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SURFACE-DUCT SONAR MEASUREMENTS (SUDS I - 1972) PROPAGATION LOS--ETC(U)
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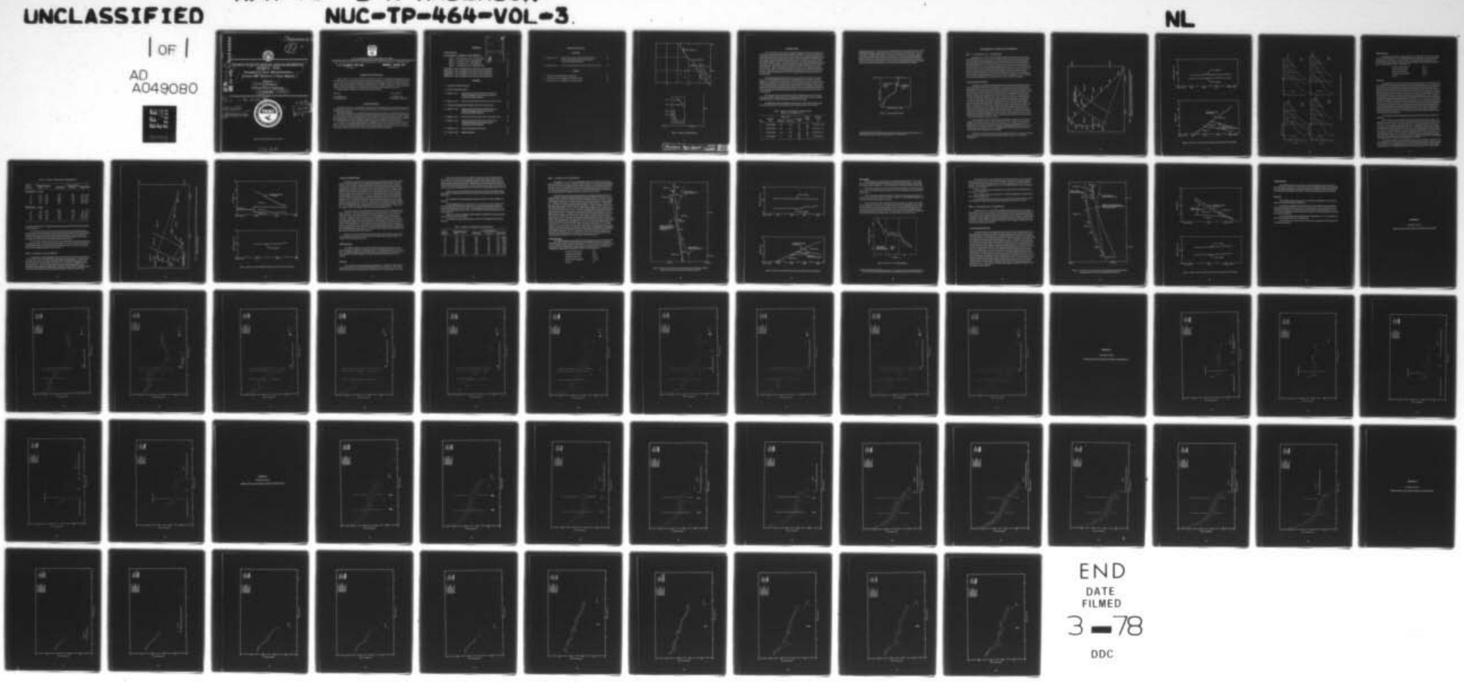

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SURFACE-DUCT SONAR MEASUREMENTS (SUDS I - 1972)

Propagation Loss Measurements. Volume III: Station 2 Data Report.

edited by
E. R. Anderson
Undersea Sciences Department

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NAVAL UNDERSEA CENTER, SAN DIEGO, CA. 92132

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

R. B. GILCHRIST, CAPT, USN
Commander

HOWARD L. BLOOD, PhD
Technical Director

ADMINISTRATIVE INFORMATION

During February 1972 the Naval Undersea Center conducted a series of 18 propagation loss experiments in three deep-water areas off the coast of California. These experiments are known as the SUrface Duct Sonar Measurements (SUDS I – 1972). This work was originally supported by the then Naval Ships Systems Command, Sonar Technology Division, PMS-302-4 and partly supported by the Office of Naval Research, code 102-OSC. The preparation of this report began in April 1973 under the sponsorship of the Naval Sea Systems Command, code 06H1-4, problem SF 52-552-602, task 19344. This report covers work from March 1971 to February 1976 and was approved for publication in April 1976.

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Technical reviewers for this report were M. A. Pedersen and R. F. Hosmer.

Released by

H. E. MORRIS, Head
Ocean Sciences Group

Under authority of

B. A. POWELL, Head
Undersea Sciences Department

ACKNOWLEDGEMENTS

The SUDS I program was a coordinated and cooperative effort involving personnel from the Undersea Sciences and the Undersea Surveillance Departments. The program was basically an Acoustic Propagation Division project developed by H. P. Bucker and H. S. Aurand.

The Principal Investigator was J. Cummins. H.P. Bucker was the Senior Scientist for the CW-pulse measurements and D. L. Keir the Senior Scientist for the explosive measurements. Additional contributions were made to experiment planning by J. R. Lovett and J. D. Pugh. Preliminary analysis of acoustical data was done by H. P. Bucker and H. E. Morris. Assisting in the preliminary data reduction and analysis of the acoustic data was J. L. Thompson, an exchange scientist from RANRL, Sidney, Australia, and R. W. Townsen. Preliminary analysis of the environmental data was done by K. W. Nelson.

H. P. Bucker was the Scientist-in-Charge aboard the *DeSteiguer*, D. G. Good was Scientist-in-Charge aboard the *Lee*, and P. A. Hanson was Scientist-in-Charge aboard the *Cape*. Assisting with the acoustic measurements at sea were: T. E. Stixrud, C. R. Lisle, N. J. Martini, D. White, and R. F. Hosmer. The assistance of the officers and men of the *DeSteiguer*, *Lee*, and *Cape* in making the propagation loss measurements program successful is acknowledged.

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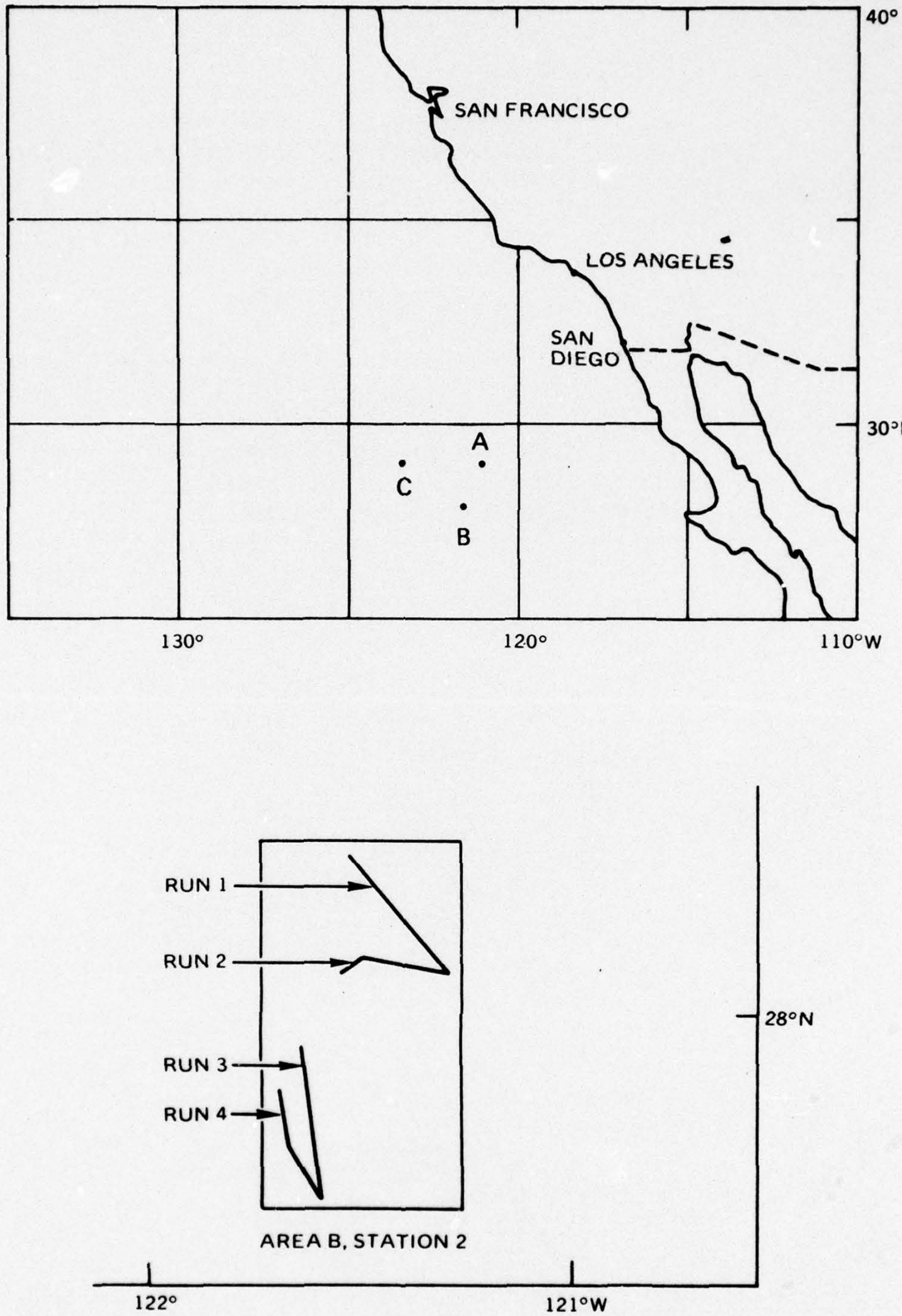

Figure 1. Location of experimental areas.

INTRODUCTION

This is the third in a series of five volumes describing the near-surface acoustic propagation loss measurements made during the SUDS I experiments. Volume I describes the experimental procedures, discusses the instrumentation used in making the propagation loss measurements, and the data reduction procedures. This volume (III) is a detailed report of the propagation loss measurements made during station 2, in which four acoustic experiments were completed. Figure 1 shows the track of the source ship during these experiments. Also shown are the locations of sound-speed profile boundaries present in the area during the experiments. Source ship's speed was 3 knots for all runs. CW pulsed sources were used on all runs. Table 1 summarizes information pertinent to the individual propagation loss runs. Listed for each run are the beginning and ending dates and times, minimum and maximum range between the source and receiver ships, frequencies used, and source and receiver depths.

The detailed propagation loss data for these experiments are contained in Appendices A-D. These appendices contain plots of propagation loss as a function of acoustic range for each frequency and receiver depth. At the bottom of each plot, remarks pertinent to that plot are indicated. The maximum acoustic range is indicated by the vertical arrow (↓) and individual noise level determinations by the symbol (∿). In addition, arrivals missing because of down periods when the recorder paper was being changed, periods when the source was inoperative, and periods when the arrivals, or most of the arrivals, were below noise are shown.

The remainder of this report discusses, for each propagation loss run, the average sound-speed profiles, average values for the AMOS parameters, and the major propagation loss features based on a visual comparison of propagation loss plots.

The AMOS near-surface propagation loss prediction model requires single average values of isothermal layer depth, depressed channel depth, sea state, and sea surface

Table 1. Summary of Propagation Loss Experiments
Station 2 14-16 February 1972

Run	Date/time LST	Range, kyd Minimum	Range, kyd Maximum	Frequency, kHz	Source Depth, m	Receiver Depth, m
1	14/1822-0024	0.2	32.4	1.5	38	5/19/47/77/120
				2.5	38	
2	15/0141-0508	10.7	29.5	1.0	39	4/17/43/72/112
				–	–	
3	15/1328-1940	0.2	25.0	3.5	38	4/17/43/72/112
				5.0	41	
4	15/2031-0052	1.7	28.1	0.4	8	4/17/43/72/112
				1.0	5	

temperature as inputs*. The isothermal layer depth is defined as the depth below the surface at which the temperature gradient from the surface is greater than -0.3°F/100 ft. Because of the effect of pressure, this results in a surface sound channel. The depressed channel is formed by an isothermal layer within the water column. This latter vertical temperature structure results in a sound-speed minimum near the top of the isothermal layer because of the effect of pressure on sound speed. The width of the depressed channel is approximately equal to the depth of the channel axis.* Figure 2 aids in defining these parameters.

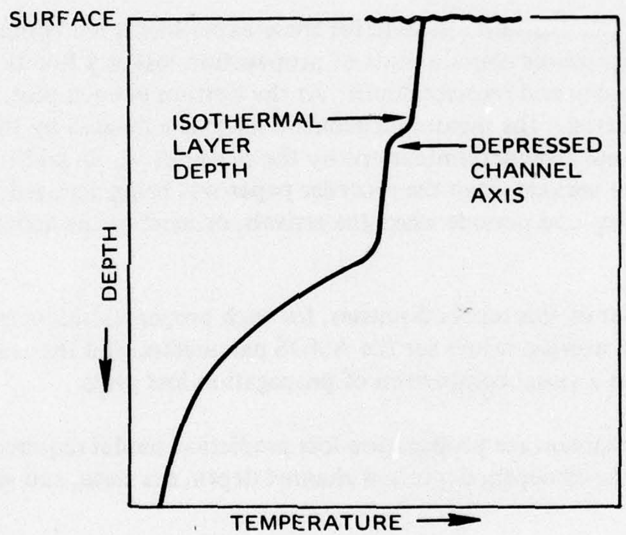

Figure 2. Vertical temperature profile.

