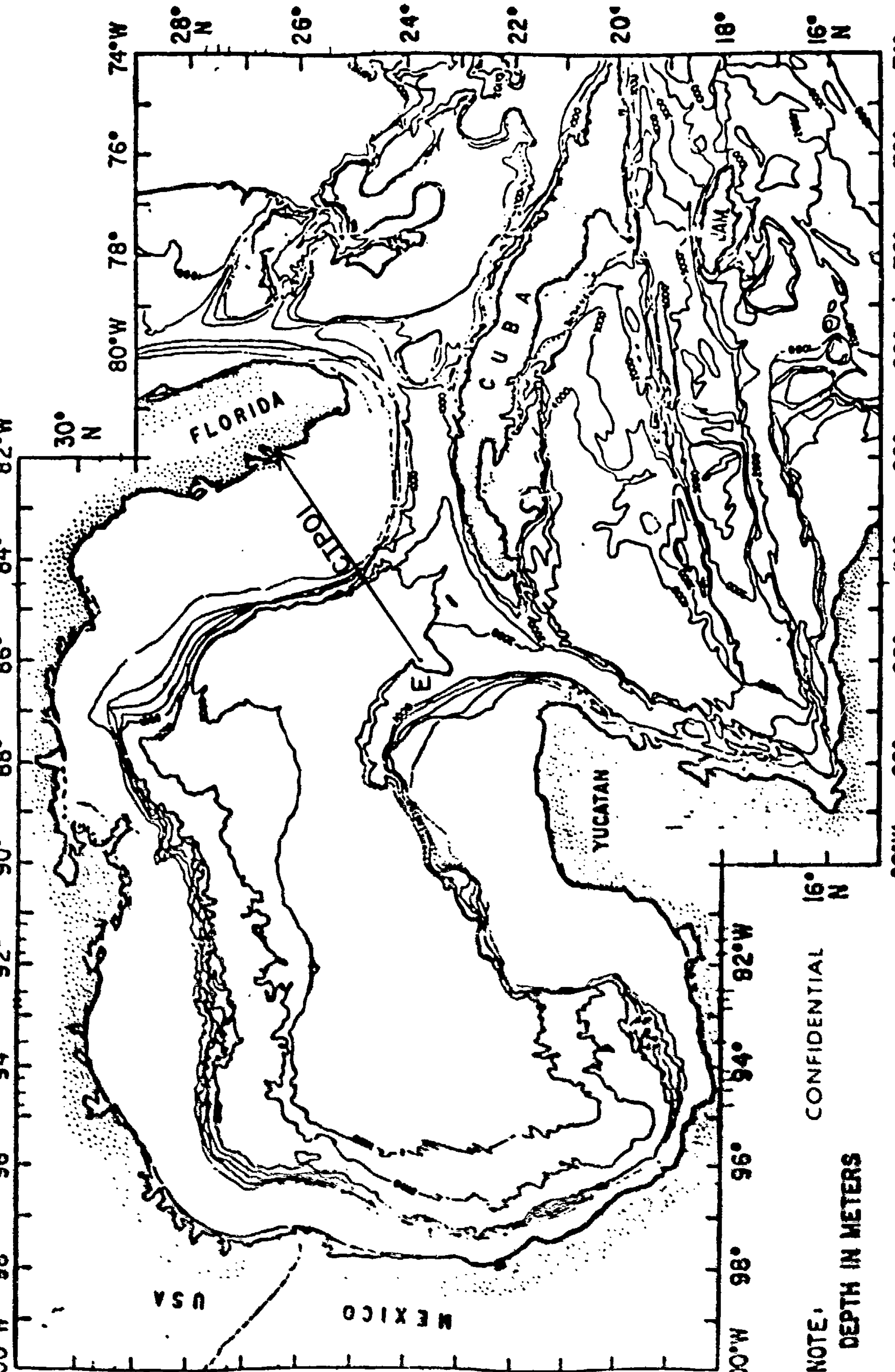
(C) This particular site offered the opportunity to observe two acoustically important effects. The presence of steep slopes and shallow banks in the southeast, southwest, and northwest quadrants offered the potential for significant bathymetric blockage of ship-radiated noise produced by ships located in these sectors. It was hypothesized that the bathymetry would serve to diminish the ambient noise contributions to the side-lobes and ambiguous beams of a mid-water line array located in the Catoche Tongue, with its near-broadside beams steered into the northeast quadrant. Additionally, the presence of a steep basin-slope-shelf transition in the bathymetry at a moderate distance from the array location afforded the opportunity to obtain transmission loss data which could be used to determine the degree to which up-slope enhancement affected the received level of a low-frequency source being towed over a highly range dependent track. The data, together with the supporting environmental observations, were to serve in a test of the ability of numerical models to correctly estimate ambient noise directionality in a complex environment, as well as their ability to handle up-slope enhancement effects on transmission loss.

(U) An extensive modeling effort was undertaken prior to the exercise. Predictions were made of transmission loss, directional noise, and omnidirectional noise for several combinations of source depth, receiver depth, and frequency. The study was centered around the Catoche Tongue site. The track of greatest interest, from a transmission loss point of view, was to the northeast along a bearing of 052° from the array location in the Catoche Tongue. This track has been designated CTP01. The array location and this principal transmission loss track are depicted in Figure 1.

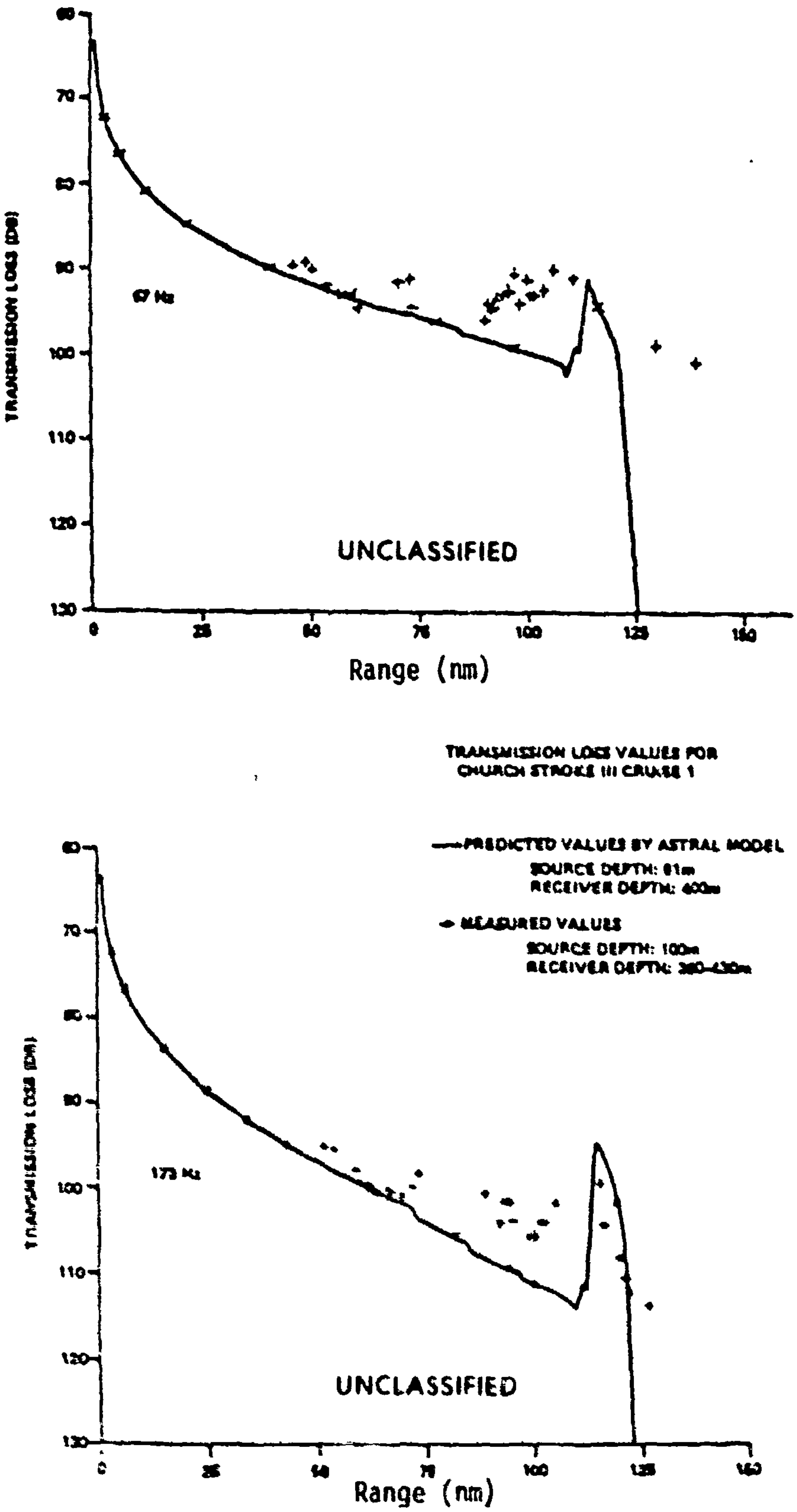
(U) Post-exercise comparisons between model predictions and measurements indicated that the pre-exercise data inputs to the models were probably inaccurate representations of the actual environment. The most probable environmentally related causes of observed discrepancies between model results and measurement results were thought to be the bottom loss estimates and the historical shipping distribution. In order to determine the degree to which the archival environmental data differed from those environmental data observed during the exercise, and to assess the resultant impact on transmission loss (TL) model results, the post-exercise analysis effort described in this report was undertaken. No attempt has been made to reconcile observed shipping with historical shipping distributions.

