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A comparison of passive propagation loss predictions as generated by the Tactical Environmental Support System (TESS v.2.2A) and ASW Tactical Decision Aid (ASWTDA v.2.1.2.1).

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A COMPARISON OF PROPAGATION LOSS OUTPUT
FROM THE TACTICAL ENVIRONMENTAL SUPPORT
SYSTEM (TESS v. 2.2A) AND
ASW TACTICAL DECISION AID (v. 2.1.2.1)
by

William M. Sawrey
March, 1993

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Second Reader: David A. Schrady

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The United States Navy uses a number of different systems to predict underwater acoustic transmission loss for operational forces. Historically, these systems have used different acoustic models and supporting databases, resulting in significantly different predictions. Major efforts to bring all acoustic models and databases under configuration control in the Oceanographic and Atmospheric Master Library (OAML) have reduced, but not eliminated, differences in acoustic predictions.

Comparisons of 1600 transmission loss runs from the AntiSubmarine Warfare Tactical Decision Aid (ASWTDA) and the Tactical Environmental Support System (TESS) were made in the Mediterranean and Sea of Japan for the months of January and July. All inputs to the acoustic models were provided by the respective system databases. Significant differences between ASWTDA and TESS in the areas investigated are evident in regions of complex bathymetry, and these differences become more acute with higher frequency.

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ABSTRACT

The United States Navy uses a number of different systems to predict underwater acoustic transmission loss for operational forces. Historically, these systems have used different acoustic models and supporting databases, resulting in significantly different predictions. Major efforts to bring all acoustic models and databases under configuration control in the Oceanographic and Atmospheric Master Library (OAML) have reduced, but not eliminated, differences in acoustic predictions.

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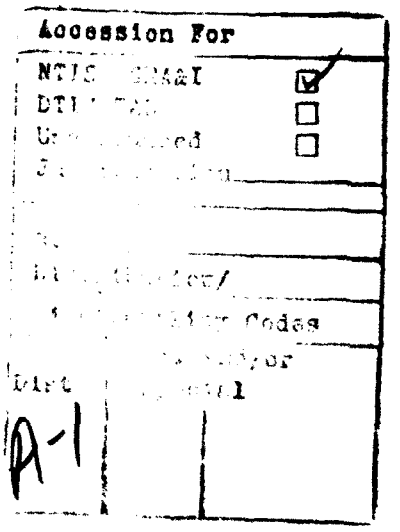

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I. INTRODUCTION

A. COMPARISON OF MODELS

Differences in Acoustic Performance Prediction (APP) systems have been noted and investigated in studies conducted over the years. In 1974, Fitzgerald reported on the Integrated Carrier Anti-Submarine Warfare Prediction System (ICAPS) with respect to the only other passive APP of the time, Fleet Numerical Weather Central's (FNWC) Acoustic Prediction System [Ref. 1]. He concluded that the ICAPS databases were not as accurate as those used by FNWC.

Writing under contract for Naval Ocean Research and Development Activity in 1980, Locklin and Scaife noted that differences in sound speed profiles derived by the Sonar In-situ Mode Assessment System (SIMAS) and ICAPS were due in part to differences in the respective APP historical water mass data. Among the conclusions cited from the contract study were that provision for a "uniformly high quality environmental data base and the usage of uniformly high quality procedures" were important considerations for any APP. [Ref. 2]

More recently, in 1992 Bird investigated the cause of prediction discrepancies noted in the latest version of SIMAS, and found same to be the result of rounding error and modeling shortfalls [Ref. 3].

B. PURPOSE OF THE THESIS

The Navy standard Tactical Environmental Support System (TESS version 2.2A) hosted on the HP-9000 series desktop computer, and a new developmental ASW Tactical Decision Aid (ASWTDA version 2.1.2.1) hosted on various SUN workstations, both implement OAML standard passive propagation loss models and some common databases, to produce passive propagation loss predictions.

Table I lists the versions of the models and databases as used by ASWTDA and TESS [Refs. 4,5].

TABLE I - DATABASE AND MODEL VERSIONS

Database or Model	TESS (v.2.2A)	ASWTDA (v.2.1.2.1)
LFBL	2.0	2.0
HFBL	2.0	2.0
DBDBC	1.0	1.0
GDEM	3.0	3.0
GEM		1.03 Note 1.
SHIP NOISE	3.0	4.0
HWS	3.0	3.0
SEDIMENT	2.0	3.0
PASSIVE RAYMODE	6.0	8.05
PE	3.0	3.0
CZ ASTRAL	2.4	2.4

Note 1 - the Generalized Environmental Model (GEM), a reduction of several of the datasets presented in the table, is employed by ASWTDA only.

In the mid-1980's, it was apparent that ASWTDA (then running on the standard desktop computer, the HP-9000) was too slow as a consequence of both hardware limitations and the massive database. ASWTDA's developing contractor, SONALYSTS, Inc., conceived a plan to reduce the database size and by consequence, the time required to access it. GEM, reduces database size by two primary means. "Contoured" data, which is real-valued (i.e., depths in meters, velocity in meters per second, etc.), and "provinced" data (which is usually integer valued, such as MGS province or bottom loss type) are reduced to subsets of similarly valued data. GEM needs to store only the value and location of a boundary between it and the next subset (figures 1,2). Next, a "reduction"

routine further reduces the quantity of boundary points, and resultant database size. The result (figure 3) is a dramatic reduction in database size as compared to the original fully populated database.[Ref. 6] Thus, ASWTDA does not use exactly the same database as TESS. GEM's creators maintain that GEM is a faithful representation of the original uncompressed data [Ref. 7]. If so, then Locklin's conclusion, that uniformity of databases between different APP's is an important consideration, should be moot. However, if the database differences are significant, fleet operators might experience significantly different predictions with identical inputs.

Leibiger states

> "... the standard against which models are judged should not be another model. To establish a suitable model assessment procedure in the light of the above considerations models should be compared with propagation loss data from experimental measurements." [Ref. 8].

This paper makes no attempt to compare outputs of ASWTDA or TESS to measured transmission loss, and makes no claims as to the accuracy or fidelity to the "real world" of either. Both ASWTDA and TESS employ the same or very similar OAML models, and insofar as this study is concerned, the comparison will be database to database vice model to model. The object of this study will be to ascertain whether standard OAML passive propagation loss models using a fully populated database (TESS) vice a GEM database (ASWTDA) will arrive at operationally similar results.

HOW PROVINCIAL DATA ARE GEMIZED

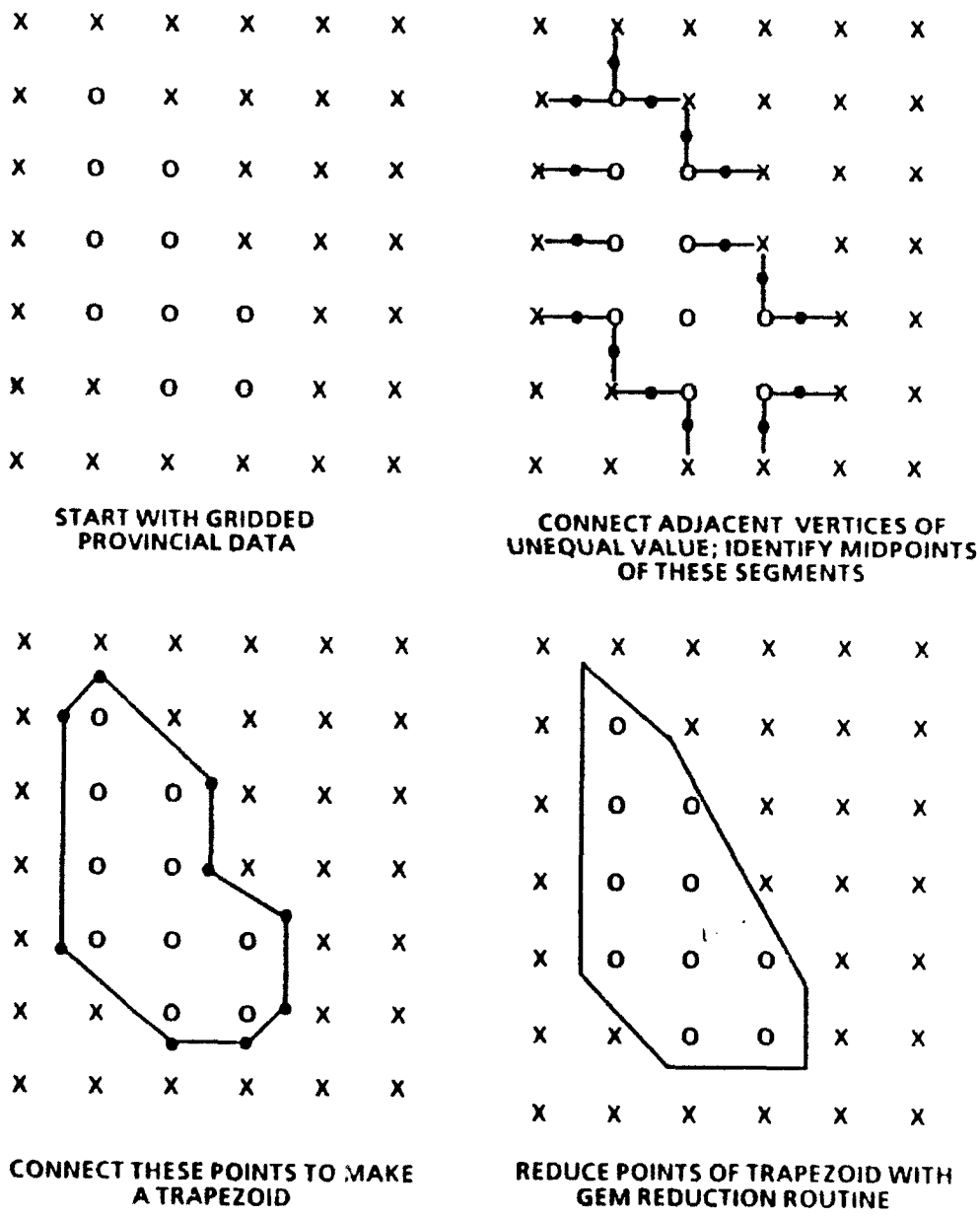
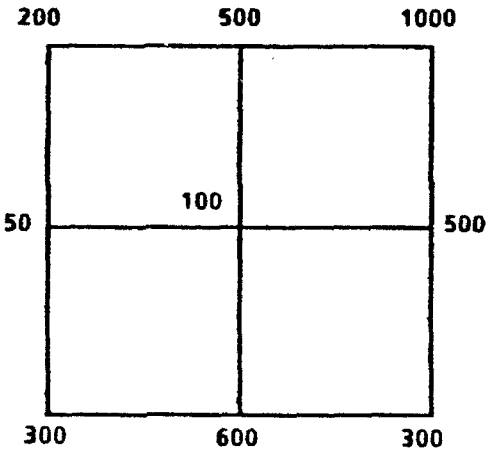
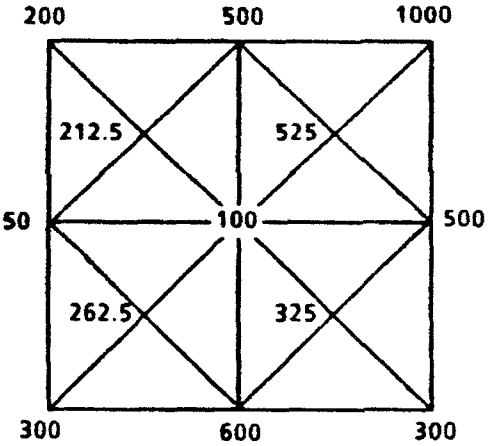


Figure 1 - Reduction of Provinced Data [Ref. 6]

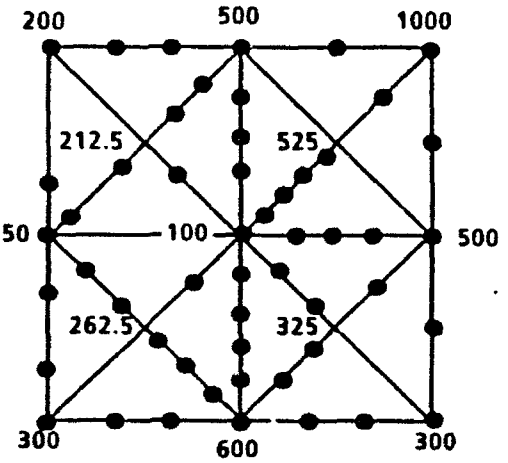
HOW CONTOUR DATA ARE GEMIZED



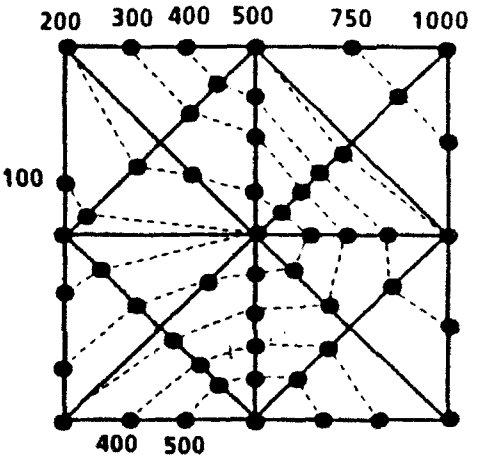
START WITH GRIDDED DATA



DETERMINE INTERSTITIAL VALUES AS $X_1 + X_2 + X_3 + X_4 \div 4$, WHERE X REPRESENTS GRID POINTS DESCRIBING SQUARE.



PERFORM LINEAR INTERPOLATIONS ON THE SIDES OF RESULTANT TRIANGES; IDENTIFY POINTS CORRESPONDING TO DESIRED CONTOUR LINES.



CONNECT POINTS TO FORM CONTOUR LINES; THIS SET IS NOW READY FOR REDUCTION ROUTINE.

Figure 2 - Reduction of Contoured Data [Ref. 6]

ENVIRONMENTAL DATA BASE STORAGE

DATA BASE	OAML		GEM		
	GRID SIZE	STORAGE (Mb)	CONTOUR	PROVINCE	STORAGE (Mb)
HISTORIC OCEAN PROFILE*	1/12°	--		X	1
DBDBC	1/12°	29	X		3
MGS	1/12°	24		X	0.6
BLUG PROVINCE	1/12°	27		X	0.2
SEDIMENT THICKNESS	1/12°	27	X		0.7
SHIPPING NOISE	1/12°, 2°, 5°	0.5		X	0.3**
HISTORIC WIND SPEED	1°	32	X		4
VOLUME SCATTERING STRENGTH	1/12°	23		X	0.8
TXBT*	1/2°	2 ÷		X	2
DBD85	1/12°	37	X		3
ETOPO5	1/12°	18	X		1

* INCLUDES SUPPLEMENTARY PROFILE DATA
** NOT GEM FORMATTED
÷ NOT PART OF THE OFFICIAL OAML DATA SET

Figure 3 - Result of GEM Reduced Environmental Datab.ses [Ref. 6]

II. DATA COLLECTION

A. DESCRIPTION OF AREAS INVESTIGATED

Two areas of current tactical interest were chosen for data collection: the central Sea of Japan, along a track from 40° 30' North, 137° 30' East to 38° 30' North 130° 30' East along a bearing of 252°; and in the Mediterranean, along the 35th parallel from 20° East to 13° East (Gulf of Sidra) on a bearing of 270°. Each track is approximately 350 nautical miles in length and consists of 50 data sampling points selected at seven nm intervals. Figures 4 and 5 illustrate the location and bathymetry of the two tracks.

In the Sea of Japan, the track crosses the Yamato and North Yamato ridges as well as the Yamato Trough and Tsushima Basin. It consists of three distinct prediction areas classified as having bottom loss five (on a scale of one to nine), is totally bottom limited in summer and primarily non-bottom limited in winter, and is sufficiently deep for good convergence zone propagation in most places during the winter months. Complex bathymetry and topographic roughness result in high loss at high frequency in the center of the track. Sediment, composed of primarily of clay and silts, has a highly variable thickness of from 160 to 1600 meters, resulting in low loss at low frequency. Sound channel axis varies from 60-200 meters. Bathymetry is shallow at the eastern end, and generally deep to the west.

In the Mediterranean Sea, the track originates on the slope of the Mediterranean Ridge, follows a steep downslope to a region of deep water in the eastern Ionian basin, across the Medina Bank, and ends on an upslope south of the Malta rise. The conditions at both ends of the track are bottom-limited while

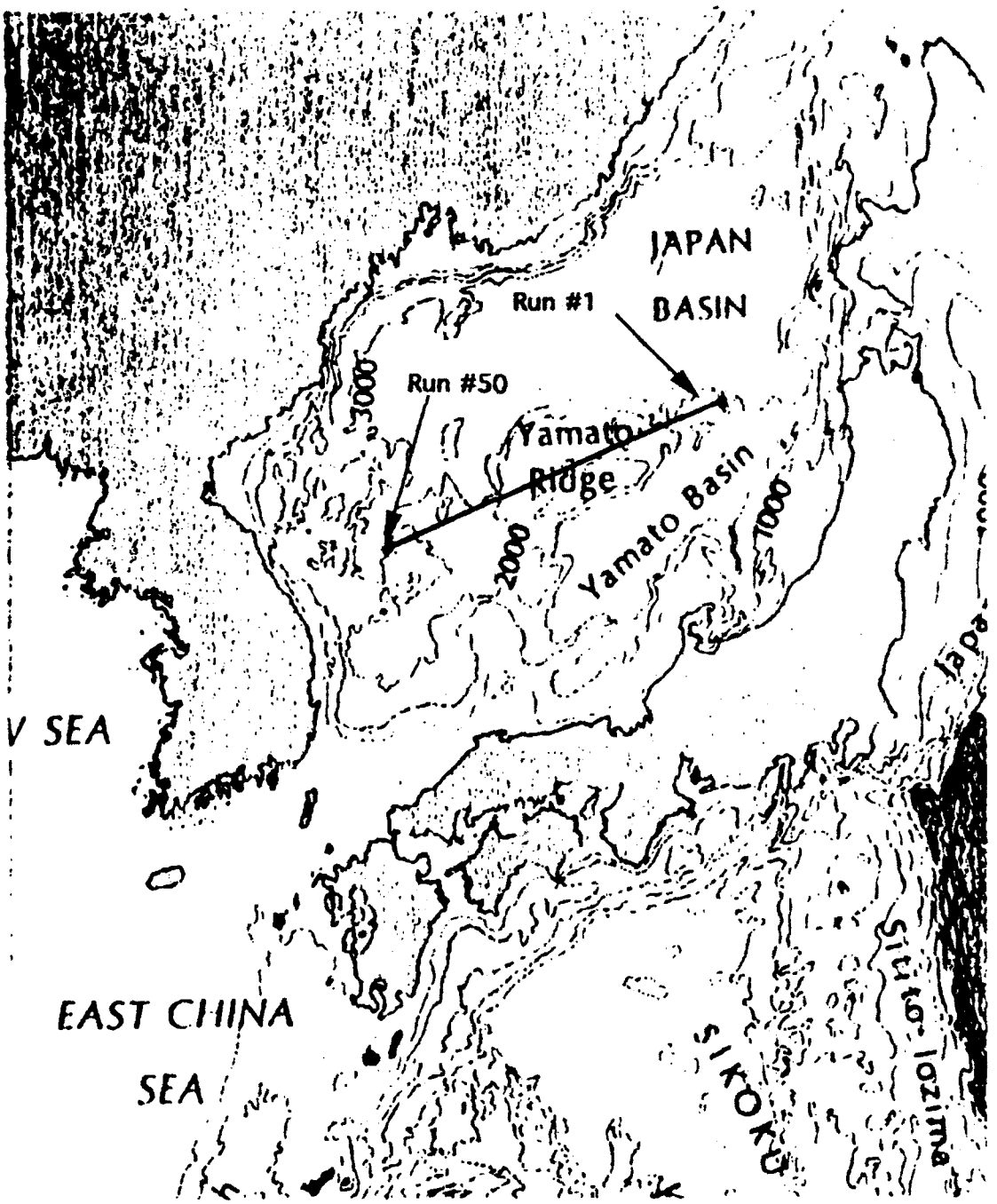


Figure 4 - Location of Data Collection Track in the Sea of Japan

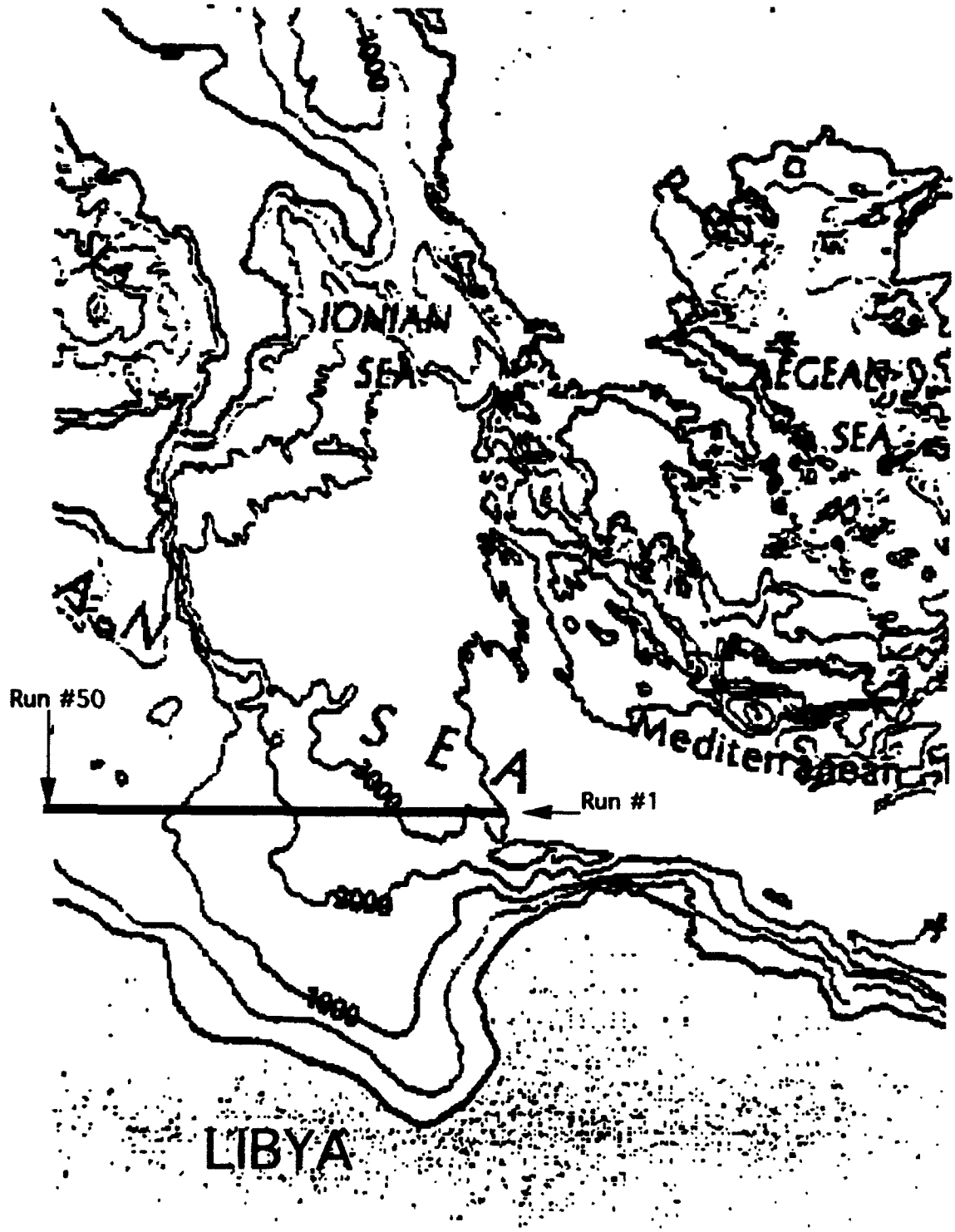


Figure 5 - Location of Data Collection Track in the Mediterranean

the center is not. Sonic layer depths move from 100 meters in winter to less than 50 meters in summer; the SVP has an extremely sharp negative gradient in summer. A sound channel axis is present during winter at approximately 150 meters and in summer moving to 200 meters. Bottom type is fine silts, clay and in the center of the track, sand and gravel. Resulting low frequency bottom loss provinces, moving from east to west, are one, three and four, corresponding to low, medium and high losses at low frequency. High frequency bottom loss ranges from four to eight to two, corresponding to medium loss at high frequency. Bathymetry from east to west shoals, from 3000 to less than 200 meters.

B. TEST PLAN

For the 1600 passive propagation loss curves generated, each propagation loss curve will be referred to as a "run", similar runs from ASWTDA and TESS will be referred to as a "run pair". An "array" consists of 50 runs, and similar arrays from ASWTDA and TESS will be referred to as an "array pair". Within any array pair, location along the track changes from run to run, but season, source frequency, source and receiver depths, bearing and model are held constant.

Thus, a total of 16 array pairs (containing the 1600 runs) were generated for a variety of locations, seasons, frequencies, depths and bearings. Appendix A describes the naming convention used in data gathering, and summarizes the data collected.

C. METHOD OF ANALYSIS

After reduction to ASCII data only (all header information deleted), data from the source APP's was read as ASCII "flat files" by MATLAB, a high-level language program that is particularly adept at matrix manipulation. Appendix B is

a summary of MATLAB programs used to manipulate and analyze the APP source data. [Ref. 9]

Insofar as the PE output from ASWTDA is range averaged while TESS is not. Appendix B also contains a program to range-average TESS PE for direct comparison to ASWTDA[Ref. 10].

Data was evaluated based on observation of statistical mean and standard deviation of the mean, and similarity of passive range prediction [Refs. 8.11].

1. Statistical Treatment

Statistically, the difference (difference in dB defined as ASWTDA value minus TESS value) of transmission loss for each data point of a run was computed to find the mean difference. The standard deviation of the difference was also computed. For each of the 16 array pairs, the mean and standard deviation were plotted versus run number, which corresponds to geographic location. Histogram distribution of the mean and standard deviation were also plotted. If predictions from the APP's are substantially the same, the mean difference will be near zero and the standard deviation of the difference will be small; a non-zero mean or high standard deviation indicates significant differences between the APP's.

Dispersion of the mean difference and standard deviation can easily be seen by viewing the distributions on a histogram. Dispersion will be small in those cases where ASWTDA and TESS behave similarly, and large in those cases where they do not.

"Bias" between ASWTDA and TESS will be seen as a mean difference, displaced from zero, on the histogram.

2. Prediction of Passive Range-to-Detection

The primary operational use of the passive propagation loss curve is prediction of direct path and extended detection ranges. Accordingly, notional Figures of Merit (FOM's) at 75, 80 and 85 dB were established, and the resulting range for each FOM over each propagation loss curve was tabulated using several short MATLAB programs listed in Appendix B.

For side-by-side comparison of ASWTDA to TESS propagation loss, MATLAB programs were written and listed in Appendix B. These MATLAB routines open run pairs, display the ASWTDA and TESS propagation loss curves (range averaged in the case of PE), and the run pair difference (ASWTDA-TESS) for each ASWTDA output point.

To calculate predicted detection ranges at notional FOM's, MATLAB scripts (one for range dependent, one for range independent models) are listed in Appendix B. Only the direct path and first "extended" ranges were considered. MATLAB scripts to process the range prediction statistics into summary data and assess whether the paired runs were "similar" or not are listed in Appendix B.

The criterion used to judge similarity was the following: run pairs were similar if their predicted direct path range difference (ASWTDA minus TESS) at a given FOM was less than 1 Kyd (predicted range less than 10 Kyd) or less than 10% of the predicted range (predicted ranges in excess 10 Kyd). For the first extended range, run pairs were judged similar if their predicted extended range difference (ASWTDA minus TESS) at a given FOM was less than 2 Kyd (predicted ranges less than 20 Kyd) or less than 10% of the predicted range (predicted ranges in excess of 20 Kyd).

In the event that one system predicted either a direct path or extended range and the other did not, the system predicting no range was given a value of zero, and the analysis considered such an event as a non-similarity.

III. RESULTS

A. STATISTICAL COMPARISON OF RAYMODE RUNS

1. Sea of Japan

Analysis of January 50 Hz runs shows tight dispersion of mean difference with most values -1.5 to +1.5 dB (one value at +5) and standard deviation 2.5 to 4. Figure 6 distribution of means indicates that ASWTDA, relative to TESS, is biased by -1 dB. At 300 Hz, the dispersion of both mean difference and standard deviation are increased, with mean difference of -0.5 to +5 dB and standard deviation of 2 to 6, Figure 7. ASWTDA agrees well with TESS proploss predictions over most of the runs, as illustrated by proploss curves in Figures 8 and 9, although ASWTDA predicts extended ranges at two to five Kyd shorter than TESS for run 11 (Figure 9) and fails to predict any extended range for run three at 300 Hz (Figure 8).

The July 20 and 500 Hz runs show markedly differing results. While the means of the 20 Hz runs are dispersed with mean difference of -1.5 to +4.5 dB and standard deviation 1.5 to 3, the 500 Hz runs show broadly dispersed mean difference of -14 to + 16 dB and standard deviation of 3 to 9.5. Figures 10 and 11, distribution of means, show ASWTDA biased at +1.5 dB (20 Hz) and at -1 dB (500 Hz) relative to TESS. Several proploss curves illustrate how well ASWTDA and TESS concur at 20 Hz and how much they differ at 500 Hz, Figures 12 and 13. In particular, run three at 500 Hz shows poor concurrence between the APP's.