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*Underwater Sound Laboratory Report 255A, Report on the Status of Project AMOS (Acoustic, Meteorological, and Oceanographic Survey), _by H. W. Marsh and M. Shulkin, March 1955 (revised May 1967)._

ENVIRONMENTAL SUMMARY AND COMMENTS

RUN 1 – 14-15 February 1972, 1822-0024 LST

During this run, 1.5- and 2.5-kHz propagation losses were measured over acoustic ranges from 200 yd to 32.4 kyd. Figure 3 shows the track of the source and receiver ships, the 1822 and 0024 LST propagation paths, and the location of two sound-speed profile shape boundaries which were crossed at about 1943 and 2100 LST at acoustic ranges from the receivers of 8.0 to 13.8 kyd. Figure 4 contains plots of source level and ranges from receivers, derived from 14 travel-time measurements, versus time of day. In Fig. 4 the range from the receivers of the sound-speed profile boundaries is shown as a function of time of day. Out to an acoustic range of 8.0 kyd the propagation was in the profile 1 volume. From 8.0 kyd to 13.8 kyd it was in the profile 1 and profile 2 volumes. For ranges greater than 13.8 kyd all three profile volumes were involved. For ranges greater than 13.8 kyd the acoustic energy propagated an increasing amount of time in the profile 3 volume.

Average Sound-Speed Profiles

Individual sound-speed profiles suggested that a sound-speed profile shape boundary was crossed between 1943 LST and 2100 LST. An examination of the individual sound-speed profile shapes showed that a transition from a surface-channel depressed-channel profile (profile 1) to a surface-channel-only profile (profile 3) occurred over a distance of about 6.3 kyd between 1950 and 2050 LST. The thermistor chain temperature measurements showed a marked surface temperature front was crossed at 2014 LST. The surface sensor recorded a temperature change of 0.9°C (about 3.0 m/sec) in a distance of approximately 2.1 kyd. The thermistor chain data also suggested that the frontal surface separating the two surface water masses extended to a depth of about 79 m. The data were averaged to obtain an average sound-speed profile representative of each of the three water volumes. Figure 5 contains a plot of these data. Also shown are the source and receiver depths. Profile 1 is characterized by a 23-m surface channel and a 38-m depressed channel with the minimum sound speed at 50 m, while profile 3 is characterized by a 30-m surface channel. The reader is reminded that the profiles in the transition volume, as represented by average profile 2, are gradually changing over a range of 6.3 kyd. Thus, profile 2 is not an average profile in the same sense as profiles 1 and 3. Over the entire source ship track there also was a 70-m refractive channel centered at 250 m.

This experiment was conducted under adverse weather conditions. The source ship reported 16- to 20-knot winds, 5- to 8-ft. waves, and 6- to 10-ft. swell. The receiver ship reported 18-knot winds, 3-ft. waves, and 6- to 10-ft. swell. As a result the receiver ship drifted about 8 nm south during the run, resulting in propagation paths that were not in the plane of the source ship track. Also, as a consequence of the adverse weather conditions, no Waverider buoy measurements were obtained.

Receivers 1 and 2 were located in a surface channel, receiver 3 in a depressed channel, receiver 4 just above the bottom of the depressed channel, and receiver 5 in the main thermocline.

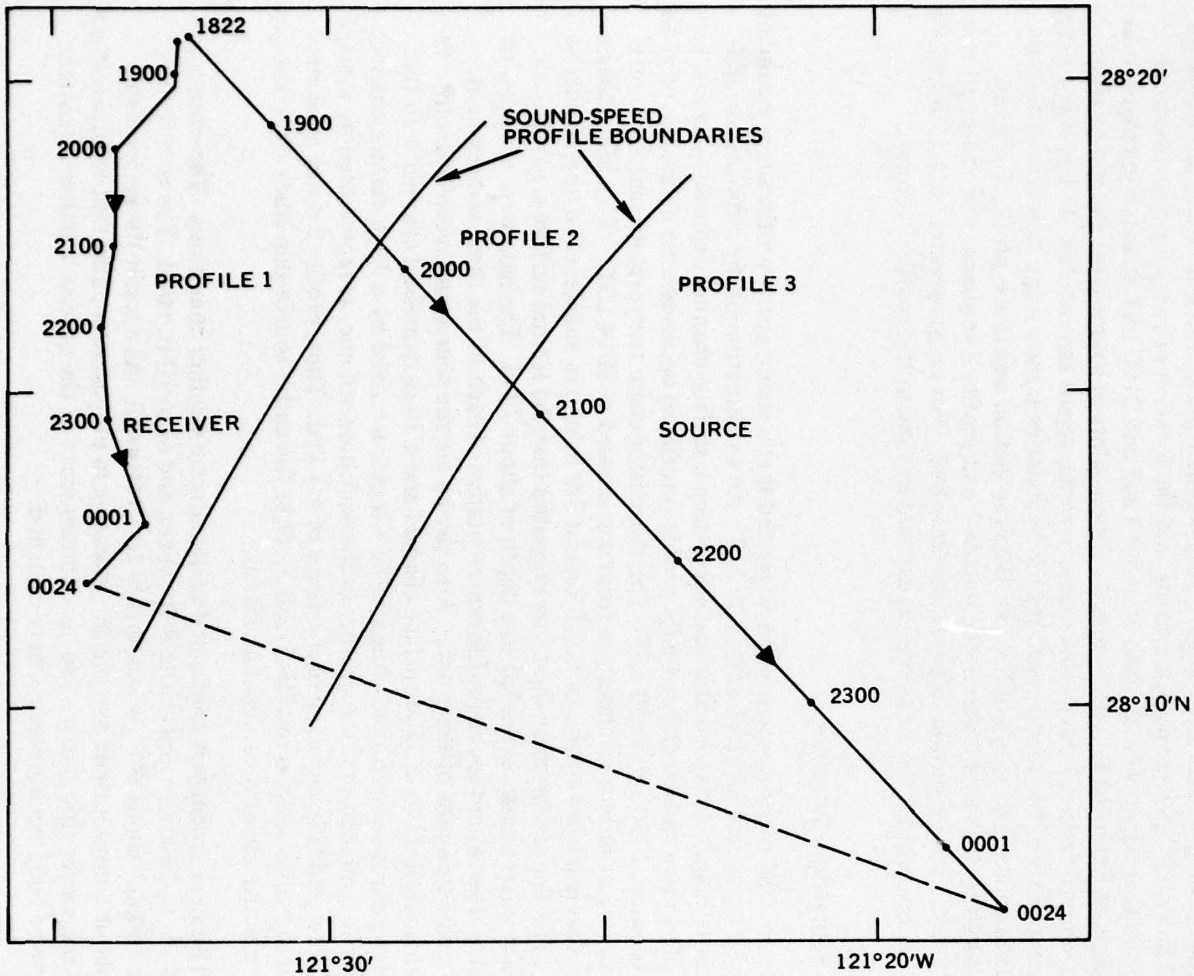


Figure 3. Station 2, run 1. Tracks of source and receiver ships, 1922 LST and 0024 LST propagation paths, and the location of sound-speed profile boundaries.

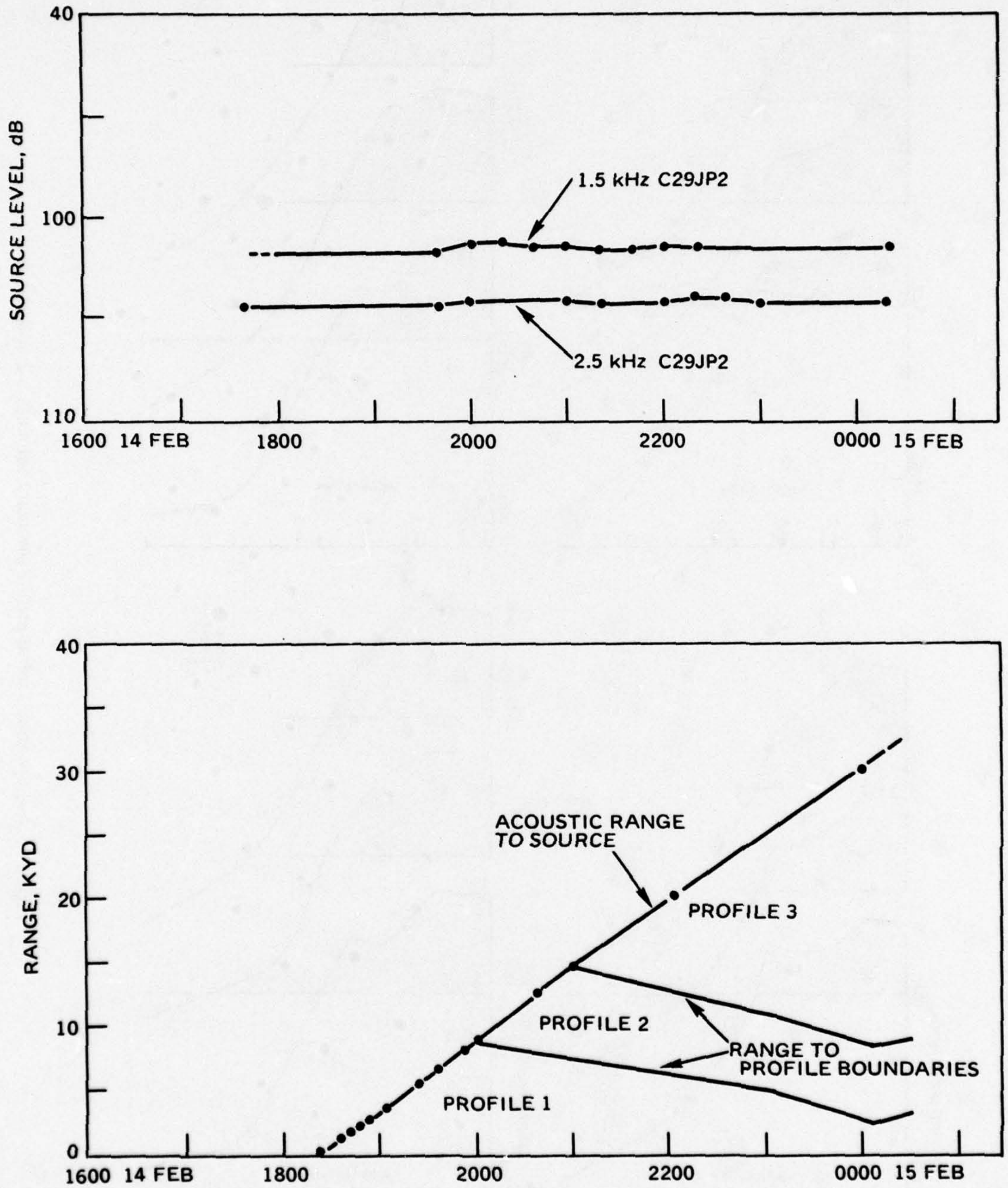


Figure 4. Station 2, run 1. Source levels and range from receiver versus time of day (LST).

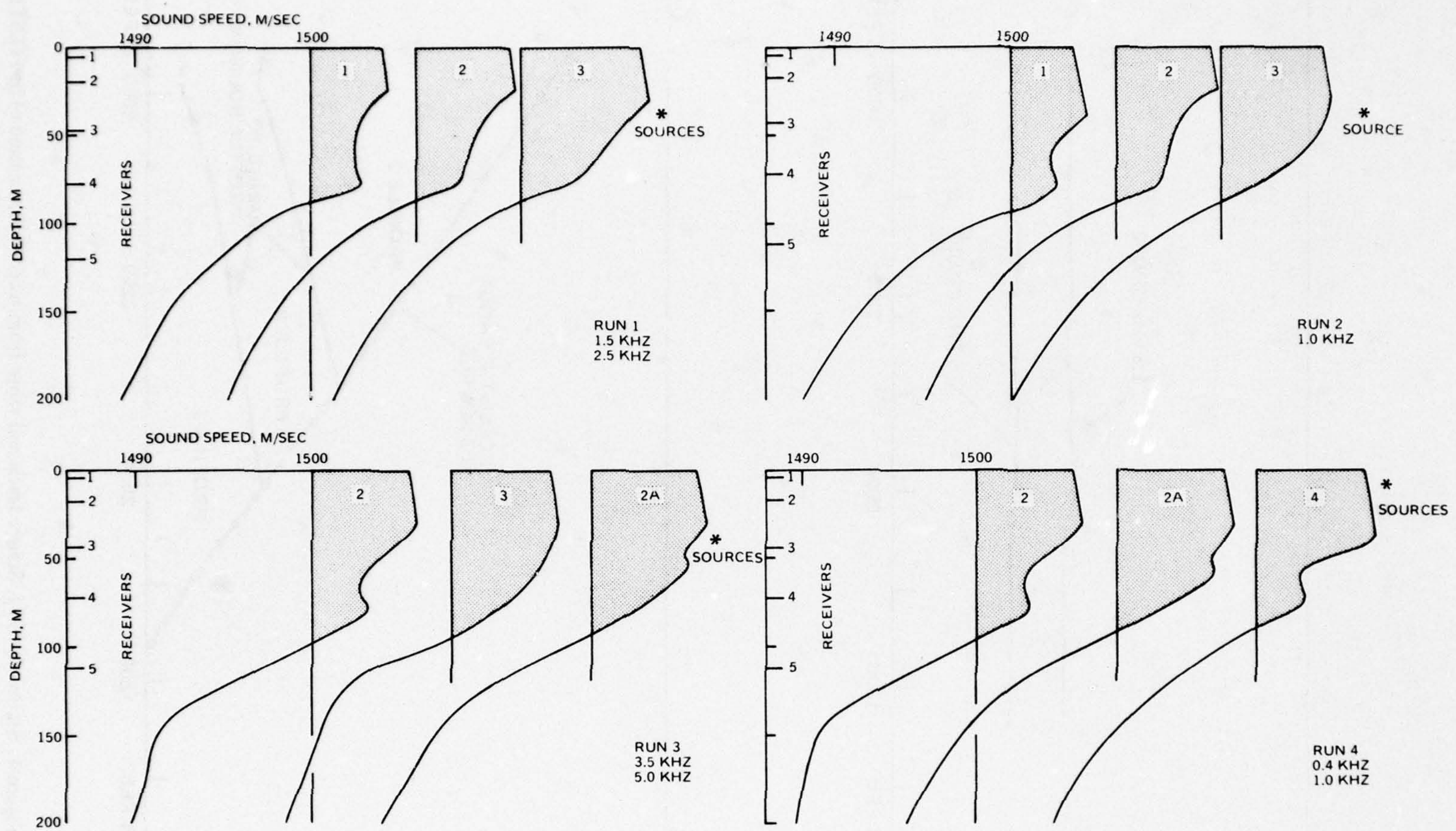


Figure 5. Average sound-speed profile summary for station 2 acoustic runs.