II. TRANSMISSION LOSS COMPARISONS (PRE-EXERCISE) (U)

(U) The plots of Figure 2 allow comparisons to be made between the measured TL values and the TL estimates derived from archival sound speed profiles, bathymetry, and bottom loss estimates extrapolated from the sparse bottom loss data available in the region. A range dependent transmission loss model (ASTRAL) was exercised to obtain the 30-40 nm range-averaged estimates shown in the plots. While one should not expect detailed agreement for this type of comparison, it



(U) Figure 1. Location of acoustic array and transmission loss track CTP01 during CHURCH STROKE III, cruise 1



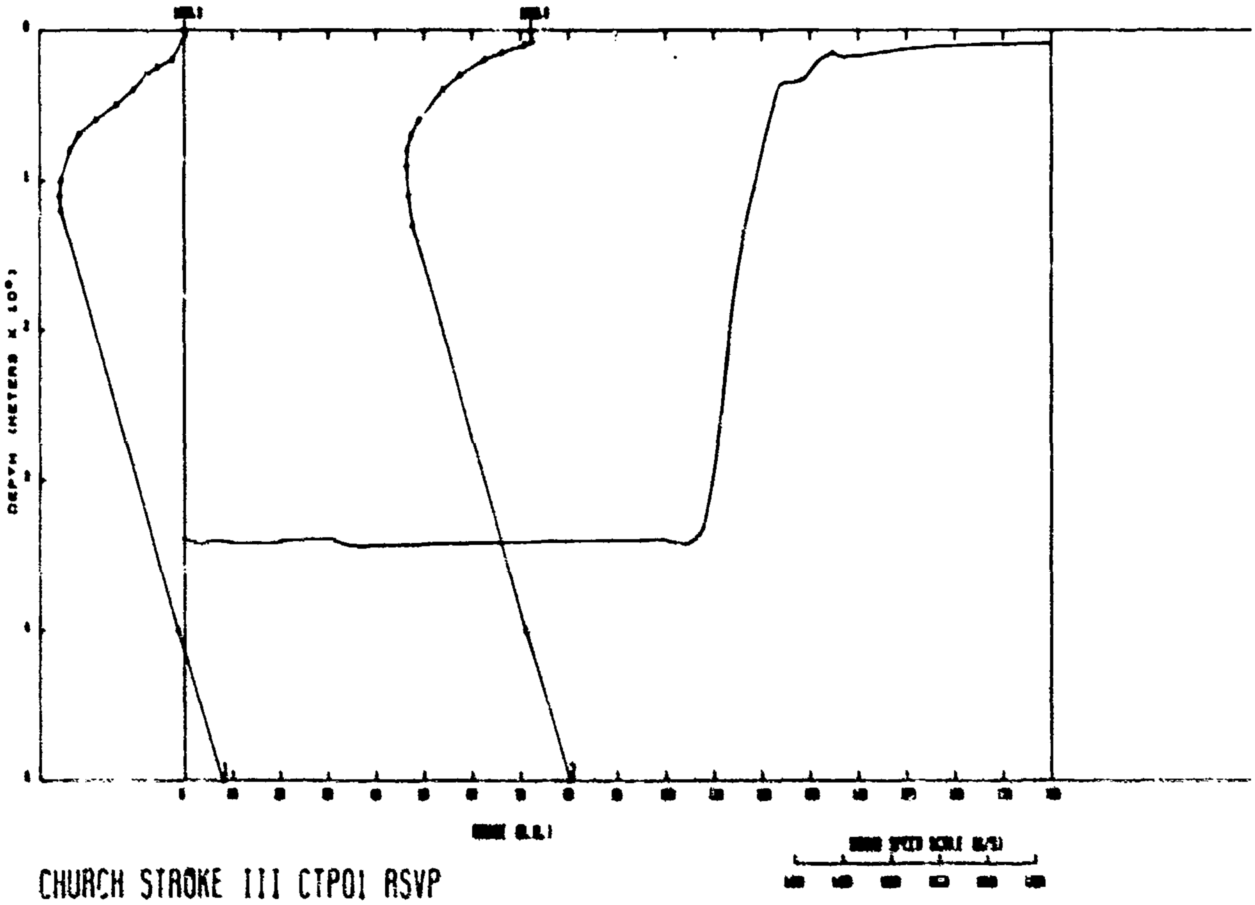
(U) Figure 2. Transmission loss values for CHURCH STROKE III, cruise 1, track CTP01 (from Tracor, 1979) appears that the model has overestimated the average TL and may have failed to accurately predict the onset of bathymetric enhancement.

(U) The degree of disagreement is sufficient to indicate that significant inaccuracies may exist in the environmental input data. Since the track is bottom limited, the bottom loss is an important parameter. An inaccurate representation of the loss due to bottom interaction could account for a substantial portion of the differences between observations and model estimates. Other environmental factors which could account for some of the TL differences include inaccurate representation of the effect of the Gulf of Mexico Loop Current on the sound speed field, and improper location of the basin-slope transition region in the archival bathymetry. These potential effects have been tested with regard to their impact on the estimated TL by comparison with actual environmental data in the cases of the sound speed and bathymetry, and by the use of various bottom loss descriptions derived from geophysical observations in the investigation of bottom interaction effects.

III. SOUND SPEED AND BATHYMETRY COMPARISONS (U)

(U) The archival environmental data used in the pre-exercise model runs are depicted in Figure 3. The bathymetry is essentially flat out to 110 nm and has an average depth of 3394 m. The slope begins at 110 nm and extends to 125 nm where the water depth is 350 m. The shelf extends from the 125 nm point, reaching land at 280 nm. One may observe a representation of the measured bathymetry along CTP01 in Figure 4. The basin floor is seen to be essentially flat with the exception of a small rise at 17 nm. Along the source track, the average depth in the basin is 3298 m, about 100 m less than the archival data indicate. The actual bathymetry indicates a basin-slope break at 111 nm, with the slope extending to 127 nm and reaching a depth of 386 m. These values are very similar to the archival bathymetry values. A visual comparison of the bathymetry depicted in Figures 3 and 4 reveals a difference in the fine detail, with the actual bathymetry showing a few features which do not appear in the archival data. The agreement between the two representations appears to be sufficient to preclude any major impact on the transmission loss estimates, particularly at low frequency.

(C) If one were looking for the effects of the Gulf Loop Current in the sound speed profiles, one would look for a subsurface sound speed maximum between 100 m and 200 m in depth. This manifestation of the salinity maximum is generally found at this depth in waters associated with the Gulf Loop Current (Nowlin and Hubertz, 1972). The archival SVPs displayed in Figure 3 show only a hint of a maximum. The only effect observed is a decreased gradient between 30 m and 200 m in the first profile. In contrast the first three profiles of Figure 4 indicate the presence of a sound speed maximum at 150 m - 160 m forming a weak channel centered about 110 m - 130 m. The fourth and fifth profiles show a weakened effect manifested as a decreased sound speed gradient between 70 m and 120 m. The sixth profile shows little indication of a salinity maximum in the 100 m to 200 m depth range. Another apparent difference between the archival and observed SVP field is the presence of a layer in the archival data. The layer depth increases from 30 m in the first profile to 75 m in the second profile located 72 nm away. The towed source was located at an average depth of 91 m; thus, it is possible that the subsurface maximum could affect the propagation since the source could be located in the resultant upper sound channel. However, it is not felt that the presence or absence of a shallow surface layer is a significant factor in the propagation.



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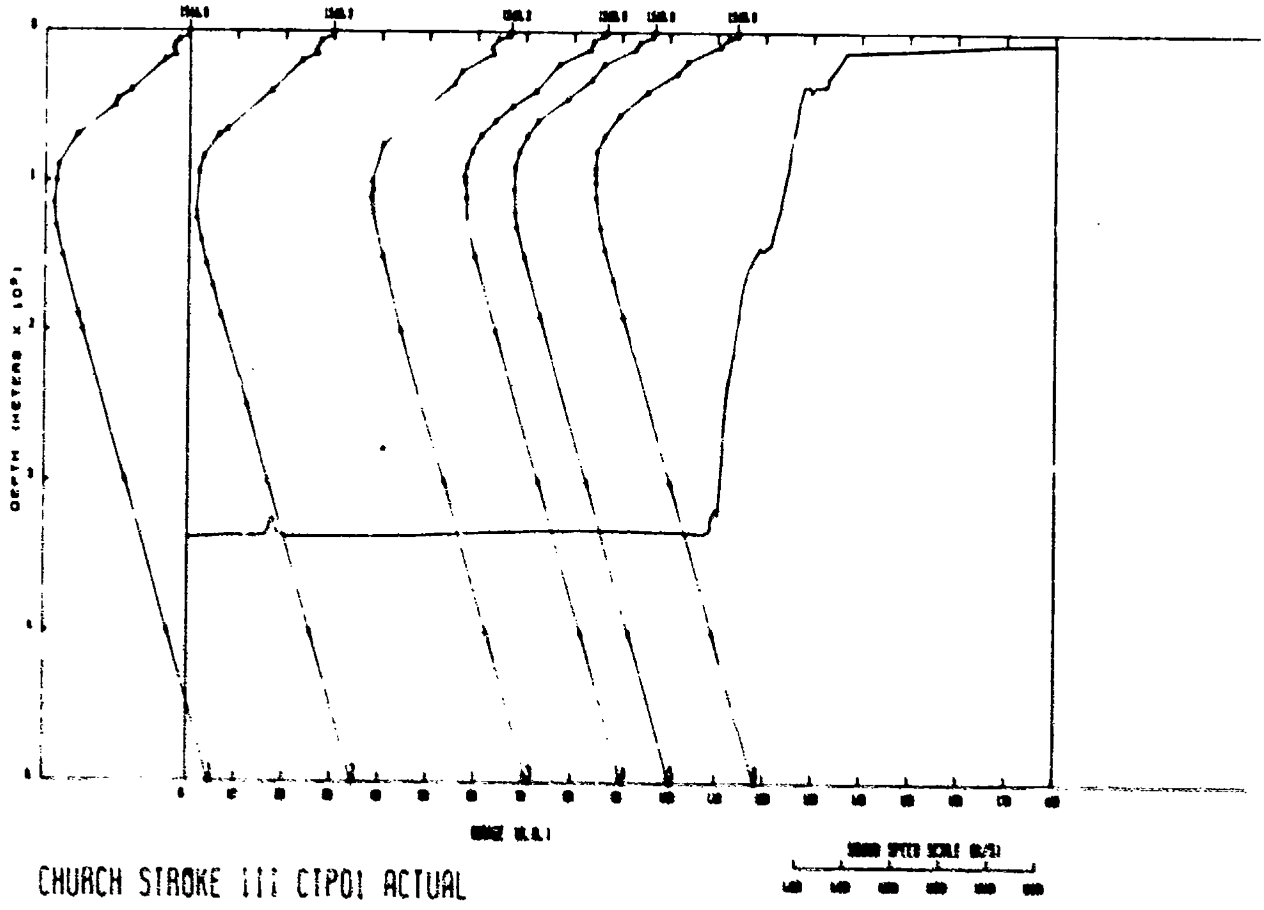
(U) Figure 3. Archival sound speed and bathymetry profiles along track CTP01