For the July array pair, if only the latter 17 runs (33 to 50) at both 20 and 500 Hz are considered, dispersion of mean difference and standard deviation

is decreased at -0. 5 to + 1.5, and 1 to 1.5 respectively (20 Hz), or -3 to +1 dB. and 3 to 5 respectively (500 Hz). Runs 33-50 in both cases were located in the southern Tsuhima Basin, in an area with relatively flat bottom, while runs 1-32 are located in an area of complex bathymetry, the Yamato Rise.

2. Mediterranean

In the Mediterranean, the first half of the track (runs 1-25) for the January array pair at 150 Hz, shows mean difference of -3 to 0 dB with standard deviation of 1 to 3. The latter half shows mean difference spreading at -6 to +1 dB and standard deviation 1 to 3. ASWTDA shows a bias of -1.5 dB relative to TESS. illustrated by the histogram of Figure 14. The 500 Hz array pair show similar results over runs 1-18. Mean difference is -3 to 0 dB and standard deviation 3 to 4, but is broadly dispersed to mean difference of -9 to +3 dB and standard deviation of 1 to 4 when the entire array pair is considered. Figure 15. A negative bias of -3 dB is indicated by the histogram. Propagation loss curves, Figures 16-17, illustrate how well ASWTDA agrees with TESS predictions at the lower frequency, and how this agreement deteriorates at the higher frequency.

Over the first 25 runs, the July array pair at 100 Hz shows mean difference very tightly dispersed at -. 5 to +1 dB with corresponding standard deviation of 1 to 2.5. Over the entire 50 runs, mean difference spreads from -4 to +4 dB with accompanying standard deviation of 1 to 4, Figure 18. At 1500 Hz. runs 1-25 show mean difference at - 2.5 to + 2.5 dB and standard deviation of 2 to 7, while considering the entire track results in spreading of mean difference from - 5 to + 23 dB and standard deviation of 1 to 11, Figure 19. Anomalous behavior over runs 32-35 was noted.

Several proploss curves for the July array pair show good concurrence between ASWTDA and TESS, at both 100 and 1500 Hz over the first half of track, while the latter half illustrates less agreement, particularly at higher frequency (figures 20 and 21). Runs 1-25 were located in an area of relatively flat bottom and deep water, while runs 26-50 are located in progressively more shallow water and areas of bathymetric relief.

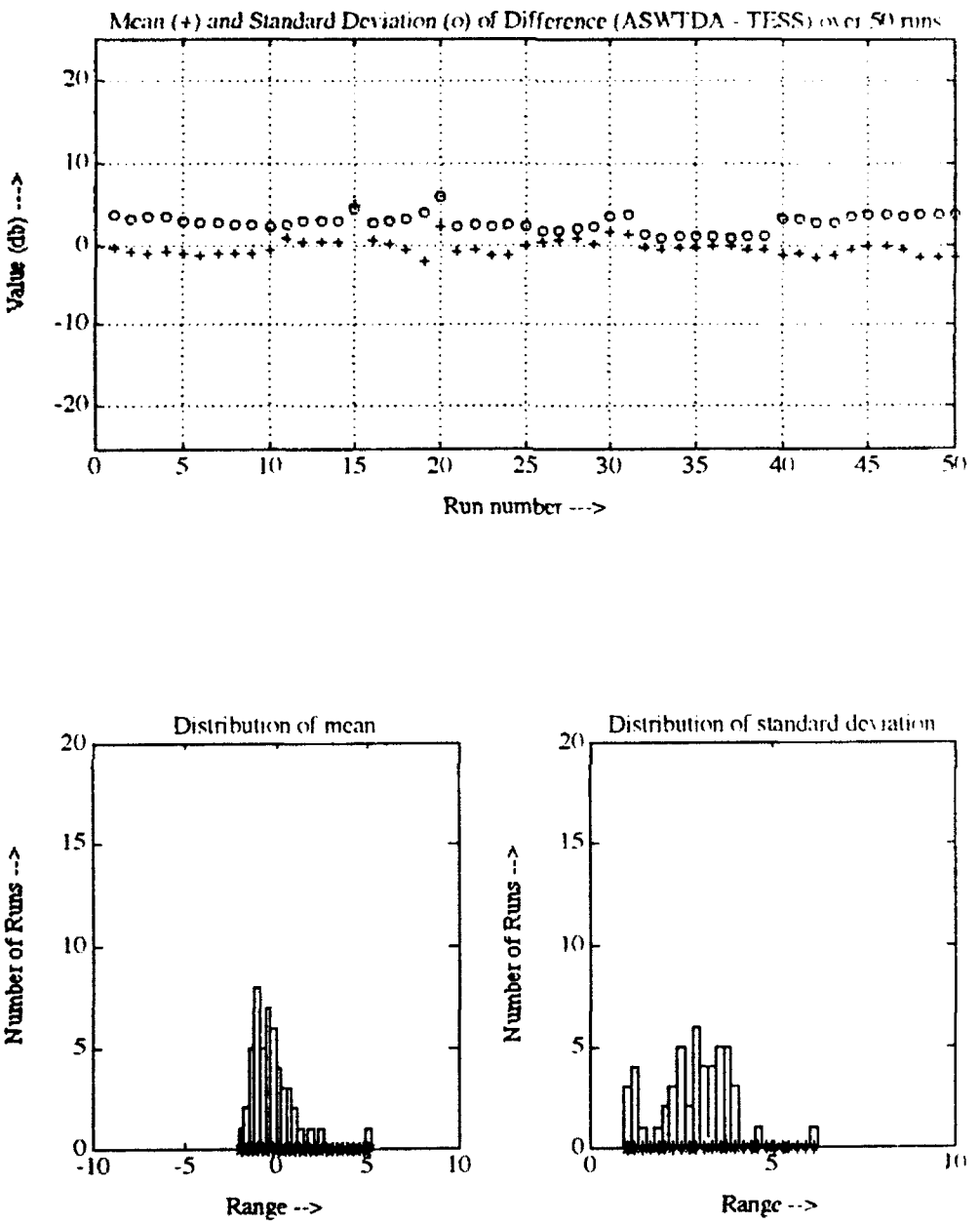


Figure 6 - Data for Sea of Japan, January, RAYMODE, 50 Hz

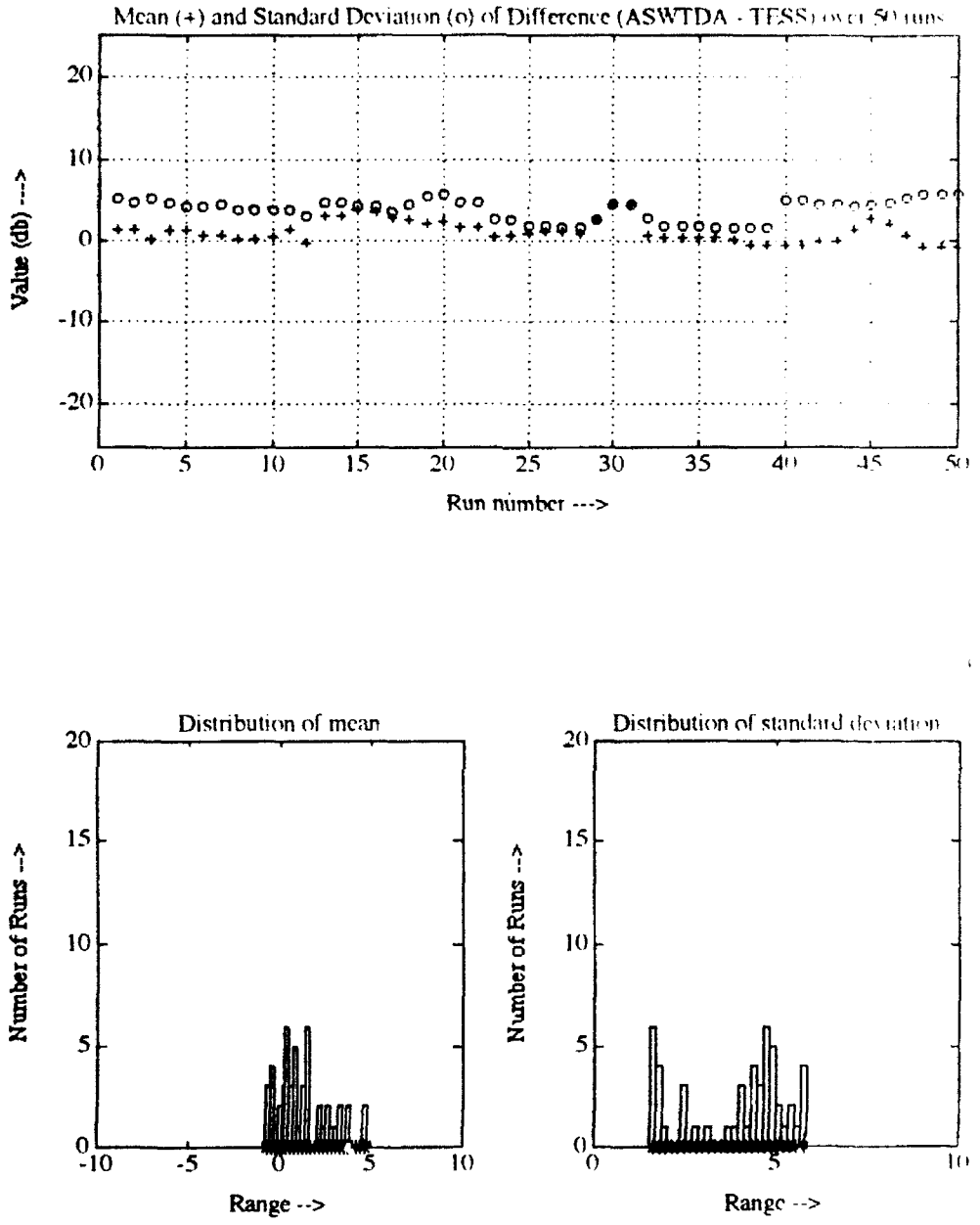
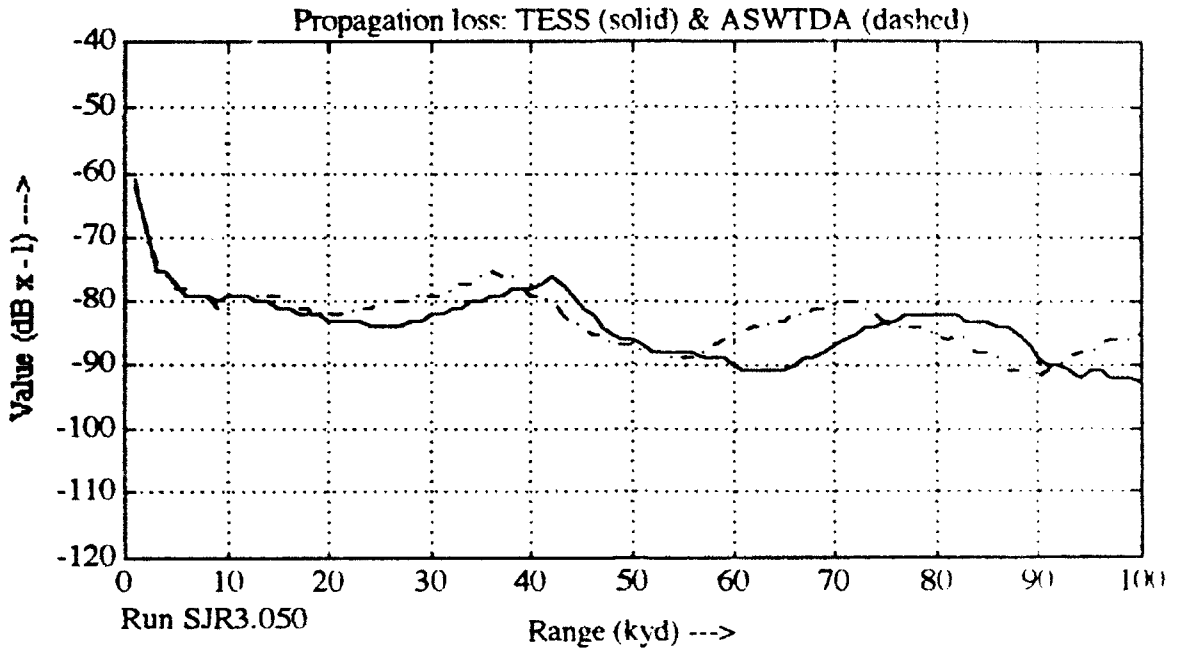


Figure 7 - Data for Sea of Japan, January, RAYMODE, 300 Hz



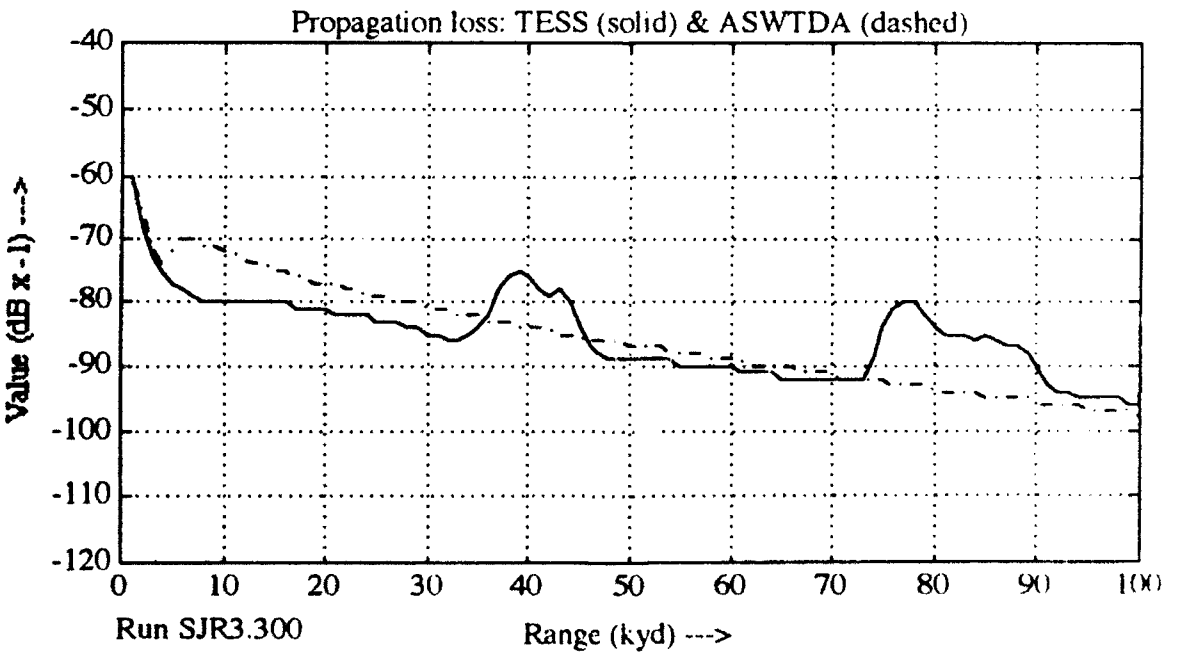
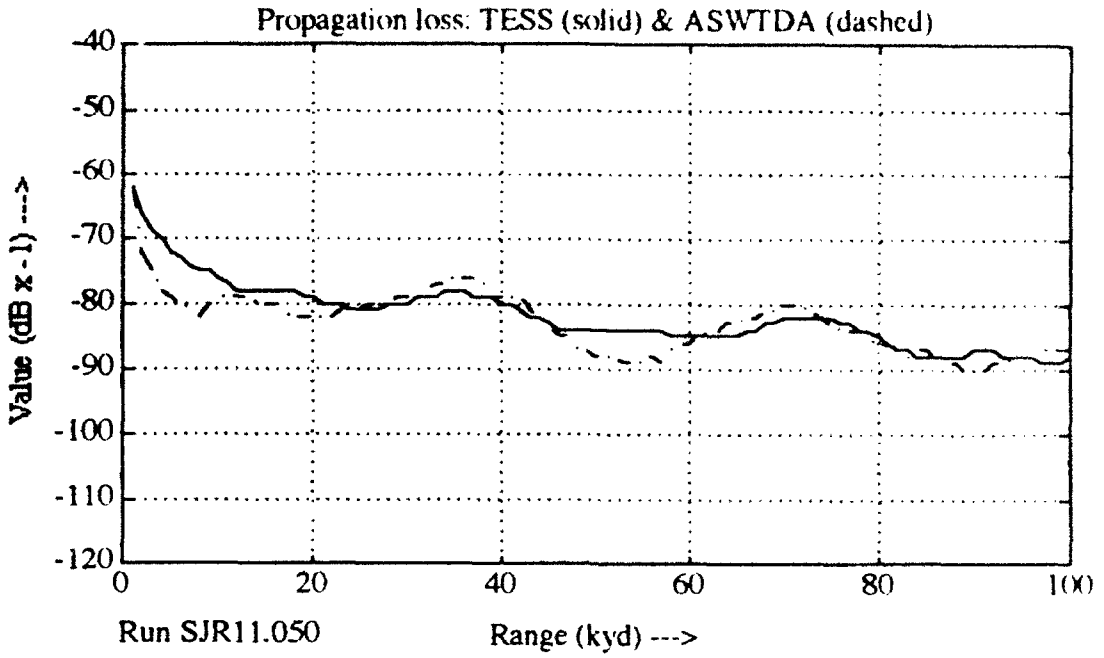


Figure 8 - Proploss for run 3, array pair SJR, 50 Hz (upper) and 300 Hz (lower)



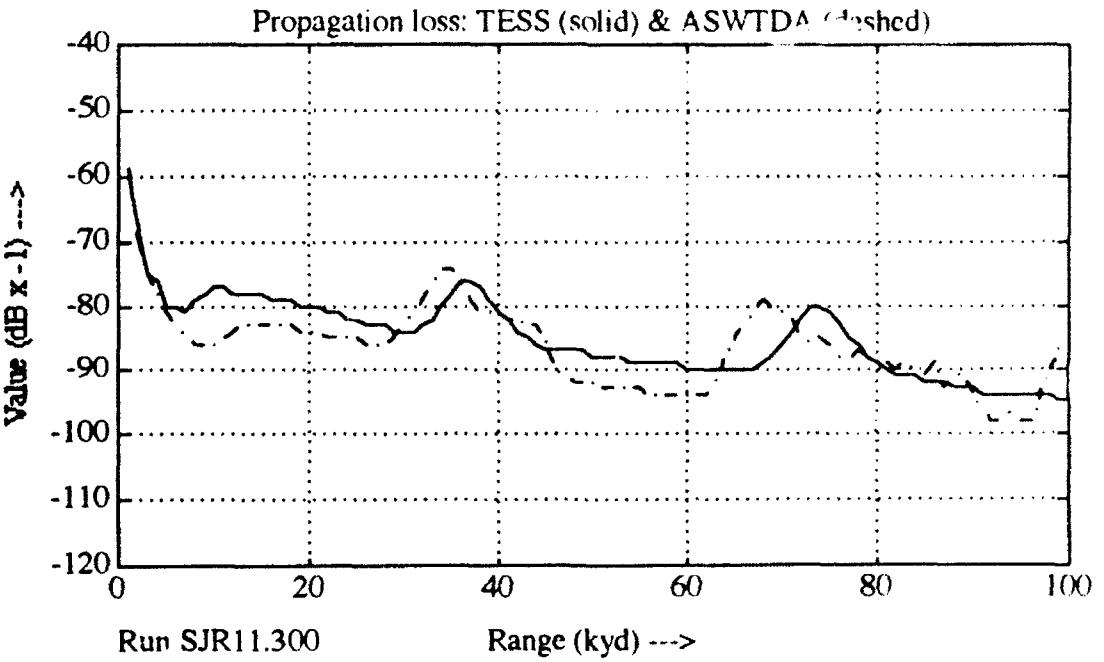
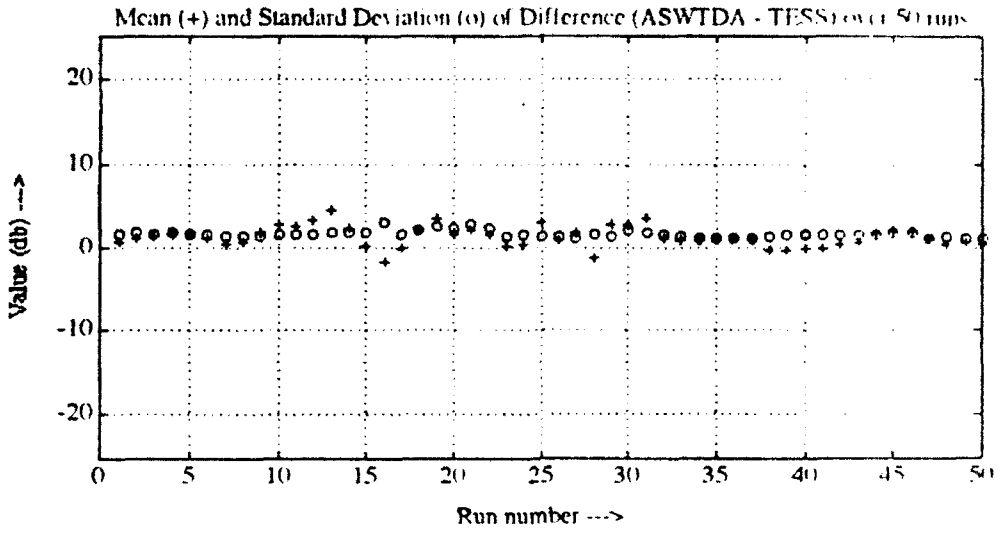


Figure 9 - Proploss for run 11, array pair SJR, 50 Hz (upper) and 300 Hz (lower)



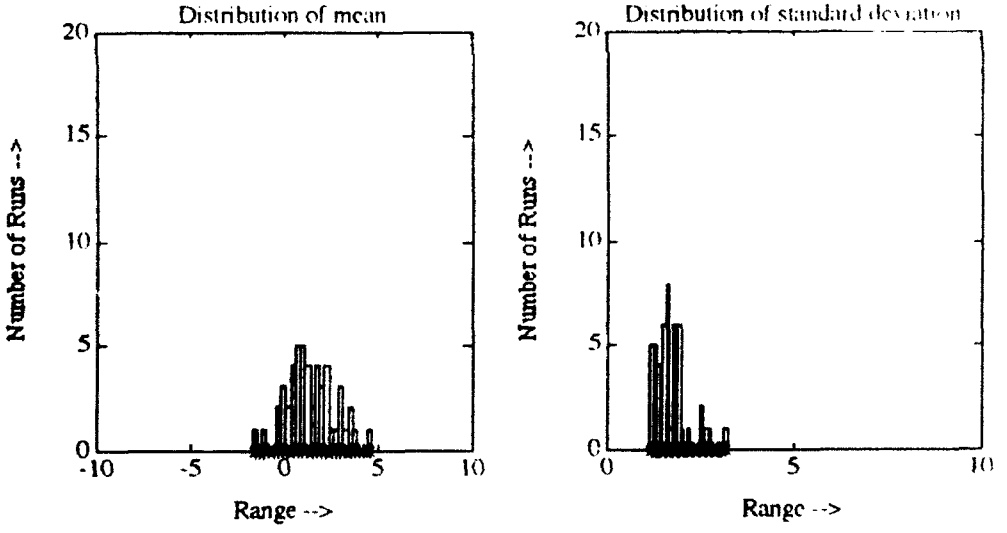
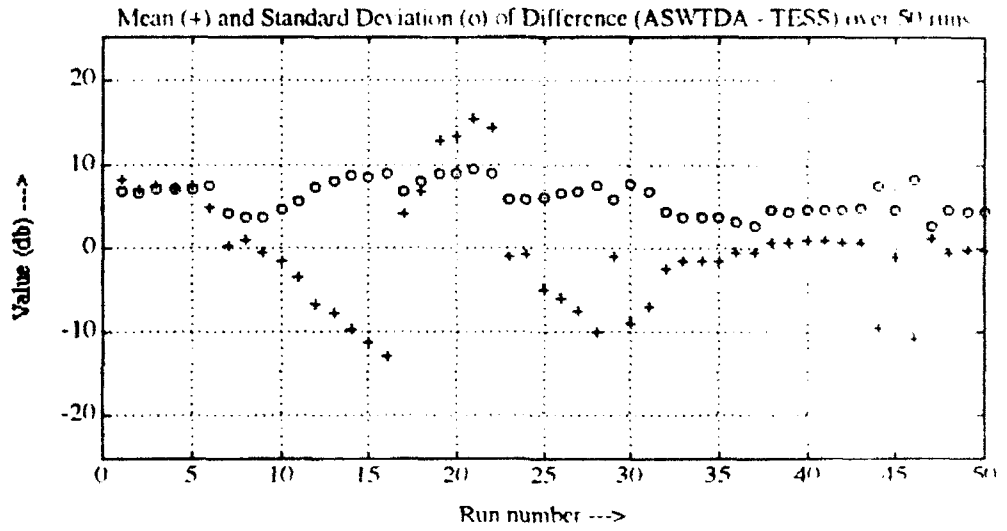


Figure 10 - Data for Sea of Japan, July, RAYMODE, 20 Hz



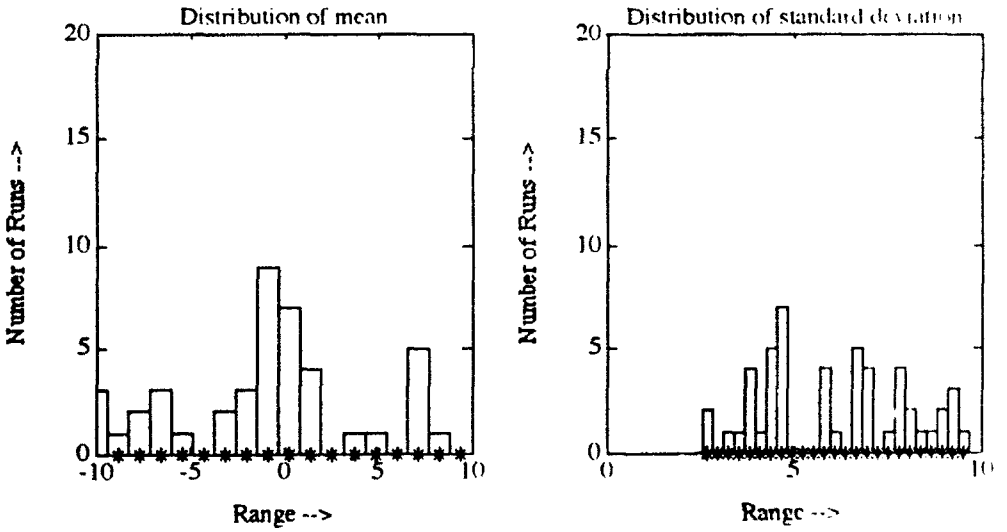
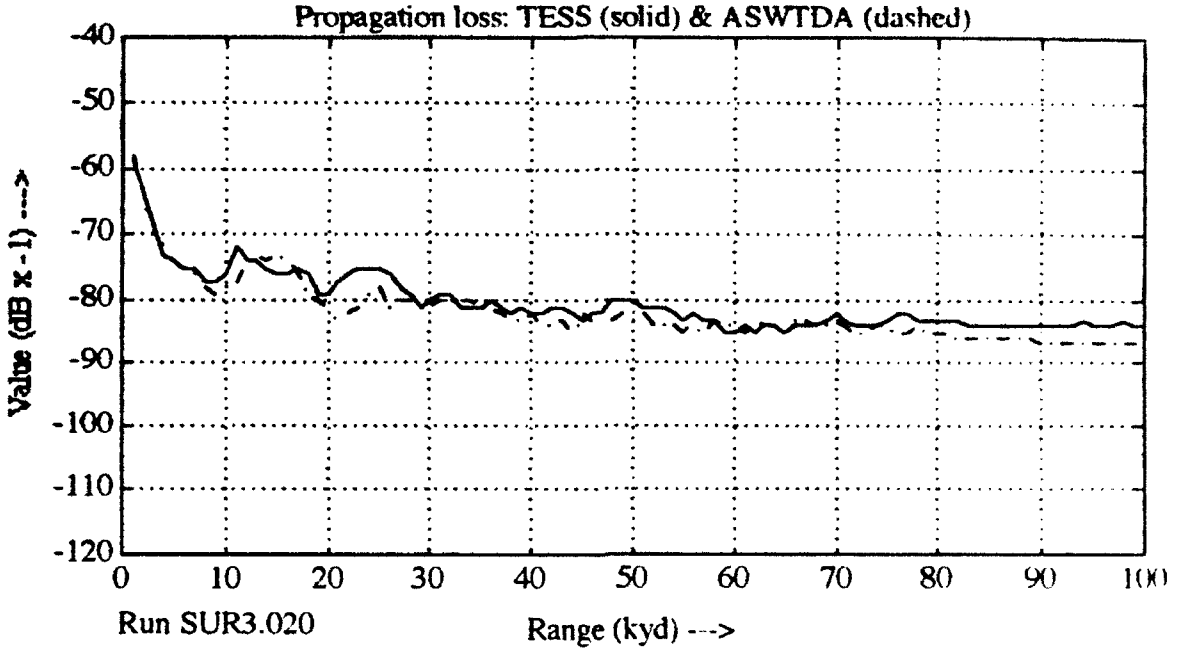