AMOS Parameters

The AMOS propagation loss model assumes that sources and receivers are in a water volume in which single values of the AMOS parameters are applicable. For this experiment this assumption is valid out to a range of 8.0 kyd. The number of observations and the average values of these parameters, derived from the thermistor chain temperature measurements and applicable to the run 1 experiment, are:

number of observations	540
isothermal layer depth	92 ft
depressed channel axis	148 ft
surface water temperature	58.3°F
sea state	3-4

Discussion

The propagation loss measurements are summarized in Appendix A. The solid vertical lines on the individual propagation loss plots indicate the range from the receivers of the sound-speed profile shape boundaries, and the dashed vertical line indicates the range from the receivers of the sound-speed discontinuity (temperature frontal surface) at the 38-m source depth. The sources were towed at a depth of 4 m above the axis of the profile 1 depressed channel and 8 m below the profile 3 surface channel. Except for the 5-m and 19-m measurements at 2.5 kHz, the propagation loss plots showed a marked increase in propagation loss, as well as a change in the propagation loss patterns, as the sources moved into the profile 3 water volume. The ranges at which the propagation loss patterns changed varied from 13.1 to 15.2 kyd. It is recalled that the sources crossed the frontal surface at an acoustic range of 12.5 kyd and entered the profile 3 water volume at a range of 13.8 kyd. The effect of the frontal surface is more dramatically demonstrated by examining the number of transmitted pulses that were below the noise level for the range intervals in which all transmitted pulses were not received. Table 2 summarizes this information for each receiver. For the indicated range interval, the number of transmitted pulses, the number of received pulses, the number of pulses below noise, and the percent of the pulses below noise are listed.

An examination of the propagation loss plots and the data in Table 2 suggests the following:

- At 1.5 kHz, for the 5-m and 19-m receivers located in the surface channel, 73.6 percent (5-m receiver) and 45.7 percent (19-m receiver) of the arrivals were below the noise level from 13.3 to 22.8 kyd. At ranges shorter than 13.3 kyd and greater than 22.8 kyd, very few of the transmitted pulses were below noise. Additionally, there was a decrease in propagation loss for ranges greater than 22.8 kyd. At 2.5 kHz the results were quite different. For the 5-m receiver only 5.1 percent of 1400 transmitted pulses were below noise for the entire run. For the 19-m receiver nearly all arrivals were above noise, except for a 3.0-kyd range interval from 19.5 to 22.5 kyd, in which 49.3 percent of the transmitted pulses were below the noise level. For these two receivers another major difference is the relatively larger pulse-to-pulse variability in propagation loss at 2.5 kHz.

- The 47-m receiver was located almost on the axis of the profile 1 depressed channel. Propagation was no better for the 47-m receiver than for other shallow receivers at ranges less than 13.3 kyd. For ranges greater than 13.3 kyd, 74.3 percent of the 1.5-kHz arrivals were below noise. For ranges greater than 14.8 kyd, 84.0 percent of the 2.5-kHz arrivals

Table 2. Summary of Propagation Loss Measurements

Receiver Depth, m	Range Interval, kyd from	Range Interval, kyd to	Number of Pulses Transmitted	Number of Pulses Received	Below Noise	
FREQUENCY: 1.5 kHz						
5	13.3	22.8	440	103	337	73.6%
19	13.9	22.8	412	194	188	45.7
47	13.3	end	840	216	624	74.3
77	15.2	end	848	80	768	90.6
120	13.1	end	748	138	610	81.6
FREQUENCY: 2.5 kHz						
5	0.0	32.4	1400	1329	71	5.1%
19	19.5	22.5	140	71	69	49.3
47	14.8	end	776	124	652	84.0
77	14.7	end	784	112	672	85.7
120	15.0	end	764	118	646	84.8

were below the noise level. At ranges shorter than these, nearly all arrivals were above noise at both frequencies.

- The 77-m receiver was located very near in depth to the horizontal temperature interface between the bottom of the two near-surface water masses and the top of the underlying cold-water mass. For acoustic ranges ranges greater than 15.2 kyd (1.5 kHz), 90.6 percent of the transmitted pulses were below noise, and for ranges greater than 14.7 kyd (2.5 kHz), 85.7 percent of the transmitted pulses were below noise.
- The 120-m receiver was located in the main thermocline well below the horizontal temperature interface. For acoustic ranges greater than 13.1 kyd (1.5 kHz), 81.6 percent of the transmitted pulses were below noise. For ranges greater than 15.0 kyd (2.5 kHz), 84.8 percent of the transmitted pulses were below noise.

RUN 2 – 15 February 1972, 0141-0508 LST

During this run 1.0-kHz propagation losses were measured over acoustic ranges from 10.7 kyd to 29.5 kyd. The 0.4-kHz source was inoperative during this run. Figure 6 shows the track of the source and receiver ships and the 0141 and 0508 LST propagation paths. This run began 1 hr 17 min after the conclusion of run 1 and may be considered as a continuation of run 1. Figure 7 contains plots of source level and ranges from receivers, derived from eight travel-time measurements, versus time of day. In Fig. 7 the range from the receivers to the sound-speed profile boundaries is shown as a function of time of day.

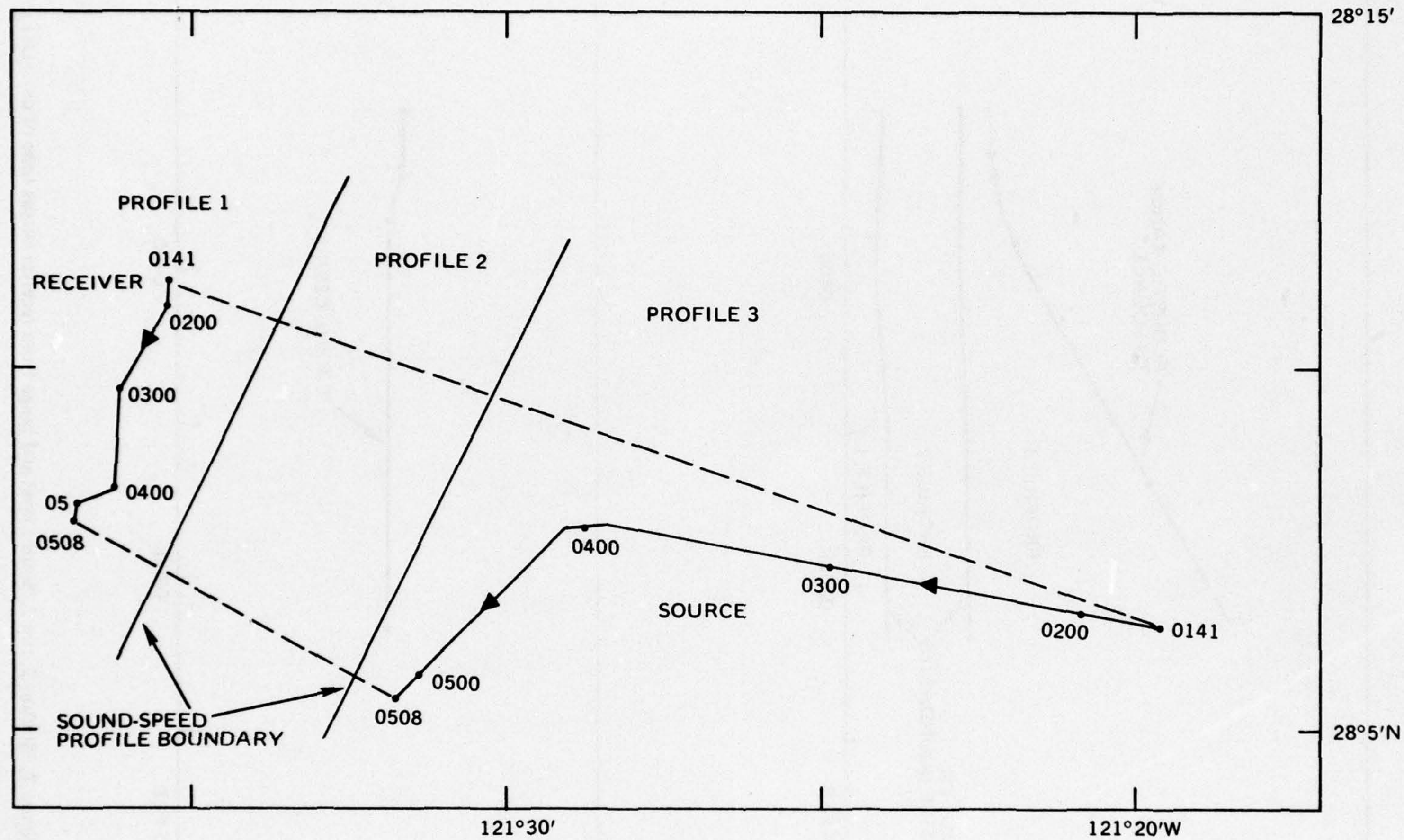


Figure 6. Station 2, run 2. Tracks of source and receiver ships, 0141 LST and 0508 LST propagation paths, and location of sound-speed profile boundaries.

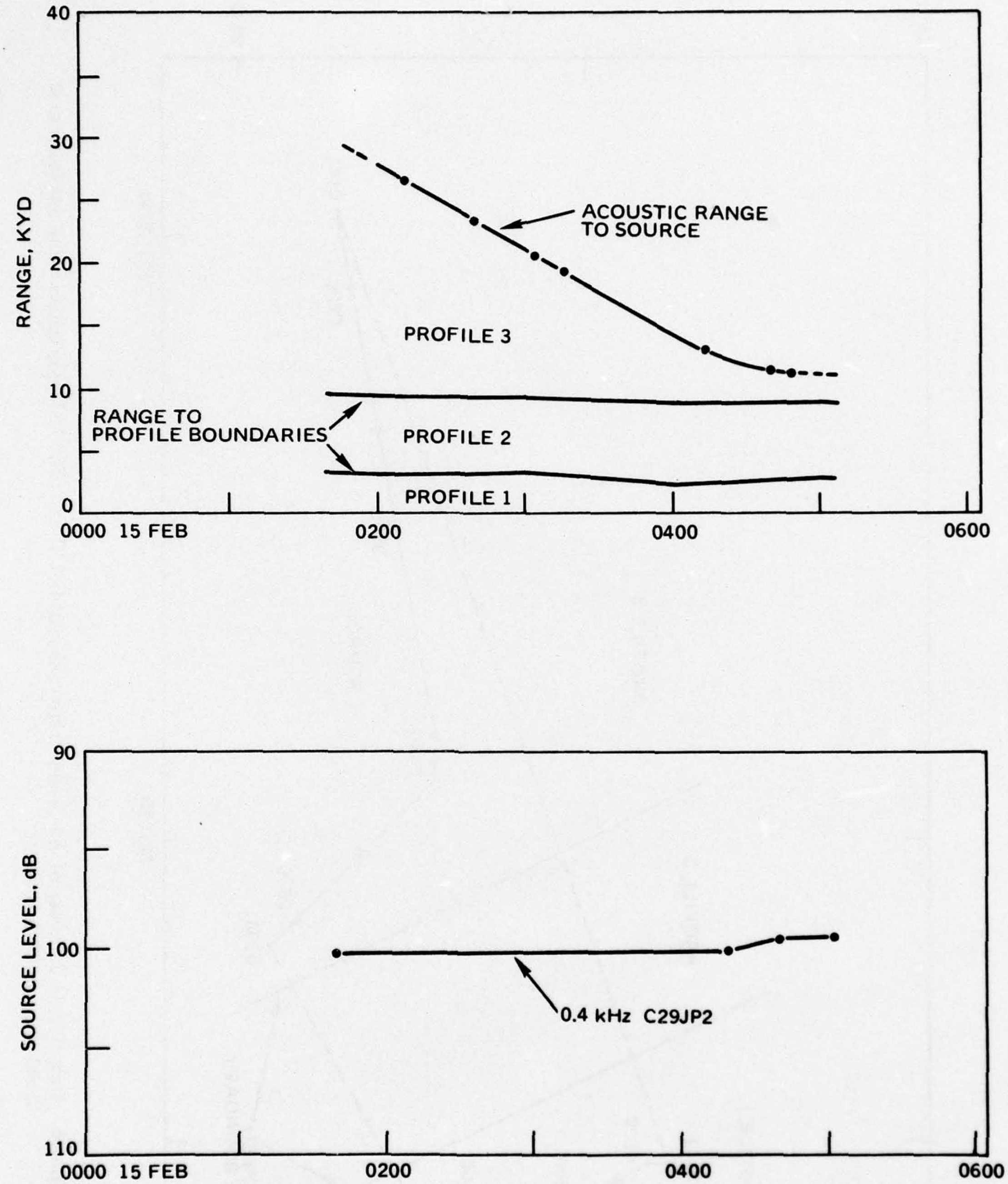


Figure 7. Station 2, run 2. Source level and range from receiver versus time of day (LST).