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(U) Figure 4. Measured sound speed and bathymetry profiles along track CTP01

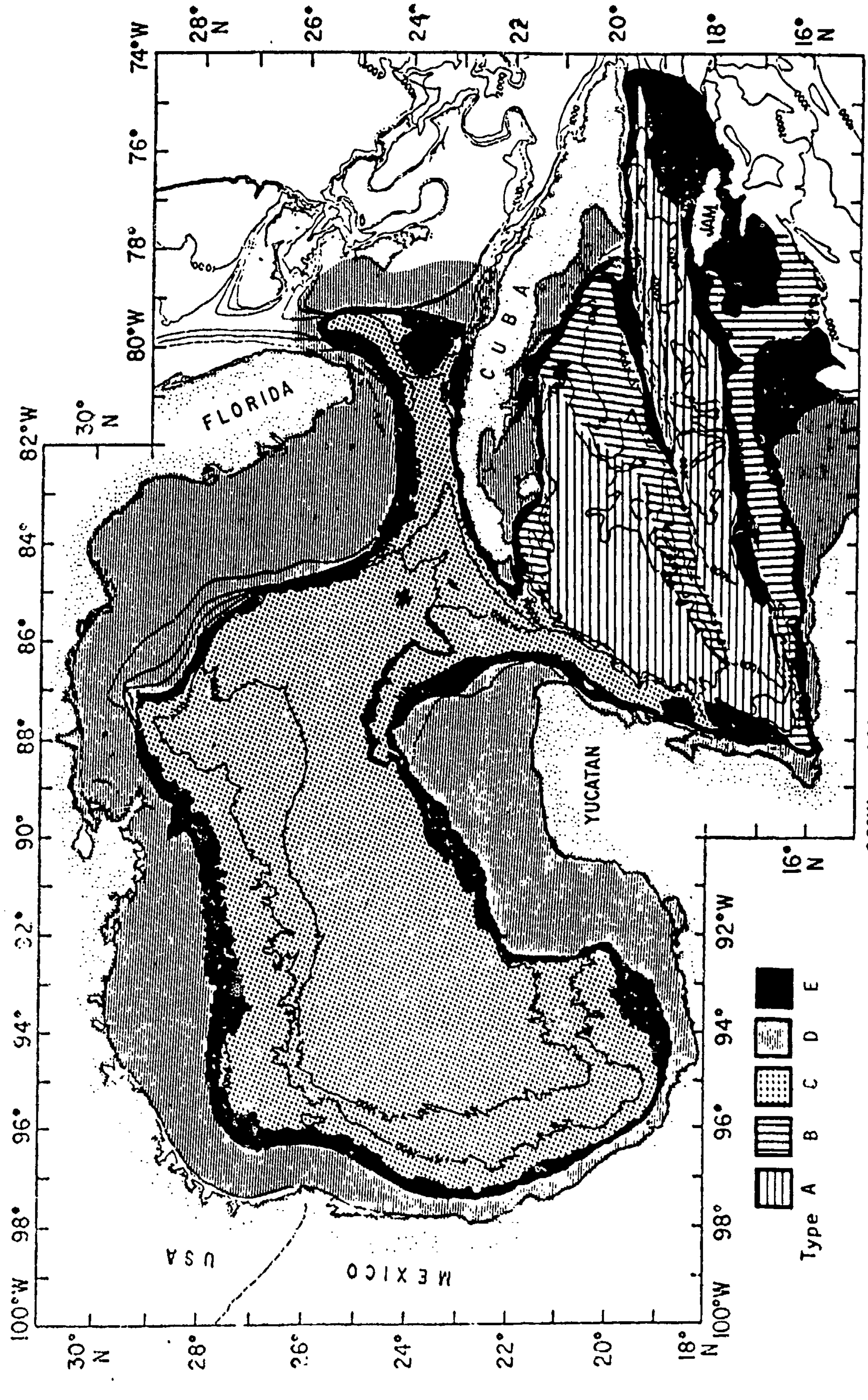
(U) A feature common to both the archival and actual SVP field is the gradual shoaling of the deep sound channel axis from about 1150 m at the beginning of the track to about 950 m at the basin-slope break.

(C) Since the actual SVP field and bathymetry were similar to their archival representations, little effort has been expended to isolate their effects. The only observable effect in the model estimates which may be related to SVP differences is a slight decrease (1-5 dB) in average TL between 67 nm and 87 nm, possibly due to the disappearance of the 150 m subsurface maximum in the actual SVP field at 67 nm. This may be an artifact, since there is little indication in the TL data of such a decrease in TL in this region of the track. Other than this region, the model results from ASTRAL using a single archival profile and a flat bottom (referred to as the 1-D case) compare very well with the ASTRAL results using the full measured environment, as displayed in Figure 4 (referred to as the 2-D case) out to the basin-slope bathymetry break. This effect indicates that the differences in basin bathymetry and SVPs are minimal for average TL calculations. More detailed calculations using a normal mode model (SNAP), which is capable of utilizing range dependent environmental inputs, indicate that SVP differences affect the detailed structure, but have little effect upon the average TL levels. This conclusion is borne out by comparisons made between 1-D SNAP results, 2-D SNAP results and TL observations along the basin portion of the source track.

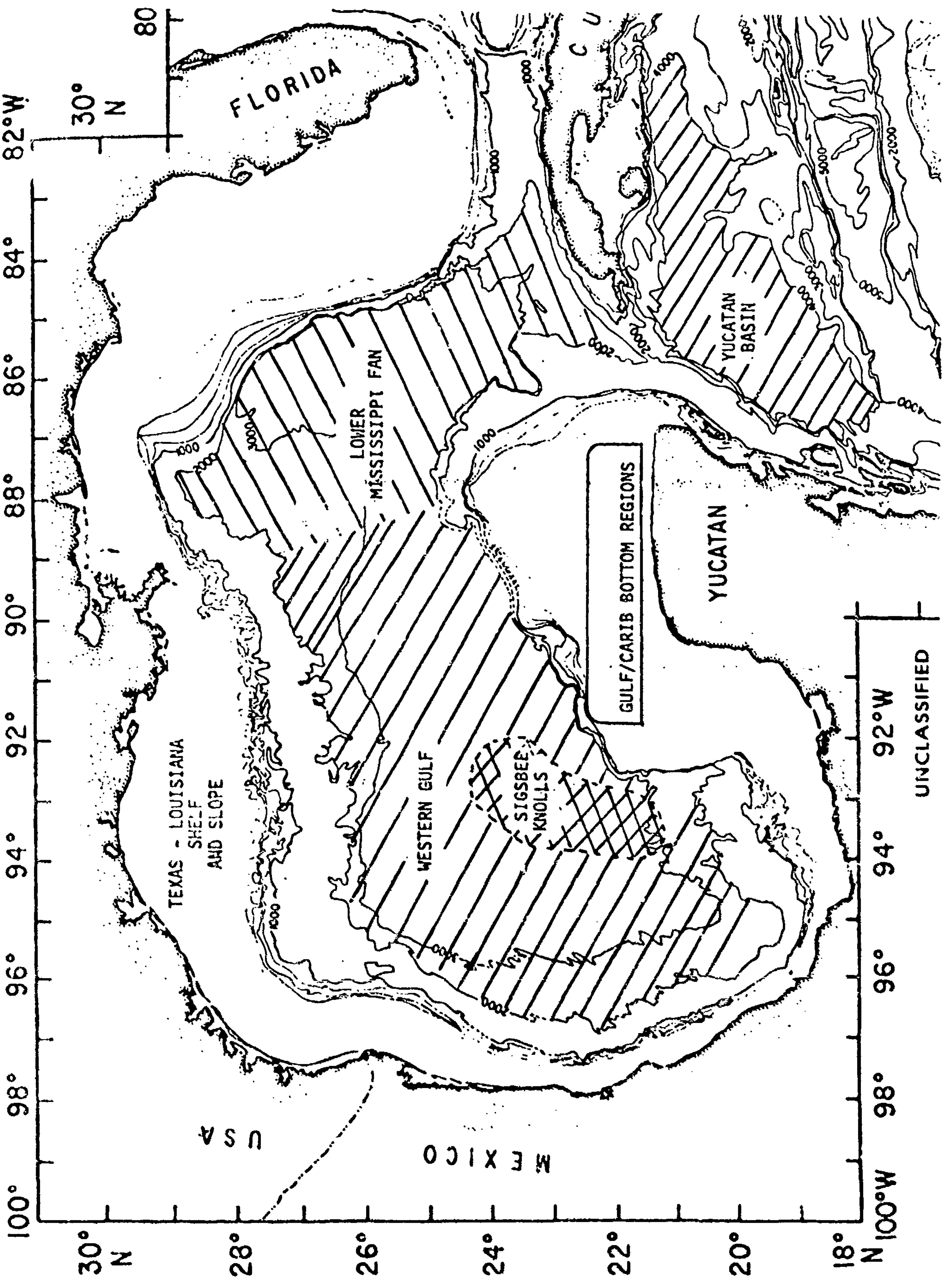
IV. BOTTOM LOSS COMPARISONS (U)