Figure 11 - Data for Sea of Japan, July, RAYMODE, 500 Hz



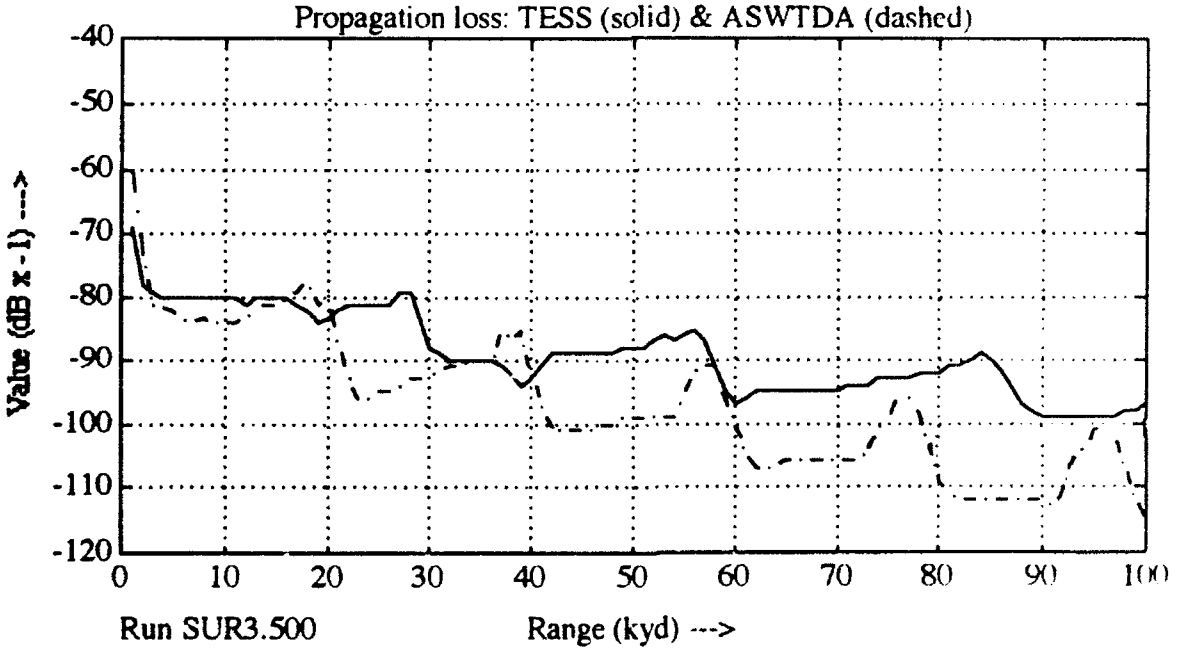
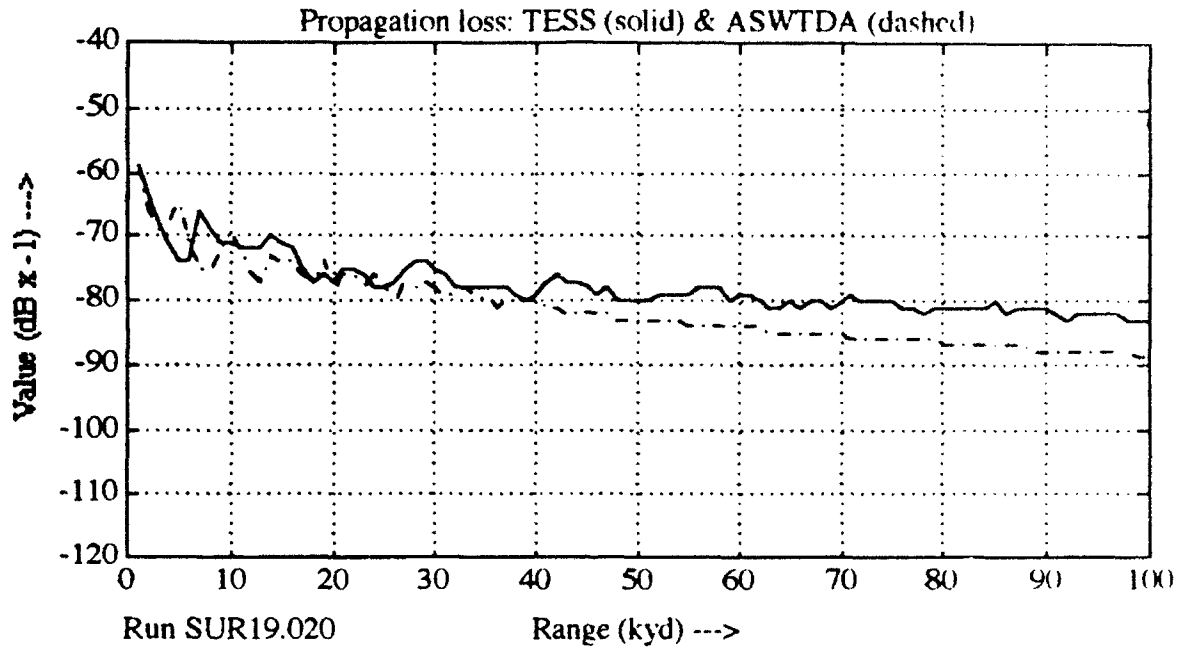


Figure 12 - Proploss for run 3, array pair SUR, 20 Hz (upper) and 500 Hz (lower)



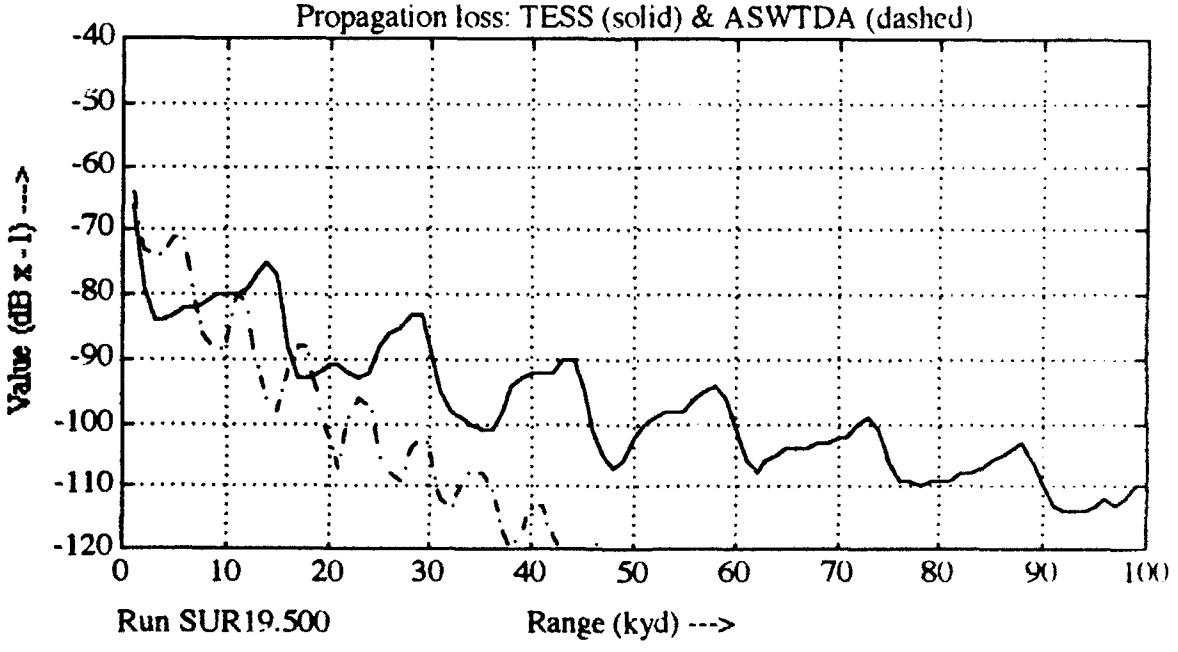


Figure 13 - Proploss for run 19, array pair SUR, 20 Hz (upper) and 500 Hz (lower)

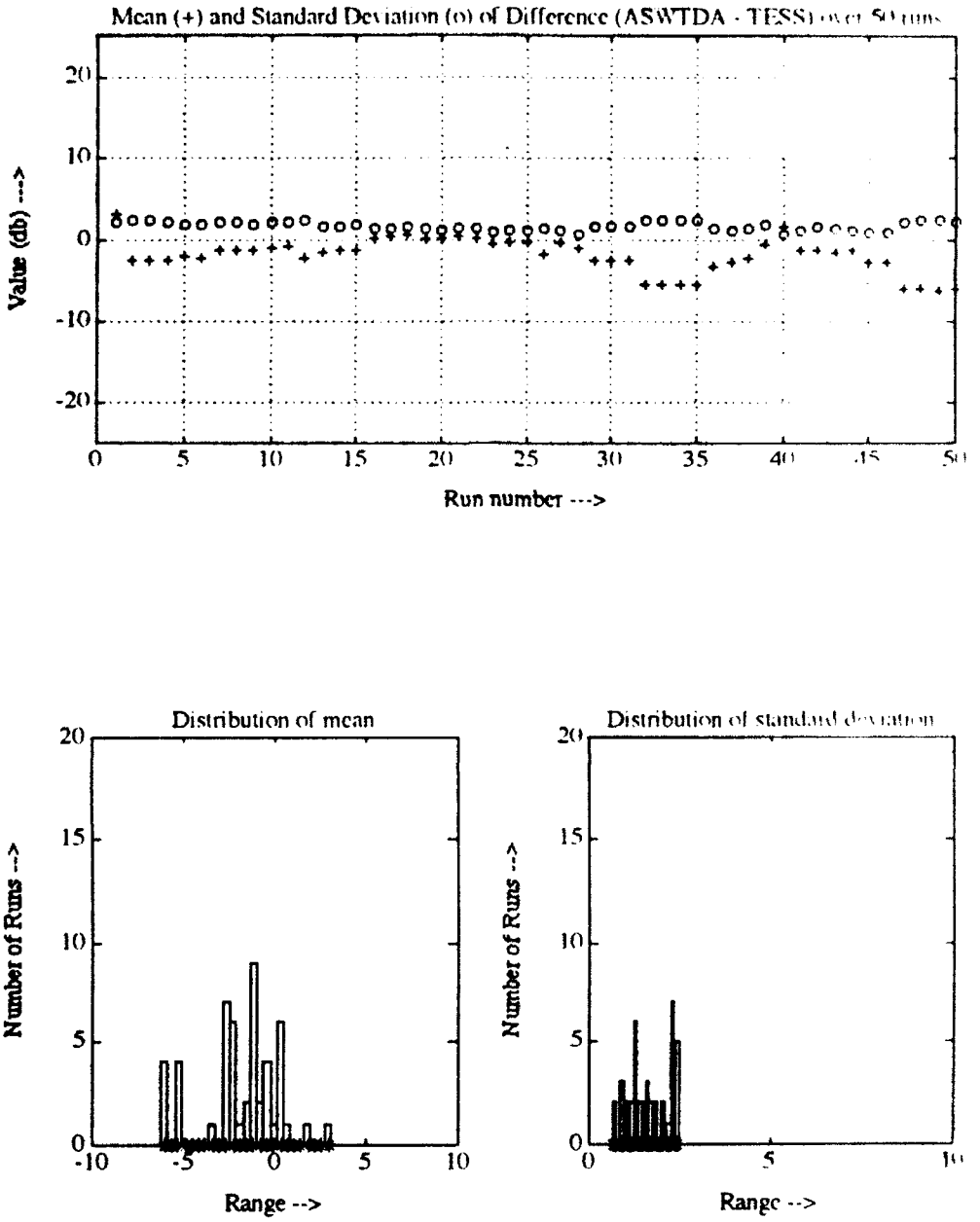


Figure 14 - Data for Mediterranean, January, RAYMODE. 150 Hz

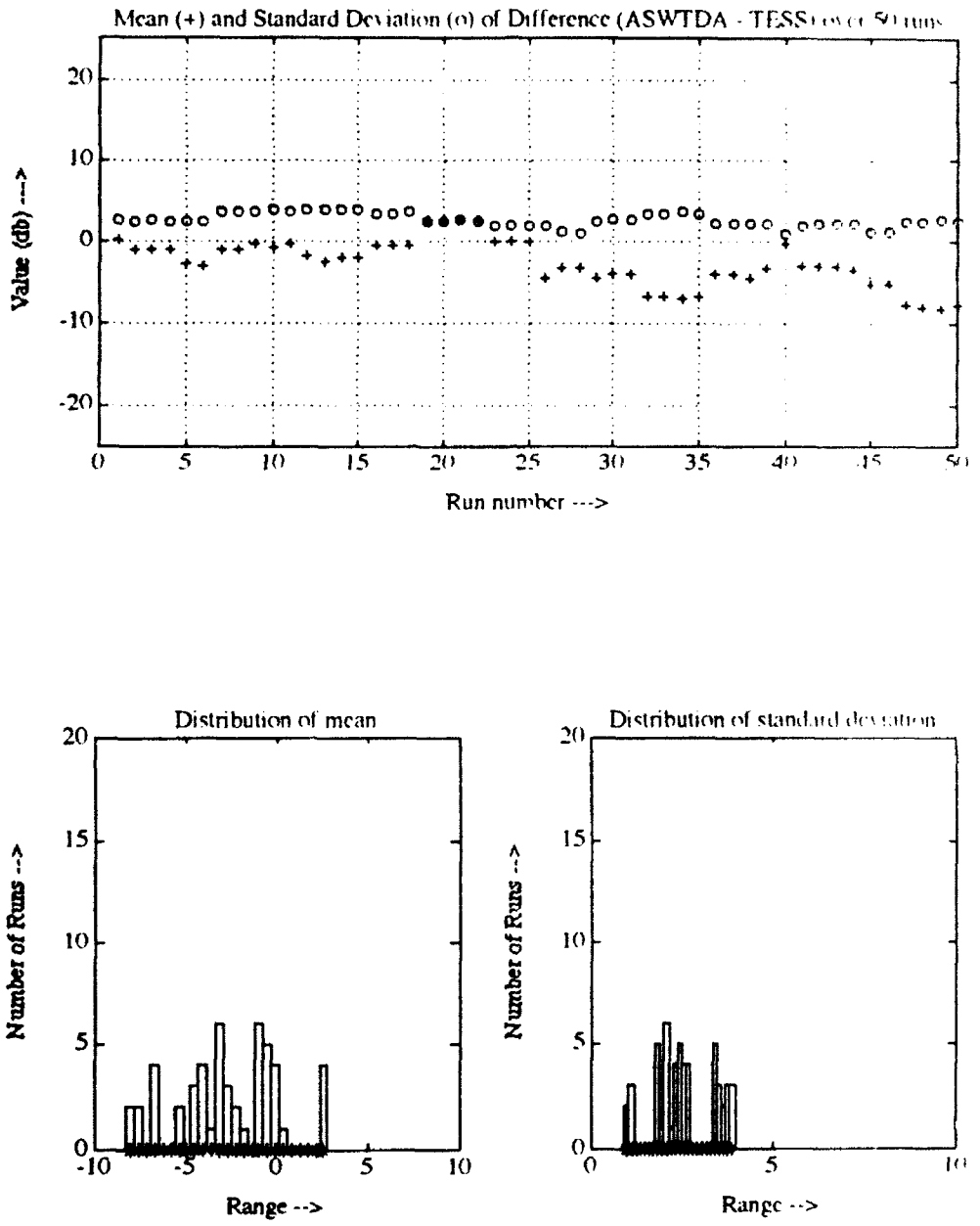
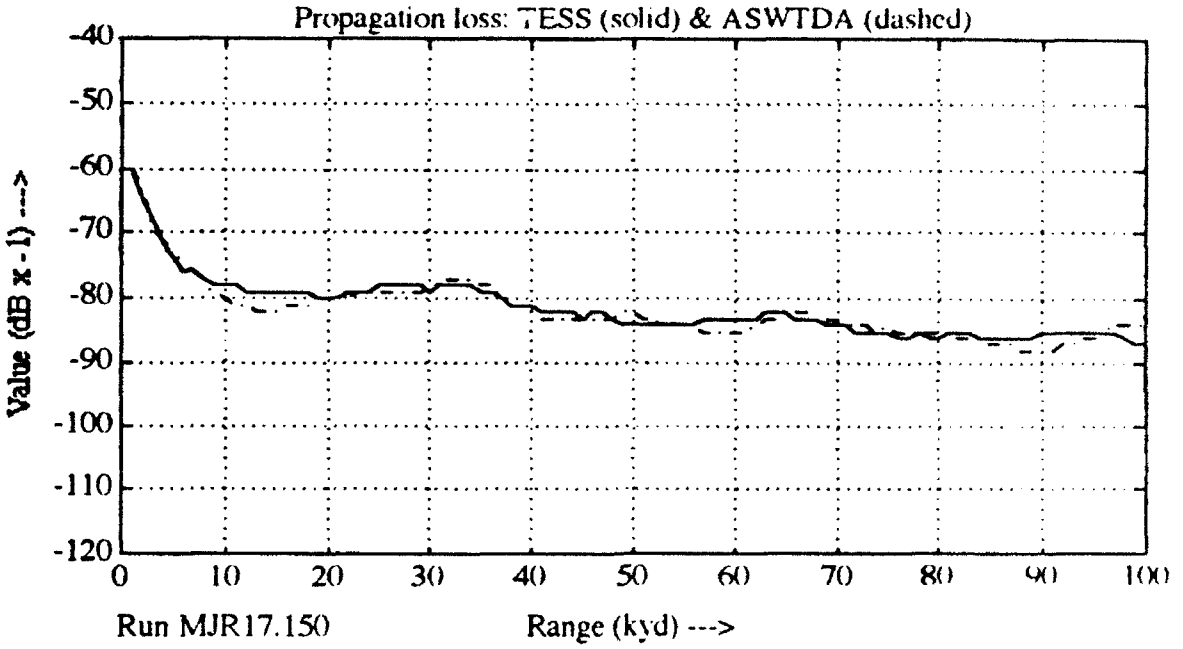


Figure 15 - Data for Mediterranean, January, RAYMODE, 500 Hz



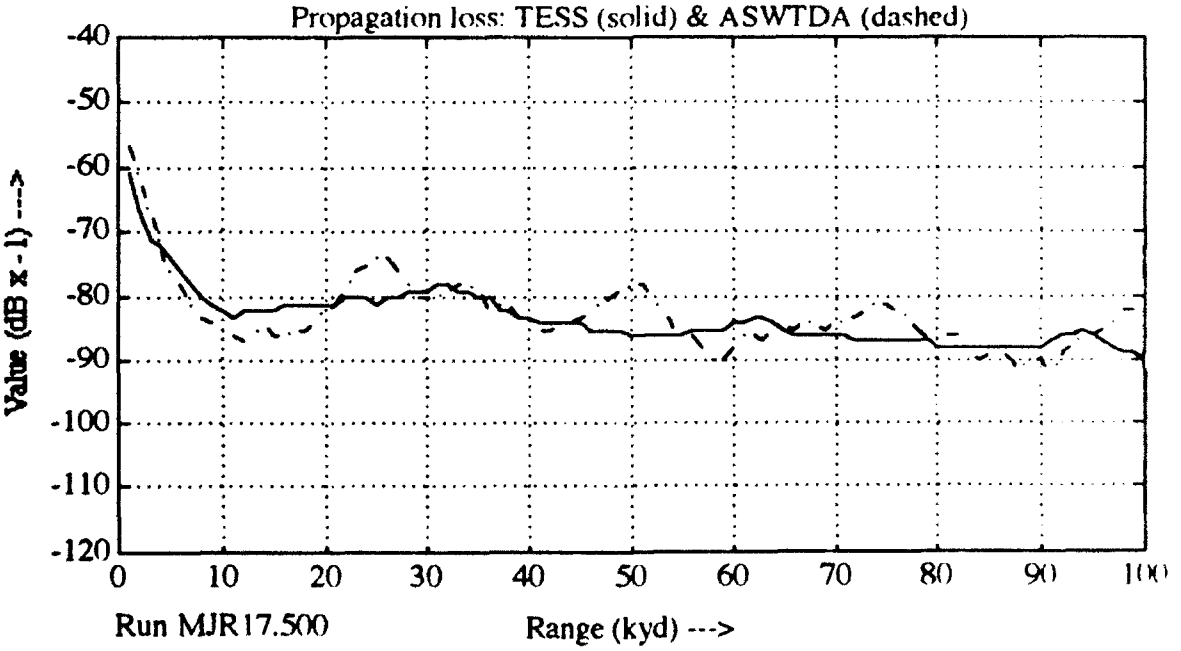
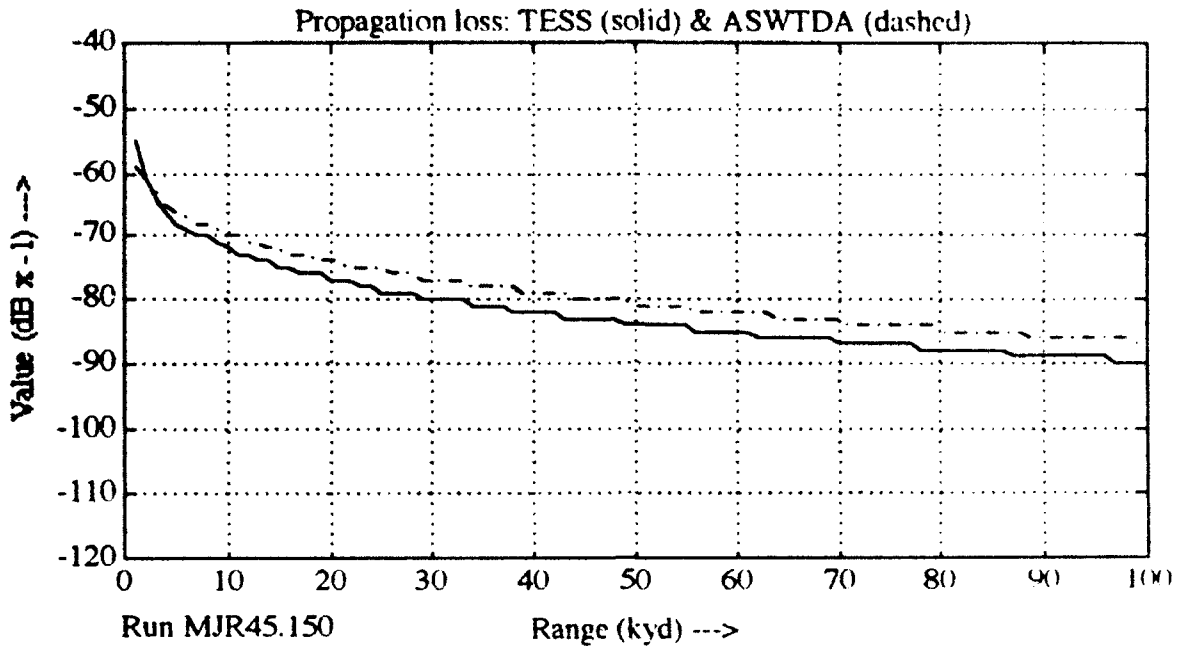


Figure 16 - Proploss for run 17, array pair MJR, 150 Hz (upper) and 500 Hz (lower)



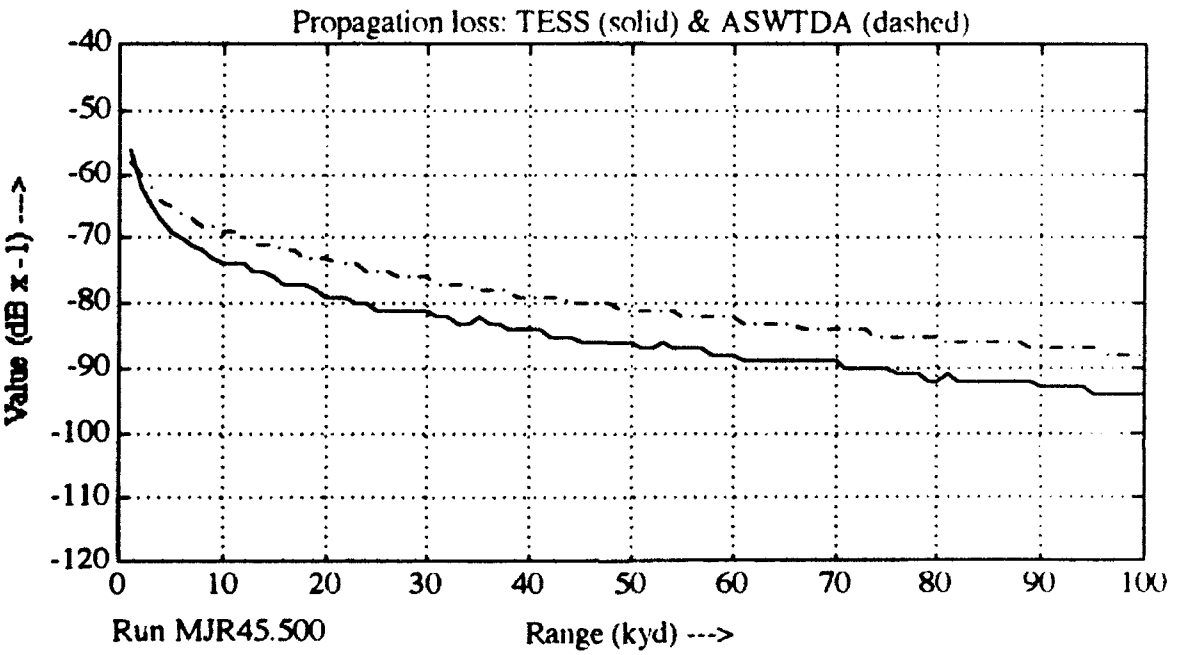
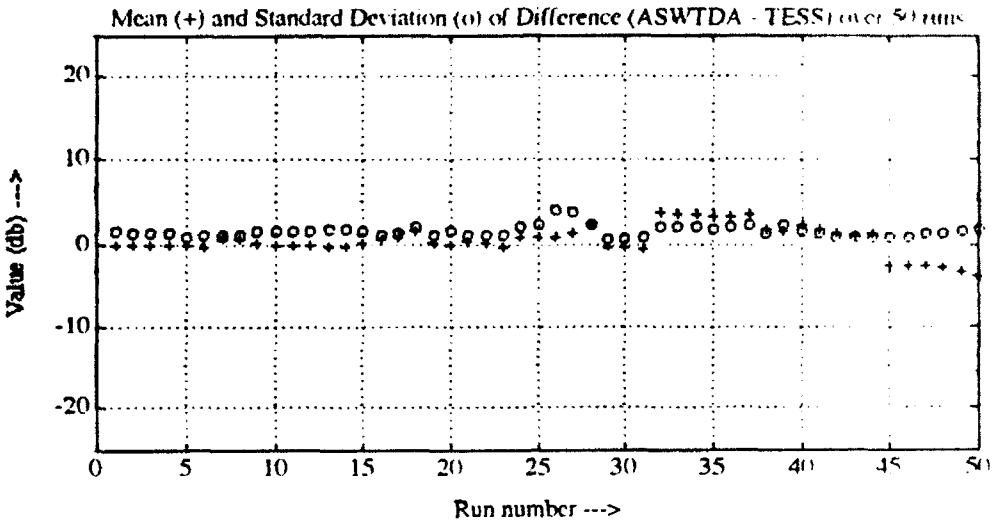


Figure 17 - Proploss for run 45, array pair MJR, 150 Hz (upper) and 500 Hz (lower)