Average Sound-Speed Profiles

Individual sound-speed profiles suggested that the southeastern edge of the profile 2 volume crossed during run 1 was recrossed between 0400 LST and 0420 LST. However, neither a plot of 10-min sound-speed profiles derived from thermistor chain temperature measurements nor a plot of all of the thermistor chain temperature measurements clearly supported the recrossing. Consequently, it was concluded that the sources remained in the profile 3 volume and receivers in the profile 1 volume, with the profile 2 volume between them, during the entire experimental run. The extrapolated location of the sound-speed profile boundaries is shown in Fig. 6. Figure 5 contains plots of the average sound-speed profiles. Profile 1 is derived from the two XBT measurements made by the receiver ship, and profile 3 is derived from the thermistor chain measurements made by the source ship. Profile 1 is characterized by a 40-m surface channel and a 36-m depressed channel, with the minimum sound speed at 60 m. Since no measurements were made in the profile 2 volume, the run 1 sound-speed profile 2 should be used in any acoustic application. A 90-m refractive channel centered at a depth of 250 m was also present during this run.

This experiment was conducted under the same adverse weather conditions that prevailed during run 1. The source ship reported 17- to 20-knot winds, 6- to 7-ft waves, and 10-ft swell. The receiver ship reported 18- to 20-knot winds, 6- to 7-ft waves, and 8- to 10-ft swell. During the course of the run, the receiving ship drifted about 4 nm south-southwest. As shown in Fig. 6, it became apparent that the run could not be closed due to the rapid southerly drift of the receiver ship, and a course change of 57 deg was executed between 0355 and 0405 LST. This resulted in near-parallel tracks with a very slow rate of closure. At 0508 LST the run was terminated at an acoustic range of 10.7 kyd. Because of the resulting geometry of the experiment, no environmental measurements were made along any of the propagation paths. Also, as a consequence of the adverse weather conditions, no Waverider buoy measurements were obtained.

Receivers 1 and 2 were located in the profile 1 40-m surface channel, receiver 3 was 3 m below the surface channel, receiver 4 was in a well-developed depressed channel, and receiver 5 was in the main thermocline.

AMOS Parameters

The AMOS propagation loss prediction model assumes that sources and receivers are in the same water volume, in which single values of the AMOS parameters are applicable. Thus, the AMOS propagation loss prediction model is not applicable to this experiment since the receiving and transmitting ships were clearly in different sound-speed profile water volumes.

Discussion

The propagation loss measurements are summarized in Appendix B. Measurements are presented only for 1.0 kHz since the 0.4-kHz projector was inoperative. The vertical lines on the plots indicate the 55-deg course change made at an acoustic range of 14.0 kyd.

The source was towed at 39 m, a depth 9 m below the profile 3 surface channel. For all but the 17-m receiver, the propagation loss plots show a range interval from 11.6 kyd to 18.2 kyd, the exact interval depending upon the receiver, where most of the transmitted pulses were below the noise level. Additionally, most of the transmitted pulses for these receivers were below noise from 23.2 to 24.1 kyd to the end of the run. For the 17-m receiver, most of the transmitted pulses were received out to the maximum range of the run.

Table 3 shows, for the indicated range intervals, the number of transmitted pulses, the number of received pulses, the number of pulses below noise, and the percent of pulses below noise.

An examination of the propagation loss plots and the data in Table 3 suggests the following:

- The propagation loss for receivers at 4, 43, 72, and 112 m are very similar, with two range intervals in which 40.4 to 80.1 percent of the transmitted pulses were below noise, depending upon the receiver depth. The propagation losses measured by the 17-m receiver were quite different, with only 10.5 percent of the transmitted pulses below noise for the entire run.
- The 17-m receiver propagation losses exhibited a modal pattern typical of simple surface channeling of acoustic energy.
- No influence of the depressed channel on the 72-m propagation losses could be detected.

Table 3. Summary of Propagation Loss Measurements

Receiver Depth, m	Range Interval, kyd from	Range Interval, kyd to	Number of Pulses Transmitted	Number of Pulses Received	Number of Pulses Below Noise	
4	11.6	17.5	282	85	197	69.9%
43	11.6	17.5	282	168	114	40.4%
72	13.4	18.2	180	54	126	70.0%
112	14.0	18.2	160	50	110	68.8%
4	23.2	end	232	50	182	78.4%
17	10.7	end	818	732	86	10.5%
43	23.2	end	232	82	170	73.3%
72	23.6	end	216	43	173	80.1%
112	24.1	end	200	46	154	77.0%

RUN 3 – 15 February 1972, 1328-1940 LST

During this run, 3.5- and 5.0-kHz propagation losses were measured over acoustic ranges from 200 yd to 25.0 kyd. Figure 8 shows the track of the source and receiving ships, the 1328 and 1940 LST propagation paths, and the location of a sound-speed profile shape boundary. Figure 9 contains plots of source level and ranges from receivers, derived from 14 travel-time measurements, versus time of day. In Fig. 9 the range from the receivers to the sound-speed profile boundaries is shown as a function of time of day.

Individual sound-speed profiles suggested that a sound-speed profile boundary was crossed between 1520 and 1540 LST and recrossed between 1700 and 1720 LST. An examination of 10-min-interval profiles showed the crossings occurred at 1531 and 1722 LST. This boundary appears to be a southern extension of one of the boundaries crossed during run 1. Profile 2 is probably the same transition profile crossed during run 1. This profile gradually changed with decreasing latitude into profile 2A. Figure 5 contains a plot of average sound-speed profiles 2 and 2A. There is a high likelihood that profile 3 is in the same water mass as profile 3 of runs 1 and 2. All three average profiles are characterized by 30-m surface channels, with the near-surface sound speed for profile 2A being about 0.5 m/sec higher than for profile 2. Profiles 2 and 2A also have minor depressed channels centered at 68 m and 50 m, respectively. Profile 3 has a 70-m refractive channel, with the minimum sound speed at 250 m. Variations in sound-speed profile shapes were noted to a depth of 400 m. Run 3 began about 12 nm south of run 2 and was conducted under the same adverse weather conditions that prevailed during runs 1 and 2. The source ship reported 20- to 22-knot winds, 5- to 7-ft. waves, and 10-ft. swell. The receiver ship reported 17- to 20-knot winds, 3- to 4-ft. waves, and 8- to 10-ft swell. During this run the source ship's track was southerly, the same direction as the drift of the receiver ship. Consequently the propagation paths closely coincide with the track of the source ship and the plane of the source ship's environmental measurements. Also, as a consequence of the adverse weather conditions, no Waverider buoy measurements were obtained. Receivers 1 and 2 were located in a 30-m surface channel and receivers 3, 4, and 5 were in the main thermocline.

AMOS Parameters

The AMOS propagation loss prediction model assumes that sources and receivers are in the same water volume, in which single values of the AMOS parameters are applicable. For this experiment this assumption was valid out to a range of 8.2 kyd. The number of observations and the average values of these parameters, derived from the thermistor chain temperature measurements, and applicable to the run 3 experiments are:

number of observations	738
isothermal layer depth	112 ft
depressed channel axis	223 ft
surface water temperature	59.2°F
sea state	3-4

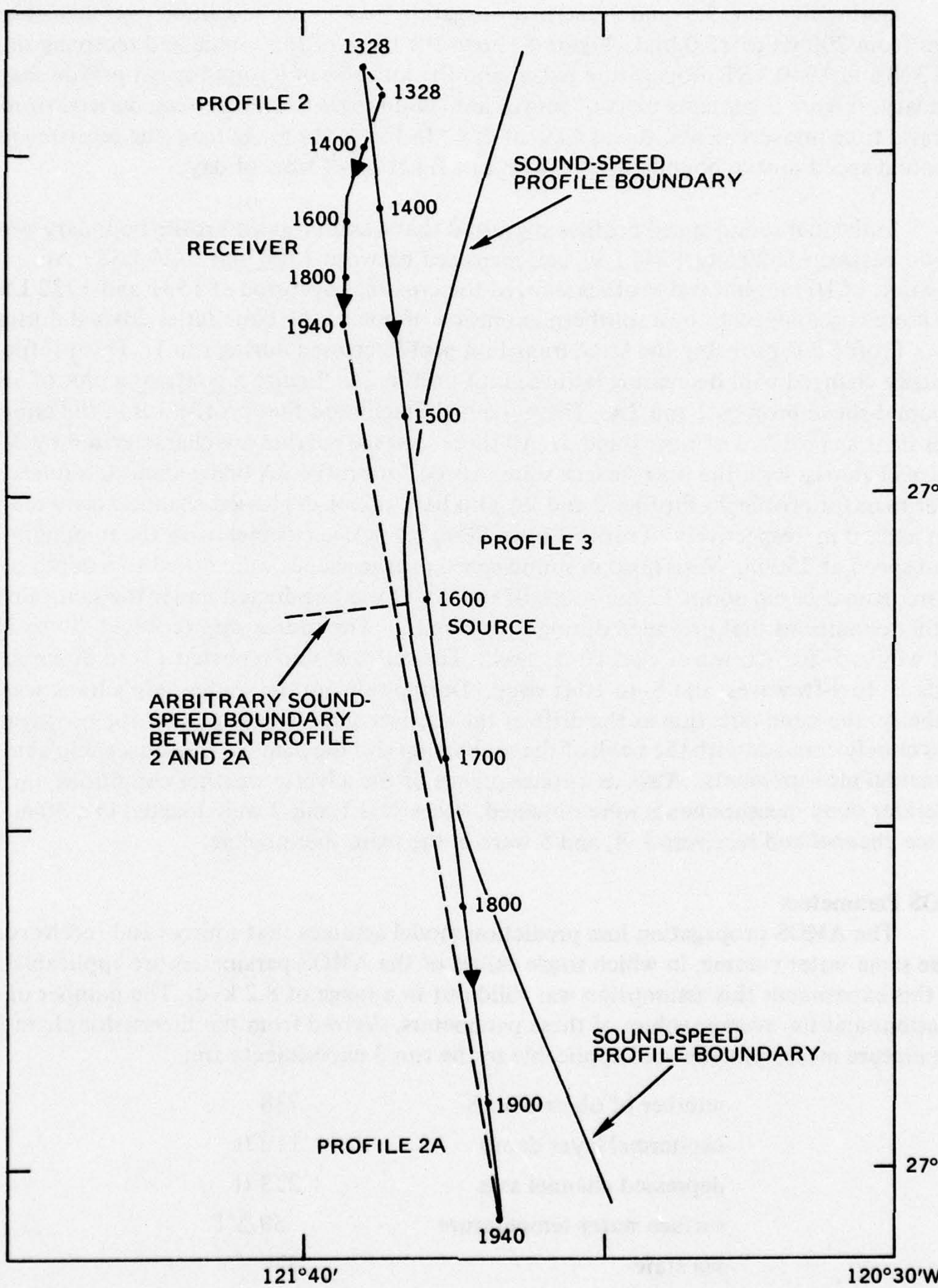


Figure 8. Station 2, run 3. Tracks of source and receiver ships, 1328 LST and 1940 LST propagation paths, and location of sound-speed profile boundaries.