(C) As a result of the environmental comparisons discussed in the previous sections, the major portion of the effort to isolate significant environmental factors was concentrated on the bottom loss description. It was known before the exercise that an adequate bottom description was not available. In an attempt to improve the state of understanding of the bottom loss in the exercise area, a pair of independent studies were undertaken. The first study, conducted by Science Applications, Inc. (SAI), concentrated on assessing the availability and quality of measurements of bottom loss in the Gulf of Mexico. Only two sites (indicated by asterisks in Fig. 5) were found to be suitable sources of directly measured bottom loss data. One was located near the Catoche Tongue and the other was located south of Cuba. Clearly this data was considered insufficient to characterize the bottom-loss characteristics of the Gulf. Using geological and geophysical data derived from Naval Air Development Center bottom-loss stations, an attempt was made to supplement the sparse measurements with bottom loss estimates derived from geoacoustic models of the seafloor. Based on these analyses, the bottom-loss in the deep areas of the Gulf of Mexico and Caribbean Sea were characterized by three sets of curves, and additional sets were defined for the slope and shelf regions. Figure 5 indicates the geographic distribution of the five bottom types (A through E). These bottom types were used in the pre-exercise modeling efforts. A second study, conducted by the Applied Research Laboratory (ARL), University of Texas, concentrated on the basin regions of the Gulf/Caribbean area. This study was wholly based upon geological and geophysical data available from surveys in the Gulf/Caribbean area. Geoacoustic descriptions of the seafloor were constructed for each of four regions as displayed in Figure 6. These geoacoustic descriptions, consisting of sound speed profiles, density, and attenuation profiles, could be used directly by certain TL models, including SNAP. Their use by certain other TL models, such as ASTRAL, required the production of bottom-loss curves prior to application. Both types of bottom description were provided.

(U) The choice of the SAI description for pre-exercise modeling was based upon the availability of bottom-loss curves for slope and shelf regions, in addition to



(U) Figure 5. Geographic assignment of bottom types by SAI (from Underwater Systems, 1979)



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(U) Figure 6. Geographic assignment of bottom regions by ARL (from Underwater Systems, 1979) the basin descriptions. This element was essential, particularly in the production of TL inputs to ambient noise models, since large numbers of noise sources are located in these shelf and slope regions.

(U) Of primary interest to this study are those bottom types which would be encountered along the source track CTP01. The SAI descriptions show the basin segment to be a type C, the slope segment to be a type E, and the shelf segment to be a type D. The ARL description, having no slope or shelf descriptions, indicates that the track falls within the Lower Mississippi Fan (LMF) region. Figures 7, 8, and 9 show the SAI bottom-loss curves, while Figure 10 is a graphical representation of the ARL geoacoustic model for the LMF region. The figure includes two possible acoustic attenuation profiles. They are labeled as L (low loss) and M (medium loss). These profiles were derived from data taken during the BEARING STAKE exercise in an area of similar geological structure (Mitchell et al., 1978).

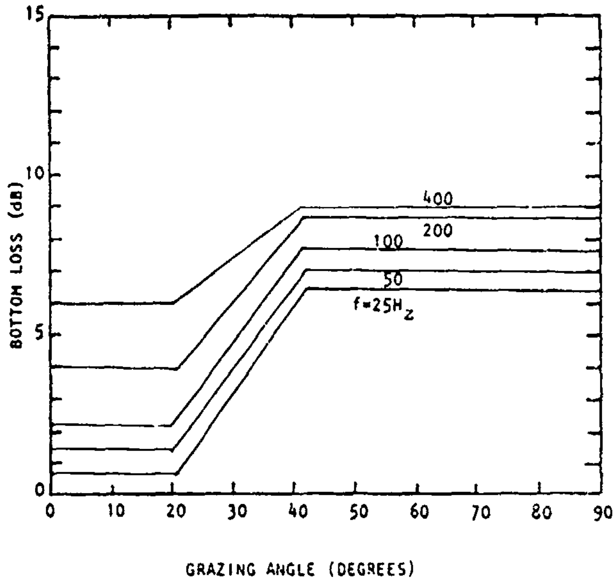
V. TRANSMISSION LOSS COMPARISONS (POST-EXERCISE) (U)

A. One-Dimensional Model Comparisons (U)

(U) The initial test of bottom loss effects on TL were conducted using ASTRAL with the 1-D environment and bottom loss curves derived from both the low and medium loss ARL geoacoustic models. The resultant curves were graphically compared with pre-exercise ASTRAL runs made with 2-D archival environmental inputs using the SAI bottom, and TL data collected during the exercise. The bottom-loss curves used in the basin segment of CTP01 are shown as Figure 11. The principal differences are to be found in the low angle (20^{o}) loss. Both ARL curves are significantly lower. The medium loss ARL curve reaches the level of the SAI curve at 40^{o}, while the low loss curve remains below 4 dB per bounce out to 55^{o}. This low curve most nearly approximates the actual basin bottom conditions, as may be observed from the TL comparison plots of Figure 12. One may observe the gradual divergence of the ASTRAL curves as bottom interactions accumulate. The low angle differences between the ARL and SAI curves lead to a difference between 2.5 and 6.0 dB at a range of 100 nm. The effect of this difference on the ambient noise predictions could be significant for nearby noise sources. Any comparisons beyond 110 nm are invalid due to the presence of the basin-slope break at that range.

(U) Further evidence that the ARL low loss geoacoustic model is the most representative is apparent from Figures 13 and 14, which show comparisons of TL predictions and data over two 40 nm range intervals of CTP 01. One may see the degree of agreement between the TL data and 1-D SNAP model predictions. The absence of any range dependence in the SVPs and bathymetry indicates that a proper representation of the bottom is sufficient to resolve most of the discrepancies between the observed TL and the pre-exercise model estimates. The agreement observable in Figure 13 indicates that the presence of the Loop Current over this range interval, as indicated by the actual SVP field of Figure 4, may not have much effect on the TL for the source depth, receiver depth, and frequency configuration of this exercise. The average level is matched quite well, and one may say that the structure is reasonably well-reproduced. The agreement in structure may be fortuitous and any final conclusions on this matter are better left to more detailed analysis. The comparison plots of Figure 14 continue to show good agreement between the 1-D SNAP estimates and the observed TL data. The two diverge beyond 110 nm, but that is to be expected in light of the onset of the slope at this range.

(U) The curves and data plotted in Figure 15 allow one to make a direct visual comparison between the 1-D model estimates of ASTRAL and SNAP using the ARL low loss bottom, the pre-exercise 2-D model estimates using archival environmental data and the SAI range dependent bottom description, and the observed TL data. The



(U) Figure 7. Bottom loss curves for SAI bottom type C (from Underwater Systems, 1979)

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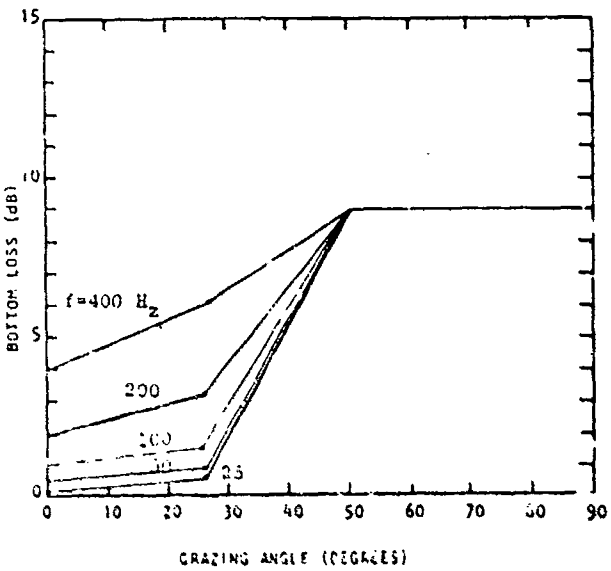

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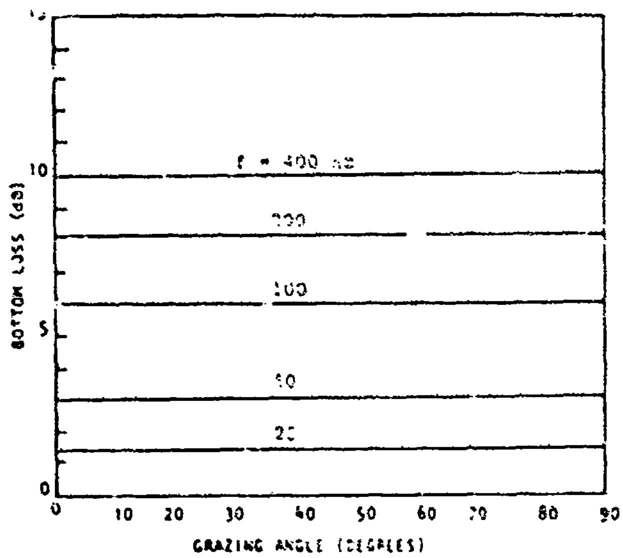
(U) Figure 8. Bottom loss curves for SAI bottom type D (from Underwater Systems, 1979)

(U) Figure 9. Bottom loss curves for SAI bottom type E (from Underwater Systems, 1979)