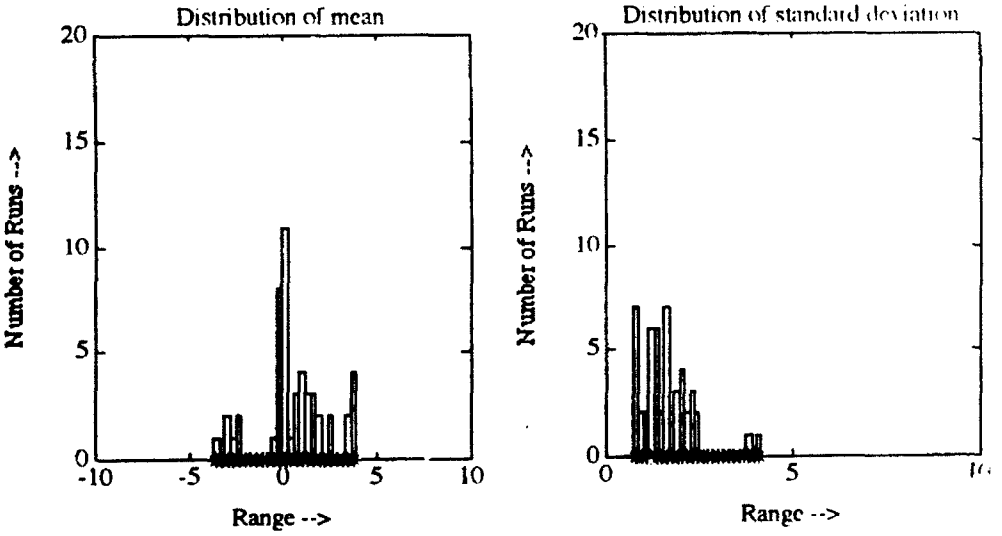


Figure 18 - Data for Mediterranean, July, RAYMODE, 100 Hz

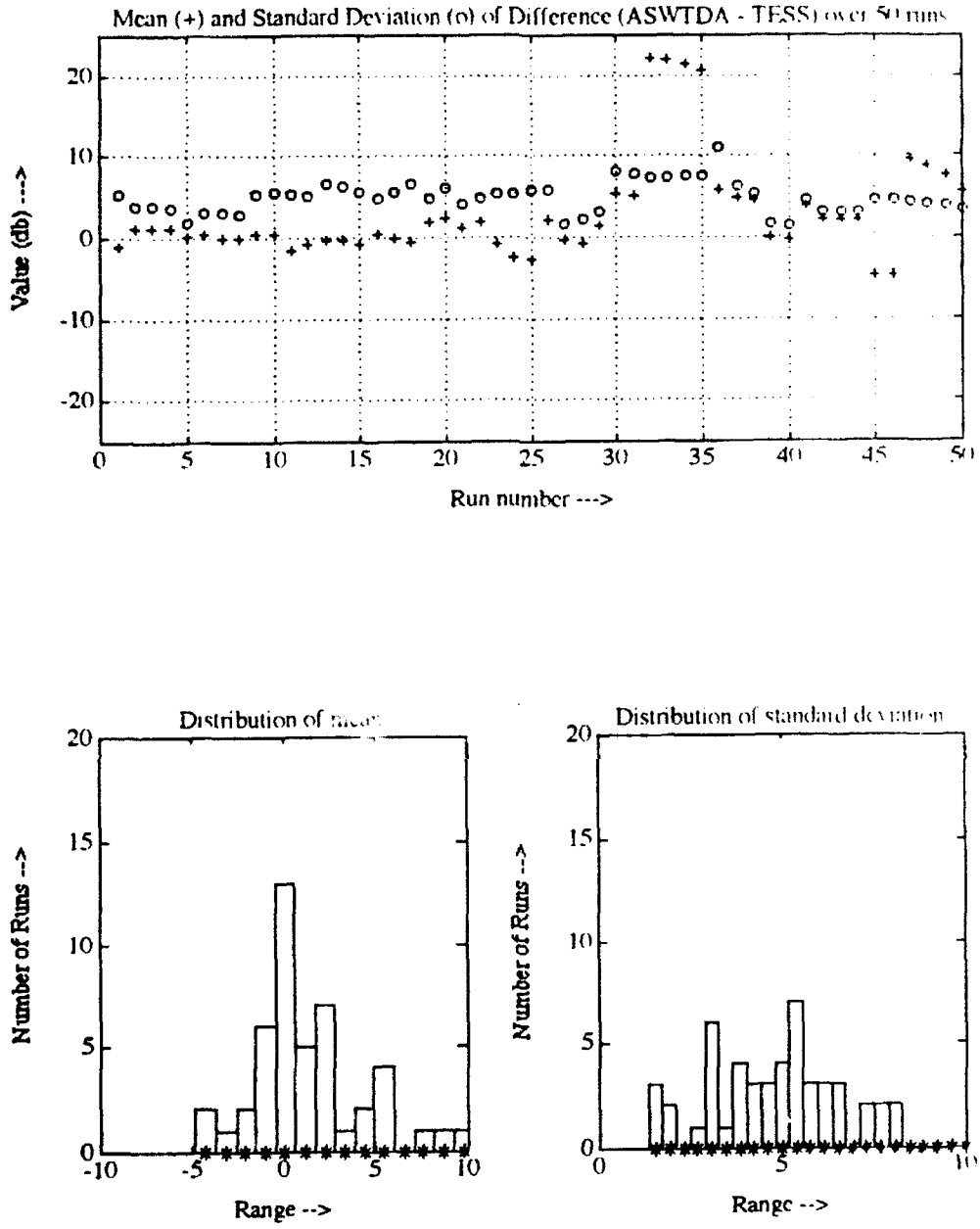
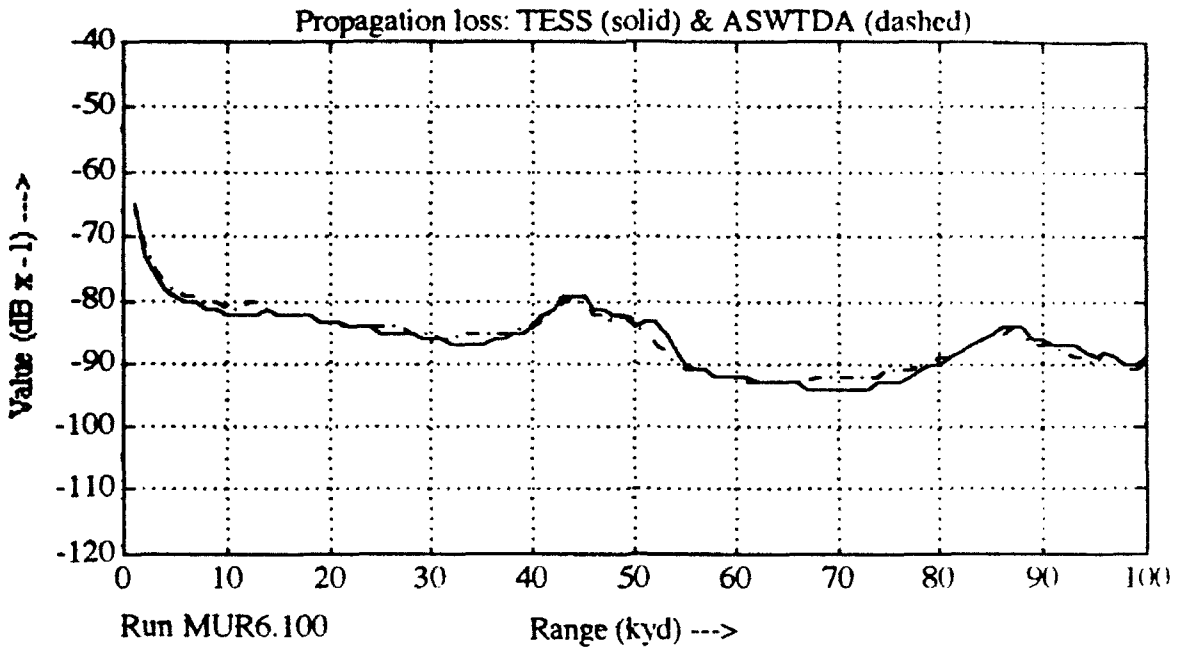


Figure 19 - Data for Mediterranean, July, RAYMODE, 1500 Hz



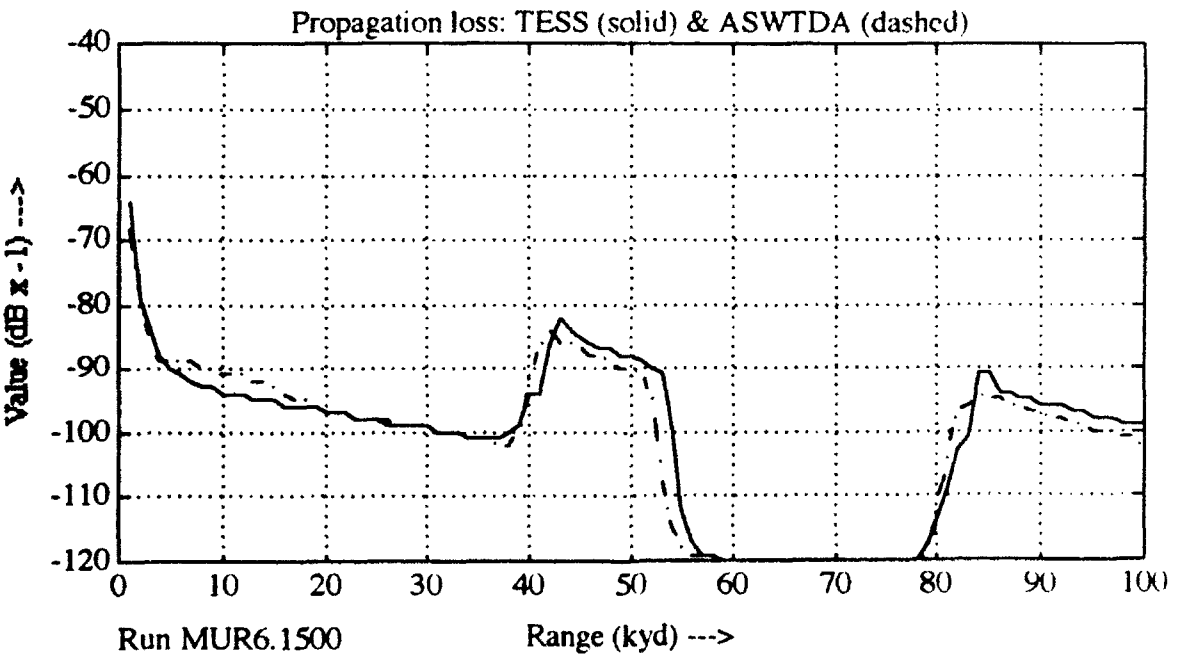
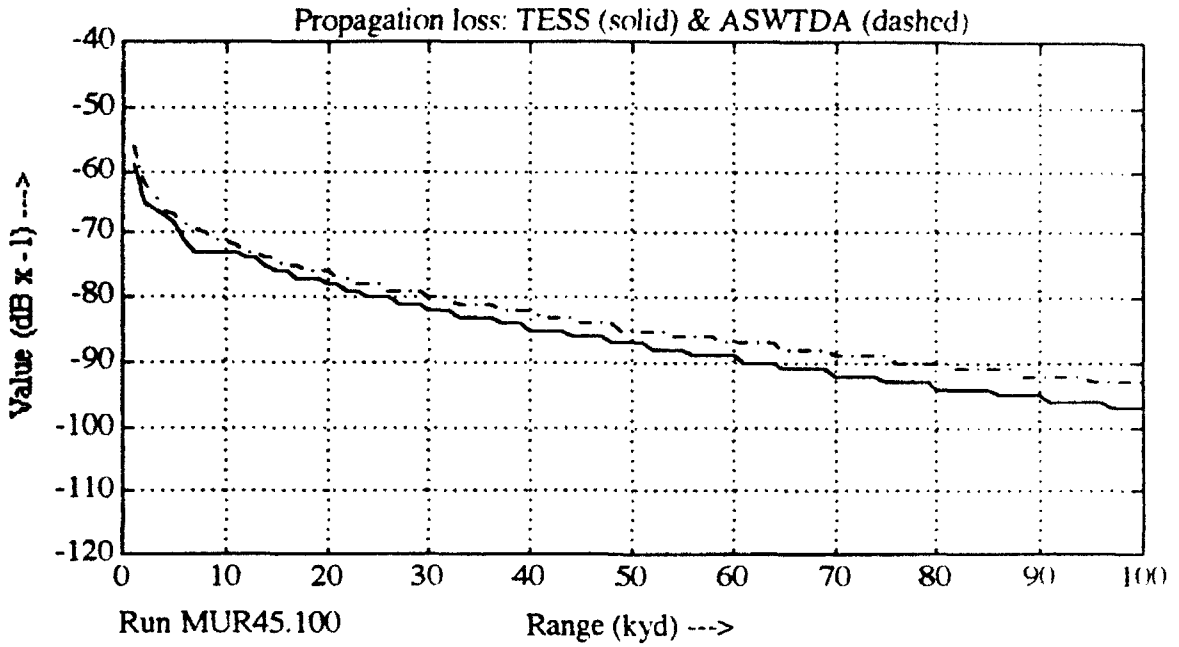


Figure 20 - Proploss for run 6, array pair MUR, 100 Hz (upper) and 1500 Hz (lower)



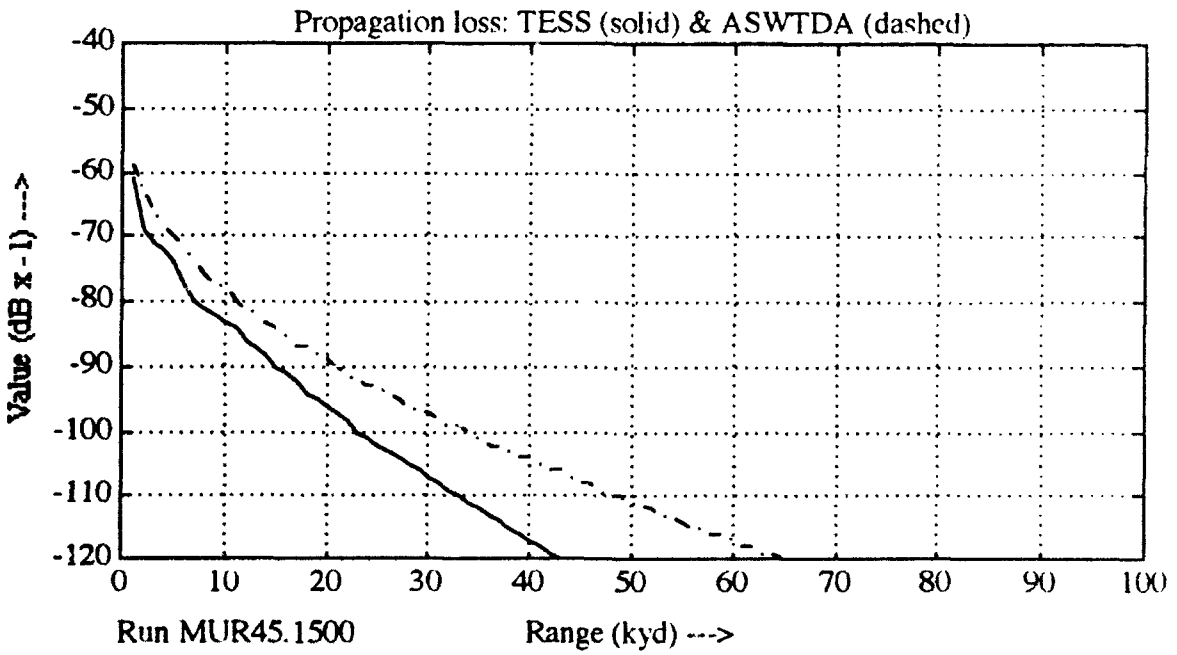


Figure 21 - Proploss for run 45, array pair MUR, 100 Hz (upper) and 1500 Hz (lower)

B. STATISTICAL COMPARISON OF ASTRAL RUNS

1. Sea of Japan

In the Sea of Japan, the January array pair shows mean difference valued at 0 to +10 dB and standard deviation from 3 to 8 (figure 22). The histogram indicates ASWTDA has a positive bias of +3 dB with respect to TESS. Fair agreement between ASWTDA and TESS proploss curves is seen in runs 3 and 49 (figure 23), but significant divergence is noted between runs 26-29 (figure 24), where predicted propagation loss varies considerably beyond 30 Kyd from the source.

The array pair for July shows mean difference for runs 1-10 at +6 to +7 dB and standard deviation of 6 to 8. Runs 28-50 were also tightly distributed at -0. 5 to +1 dB and standard deviation at 2 to 4.5. However, the midsections of the track, runs 11-27, were highly variable with standard deviation from 6 to 11 (figure 25). Over these runs, ASWTDA predicts significantly more transmission loss than TESS, and concurrence between the APP's is very poor (figures 25 and 26). The histogram of Figures 25 shows two distinct distributions of the mean, one at 0 dB (runs 28-50) and one at 7 dB (runs 1-10).

Environmental conditions in the Sea of Japan are such that runs 10-28 are bottom limited, and as previously noted in III.A.1, overlay areas of complex bathymetry.

2. Mediterranean

The January array pair shows dispersed mean difference for the first half of track (runs 1-25) at +1 to +7 dB and standard deviation of 2 to 4.5, while the second half of the track (runs 26-50) has very widely dispersed mean difference of 0 to +15 dB and standard deviation of 1 to 11. Figure 27 histogram indicates

ASWTDA biased with respect to TESS at +5 dB. Propagation loss curve, Figure 28, shows ASWTDA and TESS predicting the same general features. Figure 29 shows runs 30 and 40 with demonstrably different prediction results beyond 80 Kyd, where ASWTDA predicts total loss, while TESS does not.

The array pair for July shows the same trends as January, with the first half of track (runs 1-25) at mean difference of -1.5 to +1.5 dB and standard deviation of 1 to 6, while the second half (runs 26-50) shows wildly dispersed mean difference of -22 to +7 dB and standard deviation of 1-17. While the distribution of means from Figure 30 indicates a near zero bias, the distribution of standard deviations indicates that in some cases ASWTDA and TESS are predicting very different propagation losses. Several proploss curves illustrate both good and poor consistency between the APP's (figures 31-32).

C. STATISTICAL COMPARISON OF PARABOLIC EQUATION (PE) RUNS

1. *Sea of Japan*

In the Sea of Japan, the January array pair shows a mean difference distributed from -5 to +5 dB and standard deviation of 3 to 7. Figure 33, distribution of means, shows ASWTDA has two distinct biases at -2 and +2 dB with respect to TESS. Proploss curves from several runs (figure 34) illustrates the reason for the variability; ASWTDA curves follow the "envelope" of TESS curves but do not predict the same local values. The array pair calculations were run along a bearing of 270 degrees, across areas overlaying the Yamato Rise with complex bathymetry along most of the track.

The July array pair shows mean difference values dispersed from -4 to +3 dB and standard deviation of 2 to 5 (figure 35). The histogram shows two distinct biases, -1 dB for the latter half of track and +2,5 dB for the first half.

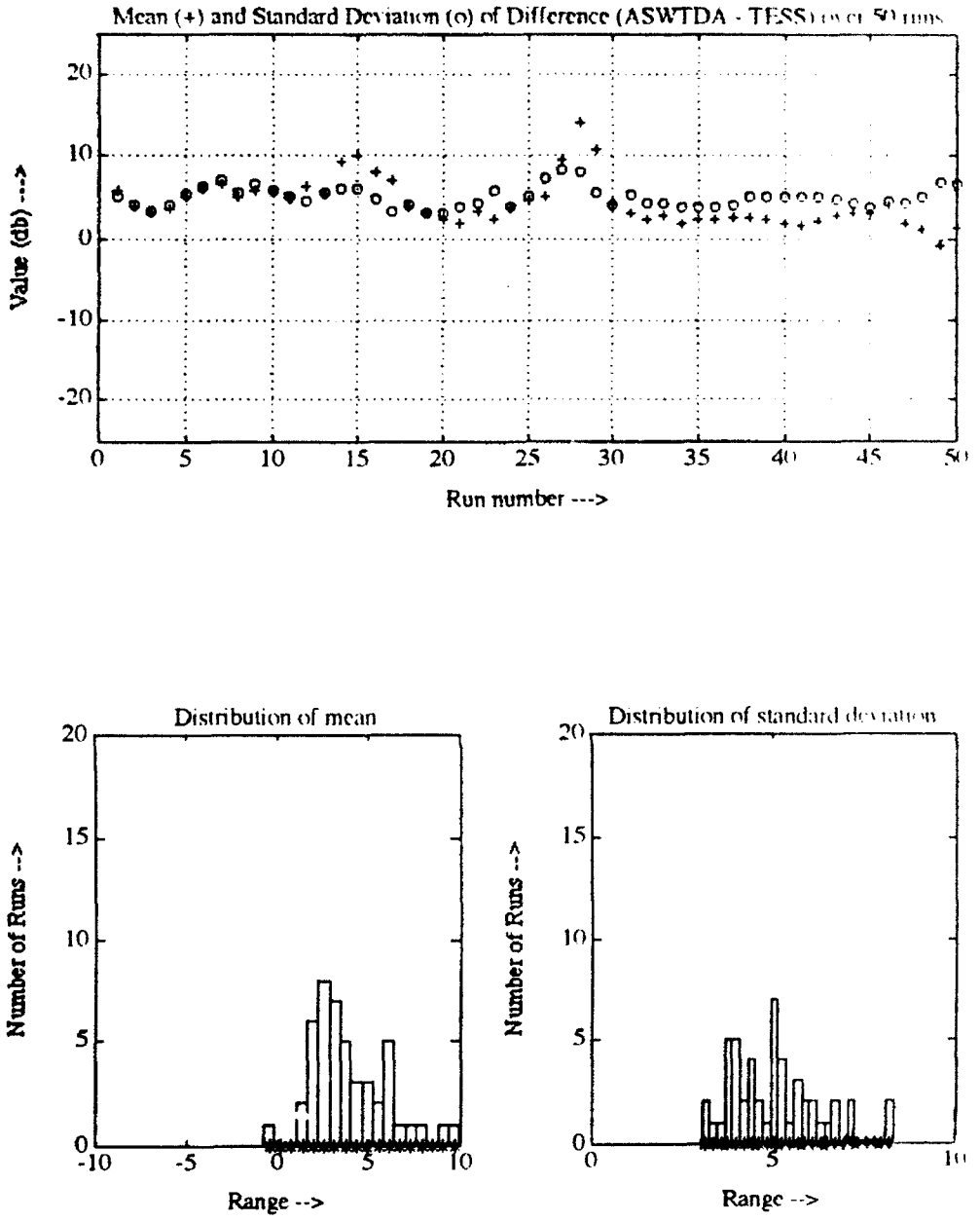
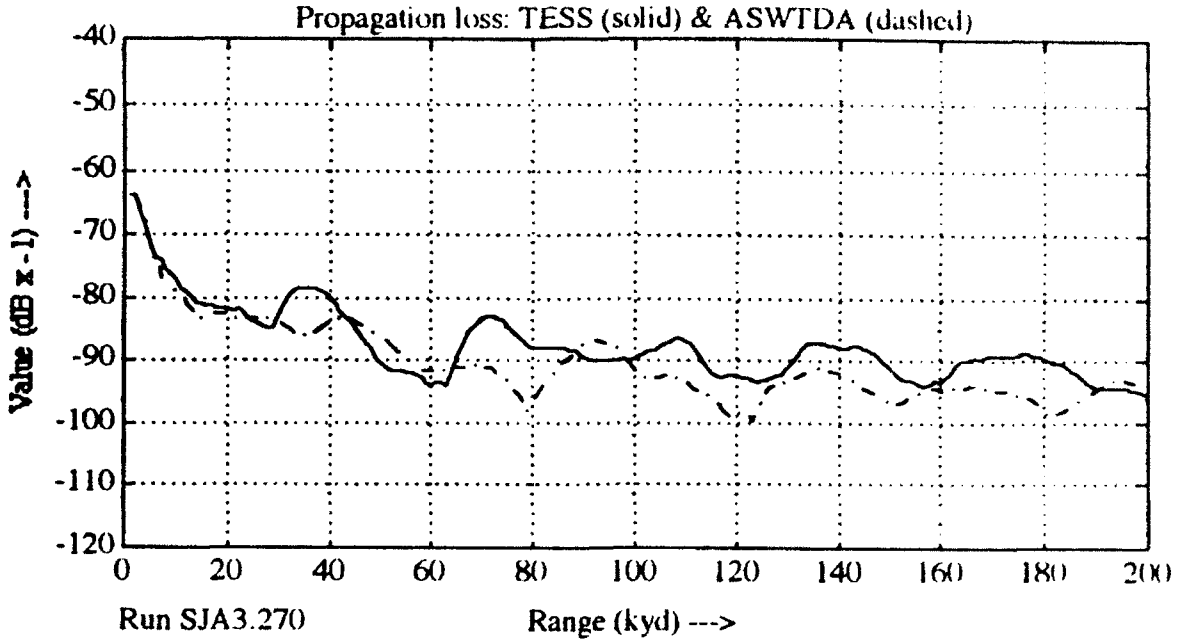


Figure 22 - Data for Sea of Japan, January. ASTRAL, 270 Degrees



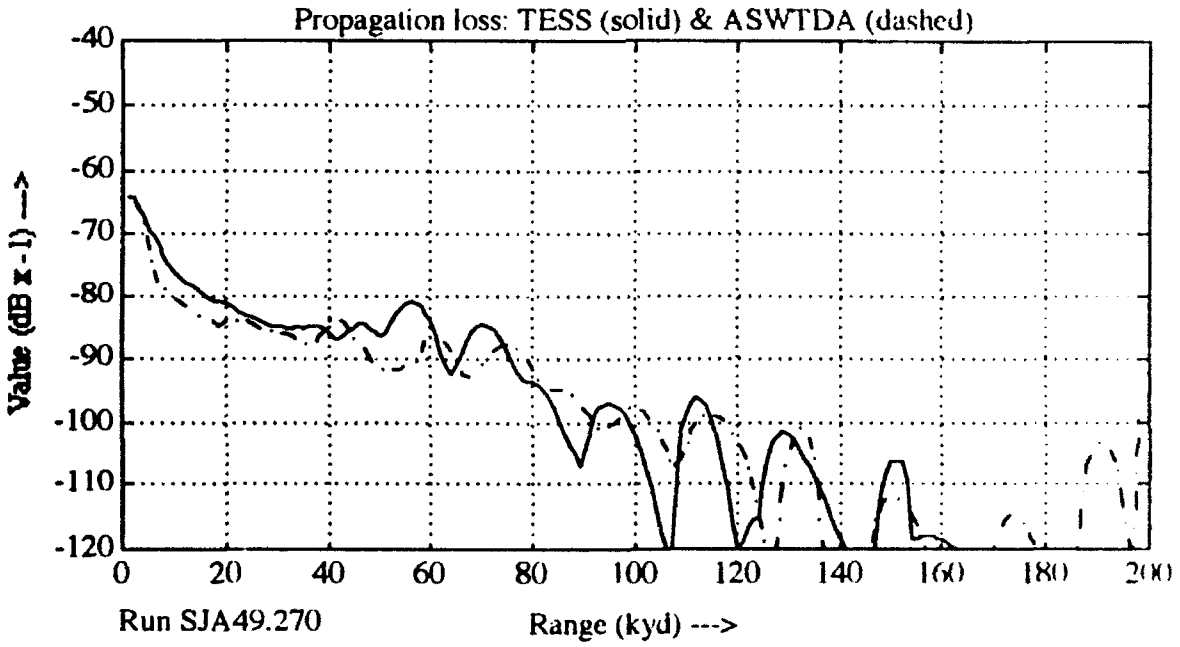
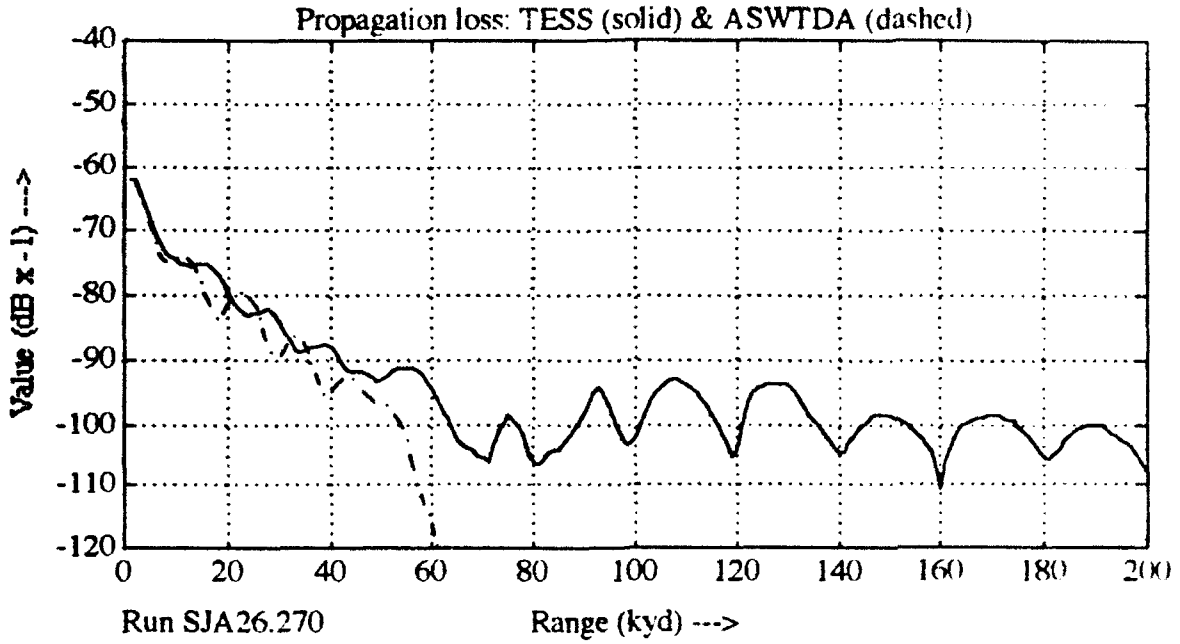


Figure 23 - Proploss for array pair SJA, run 3 (upper) and 49 (lower)