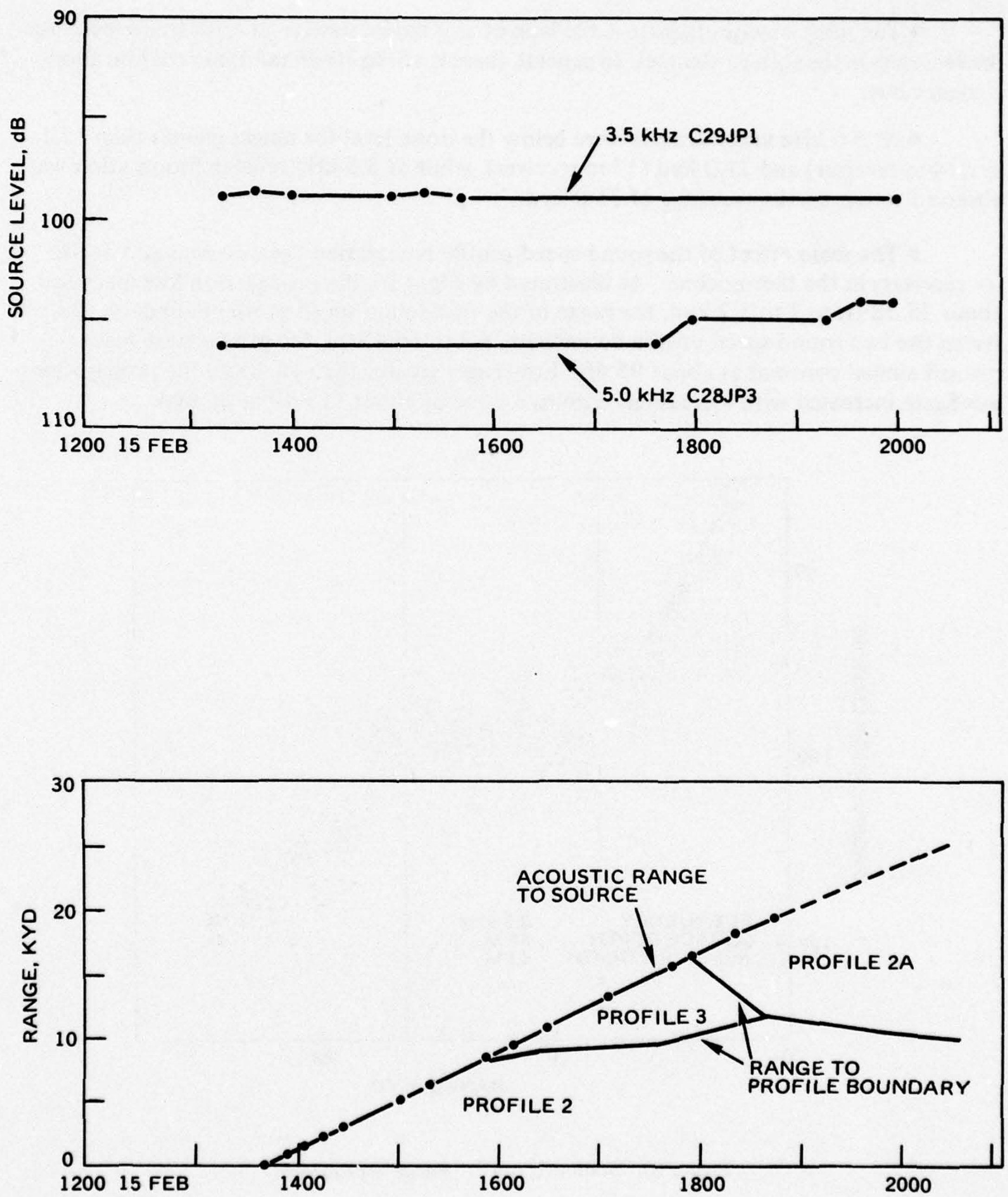


Figure 9. Station 2, run 3. Source level and range from receiver versus time of day (LST).

DISCUSSION

The propagation loss measurements are summarized in Appendix C. The vertical lines on the individual propagation loss plots indicate the range from the receivers of the sound-speed profile boundaries. A visual comparison of these plots suggest the following:

- The most obvious feature is the lack of any modal pattern at both frequencies for the receivers in the surface channel. In general, there is a 5- to 10-dB random variation about a mean value.

- At 5.0 kHz many arrivals were below the noise level for ranges greater than 19.1 kyd (4-m receiver) and 21.0 kyd (17-m receiver), while at 3.5 kHz reliable propagation was observed to the maximum range of 25.0 kyd.

- The main effect of the sound-speed profile boundaries was observed at 3.5 kHz for receivers in the thermocline. As illustrated by Fig. 10*, the propagation loss increased about 25 dB from 2 to 8.2 kyd, the range of the first sound-speed profile boundary. Between the two sound-speed profile boundaries, 8.2 to 16.4 kyd, the propagation loss remained almost constant at about 95 dB. For ranges greater than 16.4 kyd the propagation loss again increased with increasing range to a value of about 115 dB at 25 kyd.

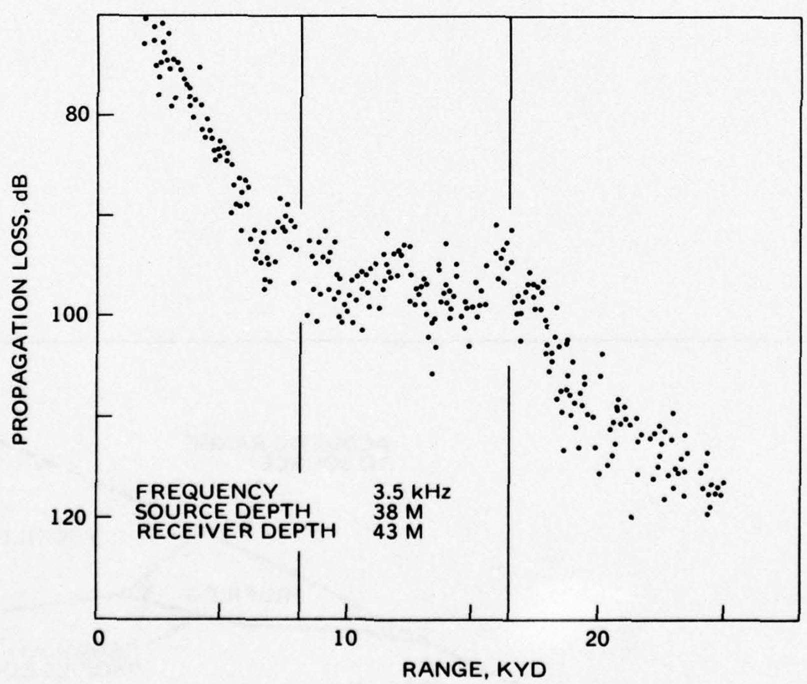


Figure 10. Station 2, run 3. Range dependence.

**A maximum of four CW pulses were transmitted each minute. For simplification, all pulses received during each minute (i.e., 1, 2, 3, or 4) were averaged. These average values are plotted on all propagation loss plots used in the text of this report.*

- At both frequencies, the propagation loss is identical for the two receivers in the surface sound channel. For receivers below the surface channel, the 3.5-kHz propagation loss is identical for all three receivers and at 5.0 kHz it is identical for the 43- and 72-m receivers. The 5.0-kHz propagation loss at 112 m is consistently greater when compared to the other receiver depths.
- The largest difference in propagation loss was observed at 5.0 kHz between the 17-m and 112-m receivers.
- At all ranges and all receiver depths, the 5.0-kHz propagation loss is greater than the 3.5-kHz propagation loss.
- At both frequencies and for the three receivers below the surface channel, many of the arrivals were below the noise level for ranges greater than 18.8 to 21.0 kyd.

RUN 4 – 15-16 February 1972, 2031-0052 LST

During this run, 0.4- and 1.0-kHz propagation losses were measured over acoustic ranges from 1.7 to 28.1 kyd. Figure 11 shows the track of the source and receiver ships, the 2031 and 0052 LST propagation paths, and the location of two sound-speed profile shape boundaries. This run began 51 min after the completion of run 3. Figure 12 contains plots of source level and ranges from receivers, derived from 14 travel-time measurements, versus time of day. In Fig. 12 the range from the receivers to the sound-speed profile boundaries is shown as a function of time of day.

Average Sound-Speed Profiles

Individual sound-speed profiles show that the track of the source ship was in a uniform water mass containing a sound-speed profile characterized by a surface channel and a depressed channel. These observations, coupled with those made during the other station 2 runs, suggest that the source ship track was west of a southerly extension of the profile 2 and 2A sound-speed profile volumes crossed during runs 1 and 3. Although no measurements were made by the receiver ship, it appears that it remained in the run 3 sound-speed profile 2 water volume during the entire run. Figure 5 contains plots of the average sound-speed profile derived from the thermistor chain measurements (profile 4). Also shown are plots of the run 3 average profiles 2 and 2A. The average sound-speed profile at the source (profile 4) is characterized by a 39-m surface channel and a 20-m depressed channel, with the minimum speed at 60m. Since the receivers are in a different sound-speed profile volume than the source, profile 4 should be used in conjunction with profiles 2 and 2A of run 3 in any acoustic study or application. This experiment was conducted under the same adverse weather conditions that prevailed during the other station 2 runs. The source ship reported 20-knot winds, 5-ft waves, and 8-ft swell, (and the receiver ship reported 15- to 20-knot winds, 4-ft waves, and 8-ft swell). During the course of the run the receiver ship drifted south about 2 nm. As a consequence of the adverse weather conditions, no Waverider buoy measurements were obtained.

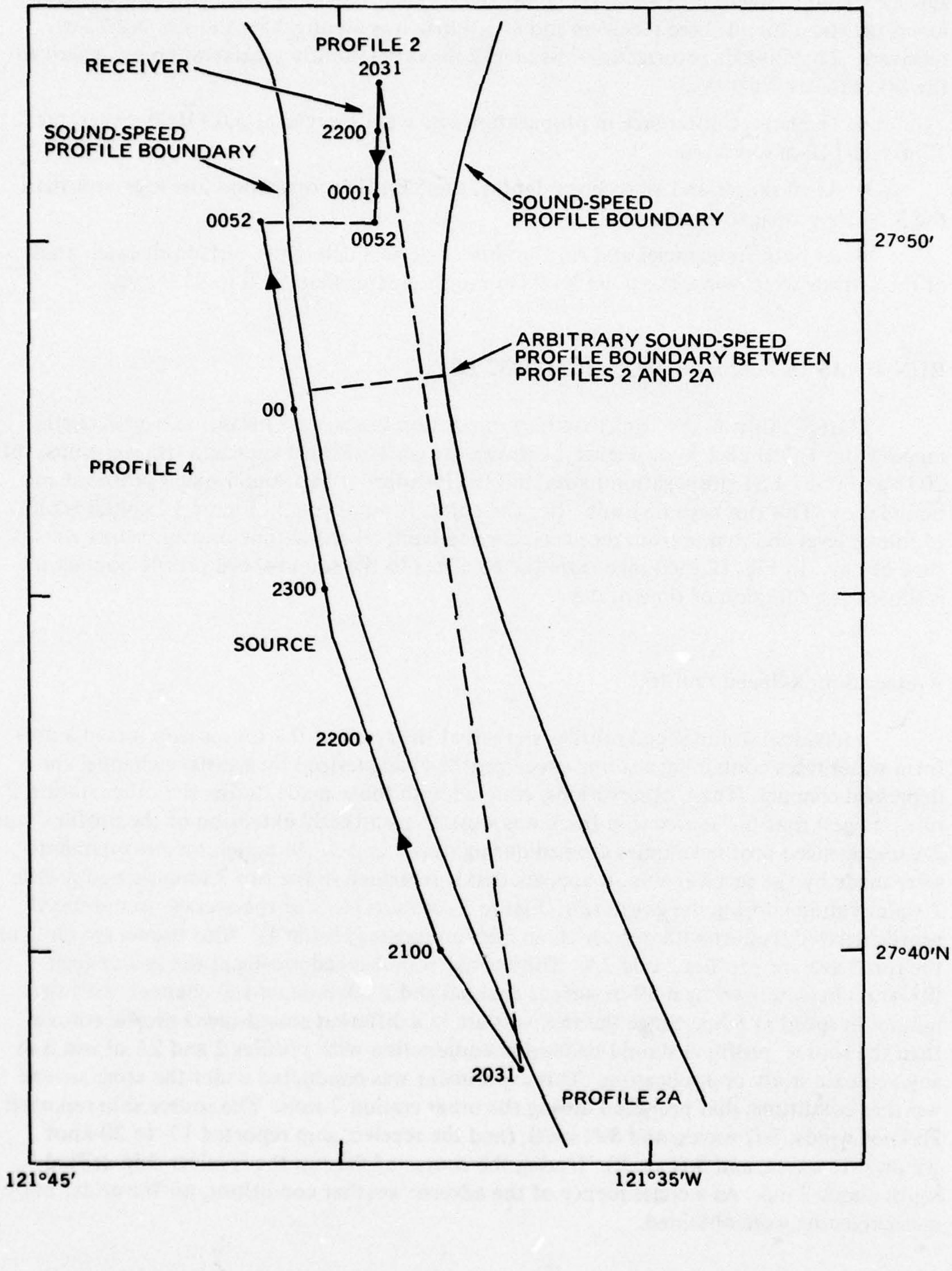


Figure 11. Station 2, run 4. Tracks of source and receiver ships, 2031 LST and 0052 LST propagation paths, and location of sound-speed profile boundaries.