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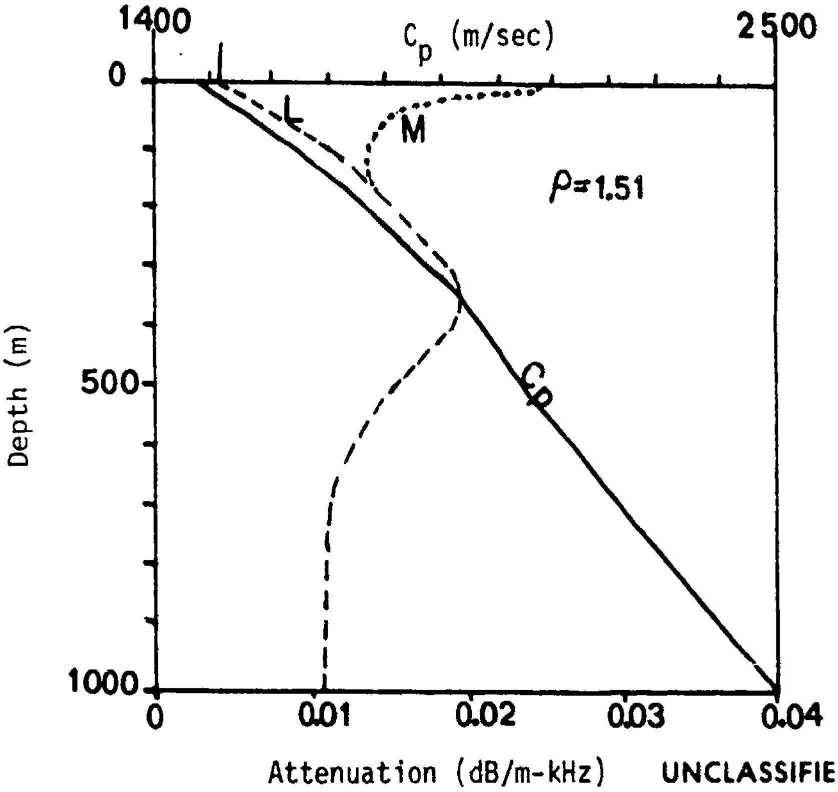

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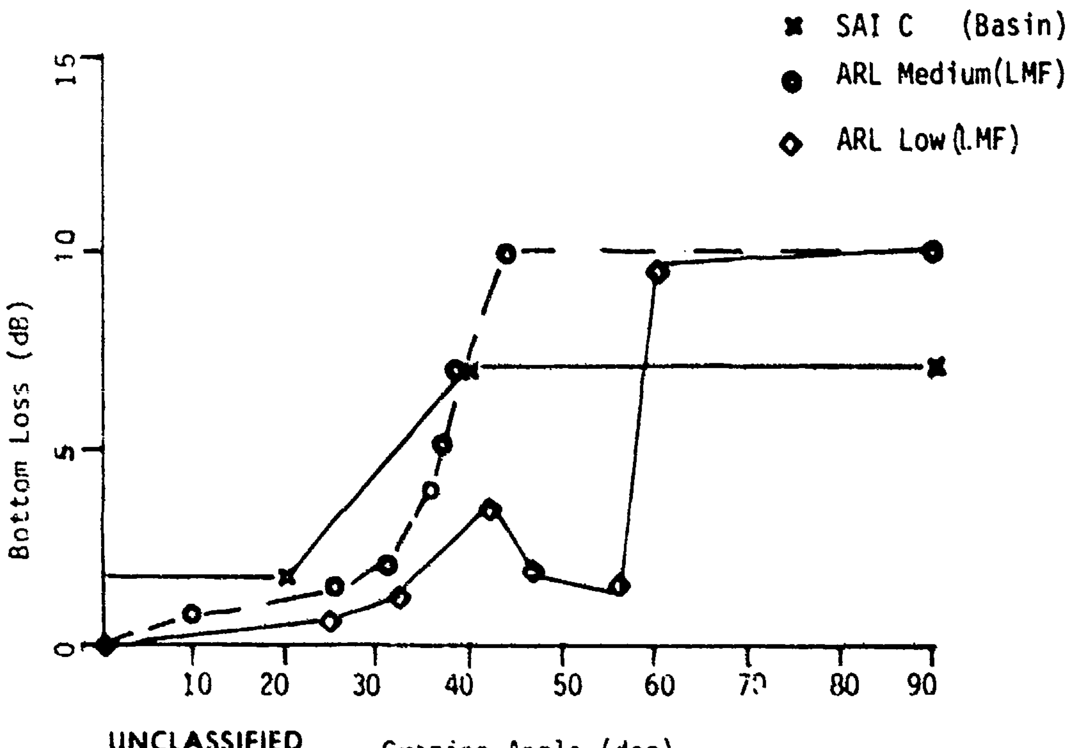
(U) Figure 10. ARL geoacoustic bottom paramters for Lower Mississippi Fan Region (from Underwater Systems, 1979)



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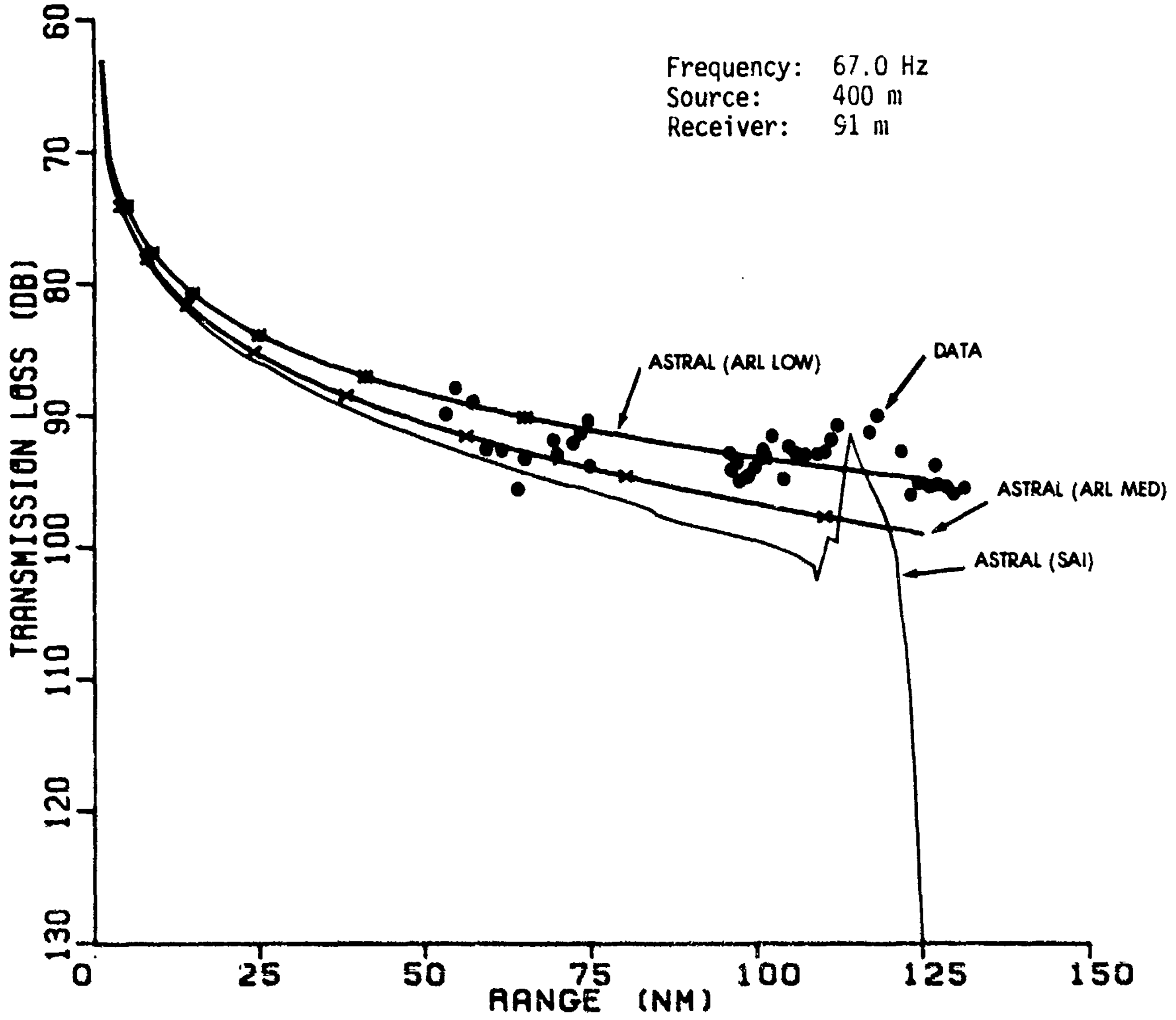
(U) Figure 11. Comparison of SAI type C and ARL Lower Mississippi Fan Region bottom loss curves for 67 Hz