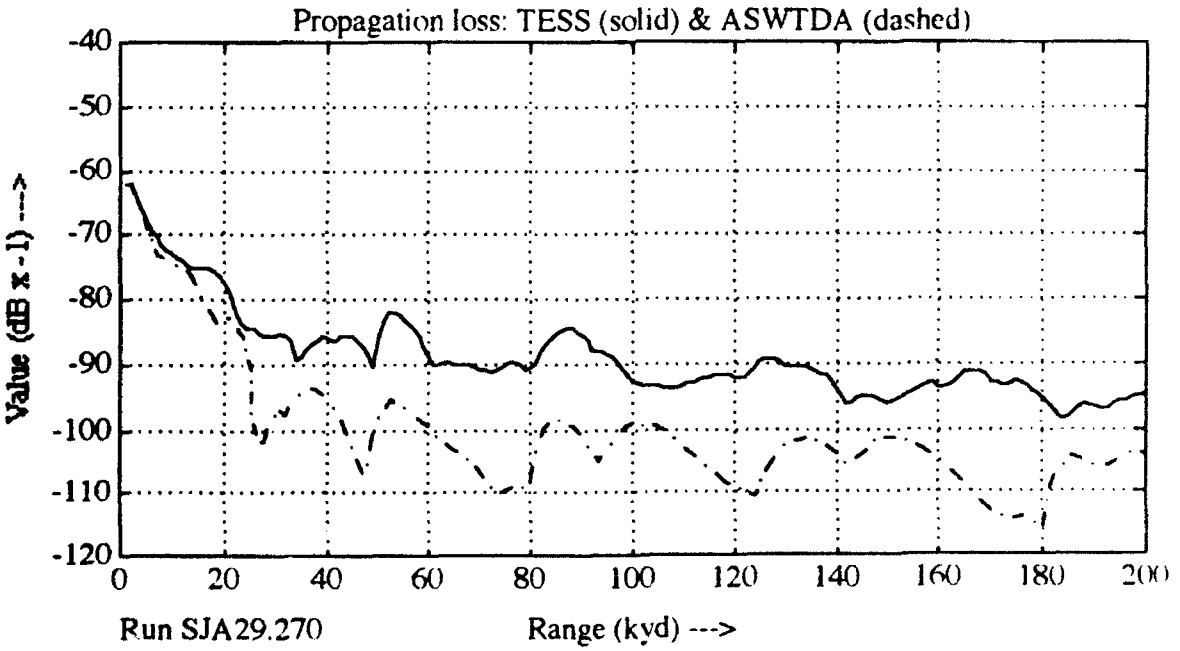


Figure 24 - Proploss for array pair SJA, run 26 (upper) and 29 (lower)

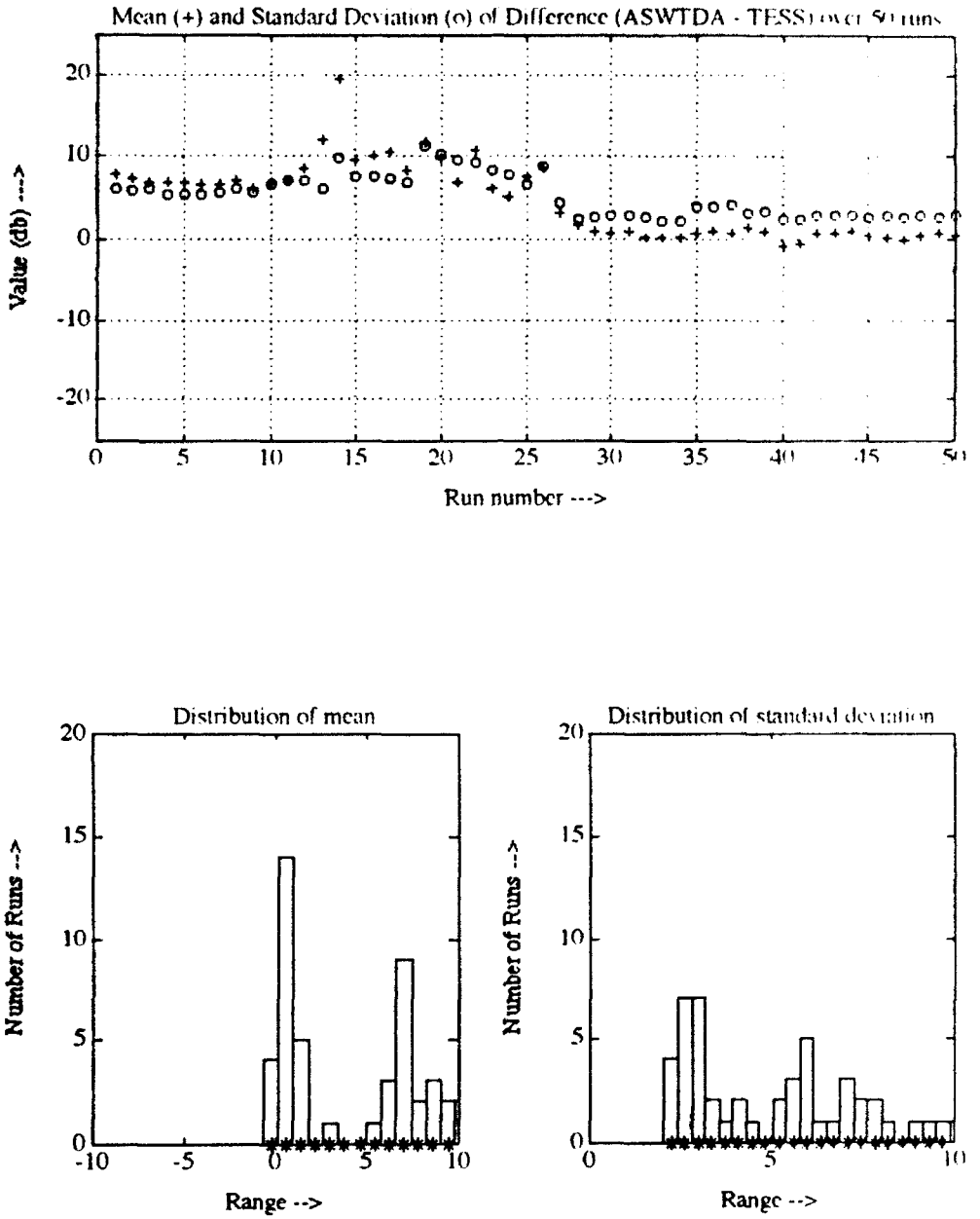
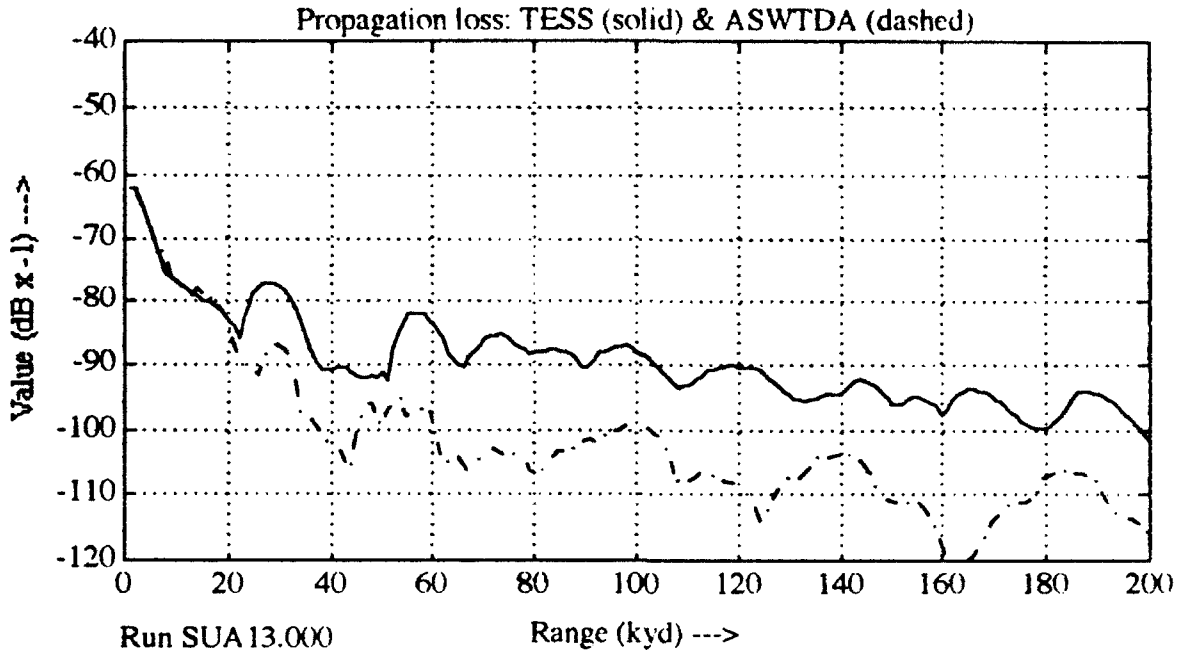


Figure 25 - Data for Sea of Japan, July, ASTRAL, 000 Degrees



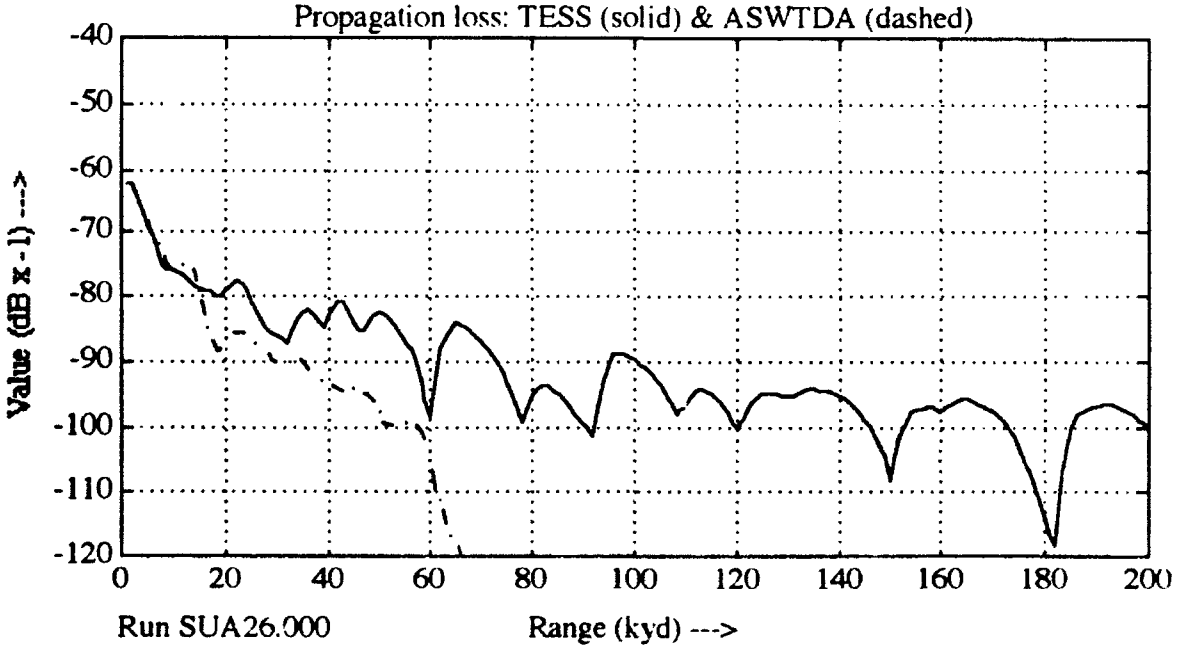


Figure 26 - Proploss for array pair SUA, run 13 (upper) and 26 (lower)

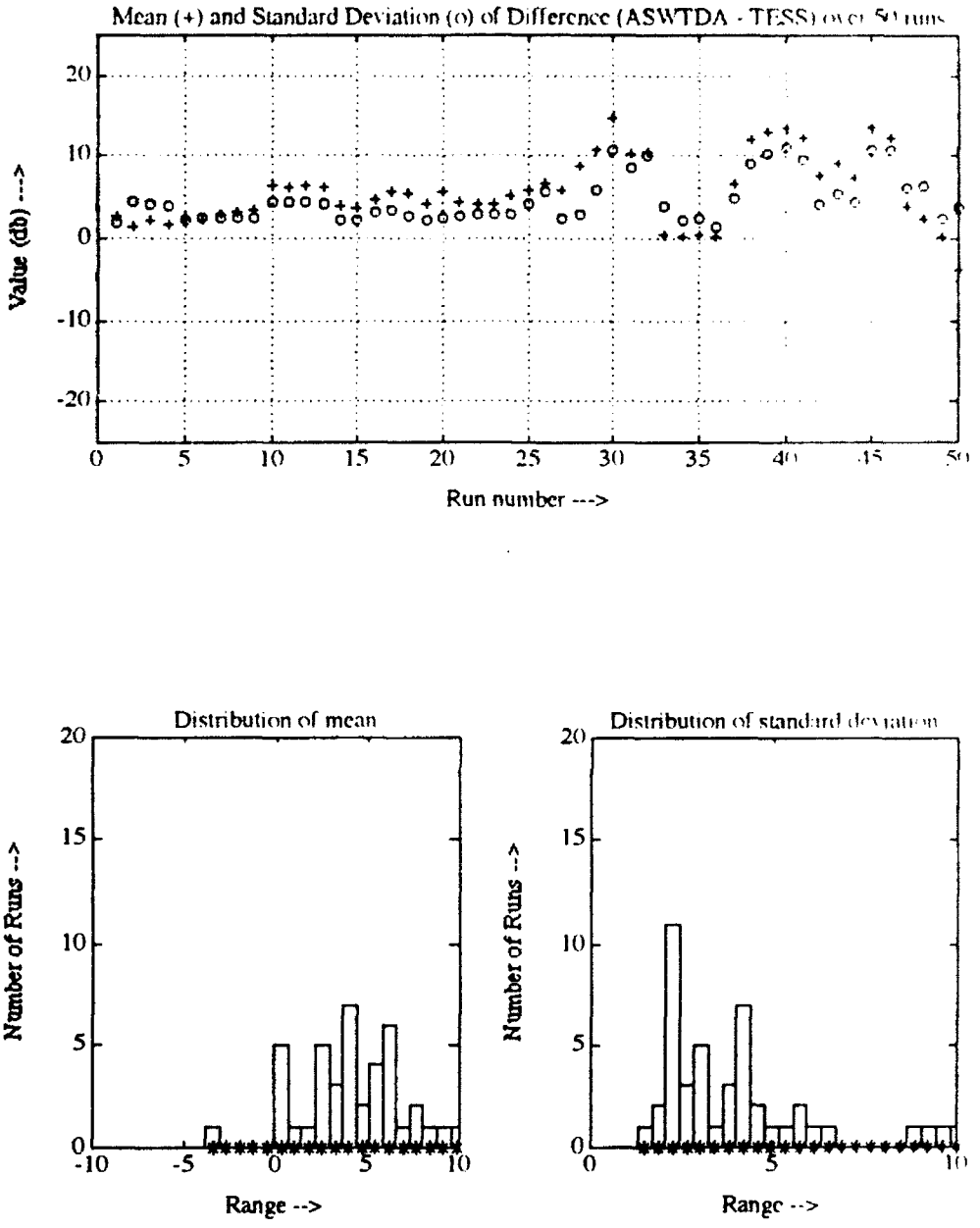
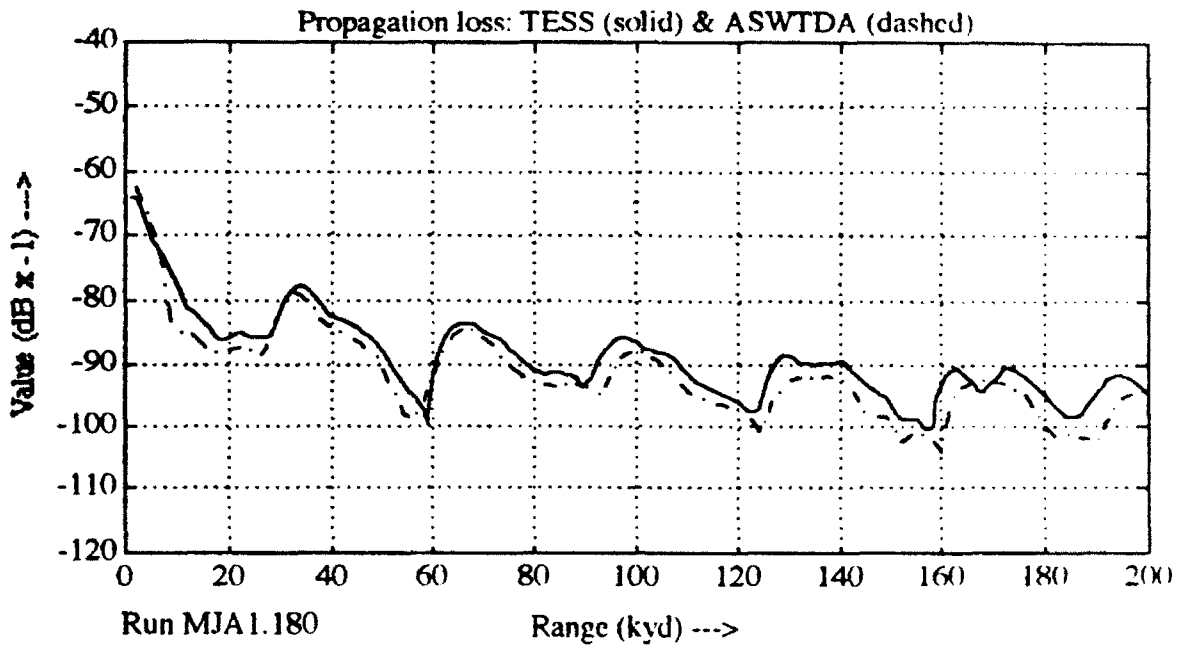


Figure 27 - Data for Mediterranean, January, ASTRAL, 180 Degrees



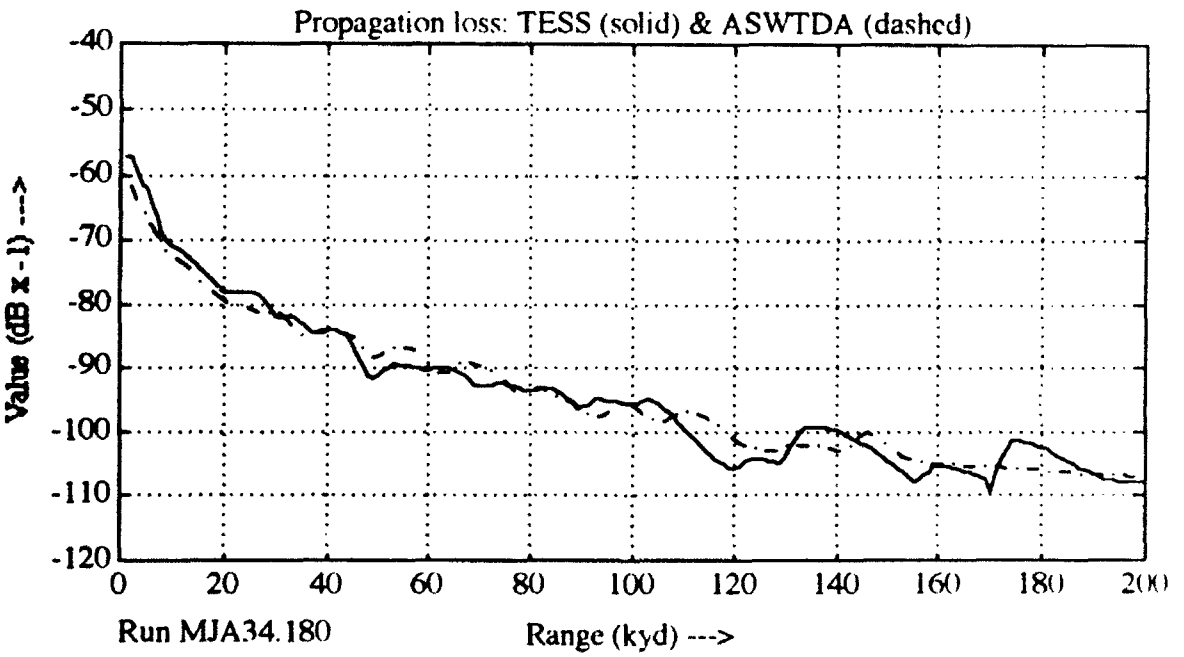
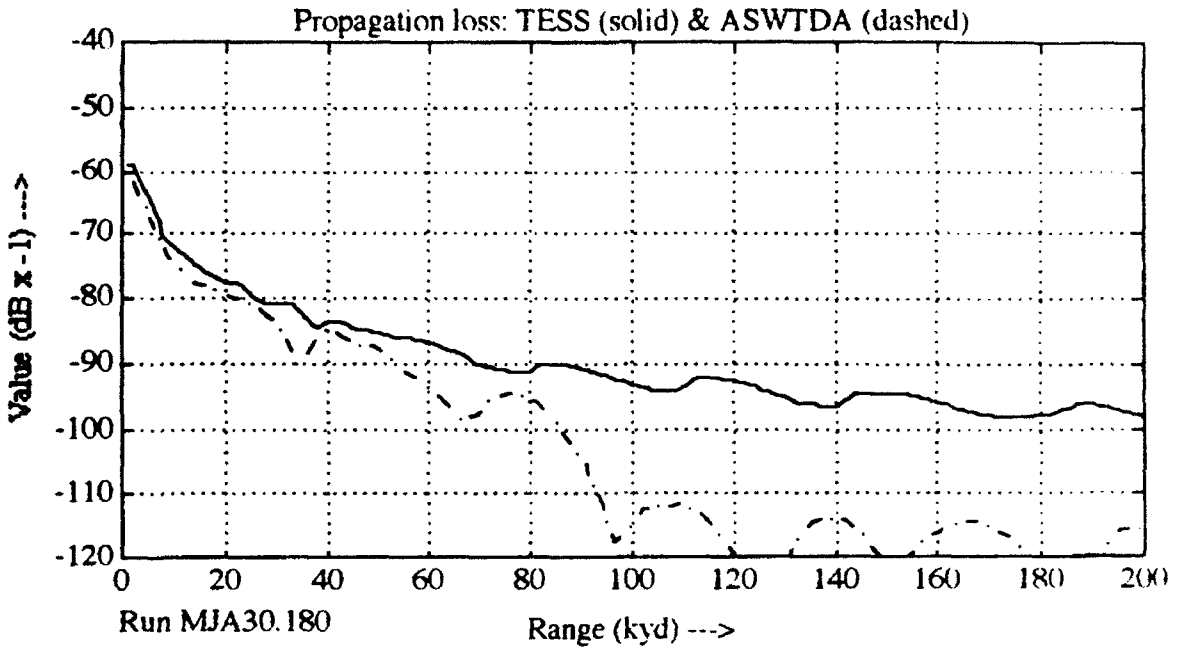


Figure 28 - Proploss for array pair MJA, run 1 (upper) and 34 (lower)



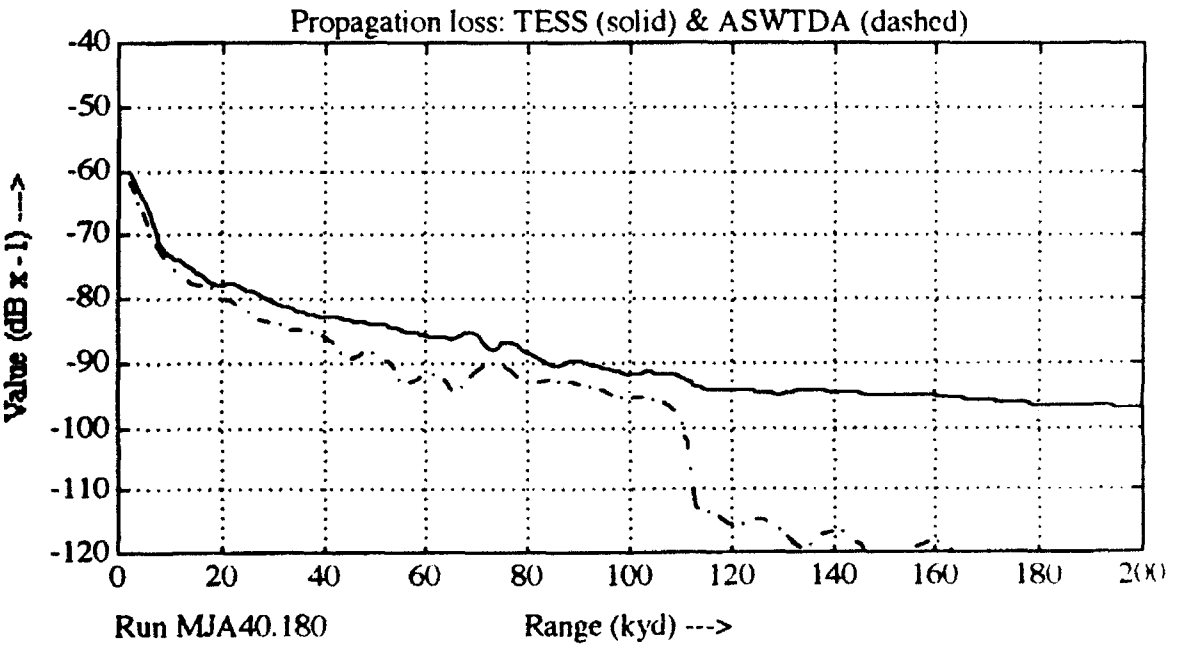


Figure 29 - Proploss for array pair MJA, run 30 (upper) and 40 (lower)

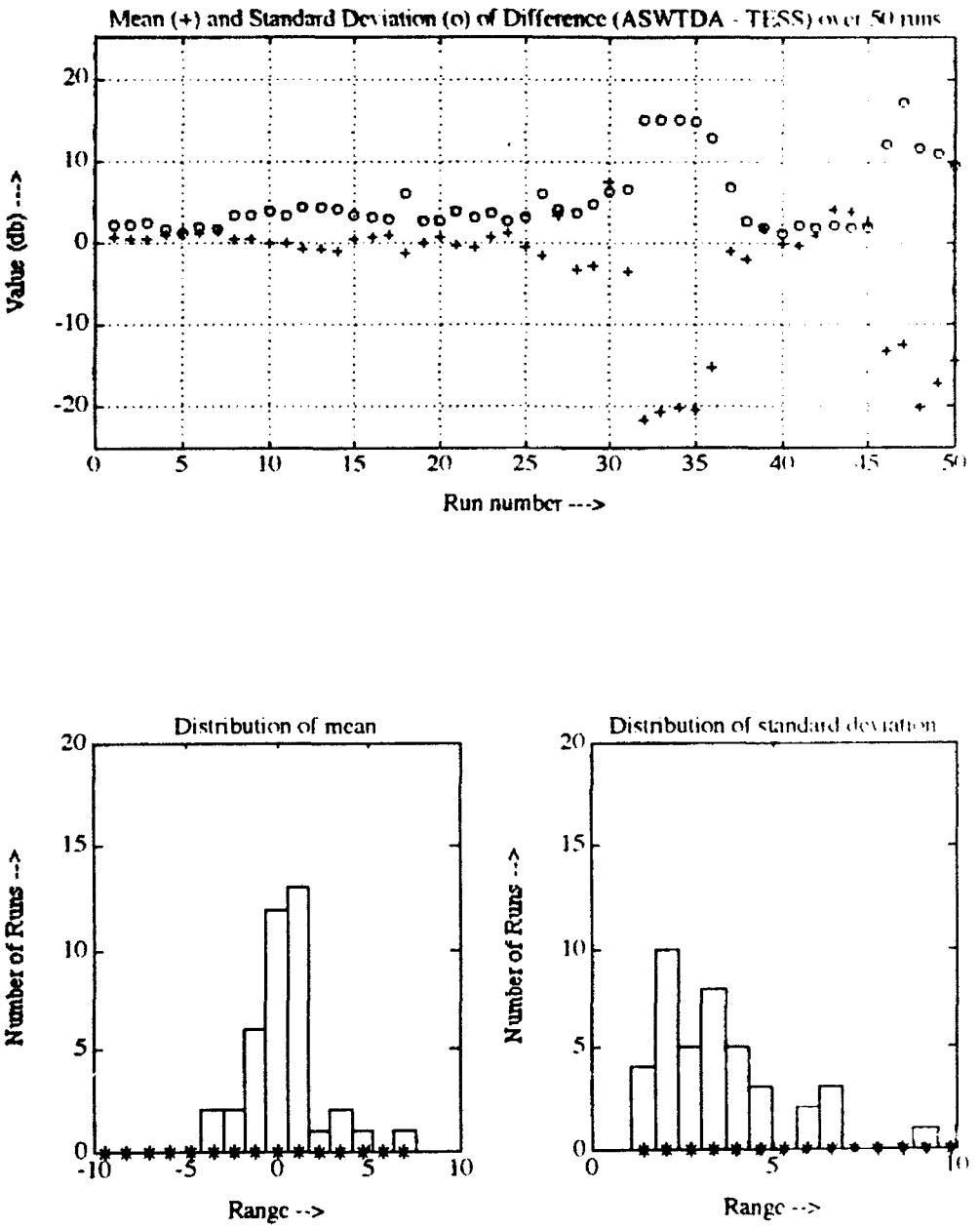
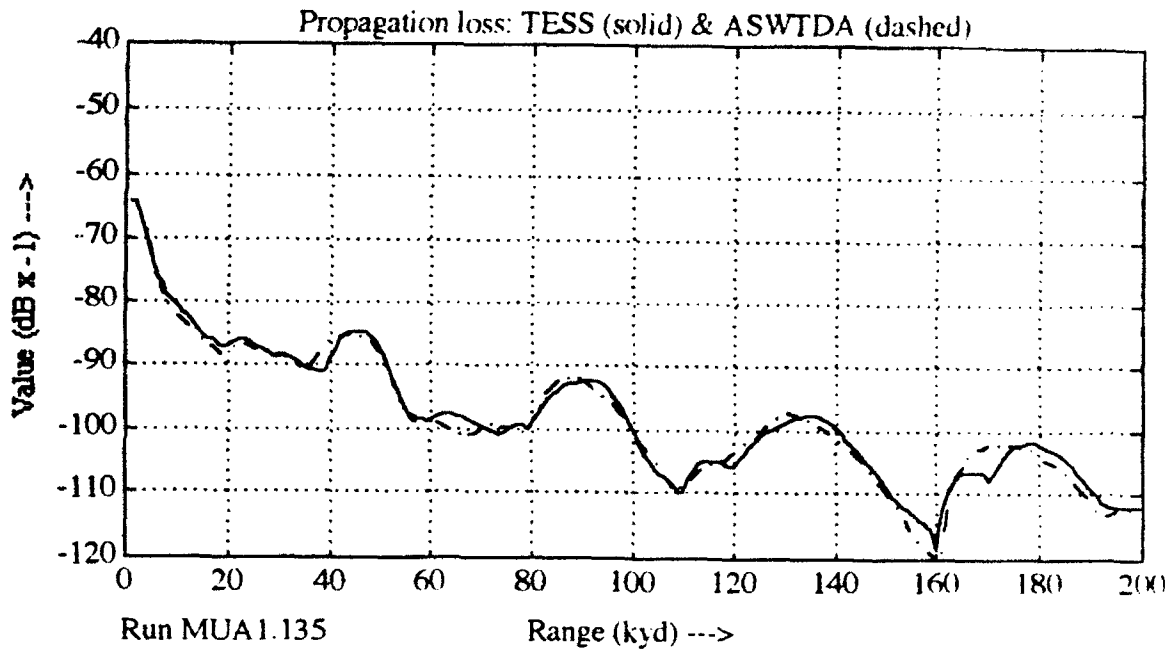