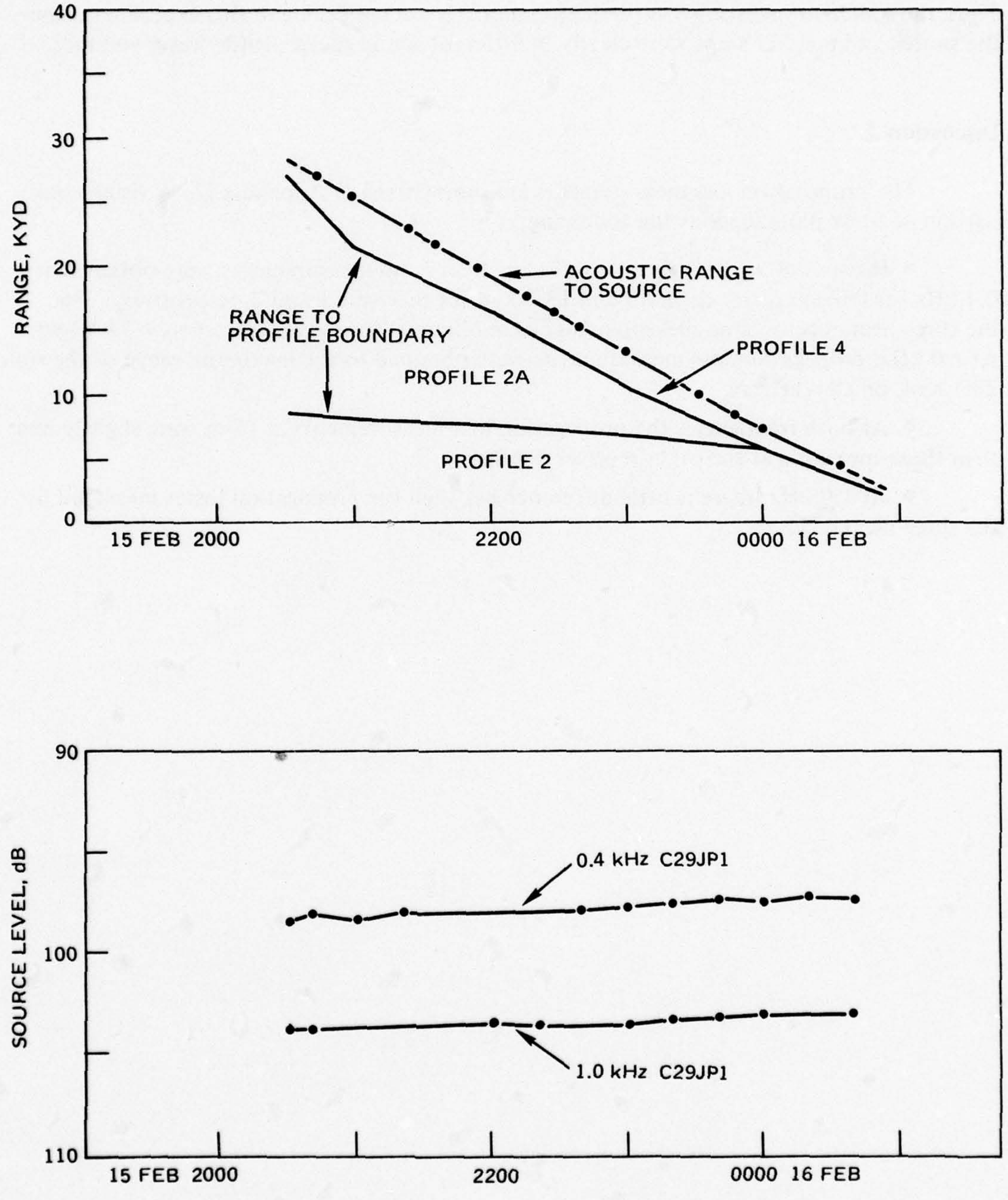


Figure 12. Station 2, run 4. Source level and range from receiver versus time of day (LST).

AMOS Parameters

The AMOS propagation loss prediction model assumes that sources and receivers are in the same water volume, in which single values of the AMOS parameters are applicable. Thus, the AMOS propagation loss prediction model is not applicable to this experiment since the source and receiver ships were clearly in different sound-speed profile water volumes.

Discussion

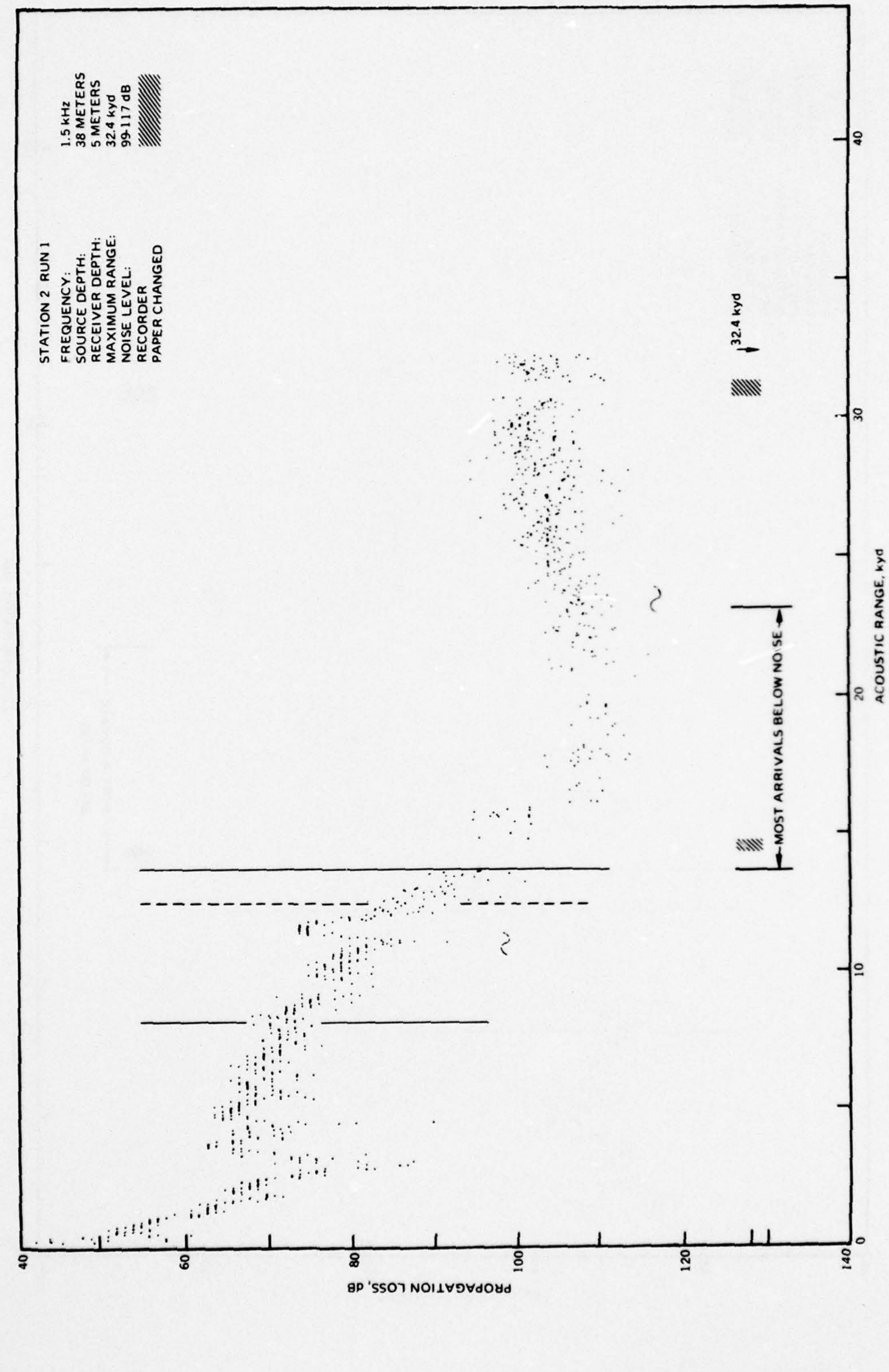
The propagation loss measurements are summarized in Appendix D. A visual comparison of these plots suggests the following:

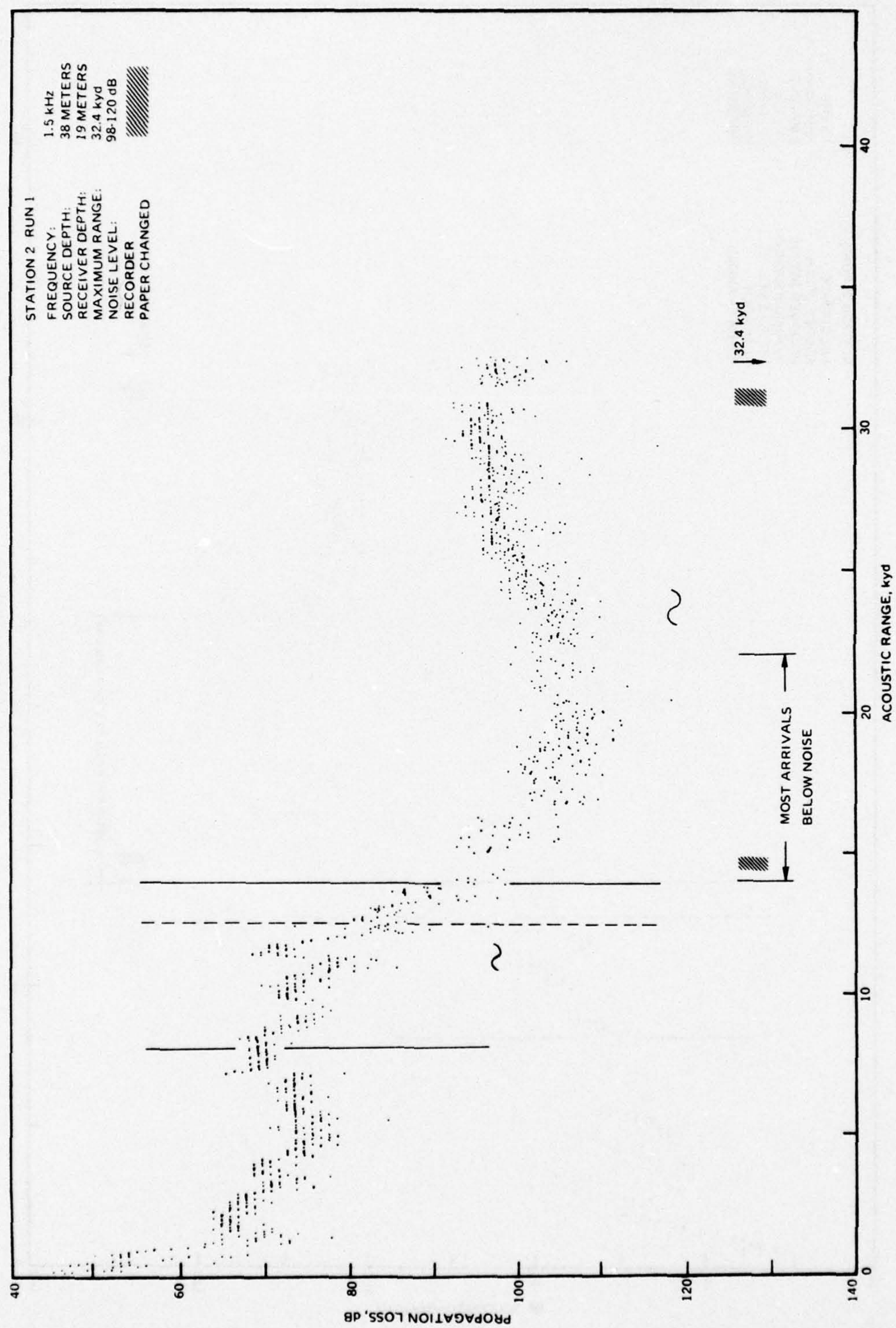
- Because of a signal-to-noise ratio less than 1, no measurements were obtained at 0.4 kHz for ranges greater than 9.3 and 13.7 kyd for receivers 1 and 2, respectively. For the three deep receivers, no measurements were obtained for ranges greater than 14.5 kyd. At 1.0 kHz, propagation loss measurements were obtained to the maximum range of the run, 28.1 kyd, on all receivers.
- At both frequencies the propagation loss measurements at 17 m were slightly less than those measured at the other receiver depths.
- At 1.0 kHz, there is little difference between the propagation losses measured by the three deep receivers.