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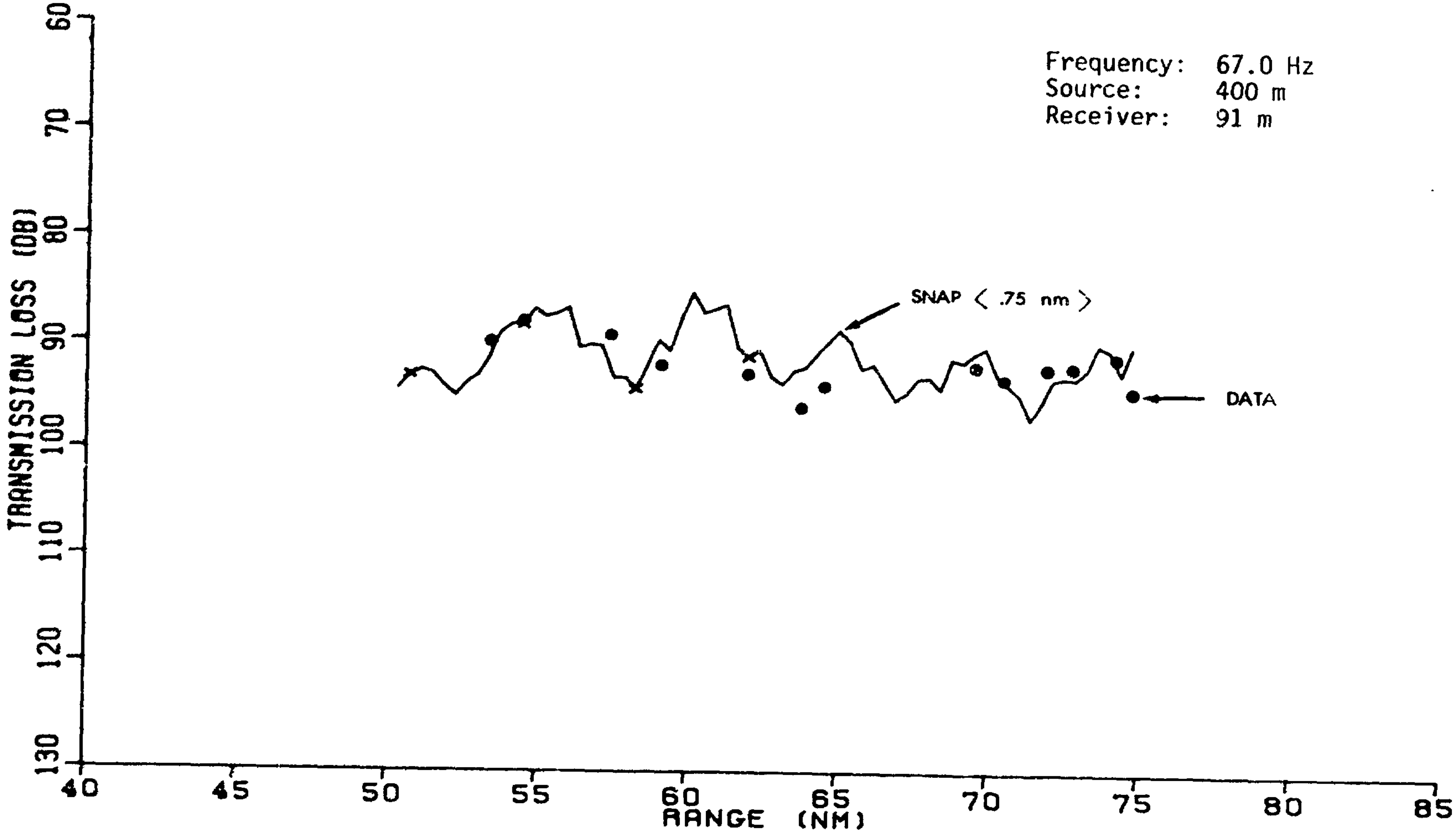
(U) Figure 12. Comparison of ASTRAL transmission loss model predictions using SAI bottom types C, D, E; ARL LMF region low and medium attenuation; and CHURCH STROKE III measurements



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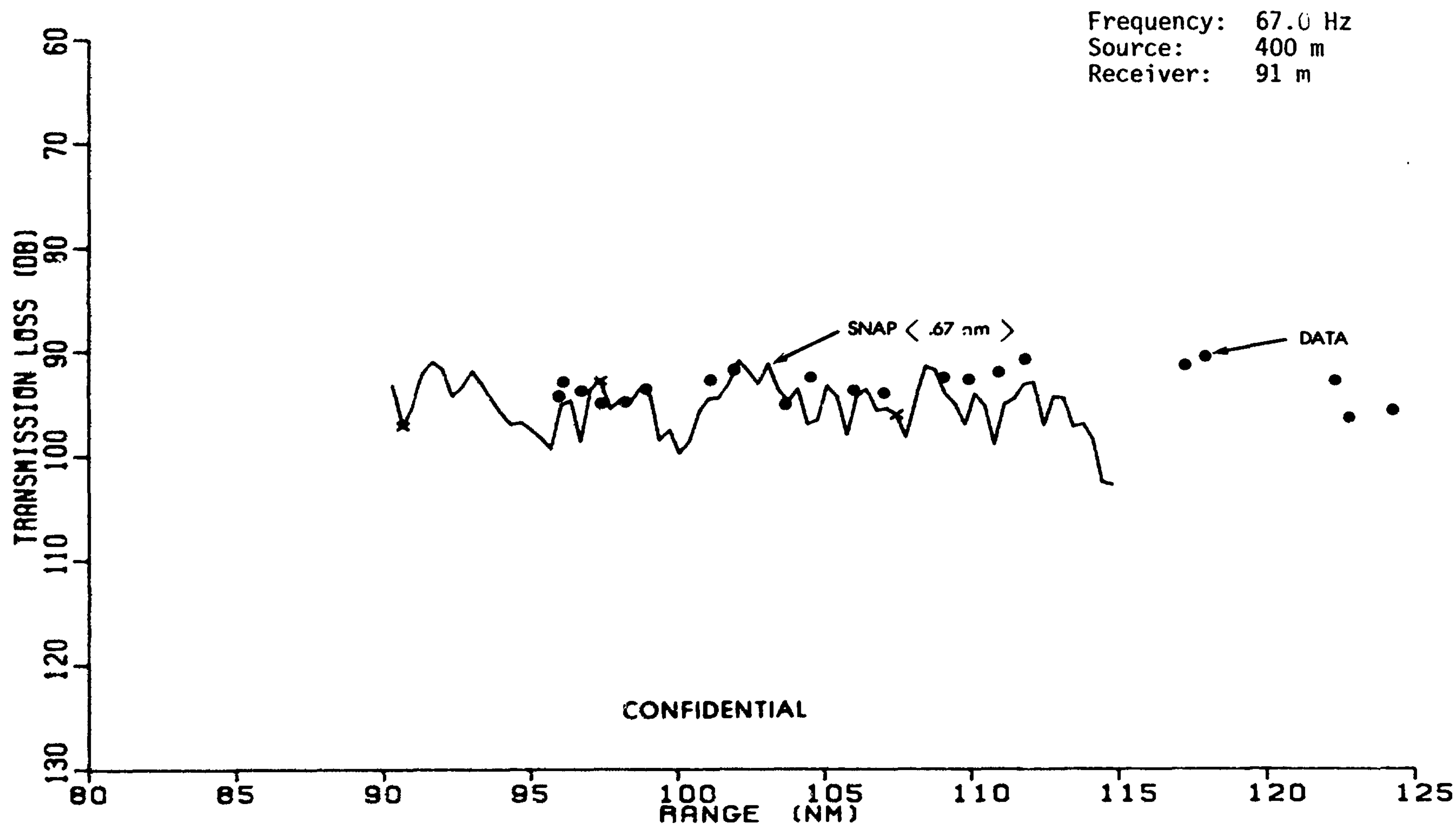
(U) Figure 13. Comparison of 1-D SNAP transmission loss estimates using ARL LMF region low attenuation bottom and CHURCH STROKE III measurements, 40-85 nm



(U) Figure 14. Comparison of SNAP 1-D transmission loss estimates using ARL LMF region low attenation bottom and CHURCH STROKE III measurements, 80-125 nm data and the SAI range dependent bottom description, and the observed TL data. The good agreement among the 1-D ASTRAL, 1-D SNAP, and observed TL data is apparent as long as the 1-D assumption is valid. Yet to be resolved is the apparent discrepancy between the data and model results beyond 110 nm.

B. Two-Dimensional Model Comparisons (U)

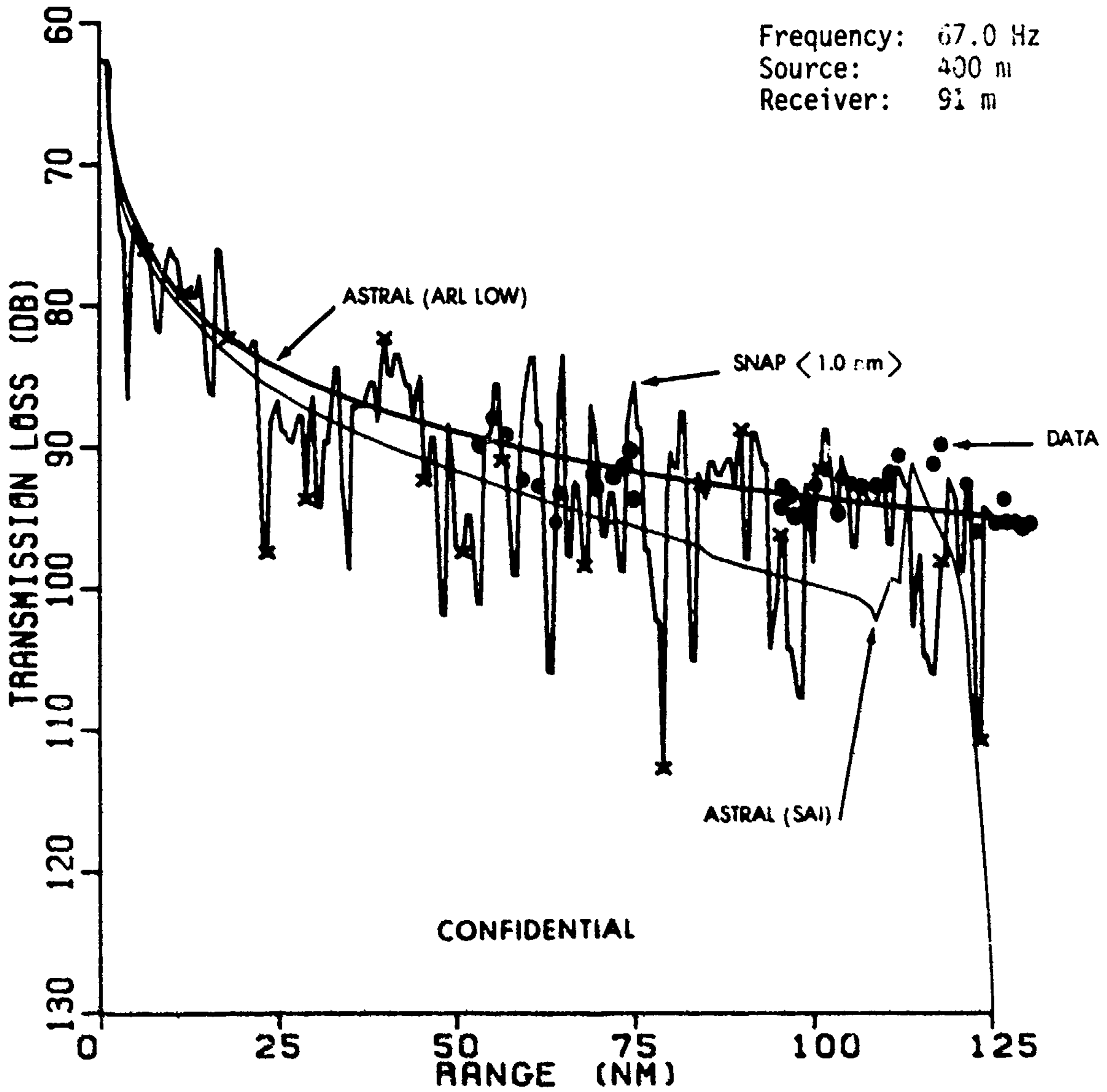
(U) Once it was determined, through 1-D model comparisons, that the ARL low loss bottom description was adequate to resolve the apparent discrepancies between the pre-exercise model estimates and observed data for the basin, several model runs were made using all available environmental data, including SVPs and bathymetry along the source track. These actual environmental data were combined with the ARL low loss bottom description to provide the inputs for ASTRAL and SNAP.