Figure 30 - Data for Mediterranean, July, ASTRAL, 135 Degrees



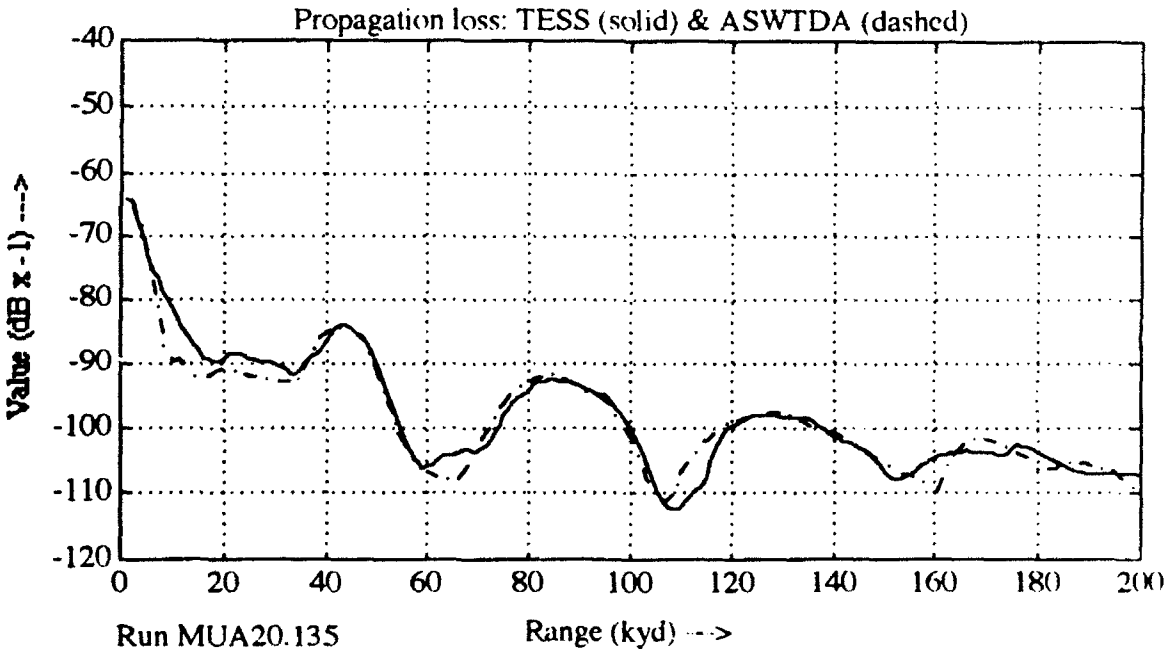
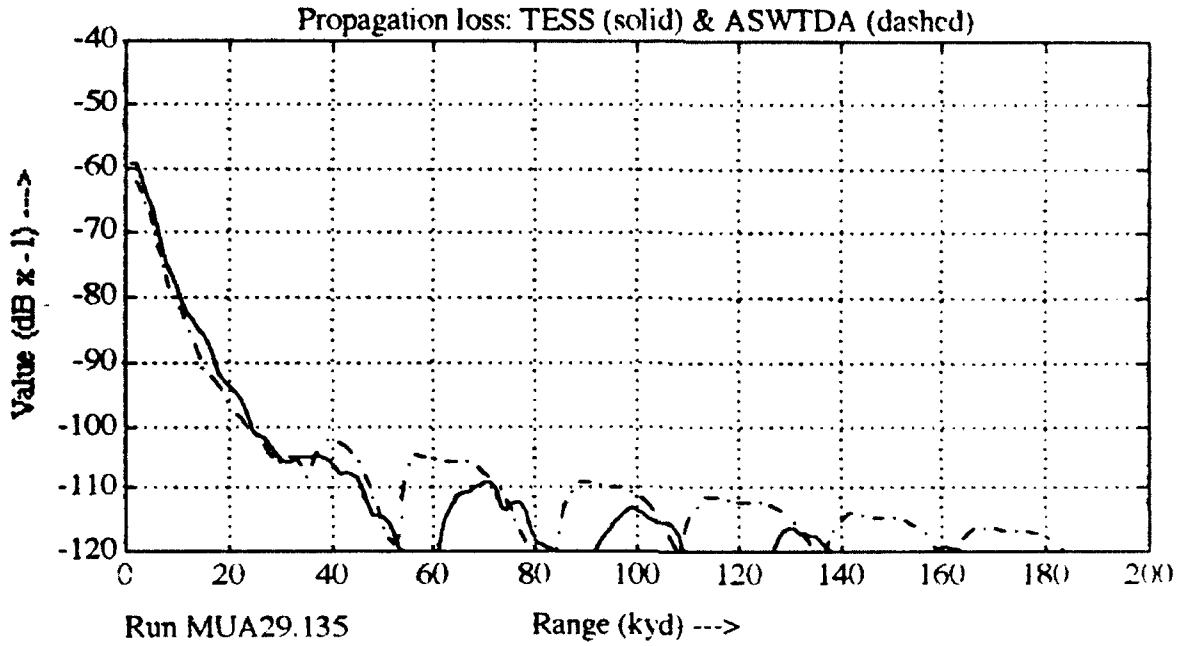


Figure 31 - Proploss for array pair MUA, run 1 (upper) and 20 (lower)



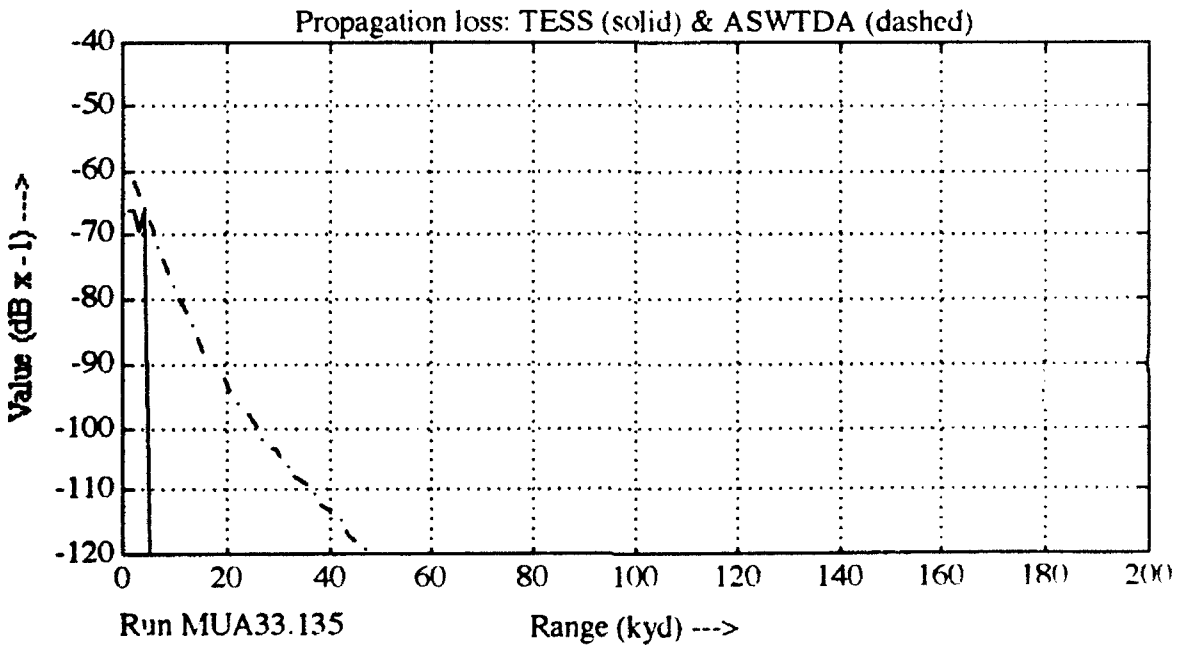
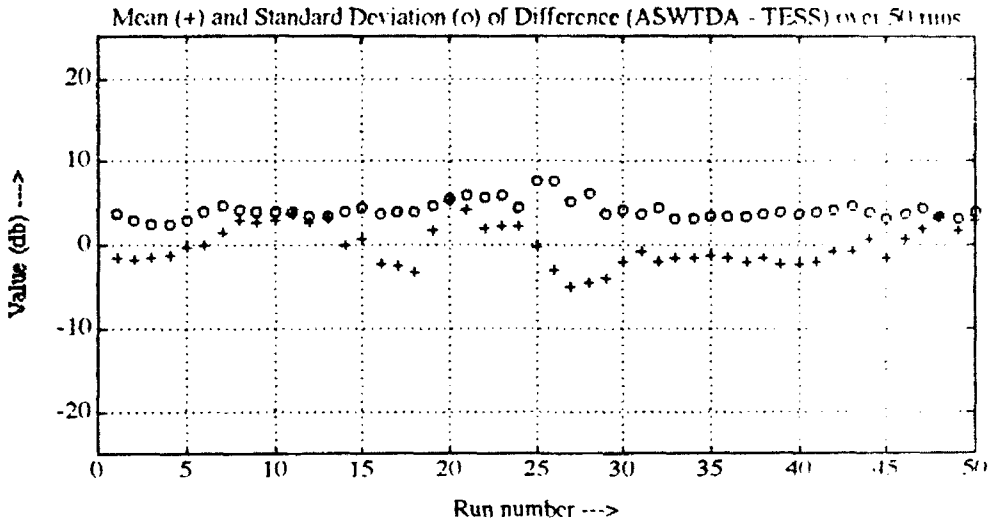


Figure 32 - Proploss for array pair MUA, run 29 (upper) and 33 (lower)



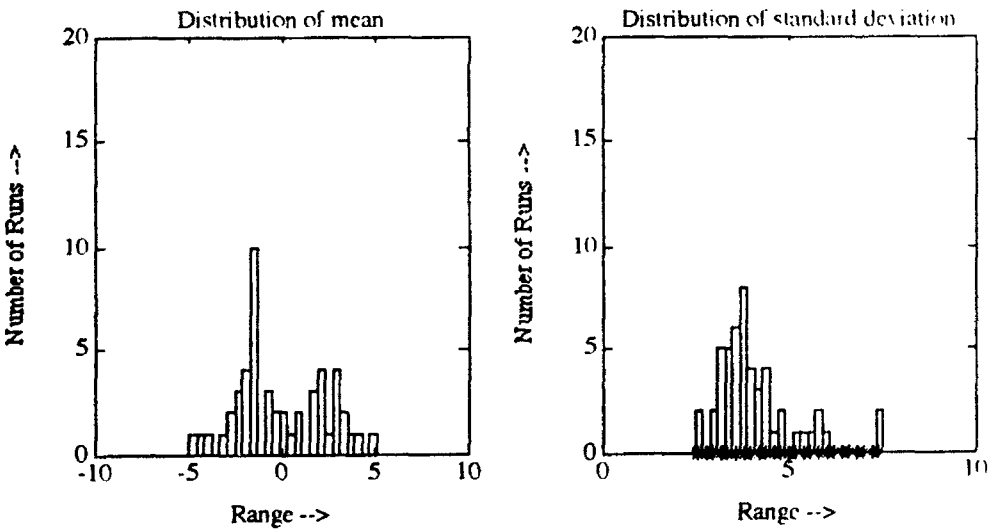
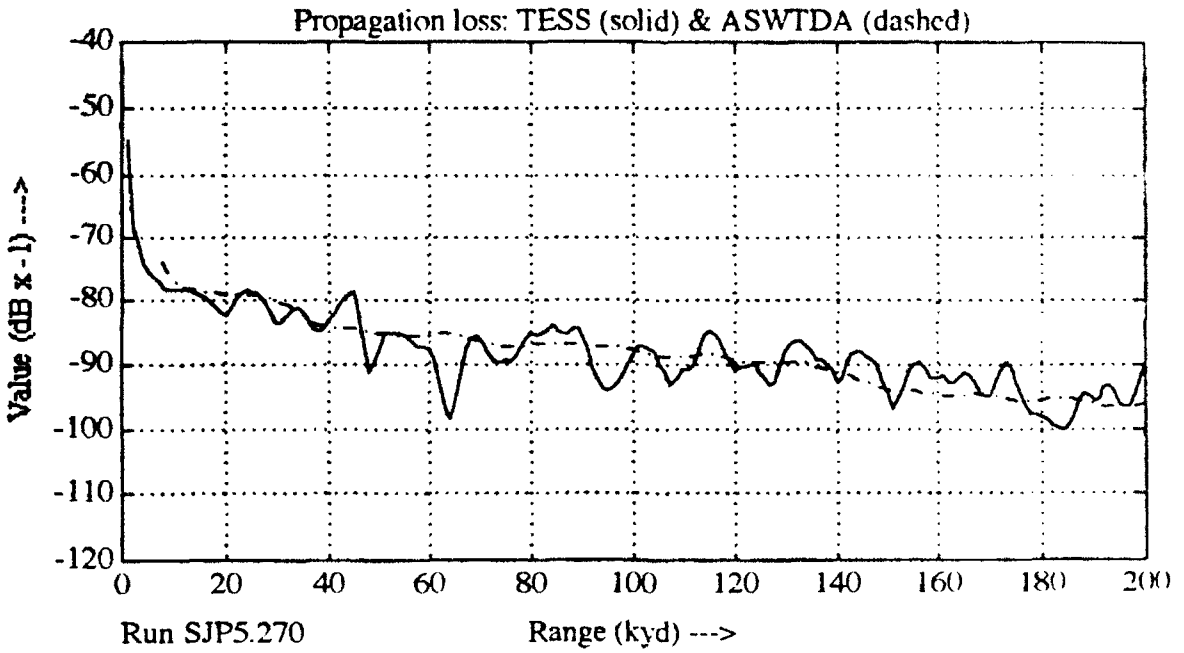


Figure 33 - Data for Sea of Japan, January, PE, 270 Degrees



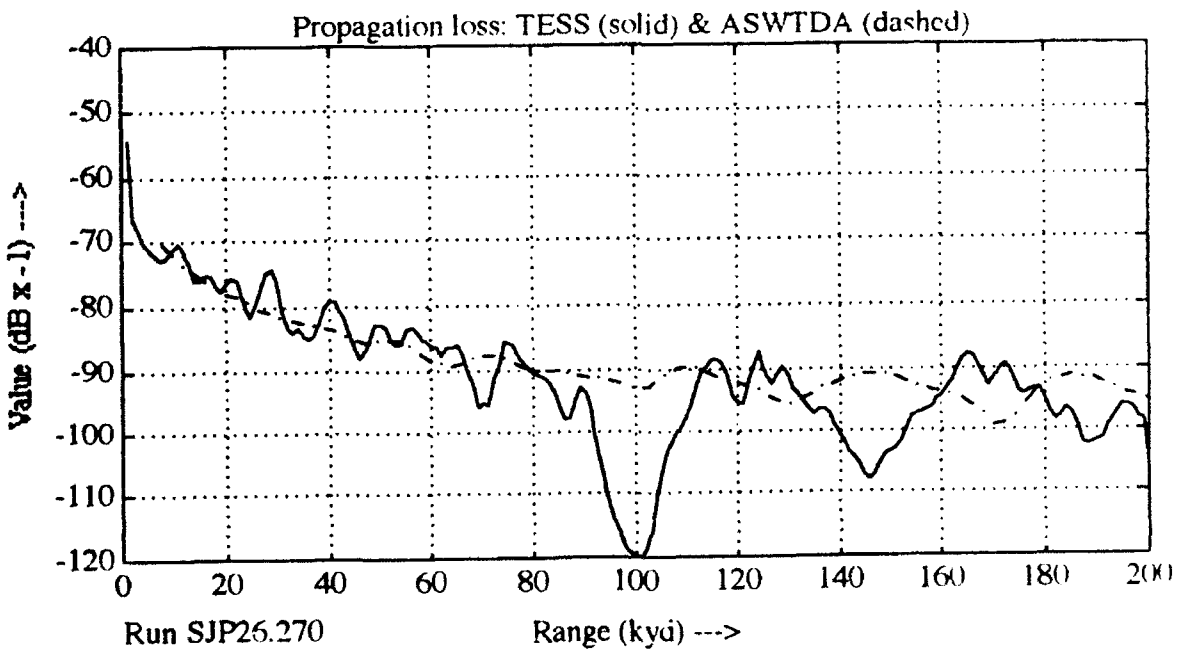


Figure 34 - Proploss for array pair SJP, run 5 (upper) and 26 (lower)

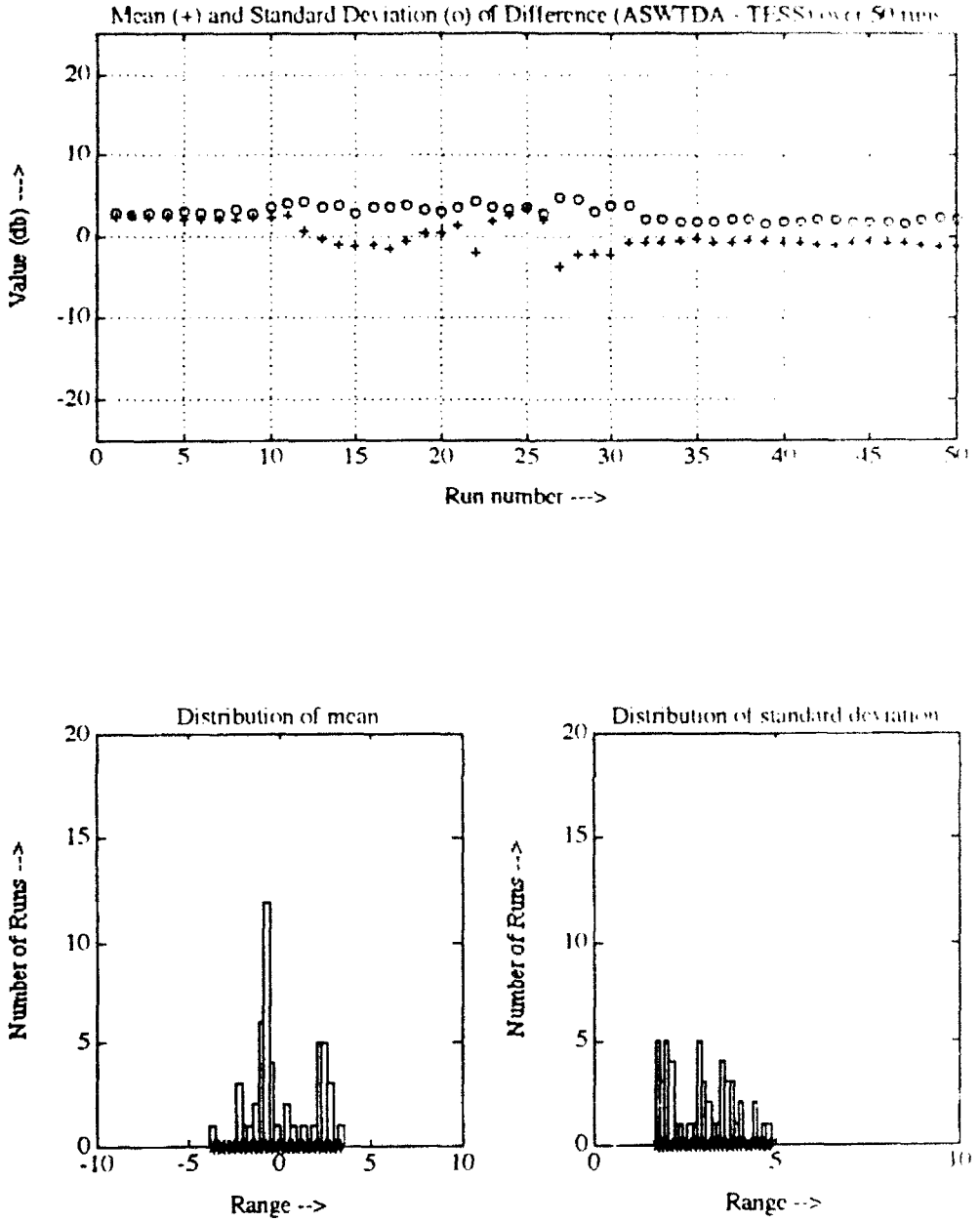


Figure 35 - Data for Sea of Japan, July, PE, 000 Degrees

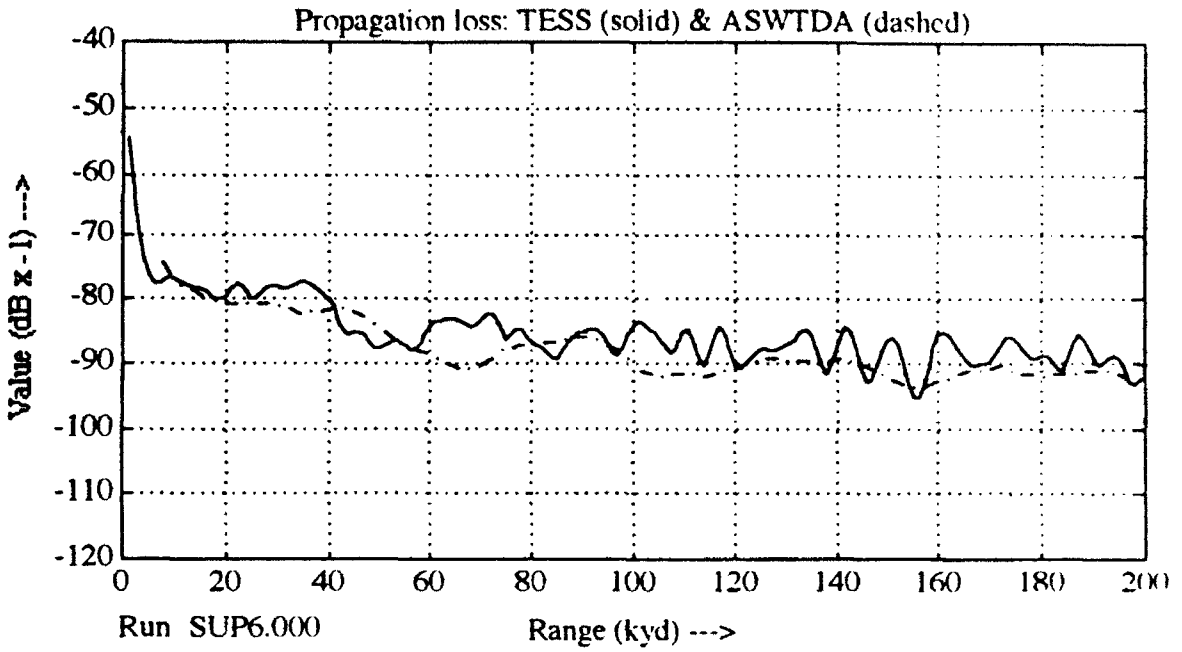
As was the case for the January data, ASWTDA followed the TESS envelope but without the local variations. Proploss curves for runs 6 and 40 illustrate the same effect (figure 36). Calculations for July data were made along a bearing of 000 degrees, with the result that for most runs, the bottom was downsloping to an abyssal plain, and considerably less bathymetrically complex than those of the January array pair .

2. Mediterranean

The January array pair shows tightly distributed mean difference of -2 to -4 dB over most of the runs (extremes of -9 to 0 dB) and standard deviation of 2 to 4. Distribution of means indicates a very pronounced bias of -2 dB (figure 37). Proploss curves show reasonable TESS to ASWTDA agreement (figure 38), though as in the case of the Sea of Japan data, ASWTDA does not show as much local variation.

For the first half of the July array pair, a very consistent mean difference of -4 to -2 dB and standard deviation of 1 to 2.5 is seen (figure 39). Means for the latter half of track vary much more than the first half. The distribution of mean differences in Figure 39 shows ASWTDA with a distinct bias of -2 dB relative to TESS. Propagation loss curves for runs 5, 22 and 35 (figure 40) illustrate a fair degree of concurrence between the APP's.

For the Mediterranean data, runs 1-27 were over a near flat, featureless basin of depth 2000 meters (and deeper), while runs 28 and above were in shallowing water.