APPENDIX A

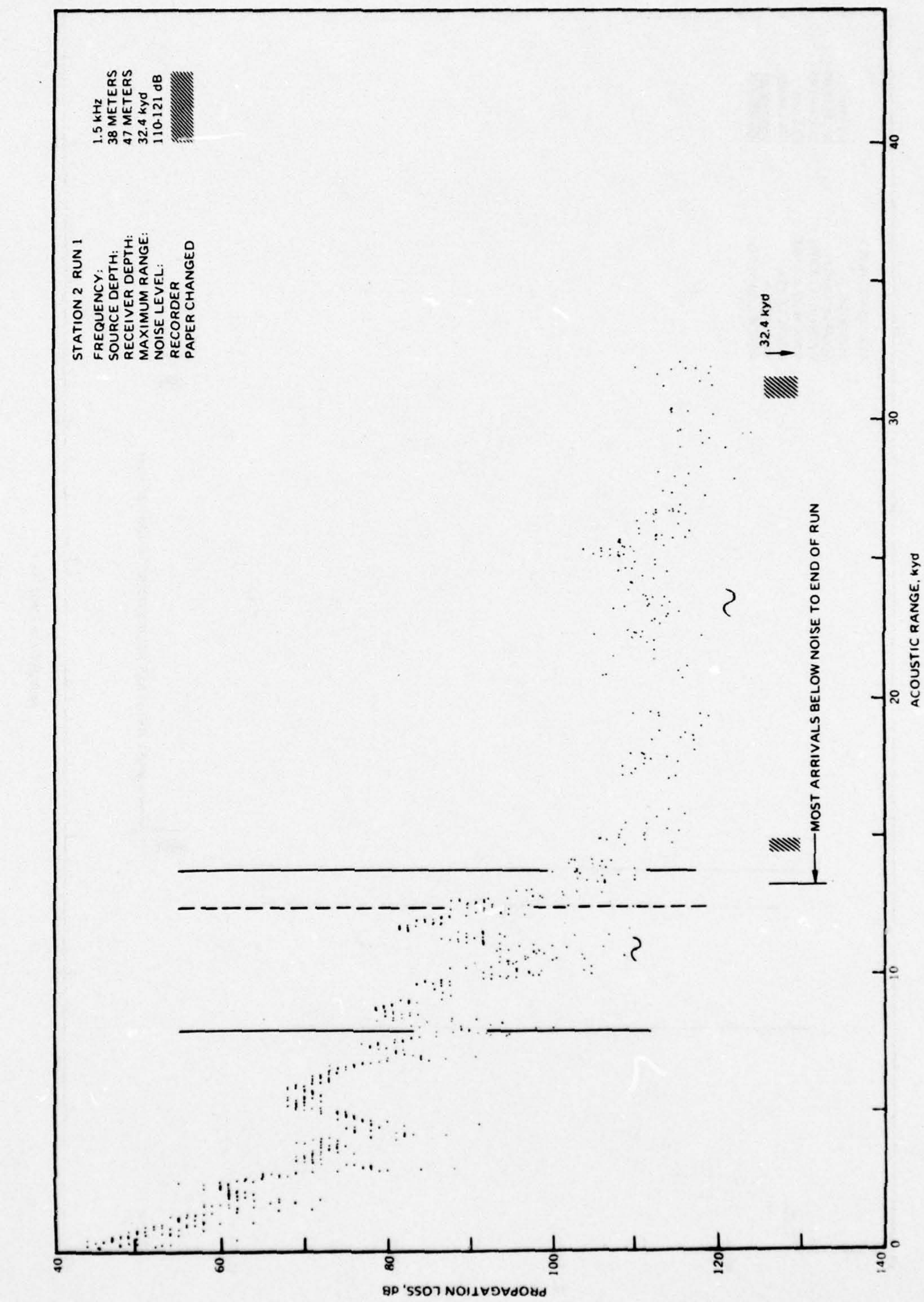
STATION 2 RUN 1

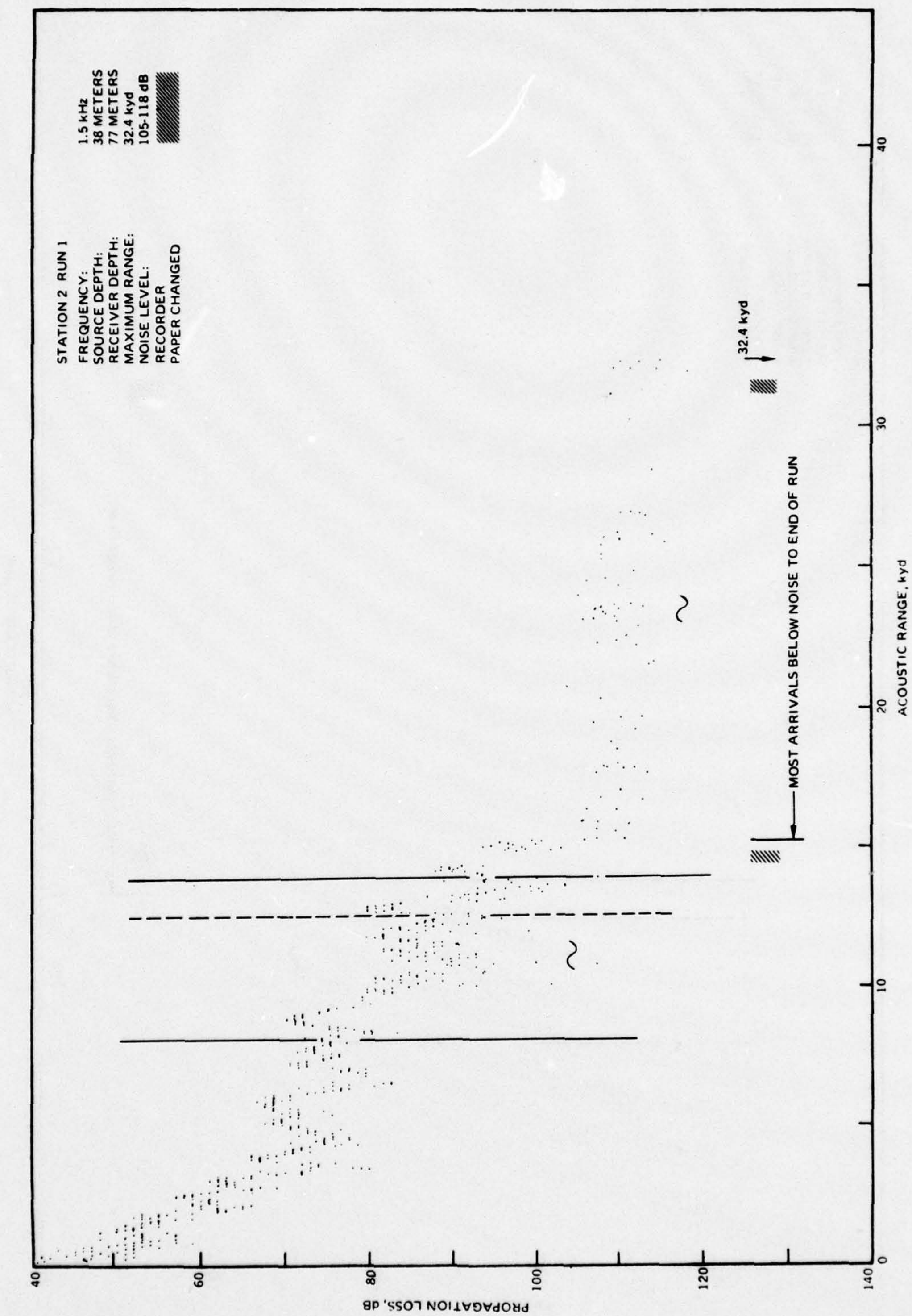
PROPAGATION LOSS VERSUS ACOUSTIC RANGE PLOTS

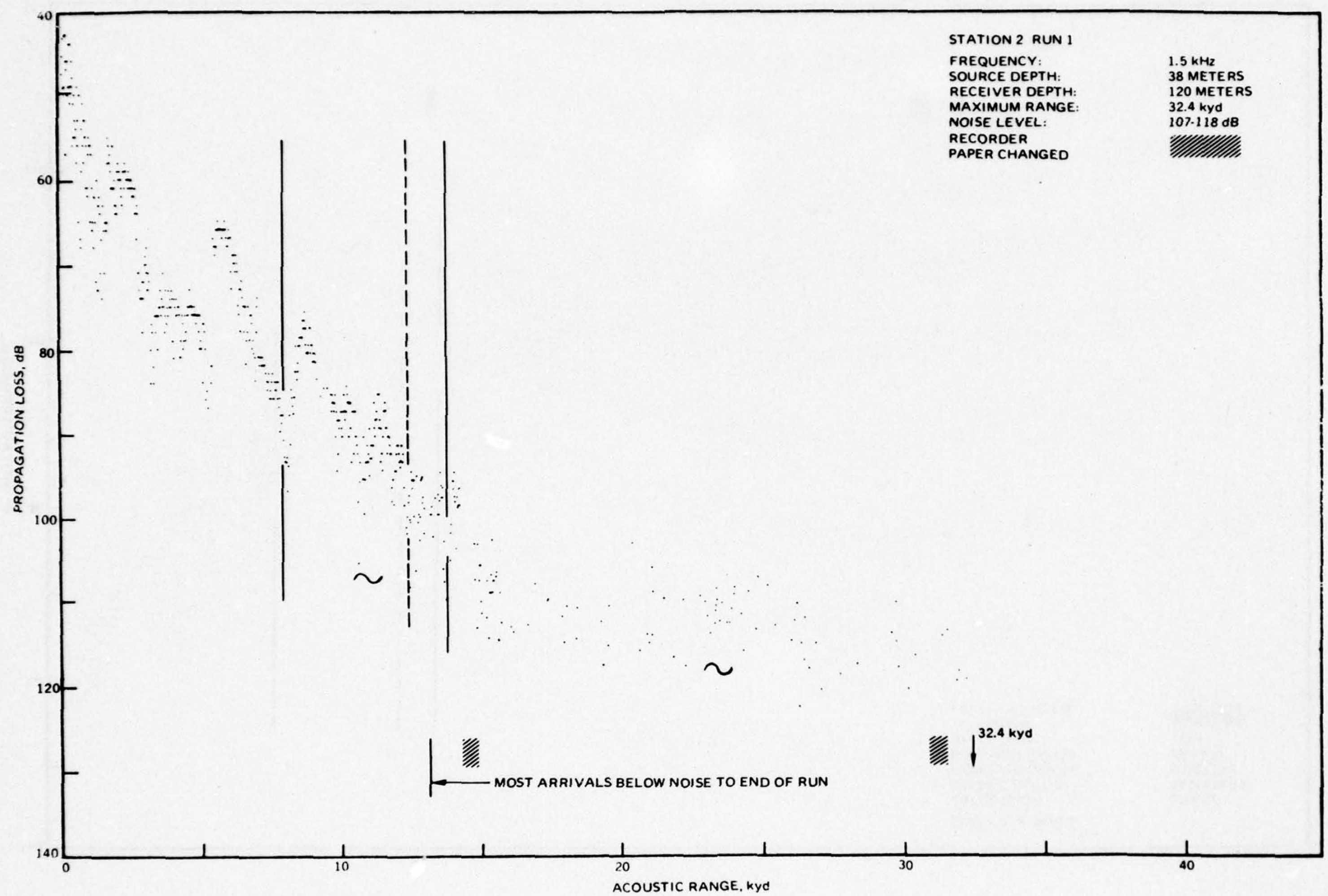

STATION 2 RUN 1
FREQUENCY: 1.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 5 METERS
MAXIMUM RANGE: 32.4 kyd
NOISE LEVEL: 99-117 dB
RECORDER PAPER CHANGED
32.4 kyd
MOST ARRIVALS BELOW NOISE
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40



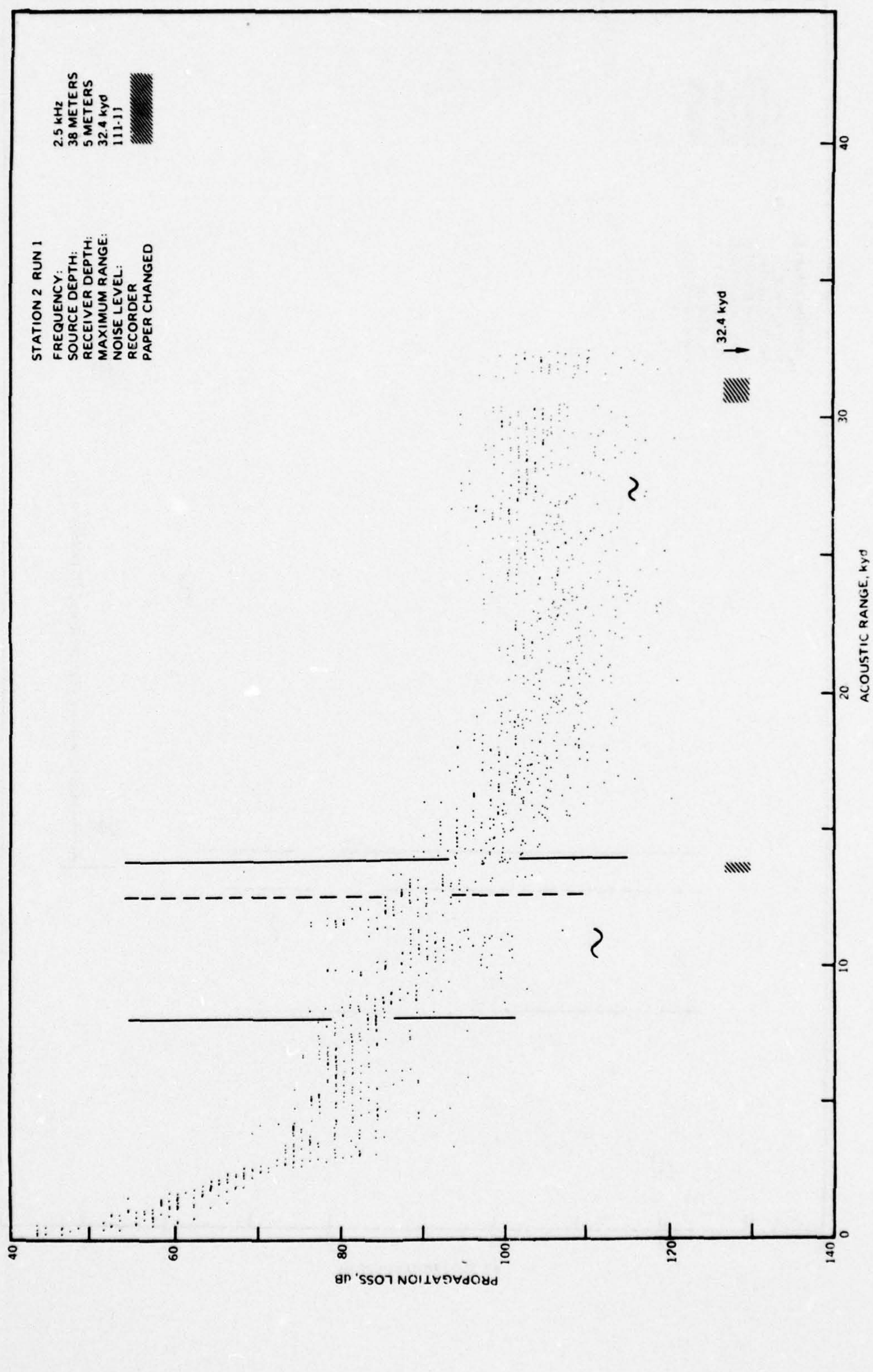
STATION 2 RUN 1
FREQUENCY: 1.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 19 METERS
MAXIMUM RANGE: 32.4 kyd
NOISE LEVEL: 98-120 dB
RECORDER
PAPER CHANGED
32.4 kyd
MOST ARRIVALS
BELOW NOISE
PROPAGATION LOSS, dB
ACOUSTIC RANGE, kyd
40
60
80
100
120
140
0
10
20
30
40