(U) Due to input difficulties when handling rapidly varying environments such as steep slopes, SNAP was exercised only in the basin. The range dependent SVP string, along with the ARL geoacoustic bottom description, was input to SNAP in an attempt to assess the impact of the Gulf Loop Current on the TL estimates. Figures 16 and 17 show comparison plots of the 2-D SNAP estimates and the observed TL data. As with the 1-D SNAP results, the agreement is good. The detailed fluctuations do not show exceptional agreement, especially between 105 nm and 110 nm on Figure 17. The cause of this increase in TL in the model estimates cannot be related to any particular feature in the environment.

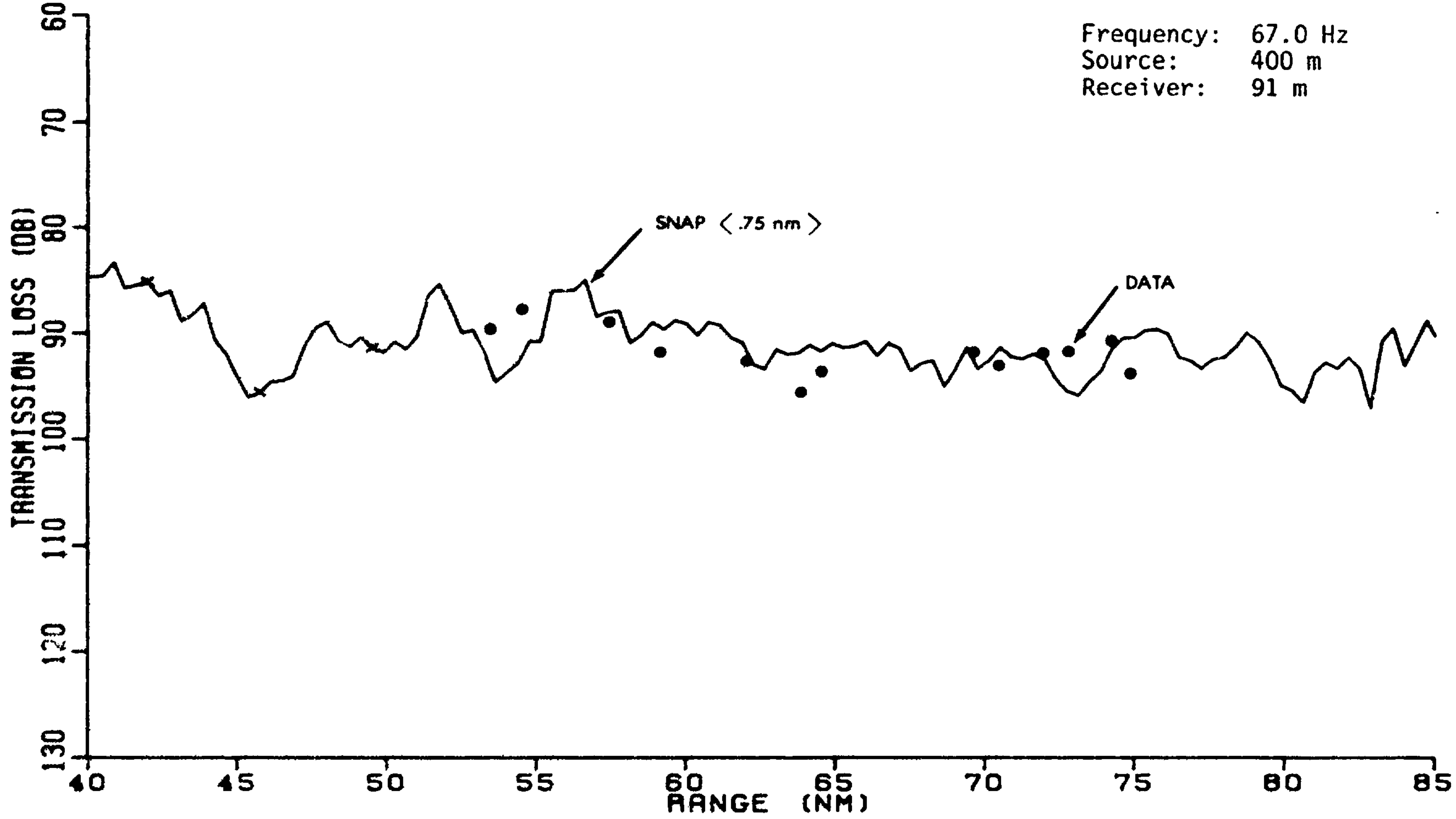
(U) Figure 18 is a composite comparison plot of the 2-D SNAP, 2-D ASTRAL, and observed TL data. The inter-model comparison shows good agreement between the SNAP and ASTRAL estimates for the basin segment (0-110 nm). An interesting feature is the small increase in the ASTRAL TL at 108 nm. This may be similar to the TL increase exhibited by SNAP at 107 nm, but is diminished and offset by the ASTRAL interval averaging. ASTRAL appears to pick up the onset of slope enhancement quite well and reproduces the rate and degree of the TL decrease as the source encounters the slope. The rapidly increasing TL beyond 127 nm is not consistent with the TL data. However, other 2-D model runs, including the Parabolic Equation model, exhibit the same rapid increase at the same range; thus, the disagreement does not appear to be unique to the ASTRAL model. Examination of the TL data reveals that the values beyond 127 nm were obtained under low signal-to-noise conditions, leading to a degree of suspicion regarding their validity.

VI. CONCLUSIONS (U)

(U) The objective of this limited examination of apparent disagreements between pre-exercist TL model estimates and observed transmission loss data was to determine the degree to which the archival environmental data differed from those environmental data observed during the measurement exercise and to assess the resultant impact on the TL model estimates. That objective has been met. The archival bathymetry has been shown to be little different from the bathymetry measured along the source track. While the historical SVP field does not indicate the strong presence of the Gulf Loop Current in contrast to the measured SVP field, the effects of this environmental difference have been shown to be somewhat insignificant for the source depth, receiver depth, and frequency configuration used in the measurements. The key factor has been shown to be the bottom description. While no direct measurements of bottom-loss were made, geoacoustic models of the seafloor were available for use in resolving discrepancies between model estimates of TL and experimental ovservations. Sensitivity studies conducted during this study led to the selection of a particular geoacoustic model consisting of a sound speed profile for the sediment, a sediment density, and an estimate of attenuation based upon previous experimental observations in a region with a similar geological



(U) Figure 15. Comparison of transmission loss estimates using ARL LMF region low attenuation bottom in 1-D SNAP and ASTRAL model runs; SAI types C, D, and E bottom in archival 2-D ASTRAL model runs; and CHURCH STROKE III measurements