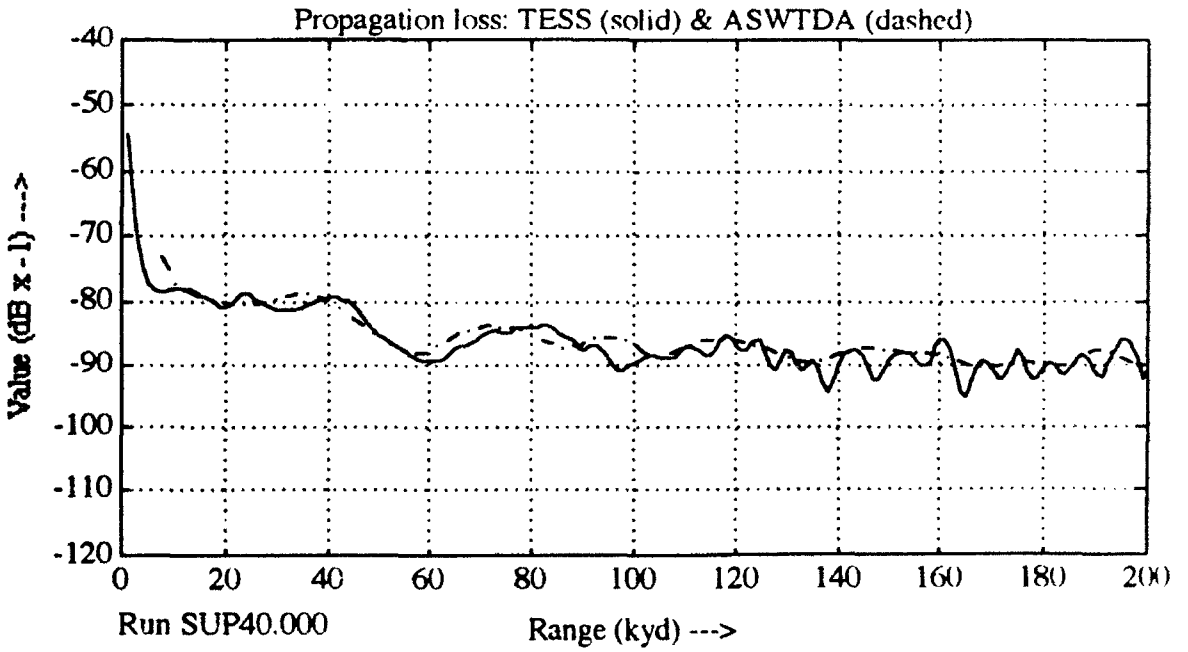
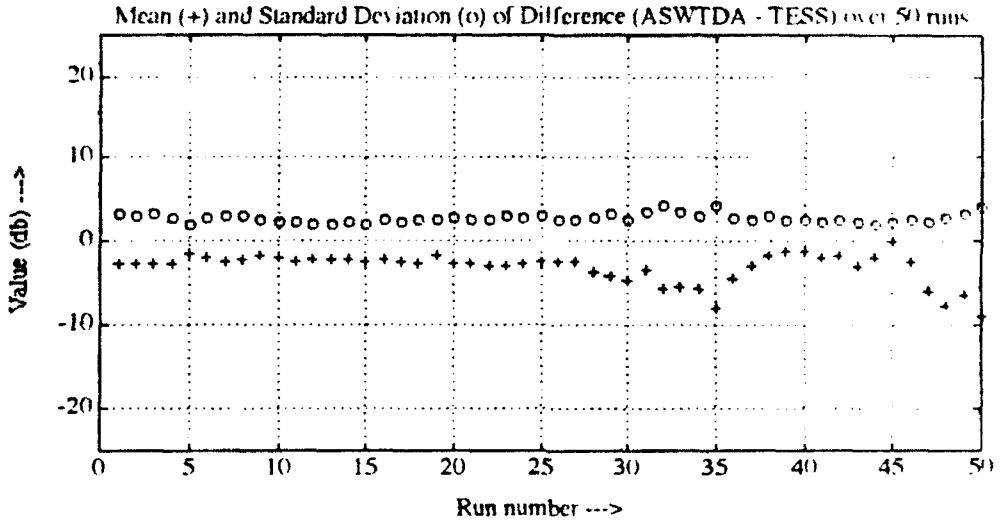


Figure 36 - Proploss for array pair SUP, run 6 (upper) and 40 (lower)



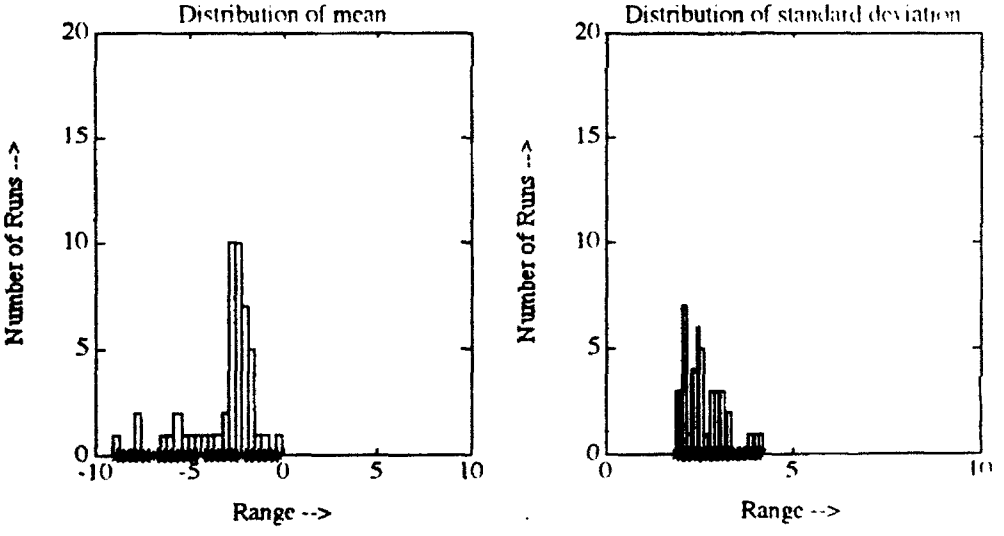
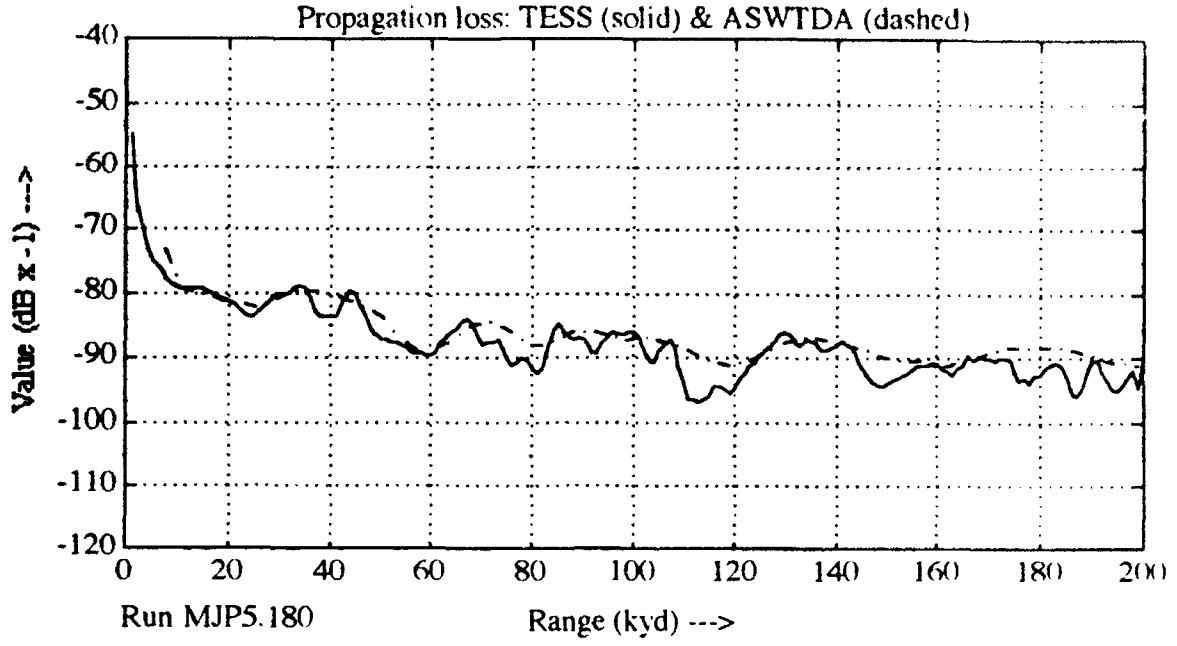


Figure 37 - Data for Mediterranean, January, PE, 180 Degrees



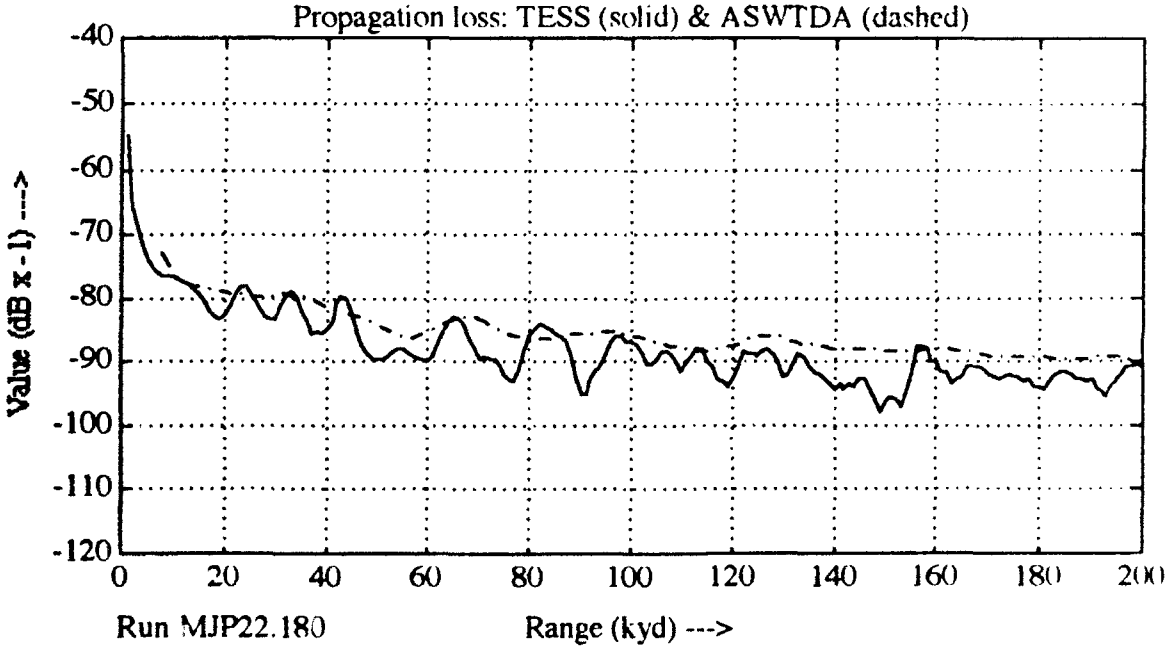


Figure 38 - Proploss for array pair MJP, run 5 (upper) and 22 (lower)

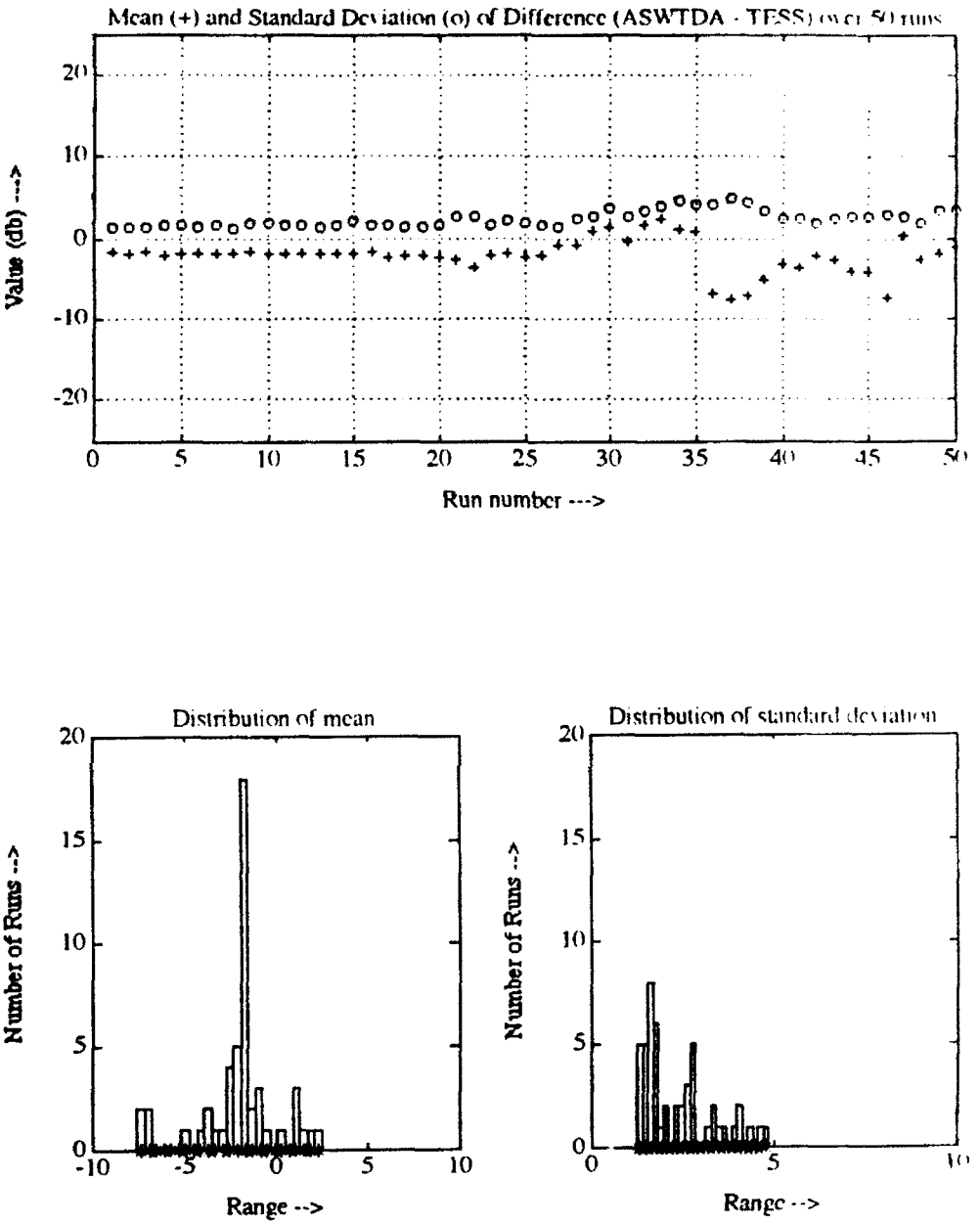
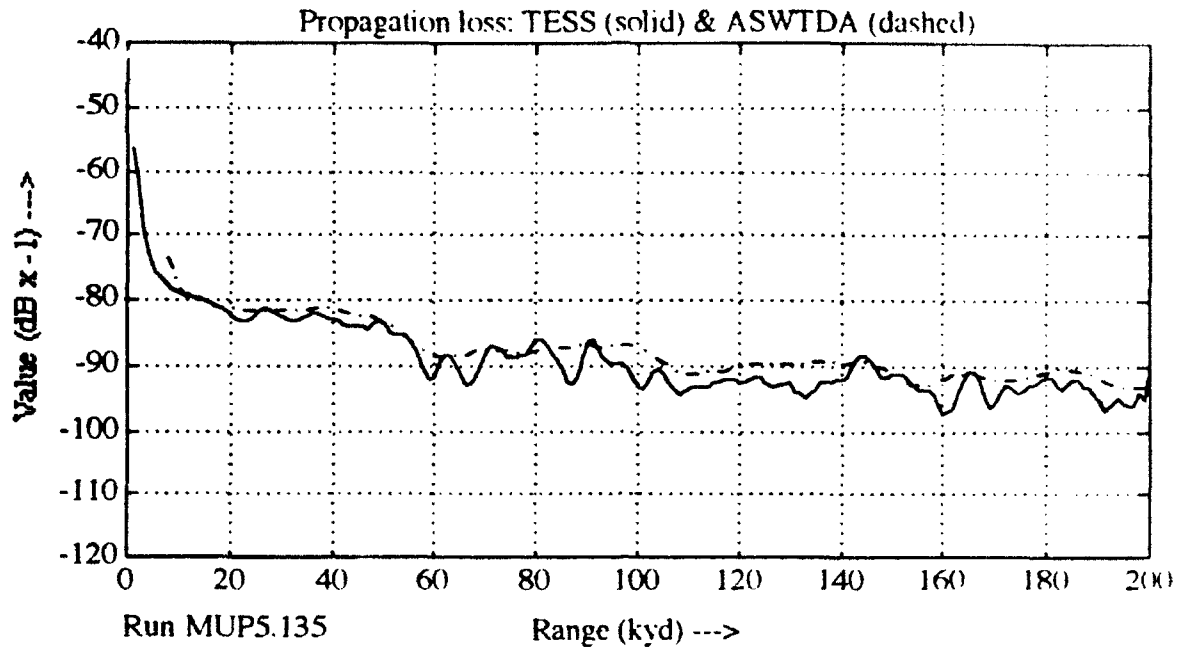


Figure 39 - Data for Mediterranean, July, PE, 135 Degrees



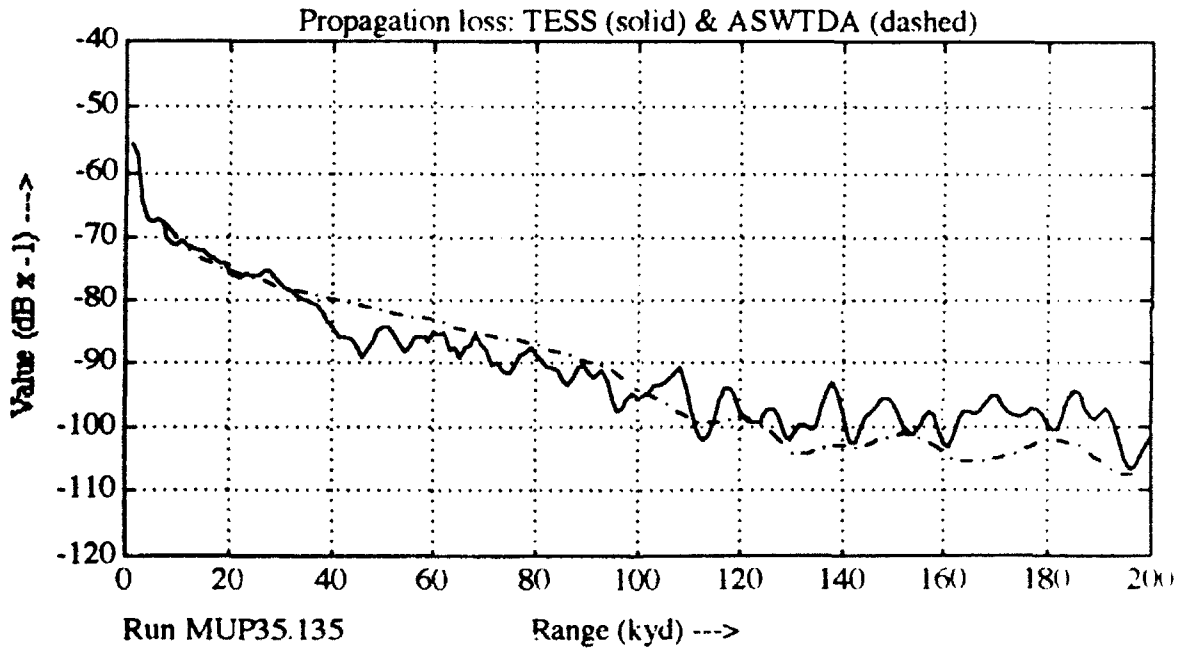


Figure 40 - Proploss for array pair MUP, run 5 (upper) and 35 (lower)

D. COMPARISON OF SIMILARITY

While sections A through C above examined the statistical aspects of the APP's, an analysis of how "similar" ASWTDA and TESS range predictions might be with respect to transmission loss and range-to-detection was also conducted.

1. Similarity between ASWTDA and TESS transmission loss

Following the convention as described in II.C.2, notional FOM's and similarity criteria were established. Using the passive sonar equation, FOM is identically propagation loss, and is used to enter the propagation loss curves as the ordinate value to determine range, the objective value [Ref. 12].

Tables II and III delineate the results for direct path and extended range detections for each array pair, in terms of similarity scores. Similarity, defined in section II.C.2, varied between 0 to 84 percent; scores of less than 50 percent are shaded and represent poor concurrence between ASWTDA and TESS.

For direct path ranges, ASWTDA concurrence with TESS is best at lowest FOM using RAYMODE, and worst at lowest FOM using PE. Table III suggests that for extended ranges (bottom bounce, convergence zone) much variability exists. ASWTDA agreed best with TESS at lowest FOM using RAYMODE, and worst at the medium FOM using ASTRAL. As previously noted, there was less agreement between the APP' at higher frequencies.

2. Range-to-detection difference between ASWTDA and TESS

To assess the likely overall error in predicting range-to-detection, the mean value of point-to-point difference between the APP's was calculated, and is tabulated in Tables IV and V. Observation of the data (Table IV) indicates that for direct path ranges, agreement between the APP's is best at the lowest FOM. The magnitude of the mean range error is .4 to 2.7 Kyd for RAYMODE, .3 to 2.3 Kyd

for ASTRAL, and 2.7 to 6.5 Kyd for PE. For RAYMODE and ASTRAL models, the range error is variable in sign, while for PE, ASWTDA shows a consistent negative bias (ASWTDA always predicts shorter ranges than TESS). In general, direct path range differences between ASWTDA and TESS on the order of plus or minus several Kyd can be expected using RAYMODE or ASTRAL, and minus four to five Kyd can be expected using PE.

Table V shows that at extended range the magnitude of the range difference between ASWTDA and TESS varies enormously between winter and summer cases for RAYMODE at the lowest FOM. The sign of the error varies for both RAYMODE and ASTRAL, but as in the case of direct path predictions, is consistently negative for PE.

3. Similarity versus geographic location

Trends in similarity between the three models used in ASWTDA and TESS are noted at some geographic locations. At the lowest FOM analyzed (75 dB), Sea of Japan runs 17 through 22 produced poor similarity scores in all 3 models over both seasons, while runs 4 through 8, 23 through 25 and 38 through 41 resulted in much better similarity scores. Track one, runs 17 through 22 in the Sea of Japan were located over the Yamato Trough, in areas of rapidly changing bathymetric relief.

Mediterranean runs 2 through 18 produced high similarity scores, runs 19-36 were variable in score, and runs 37 through 50 produced poor similarity. Track 2 through the Mediterranean was such that runs 25 through 50 were located in progressively shallowing waters. Bathymetry is responsible for the very different predictions noted between ASWTDA and TESS.

At FOM of 80 dB, results were similar to the 75 dB case. Concurrence between the APP's occurs only in regions of deep water with near flat bottom over the length of proploss calculation.

TABLE II. - SIMILARITY SCORES -

PERCENT OF ASWTDA TO TESS WITH SIMILAR RANGE PREDICTIONS

DIRECT PATH

Array Pair				FOM=75	FOM=80	FOM=85
Sea of Japan	- January	- RAYMODE -	50 Hz	84	26	42
Sea of Japan	- January	- RAYMODE -	300 Hz	84	32	38
Sea of Japan	- July	- RAYMODE -	20 Hz	30	44	38
Sea of Japan	- July	- RAYMODE -	500 Hz	84	38	18
Mediterranean	- January	- RAYMODE -	150 Hz	56	18	16
Mediterranean	- January	- RAYMODE -	500 Hz	32	12	10
Mediterranean	- July	- RAYMODE -	100 Hz	62	38	44
Mediterranean	- July	- RAYMODE -	1500 Hz	58	70	44
Sea of Japan	- January	- ASTRAL -	270 °	24	8	4
Sea of Japan	- July	- ASTRAL -	000 °	40	8	26
Mediterranean	- January	- ASTRAL -	180 °	17	10	16
Mediterranean	- July	- ASTRAL -	135 °	60	24	10
Sea of Japan	- January	- PE -	270 °	6	2	0
Sea of Japan	- July	- PE -	000 °	14	44	48
Mediterranean	- January	- PE -	180 °	2	22	22
Mediterranean	- July	- PE -	135 °	10	24	34

Similarity scores of less than 50% are shaded and represent poor concurrence between ASWTDA and TESS.

TABLE III - SIMILARITY SCORES -

PERCENT OF ASWTDA TO TESS WITH SIMILAR RANGE PREDICTIONS

EXTENDED RANGE

Array Pair	FOM=75	FOM=80	FOM=85
Sea of Japan - January - RAYMODE - 50 Hz	0	24	16
Sea of Japan - January - RAYMODE - 300 Hz	28	42	18
Sea of Japan - July - RAYMODE - 20 Hz	46	20	16
Sea of Japan - July - RAYMODE - 500 Hz	12	14	12
Mediterranean - January - RAYMODE - 150 Hz	0	6	8
Mediterranean - January - RAYMODE - 500 Hz	2	20	16
Mediterranean - July - RAYMODE - 100 Hz	0	44	30
Mediterranean - July - RAYMODE - 1500 Hz	0	0	26
Sea of Japan - January - ASTRAL - 270 °	0	0	2
Sea of Japan - July - ASTRAL - 000 °	0	6	0
Mediterranean - January - ASTRAL - 180 °	0	10	2
Mediterranean - July - ASTRAL - 135 °	0	0	28
Sea of Japan - January - PE - 270 °	0	2	0
Sea of Japan - July - PE - 000 °	0	16	41
Mediterranean - January - PE - 180 °	0	22	30
Mediterranean - July - PE - 135 °	0	0	0

Similarity scores of less than 50% are shaded and represent poor concurrence between ASWTDA and TESS.

TABLE IV - PREDICTED MEAN RANGE DIFFERENCE IN KYDS

FOR 3 FOM'S - ASWTDA MINUS TESS

DIRECT PATH

Array Pair	FOM=75	FOM=80	FOM=85
Sea of Japan - January - RAYMODE - 50 Hz	**-1.5**	**4.1**	**3.3**
Sea of Japan - January - RAYMODE - 300 Hz	**-1.7**	**3.2**	**12.0**
Sea of Japan - July - RAYMODE - 20 Hz	**2.4**	**5.3**	**-3.7**
Sea of Japan - July - RAYMODE - 500 Hz	**-0.4**	**0.8**	**-4.0**
Mediterranean - January - RAYMODE - 150 Hz	**-2.7**	**-3.5**	**-19.6**
Mediterranean - January - RAYMODE - 500 Hz	**-3.4**	**-5.1**	**-16.9**
Mediterranean - July - RAYMODE - 100 Hz	**-0.8**	**0.9**	**0.6**
Mediterranean - July - RAYMODE - 1500 Hz	**1.1**	**1.5**	**2.9**
Sea of Japan - January - ASTRAL - 270 °	**1.5**	**3.9**	**8.3**
Sea of Japan - July - ASTRAL - 000 °	**0.6**	**3.6**	**10.8**
Mediterranean - January - ASTRAL - 180 °	**2.3**	**9.2**	**14.1**
Mediterranean - July - ASTRAL - 135 °	**-0.3**	**-0.2**	**-0.8**
Sea of Japan - January - PE - 270 °	**-4.6**	**-10.8**	**-24.4**
Sea of Japan - July - PE - 000 °	**-2.7**	**-0.5**	**-6.2**
Mediterranean - January - PE - 180 °	**-6.5**	**-13.1**	**-22.2**
Mediterranean - July - PE - 135 °	**-3.8**	**-7.8**	**-14.3**

TABLE V - PREDICTED MEAN RANGE DIFFERENCE IN KYDS

FOR 3 FOM'S - ASWTDA MINUS TESS

EXTENDED RANGE

Array Pair	FOM=75	FOM=80	FOM=85
Sea of Japan - January - RAYMODE - 50 Hz	**-22.1**	**13.9**	**-14.8**
Sea of Japan - January - RAYMODE - 300 Hz	**-17.5**	**-2.1**	**-0.41**
Sea of Japan - July - RAYMODE - 20 Hz	**0.4**	**-1.3**	**-26.2**
Sea of Japan - July - RAYMODE - 500 Hz	**-1.8**	**-6.4**	**-6.1**
Mediterranean - January - RAYMODE - 150 Hz	-	**-7.8**	**-3.8**
Mediterranean - January - RAYMODE - 500 Hz	**-25.0**	**-8.2**	**18.9**
Mediterranean - July - RAYMODE - 100 Hz	-	**-1.5**	**2.9**
Mediterranean - July - RAYMODE - 1500 Hz	-	-	**-12.6**
Sea of Japan - January - ASTRAL - 270 °	-	**21.6**	**6.6**
Sea of Japan - July - ASTRAL - 000 °	-	**-2.3**	**11.2**
Mediterranean - January - ASTRAL - 180 °	-	**-8.2**	**5.8**
Mediterranean - July - ASTRAL - 135 °	-	-	**-4.4**
Sea of Japan - January - PE - 270 °	-	**-4.8**	**-35.4**
Sea of Japan - July - PE - 000 °	-	**-3.6**	**-9.4**
Mediterranean - January - PE - 180 °	-	**-1.5**	**-11.8**
Mediterranean - July - PE - 135 °	-	-	**-15.6**

IV. CONCLUSIONS

ASWTDA and TESS do not produce consistently similar predictions in transmission loss or range-to-detection. Wide variations in the mean difference and standard deviation between the systems, as well as wide fluctuations in predicted transmission loss and range, have been demonstrated for both the Sea of Japan and the Mediterranean, during both January and July, for all source frequencies, source and receiver depths and bearings investigated. Mean differences between ASWTDA and TESS for individual runs over the length of tracks one and two are shown to vary by as much as ± 20 dB with standard deviation as much as 15 dB.

Similarity scores of ASWTDA and TESS as measured by transmission losses and resulting range-to-detection are also highly variable. RAYMODE shows the best overall similarity, while ASTRAL was the worst. Relative to TESS, ASWTDA shows a constant negative range bias for the PE model, and a mixed positive/negative bias for the ASTRAL and RAYMODE models. Transmission loss differences relative to TESS output will be on the order of several dB for RAYMODE, plus or minus four to six dB for ASTRAL, and minus four to minus six dB for PE. Range bias expected for RAYMODE is of the order of several Kyd, five Kyd for ASTRAL and ten Kyd for PE at direct path ranges. Range bias for extended ranges is highly variable; relative to TESS, ASWTDA shows a constant negative range bias when PE is considered, and mixed negative/positive bias for RAYMODE and ASTRAL, but in many cases observed, ASWTDA predicts no extended range when TESS does.

Bathymetry over the acoustic path and initial water depth appear to be important factors in determining how well ASWTDA and TESS agree. Over relatively flat bottom and deep water conditions, all models show some degree of similarity of prediction at direct path ranges. However, regions of complex bathymetry (Sea of Japan) and water depths less than 1000 meters (Mediterranean) are coincident with highly variable predictions between the APP's. Similarity of prediction under all conditions for extended ranges was very poor.

No attempt to benchmark either ASWTDA or TESS to empirically gathered data was attempted, thus no conclusion as regards which of these APP's might better reflect reality is made. However, inasmuch as TESS represents a Navy standard Acoustic Prediction Product, ASWTDA is seldom in agreement with the current standard.

Because the models used by ASWTDA and TESS are identical (excepting RAYMODE, where the best concurrence was obtained), it is concluded that ASWTDA's GEM database is significantly different than TESS's standard OAML database.

Using the similarity criterion developed in Chapter II, and after analysis of transmission losses and predicted range-to-detection, it is seen that ASWTDA output is not similar to TESS output. It is likely that fleet operators using both TESS and ASWTDA will obtain significantly different predictions of passive propagation loss and range-to-detection.

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4. SONALYSTS, Inc., facsimile *Database versions of ASWTDA v.2.1.2.1*, 23 February 1993.

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8. Naval Underwater Systems Center, NUSC-TM-771245, *Criteria for Propagation Loss Model Assessment for APP Application*, Leibiger, G.A., pp.5, 7 December 1977.

9. Rovero, J.P., LCDR USN, *Binary to ASCII Conversion Program*, December 1992

10. Telephone conversation between Elanor Holmes, Advanced Technology Incorporated, and the author, 4 February 1993.

11. Etter, Paul C., *Underwater Acoustic Modeling*, Elsevier Science Publishers, Ltd, New York, New York, 1991, pp.239-244

12. Urick, Robert J., *Principles of Underwater Sound*, Third Edition, McGraw -Hill Book Company, New York, New York, 1983, pp. 407.

APPENDIX A

A. RUN IDENTIFICATION

Each propagation loss run was uniquely identified by an alphanumeric code as follows: { A B C x . num }, where uppercase denotes ASWTDA and lowercase TESS, "A" represents location (M = Mediterranean, S = Sea of Japan), "B" represents season (J = January, U = July), "C" represents model (A = ASTRAL, P = PE, R = RAYMODE), "x" designates the sequential run number form East to West, and "num" designates either the bearing of the run from track (range dependent models) or frequency of the run (range independent model). Table VI summarizes the data collection.