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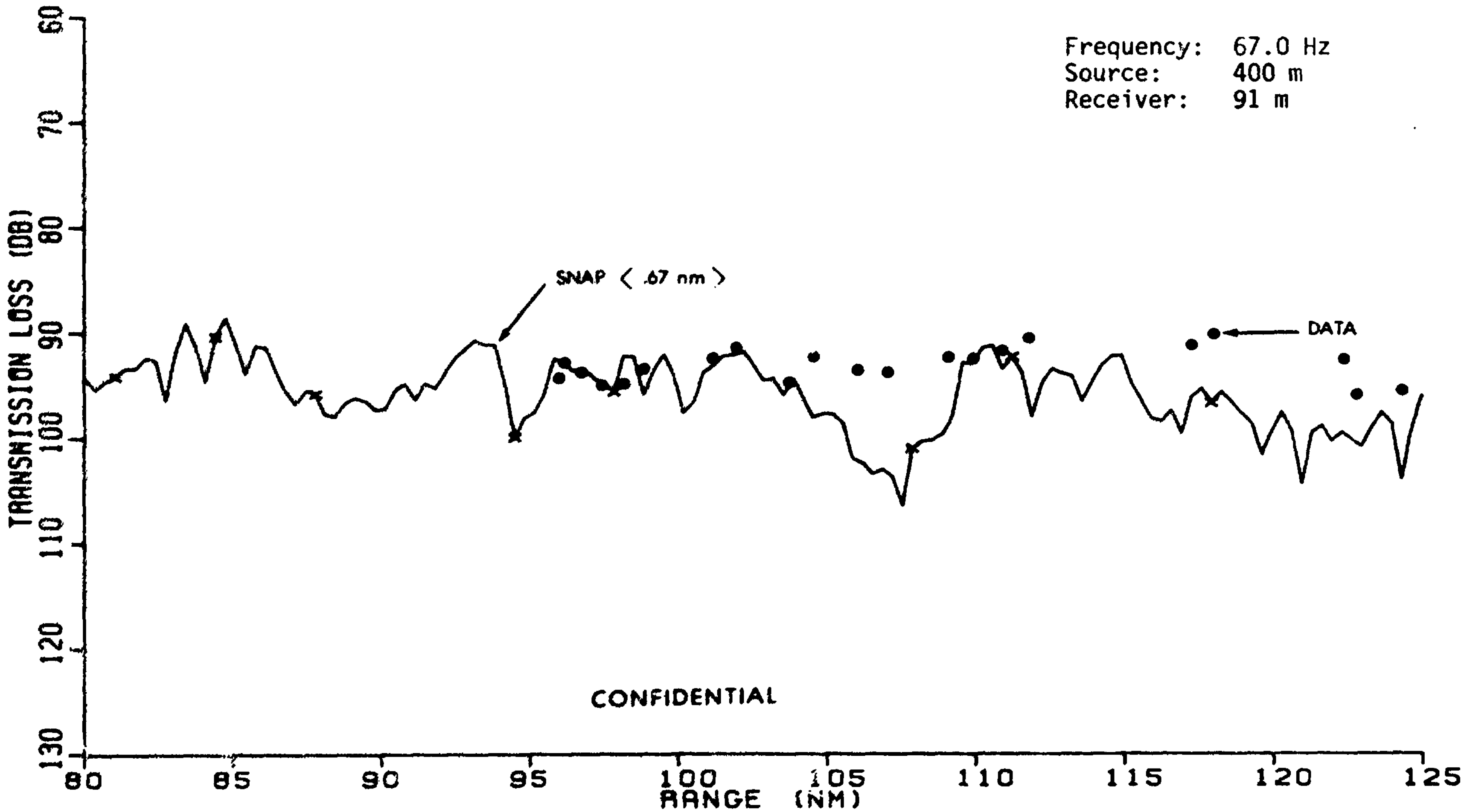
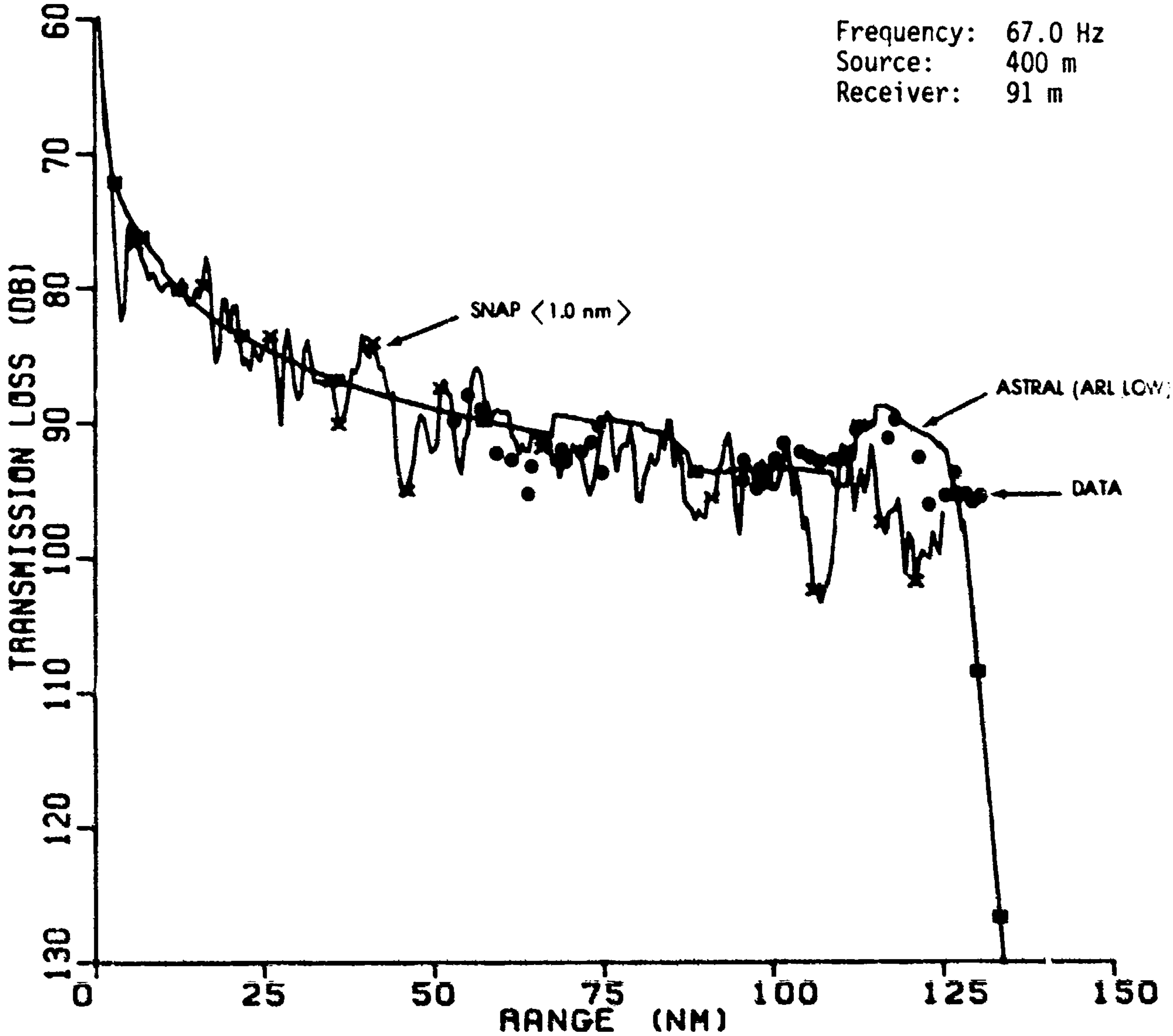
(U) Figure 16. Comparison of SNAP 2-D transmission loss estimates using measured sound speed and bathymetry, and ARL LMF region low attenuation bottom; and CHURCH STROKE III measurements, 40-85 nm



(U) Figure 17. Comparison of SNAP 2-D transmission loss estimates using measured sound speed and bathymetry, and ARL LMF region low attenuation bottom; and CHURCH STROKE III measurements, 80-125 nm



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(U) Figure 18. Comparison of transmission loss estimates using ARL LMF region low attenuation bottom, measured sound speed and bathymetry in 2-D SNAP and ASTRAL model runs; and CHURCH STROKE III measurements history. The use of this geoacoustic model and its bottom-loss derivative in TL model estimates led to good agreement between the observed levels and the model estimates. There was some indication of agreement with regard to the more detailed structures of the observations and model estimates for track segments in the basin, but additional investigations must be pursued to resolve certain significant structure differences observed for other track segments, including portions over the slope and shelf. ASTRAL was shown to reproduce the average TL, the onset of slope enhancement, and the degree of slope enhancement fairly well, but disagreement remains between ASTRAL estimates and observations at the extreme range of the source track. The observations indicate sustained propagation beyond 127 nm, while ASTRAL indicates a rapidly increasing TL beyond this range, a result consistent with a PE model result for the same environment. However, low signal-to-noise ratios in the TL data at this extreme range cause the validity of these data to be suspect.

VII. RECOMMENDATIONS (U)

(C) While there is now a degree of confidence in the bottom-loss description for the basin regions, some questions still remain as to the reflectivity of the slope and shelf regions. Additional investigations of bottom properties in these areas might shed some light on the validity of the SAI bottom descriptions. A model study to assess the sensitivity of TL to slope and shelf reflectivity should be conducted. Once confidence is gained in the ability to properly estimate TL for this region, investigations should proceed to resolve differences between predicted and observed ambient noise levels and directionality. This will entail examination of the actual versus archival ship counts and some investigation of the validity of assumptions made during the aerial shipping surveys. The conditions and assumptions under which the ambient noise directionality was determined should be examined with respect to the probability that similar conditions can be simulated during ambient noise model calculations. In particular, the averaging intervals, the array configuration, the degree of array tilt, and the noise deconvolution method should be examined. Once confidence is gained in the quality of model input data and experimental observations, appropriate ambient noise model runs should then proceed. The results of these model runs should then be compared with experimental observations with an interest in identifying remaining discrepancies and, if possible, pointing out remaining data and model deficiencies.

(U) The final result of any further post-analysis should be an identification of key data base and model deficiencies and a set of recommendations for collecting the appropriate data or upgrading and modifying the current modeling capability.

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Johns Hopkins Road
Laurel, MD 20810
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W. L. May — 1
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Palisades Geophysical Inst., Inc.
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P. O. Box 396
Blauvelt, NY 10913 — 1

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Applied Research Laboratories
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Austin, TX 78712
Attn: G. E. Ellis — 1
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Attn: E. E. Hays 2

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1 Whippany Road
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Rockville, MD 20852
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San Diego, CA 92110 1

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ocean Acoustics; Transmission Loss; Acoustic Models; Environmental Effects; Geoacoustic Models; Low Frequency; Model Sensitivity

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

(U) Acoustic transmission loss data were acquired during Cruise 1 of the CHURCH STROKE III Exercise of July 1979. Initial comparisons of observed transmission loss data, with pre-exercise model predictions made using the ASTRAL model with historical environmental data inputs indicated a considerable degree of disagreement. A series of post-exercise model runs were undertaken to isolate the enviornmental factors contributing to the observed disagreement. Model runs using a range-dependent normal mode model (SNAP)

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DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
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SUITE 1425
ARLINGTON VA 22203-1995

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