B. METHOD OF COLLECTION

Data from TESS was generated in ten run increments, consistent with the Ocean Environmental File size. A directory ({storage directory})was created under "/envsys/users/" for storage of data, and after display of either range dependent or range independent plots on the HP-9020 display, the second terminal was used to access the file generating the plot, then move and rename to the storage directory using HP-UX commands as follows:

- cd /envsys/users < Switch to directory in which graphics files stored
- ls *.gp < List all files with suffix "gp" - only graphics files are so named
- mv *.gp {storage directory}/ABCx.num < Move and rename graphics file
- ls -l {storage directory} < Check the contents of directory to ensure new file transferred properly

- more {storage directory} / {file name} < Open file to see contents

By ensuring the /users directory is free of .gp suffix files, one may be certain that only the most recently generated file (the last graph displayed) is written to storage.

After completion of all data collection, 800 files were transferred by means of a direct hardware connection from the HP-9020 printer port to a PC serial port using a communications software package and the HP-UX print command,

- lp {filename} > /dev/rfd0

Data was received by the PC and transferred in ASCII format to 3.5" floppy discs. A Macintosh was used to read and analyze the data. ASWTDA data from PE and ASTRAL was accessed after plot generation by pulling down a Motif window, using the "new window" selection, changing to the appropriate directory, then moving and renaming the file to a separate storage directory created to hold the data as in TESS. ASTRAL data was found in ASCII format and immediately accessible, although a large proportion of the file was header and other information not required for this analysis. Using the Unix editor "vi", the superfluous data was deleted and only range/propagation loss vectors saved. RAYMODE data was not stored for retrieval as in ASTRAL or PE. Instead, using the "TDA", "Range Independent","Proploss","Info" selections from the menu bar, a tabular summary of RAYMODE range and propagation loss is displayed. By using the mouse and left button to highlight the vectors, then "vi" to open an editor in an open window, the center mouse button was used to copy the data to a new text file with appropriate name. The following is a summary of SUN Unix commands used for data retrieval:

- mkdir /{ storage directory } { Create a storage directory for data - its convenient to have the directory under the current working directory

- cd /home/tdacm/exe/data/tactical { Both directorys contain files named
  - or - /home/tdacm/exe/exec "OUTPUT.LOG" (ASTRAL) and "for042.dat" (PE)

After generating ASTRAL or PE graphs,

- ls -l | more { Check to see if time listed is the current time

It was noted that ASWTDA would, seemingly at random, store OUTPUT.LOG and for042.dat files in either location (/tactical or /exec), and thus it is necessary to check time stamp of appropriate file to ensure it was recently created. Before running another propagation loss computation,

- mv OUTPUT.LOG { storage directory } / {filename}
  - or - for042.dat { storage directory } / {filename}

After files are created,

- vi {new filename} in an open window opens the text editor to scrub unneeded header information or to move and name RAYMODE data stored with the mouse.

Data from ASWTDA was stored directly onto 3.5" floppy discs formatted by SUN Unix "bar" command in ASCII format. Using a Unix server and ethernet, the files were transferred to a Macintosh for analysis.

TABLE VI - DATA COLLECTION SUMMARY

APP	Loc	Time	Model	Brg (deg)	Freq (hz)	Source (feet)	Rcvr (feet)	Run i.d. (*)
ASWTDA	SOJ	Jan	PE	270	50	100	400	SJRx.270
ASWTDA	SOJ	Jan	AST	270	400	100	400	SJAx.270
ASWTDA	SOJ	Jan	RAY	N/A	50	100	100	SJRX.050
ASWTDA	SOJ	Jan	RAY	N/A	300	100	100	SJRx.300
ASWTDA	SOJ	Jul	PE	000	25	300	500	SUPx.000
ASWTDA	SOJ	Jul	AST	000	800	300	500	SUAx.000
ASWTDA	SOJ	Jul	RAY	N/A	20	300	100	SURx.020
ASWTDA	SOJ	Jul	RAY	N/A	500	300	100	SURx.500
TESS	SOJ	Jan	PE	270	50	100	400	sjrx.270
TESS	SOJ	Jan	AST	270	400	100	400	sjax.270
TESS	SOJ	Jan	RAY	N/A	50	100	100	sjrx.050
TESS	SOJ	Jan	RAY	N/A	300	100	100	sjrx.300
TESS	SOJ	Jul	PE	000	25	300	500	supx.000
TESS	SOJ	Jul	AST	000	800	300	500	suax.000
TESS	SOJ	Jul	RAY	N/A	20	300	100	surx.020
TESS	SOJ	Jul	RAY	N/A	500	300	100	surx.500
ASWTDA	Med	Jan	PE	180	80	60	400	MJPx.180
ASWTDA	Med	Jan	AST	180	600	60	400	MJAx.180
ASWTDA	Med	Jan	RAY	N/A	150	300	300	MJRx.150
ASWTDA	Med	Jan	RAY	N/A	500	300	300	MJRx.500
ASWTDA	Med	Jul	PE	135	100	1000+	60	MUPx.135
ASWTDA	Med	Jul	AST	135	1000	1000+	60	MUAx.135
ASWTDA	Med	Jul	RAY	N/A	100	30	100	MURx.100
ASWTDA	Med	Jul	RAY	N/A	1500	30	100	MURx.1500
TESS	Med	Jan	PE	180	80	60	400	mjpx.180
TESS	Med	Jan	AST	180	600	300	400	mjax.180
TESS	Med	Jan	RAY	N/A	150	30	100	mjrx.100
TESS	Med	Jan	RAY	N/A	500	30	100	mjrx.1500
TESS	Med	Jul	PE	135	100	1000+	60	mupx.135
TESS	Med	Jul	AST	135	1000	1000+	60	muax.135
TESS	Med	Jul	RAY	N/A	100	300	100	murx.100
TESS	Med	Jul	RAY	N/A	1500	30	100	murx.1500

* - run id explained in paragraph A above

+ - depth modified to keep source two wavelengths above the bottom in water less than 1000 feet in depth

APPENDIX B

A. "TL"

The Fortran program listed below converts ASWTDA binary format (PE output) to ASCII output. Load into any directory and run by calling filename.

```
      character*32 infile, outfile
      character*9  when
      integer*2    ititl(40), nr, nz, nprof, nbotm, nthb, nd
      real         f, zs, xz(20), xr, thmin, thmax, thc, d1, d2
      real         tthb(20), rthb(20), rplot, tl(20)
      print *,'Enter input file (for042.dat format) name:'
      read(5,*)infile
      open(unit=1,form='unformatted',status='old',file=infile)
      print *,'Enter output file name:'
      read(5,*)outfile
      open(unit=2,status='new',file=outfile)
c     READ THE HEADER RECORD OF THE TL FILE
      read(1)ititl,when,f,zs,nr,nz,(xz(i),i=1,nz)
c     write out four lines of header information
      print *,ititl
      write(2,*)ititl
      print *,when,f,zs,nr,nz,(xz(i),i=1,nz)
      write(2,*)when,f,zs,nr,nz,(xz(i),i=1,nz)
      print *,'RANGE     TL'
      write(2,*)'RANGE    TL'
```

```
      print *,'-----------------------------------'
      write(2,*)'-----------------------------------'
      nd = 1
      print *,'Number of depths is ',nd
c     read the range and tl values, print them to screen and c     to the output file
      do 33 j=1,400
        read(1,end=888,err=999)rplot,(tl(i),i=1,nd)
        write(2,*)rplot,(tl(i),i=1,nd)
   33 continue
  888 print *,'End of file on .042 file'
      close(1)
      close(2)
      print *,'Normal termination'
      stop
  999 close(1)
      close(2)
      print *,'Abnormal termination'
      stop
      end
```

B. "TESTOPEN.M"

```
% MATLAB program to test ASCII "flat files" generated by ASWTDA & TESS
% - test is successful if files load. If this program fails to open the file(s), it may be
% due to one or more of the following:
% - extraneous characters (header data, nonprintable characters,etc)
```

```
% - data format (MATLAB wants to see a matrix with all rows/columns having
% equal size)
% change i, name1 & name2 to appropriate input files
name1 = 'sjr_300_';  name2 = '.dat';
for i = 1: 50
eval( [ 'load ', name1, int2str(i), name2 ] )
end
```

C. "RNG_AVG.M"

```
  % Matlab program  to range-average TESS PE data
clear
% Output stored as "tavg.xxx" (m by n) array having same size as TESS input
% Change next line to reflect TESS input file name
name1 = 'sup_';  name2 = '.000'; name3 = 'tavg'; name4 = '.000';
for i = 1:50
 eval(['load ',name1,int2str(i),name2]);
 TES = eval([name1,int2str(i)]);
 [m,n] = size(TES); z = 1;
 for x = 1:m
  for y = 1:n
   UTES(z) = TES(x,y);
   RTES(z) = TES(x,y); z = z+1;
  end
 end
 for g = 3:(m*n)-2
```

```
    RTES(g) = (UTES(g-2) + 2*UTES(g-1) + 3*UTES(g) + 2*UTES(g+1) +
UTES(g+2))/9;
 end
 zz = 1;
 for x = 1:m
  for y = 1:n
   tavg(x,y) = RTES(zz); zz = zz+1;
  end
 end
% Uncomment next line to see range vs non-range averaged TESS
% a = 1:m*n; plot(a,-UTES,'-',a,-RTES,'--'); grid; pause;
 eval(['save ',name3,int2str(i),name4,' tavg' ]);
 clear a g m n x y z zz RTES TES UTES tavg
end
```

D. "RNG_DEP.M"

```
   % MATLAB program to interpolate TESS at ASWTDA data points, PE and
% ASTRAL inputsn.b. - ASWTDA PE &ASTRAL outputs range in nm; TESS
% outputs range in kydoutput stored as "stat_t{name1}"
clear
% change name1 & name3 to appropriate input file names
name1 = 'CMUP'; name2 = 'tavg';  name3 = '.135';  name4 = 'stat_';
for i = 1:50
   eval(['load ',name1,int2str(i),name3]);
   eval(['load ',name2,int2str(i),name3]);
   ASW = eval([name1,int2str(i)]);
```

```
  TES = tavg;
% change nm to kyd
  v1 = [ 2.0254*ASW(:,1), ASW(:,2) ];
  [m,n] = size(TES);  z=1;
  for x = 1:m
    for y = 1:n
      v2(z,2) = TES(x,y); v2(z,1) = z;  z=z+1;
    end
  end
% uc = upper counter  lc = lower counter
% uv = upper value    lv = lower value
% s = slope  inc = increment  ev = interpolation matrix
  [m1,n1] = size(v1); [m2,n2] = size(v2);
% limit proploss to 120 db
  for k = -m1 : -1
    if v1(-k,2) > 120
      v1(-k,:) = [ ];
    end
  end
  [m1,n1] = size(v1);  zz = 1;
  while v1(zz,1) <  v2(m2,1)
    uc = v2(ceil(v1(zz,1)),1); lc = v2(floor(v1(zz,1)),1);
    uv = v2(uc,2); lv = v2(lc,2); s = uv - lv; inc = (v1(zz,1) - lc)*s; ev(zz) = inc +
lv;
      if zz == m1, zz=zz+1; break,end
```

```
    zz = zz+1;
   end
% comp = comparrison matrix (ASWTDA, interpolated TESS, difference)
   comp(:,1) = v1(1:(zz-1),2); comp(:,2) = ev';
   comp(:,3) = comp(:,1) - comp(:,2);
% uncomment the next 3 lines to see ASWTDA vs TESS & difference
% b = 1:m1; c = 1:m2; axis([0,200,-120,-40]);
% plot( v1(:,1), -v1(:,2), '-', v2(:,1), -v2(:,2), '-.' ); grid; pause;
% clg; axis([ 0, 64, -20, 20]); plot( comp(:,3) ); grid; pause; clg; axis;
   sdev = std(comp(:,3)); avg = mean(comp(:,3));
   sdev
   avg
   stat(i,1) = i; stat(i,2) = sdev;  stat(i,3) = avg; stat(i,4) = m1;
 % uncomment next 2 lines to store individual run differences
% t = comp(:,3); fname = ' t'; gname = 'difference_avgmup';
% eval( [ 'save ', gname, int2str(i), fname ] );
  clear comp ev inc k lc lv m m1 m2 n n1 n2 s uc uv v1 v2 x y z zz
end
eval(['save ',stat_t,name1,' stat'])
```

E. "RNG_INDEP.M"

```
   % MATLAB program to interpolate TESS at ASWTDA data points,
%RAYMODE  inputs .. n.b. - ASWTDA /RAYMODE outputs range in kyd;
% TESS outputs range in kyd
% output stored as "stat_t{name1}"
clear
```

```
% change name1 & name3 to appropriate input file names
name1 = 'SJR'; name2 = 'sjr_'; name3 = '.300'; name4 = 'stat_';
for i = 1:50
  eval( [' load ', name1, int2str(i), name3 ] );
  eval( [ 'load ', name2, int2str(i), name3 ] );
  ASW = eval( [ name1,int2str(i) ] ); TES = eval( [ name2,int2str(i) ] );
  v1 = ASW; [m,n] = size(TES); z=1;
  for x = 1:m
    for y = 1:n
      v2(z,2) = TES(x,y); v2(z,1) = z; z=z+1;
    end
  end
% uc = upper counter  lc = lower counter
% uv = upper value    lv = lower value
% s = slope  inc = increment  ev = interpolation matrix
  [m1,n1] = size(v1); [m2,n2] = size(v2);
% limit proploss to 120 db
  for k = -m1:-1
    if v1(-k,2) > 120
      v1(-k,:) = [ ];
    end
  end
  [m1,n1] = size(v1); zz = 1;
  while v1(zz,1) < v2(m2,1)
    uc = v2(ceil(v1(zz,1)),1); lc = v2(floor(v1(zz,1)),1);
```

```
      uv = v2(uc,2); lv = v2(lc,2); s = uv - lv; inc = (v1(zz,1) - lc)*s; ev(zz) = inc +
lv;
        if zz == m1,zz=zz+1;break,end
      zz = zz+1;
    end
% comp = comparrison matrix (ASWTDA, interpolated TESS, difference)
   comp(:,1) = v1(1:(zz-1),2); comp(:,2) = ev' ;
   comp(:,3) = comp(:,1) - comp(:,2);
% uncomment the next 3 lines to see ASWTDA vs TESS & difference
% b = 1:m1; c = 1:m2; axis([0,200,-120,-40]);
% plot(v1(:,1), -v1(:,2), '-', v2(:,1), -v2(:,2), '-.'); grid; pause;
% clg; axis( [ 0,64,-20,20 ] ); plot(comp(:,3)); grid; pause; clg; axis;
   sdev = std(comp(:,3)); avg = mean(comp(:,3));
   sdev
   avg
   stat(i,1) = i; stat(i,2) = sdev;
   stat(i,3) = avg; stat(i,4) = m1;
% uncomment next 2 lines to store individual run differences
% t = comp(:,3); fname = ' t'; gname = 'difference_avgmup';
% eval(['save ',gname,int2str(ii), fname]);
 clear comp ev inc k lc lv m m1 m2 n n1 n2 s uc uv v1 v2 x y z zz
 end
 eval(['save ',stat_t,name1,' stat'])
```

F. "STAT_PLOT.M"

```
  % MATLAB program to output & plot difference & sigma statistics ..
% ASWTDA - TESS
clear
% change next line to appropriate input file (stat_{filename})
 load stat_mua
 b = stat(:,1); a = 2*ones(b); axis([0,50,-25,25]);
 plot(b,stat(:,2),'o',b,stat(:,3),'+'); grid;
 xlabel('Run number --->'); ylabel('Value (db) --->');
 title('<MUA Brg=135 F=1000>  Mean (+) and Standard Deviation (o) for Delta
       ...= (ASWTDA - TESS) over 50 runs');
 pause;
 m = zeros(1:50); axis([0,10,-1,1]);
 subplot(222),plot(stat(:,2),m,'x'); title('Scatter plot - standard deviations');
 axis([ 0,10,0,20]);
 subplot(224),hist(stat(:,2),25); title('Distribution of standard deviations');
 axis([-10,10,-1,1]);
 subplot(221),plot(stat(:,3),m,'+'); title('Scatter plot - means '); axis([-10,10,0,20]);
 subplot(223),hist(stat(:,3),25); title('Distribution of means ');
text(.2,0,'Scatter plots and histograms for Delta = (ASWTDA - TESS) over 50
runs','sc'); pause; axis; clg;
```

G. "PLOT_RDEP.M"

```
   % MATLAB program to plot successive runs of ASWTDA & TESS for analysis
% PE & ASTRAL inputs
% n.b. - ASWTDA PE & ASTRAL outputs range in nm; TESS outputs range in
kyd
clear
% change names to apprpriate input files
name1 = 'tavg'; name2 = 'CMUP'; name3 = '.135';
for i = 1:50
i
 eval(['load ',name1,int2str(i),name3]);
 eval(['load ',name2,int2str(i),name3]);
% uncomment the following 2 lines for 'ASTRAL' data
% tess = eval([name1,int2str(i)]);
% tes(:) = tess';
% uncomment the following line for 'PE' range averaged data
 tes(:) = tavg'; ASW = eval([name2,int2str(i)]);
 m = length(tes); [p,q] = size(ASW);  axis( [ 0,200,-120,-40 ] ); a = 1:m;
 plot( a, -tes, '-', 2.0254*ASW(:,1), -ASW(:,2), '-.');grid;
 title('Propagation loss: TESS (-) & ASWTDA (-.)');
 xlabel('Range (kyd) --->'); ylabel('Value (db) --->');
% Keyboard prompt ( >>K  ) allows entry of labels at keyboard
% using "gtext" ... press return when complete
 keyboard; clg; clear tes tavg;
end
```

H. "PLOT_RINDEP.M"

```
  % MATLAB program to plot successive runs of ASWTDA & TESS for analysis
% RAYMODE inputs
% n.b. - ASWTDA RAYMODE outputs are in kyd
clear
for i = 1:50
i
% change names to appropriate input files
 name1 = 'mur_'; name2 = 'MUR'; name3 = '.100';
 eval(['load ',name1,int2str(i),name3]);
 eval(['load ',name2,int2str(i),name3]);
 tess = eval([name1,int2str(i)]); tes(:) = tess'; ASW = eval( [ name2,int2str(i) ] );
% eliminate extraneous data column
 ASW(:,1) = [ ];
 m = length(tes); [p,q] = size(ASW);  axis( [ 0,100,-120,-40 ] ); a = 1:m;
 plot( a, -tes, '-', ASW(:,1), -ASW(:,2)', '-.'); grid;
 title('Propagation loss: TESS (-) & ASWTDA (-.)');
 xlabel('Range (kyd) --->'); ylabel('Value (db) --->');
 % Keyboard prompt ( >>K  ) allows entry of labels at keyboard
 % using "gtext" ... press return when complete
 keyboard;  clg;
end
```

I. "FOM2RNG_DEP.M"

```
   % MATLAB program to convert FOMs to corresponding ranges
% PE & ASTRAL inputs
% output values as "{name4}{fom}"
% n.b. - ASWTDA PE & ASTRAL outputs are in nm
clear
% change names to appropriate input files
name1 = 'SJP' ; name2 = 'sjp_'; name3 = '.270'; name4 = 'SJP_rng_fom';
for fom = [75 80 85]
 fom
 for i = 1:50
   a = 0; b = 0; c = 0; d = 0; e = 0; f = 0;
   atog = 0; btog = 0; ctog = 0; dtog = 0; etog = 0; ftog = 0;
   eval(['load ',name1,int2str(i),name3]);
   eval(['load ',name2,int2str(i),name3]);
   v1 = eval([name1,int2str(i)]);
% convert nm to kyd
   v1(:,1) = 2.0254*v1(:,1);
   TES(:) = eval([name2,int2str(i)])'; v2(:,2) = TES;
   m2 = length(TES);
    for j = 1:m2
      v2(j,1)=j;
    end
  [m1 n1] = size(v1);
% limit proploss to 120 db
```

```
    for k = -m1:-1
      if v1(-k,2) > 120
        v1(-k,:) = [];
      end
    end
  [m1 n1] = size(v1);
% a&d = limit of direct path detection range
% b&e = first extended range detection
% c&f = limit of extended range detection
% 'tog' = toggle
 for ii = 1:m1
    if ii == m1,break,end
  if (v1(ii,2) <= fom) & (v1(ii+1,2) > fom) & (atog == 0)
    atog = 1;
    a = ( (fom - v1(ii,2) ) / ( v1(ii+1,2) - v1(ii,2) )) * ( v1(ii+1,1) - v1(ii,1) ) + v1(ii,1);
  end
  if (v1(ii,2) > fom) & (v1(ii+1,2) <= fom) & (btog == 0)
    btog = 1;
    b = ( (fom - v1(ii,2) ) / ( v1(ii+1,2) - v1(ii,2) )) * ( v1(ii+1,1) - v1(ii,1) ) + v1(ii,1);
  end
  if (v1(ii,2) <= fom) & (v1(ii+1,2) > fom) & (btog ==1) & (ctog == 0)
    ctog = 1;
    c = ( (fom - v1(ii,2) ) / ( v1(ii+1,2) - v1(ii,2) )) * ( v1(ii+1,1) - v1(ii,1) ) + v1(ii,1);
  end
 end
```

```
for iii = 1:m2
 if iii == m2,break,end
 if (v2(iii,2) <= fom) & (v2(iii+1,2) > fom) & (dtog == 0)
  dtog = 1;
  d = ( (fom - v2(iii,2) ) / ( v2(iii+1,2) - v2(iii,2) )) * ( v2(iii+1,1) - v2(iii,1) ) +
      v2(iii,1);
 end
 if (v2(iii,2) > fom) & (v2(iii+1,2) <= fom) & (etog == ∪,
  etog = 1;
  e = ( (fom - v2(iii,2) ) / ( v2(iii+1,2) - v2(iii,2) )) * ( v2(iii+1,1) - v2(iii,1) ) +
      v2(iii,1):
 end
 if (v2(iii,2) <= fom) & (v2(iii+1,2) > fom) & (etog ==1) & (ftog == 0)
  ftog = 1;
  f = (( fom - v2(iii,2) ) / ( v2(iii+1,2) - v2(iii,2) )) * ( v2(iii+1,1) - v2(iii,1) ) +
      v2(iii,1);
 end
end
% set detection to max range if fom > all proploss elements
 if a == 0 & v1(m1,2) < fom
  a = v1(m1,1);
 end
 if d == 0 & v2(m2,2) < fom
  d = v2(m2,1);
 end
```

```
 rng(i,1)= a; rng(i,2)= b; rng(i,3)= c;  rng(i,4)= d; rng(i,5)= e; rng(i,6)= f;
 clear a b c d e f atog btog ctog dtog etog ftog v1 v2 TES ii iii j k m1 m2 n1
end
 eval(['save ',name4,int2str(fom),' rng']);
 clear rng
end
```

J. "FOM2RNG_INDEP.M"

```
   % MATLAB program to convert FOMs to corresponding ranges
% RAYMODE inputs
% output values as "{name4}{fom}"
% n.b. - ASWTDA & TESS RAYMODE outputs are in kyd
clear
% change names to appropriate input files
name1 = 'SJP' ; name2 = 'sjp_'; name3 = '.270'; name4 = 'SJP_rng_fom';
for fom = [75 80 85]
 fom
 for i = 1:50
   a = 0; b = 0; c = 0; d = 0; e = 0; f = 0;
   atog = 0; btog = 0; ctog = 0; dtog = 0; etog = 0; ftog = 0;
   eval(['load ',name1,int2str(i),name3]);
   eval(['load ',name2,int2str(i),name3]);
   v1 = eval([name1,int2str(i)]);
% delete superfluous column 1 data
  v1(:,1) = [ ];
   TES(:) = eval([name2,int2str(i)])'; v2(:,2) = TES;  m2 = length(TES);
```

```
    for j = 1:m2
      v2(j,1)=j;
    end
  [m1 n1] = size(v1);
% limit proploss to 120 db
    for k = -m1:-1
      if v1(-k,2) > 120
        v1(-k,:) = [];
      end
    end
  [m1 n1] = size(v1);
% a&d = limit of direct path detection range
% b&e = first extended range detection
% c&f = limit of extended range detection
% 'tog' = toggle
 for ii = 1:m1
    if ii == m1,break,end
  if (v1(ii,2) <= fom) & (v1(ii+1,2) > fom) & (atog == 0)
    atog = 1;
   a = ( (fom - v1(ii,2) ) / ( v1(ii+1,2) - v1(ii,2) )) * ( v1(ii+1,1) - v1(ii,1) ) + v1(ii,1);
  end
  if (v1(ii,2) > fom) & (v1(ii+1,2) <= fom) & (btog == 0)
    btog = 1;
   b = ( (fom - v1(ii,2) ) / ( v1(ii+1,2) - v1(ii,2) )) * ( v1(ii+1,1) - v1(ii,1) ) + v1(ii,1);
  end
```

```
  if (v1(ii,2) <= fom) & (v1(ii+1,2) > fom) & (btog ==1) & (ctog == 0)
    ctog = 1;
    c = ( (fom - v1(ii,2) ) / ( v1(ii+1,2) - v1(ii,2) )) * ( v1(ii+1,1) - v1(ii,1) ) + v1(ii,1);
  end
 end
 for iii = 1:m2
  if iii == m2,break,end
  if (v2(iii,2) <= fom) & (v2(iii+1,2) > fom) & (dtog == 0)
    dtog = 1;
    d = ( (fom - v2(iii,2) ) / ( v2(iii+1,2) - v2(iii,2) )) * ( v2(iii+1,1) - v2(iii,1) ) +
v2(iii,1);
  end
  if (v2(iii,2) > fom) & (v2(iii+1,2) <= fom) & (etog == 0)
    etog = 1;
    e = ( (fom - v2(iii,2) ) / ( v2(iii+1,2) - v2(iii,2) )) * ( v2(iii+1,1) - v2(iii,1) ) +
v2(iii,1);
  end
  if (v2(iii,2) <= fom) & (v2(iii+1,2) > fom) & (etog ==1) & (ftog == 0)
    ftog = 1;
    f = (( fom - v2(iii,2) ) / ( v2(iii+1,2) - v2(iii,2) )) * ( v2(iii+1,1) - v2(iii,1) ) +
v2(iii,1);
  end
 end
% set detection to max range if fom > all proploss elements
 if a == 0 & v1(m1,2) < fom
```

```
    a = v1(m1,1);
  end
  if d == 0 & v2(m2,2) < fom
    d = v2(m2,1);
  end
  rng(i,1)= a; rng(i,2)= b; rng(i,3)= c;  rng(i,4)= d; rng(i,5)= e; rng(i,6)= f;
  clear a b c d e f atog btog ctog dtog etog ftog v1 v2 TES ii iii j k m1 m2 n1
 end
  eval(['save ',name4,int2str(fom),' rng']);
  clear rng
end
```

K. "FOM.M"

```
   % MATLAB program to compute predicted range of detection for ASWTDA
% and TESS proploss inputs
% Outputs as "{name2}{fom}"
% da = range of direct path  detection in kyds
% alpha =  difference   "        "       "   (ASWTDA - TESS)
% db = range to 1st extended detection  in kyds
% beta =  difference    "        "       "   (ASWTDA - TESS)
clear
% Change name1 & name 2 to appropriate input files
name1 = 'SJP_rng_fom' ; name2 = 'fom_results';
for fom = [75 80 85]
 eval(['load ',name1,int2str(fom)]);
  for i = 1:50
```

```
    da(i) = 0; alpha(i) = 0; db(i) = 0; beta(i) = 0;
     if rng(i,1) > 0 & rng(i,4) > 0
       da(i) = rng(i,4) - rng(i,1); alpha(i) = da(i) / max( rng(i,1), rng(i,4) );
     end
     if rng(i,2) > 0 & rng(i,5) > 0
       db(i) = rng(i,5) - rng(i,2); beta(i) = db(i) / max( rng(i,2), rng(i,5) );
     end
   end
  da = da'; alpha = alpha'; db = db'; beta = beta';
  rng(:,7) = da; rng(:,8) = abs(alpha);  rng(:,9) = db; rng(:,10) = abs(beta);
  rng = (round(100*rng))/100;
  eval(['save ',name2,int2str(fom),' rng']);
  clear rng da db alpha beta i
end
```

L. "SIM.M"

```
   % MATLAB program to compute "similarity"
% Output as {name2}{fom}
clear
name1 = 'MUR1500_rng_fom'; name2 = 'sim1500';
for fom = [75 80 85]
  j = 0; k = 0;
  eval(['load ',name1,int2str(fom)]);
% rdp = range of direct path   rex = range of extended path
  rdp = rng(:,7:8); rex = rng(:,9:10);
% remove 'notest' elements
```

```
for i = -50:-1
  if rdp(-i,2) == 0
    rdp(-i,:) = [];
  end
  if rex(-i,2) == 0
    rex(-i,:) = [];
  end
end
% count elements whose range difference is less than 10%
if isempty(rdp) ~= 1
  mdp = length(rdp(:,1));
  for ii = 1:mdp
    if rdp(ii,2) <= .1
      j = j+1;
    end
  end
  sim(1) = mdp; sim(2) = j; sim(3) = sim(2)/sim(1);
end
if isempty(rex) ~= 1
  mex = length(rex(:,1));
  for iii = 1:mex
    if rex(iii,2) <= .1
      k = k+1;
    end
  end
```

```
    sim(4) = mex; sim(5) = k; sim(6) = sim(5)/sim(4);
  end
  eval(['save ',name2,int2str(fom),' sim']);
% clear i ii iii j k mdp mex rdp rex rng
end
```

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