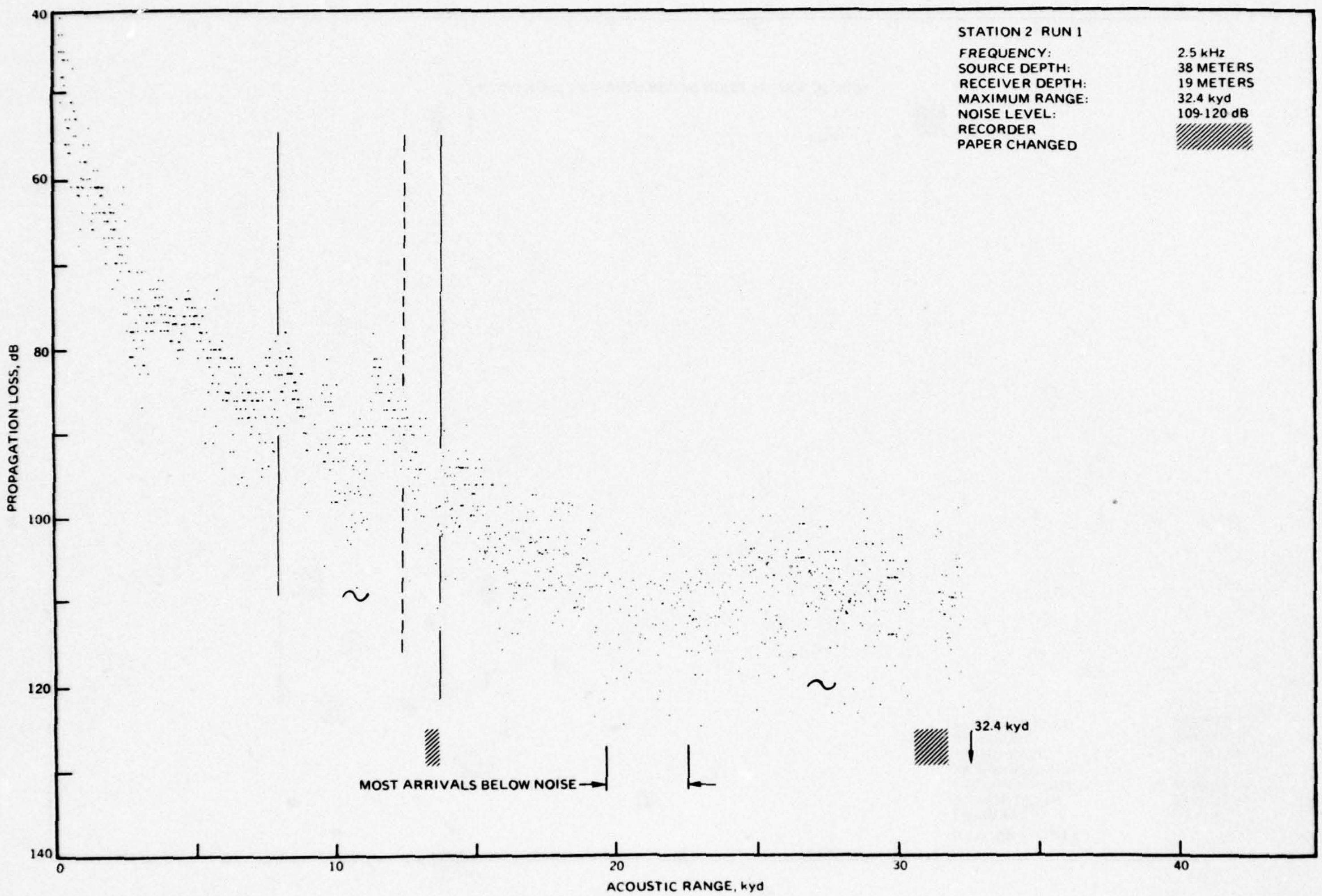

STATION 2 RUN 1
FREQUENCY: 1.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 47 METERS
MAXIMUM RANGE: 32.4 kyd
NOISE LEVEL: 110-121 dB
RECORDER PAPER CHANGED
32.4 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40

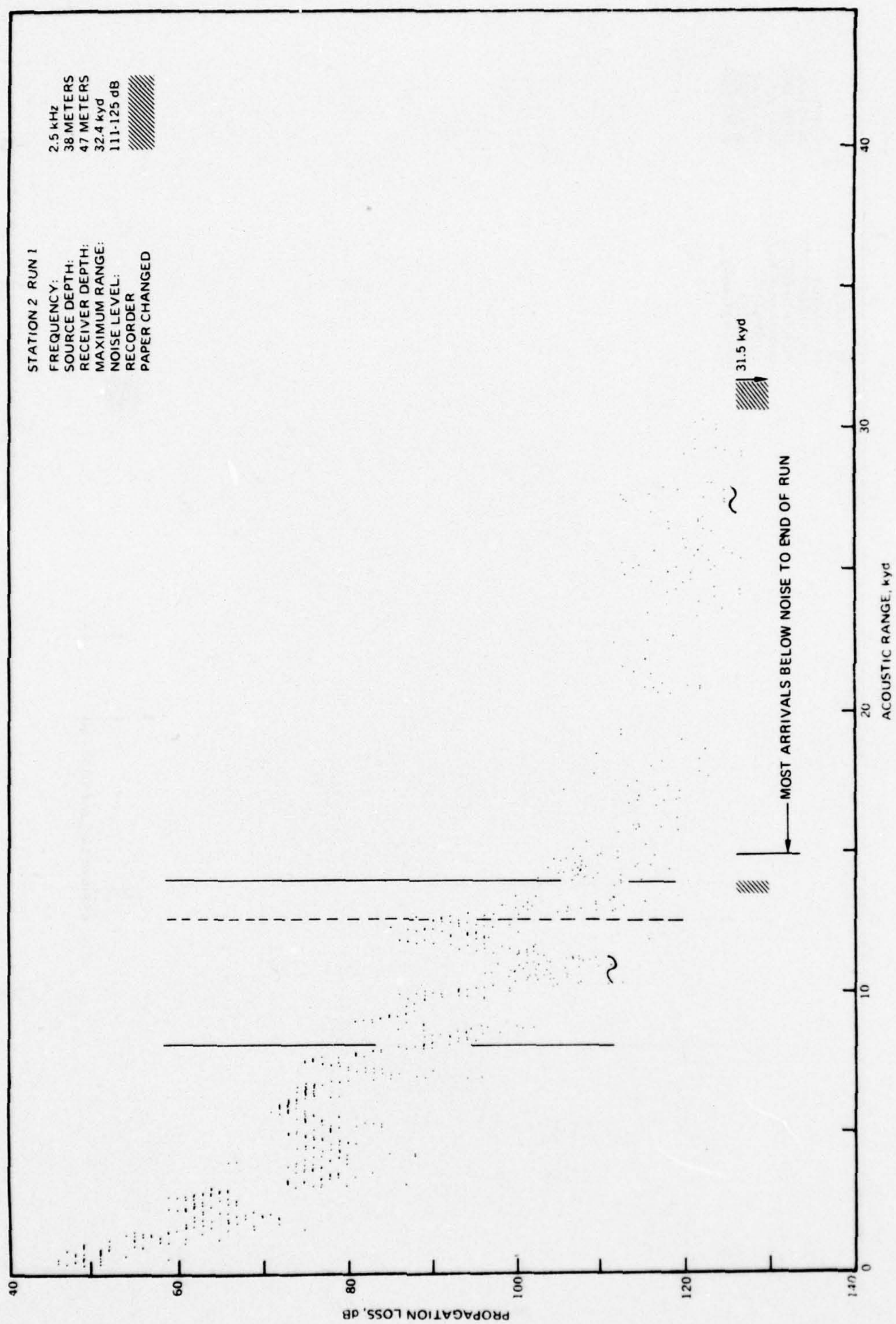

STATION 2 RUN 1
FREQUENCY: 1.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 77 METERS
MAXIMUM RANGE: 32.4 kyd
NOISE LEVEL: 105-118 dB
RECORDER
PAPER CHANGED
32.4 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
ACOUSTIC RANGE, kyd
40
60
80
100
120
140
0
10
20
30
40

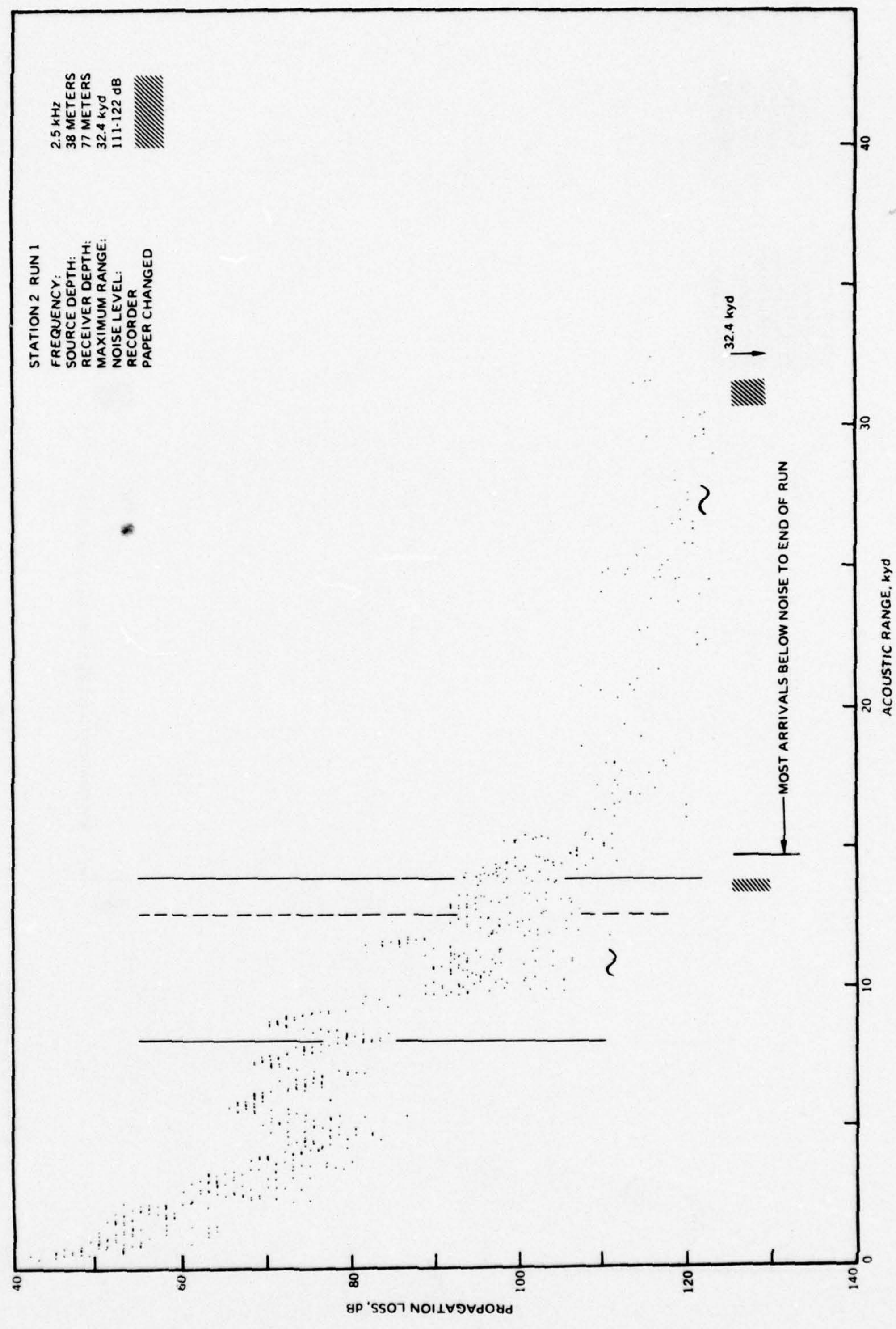


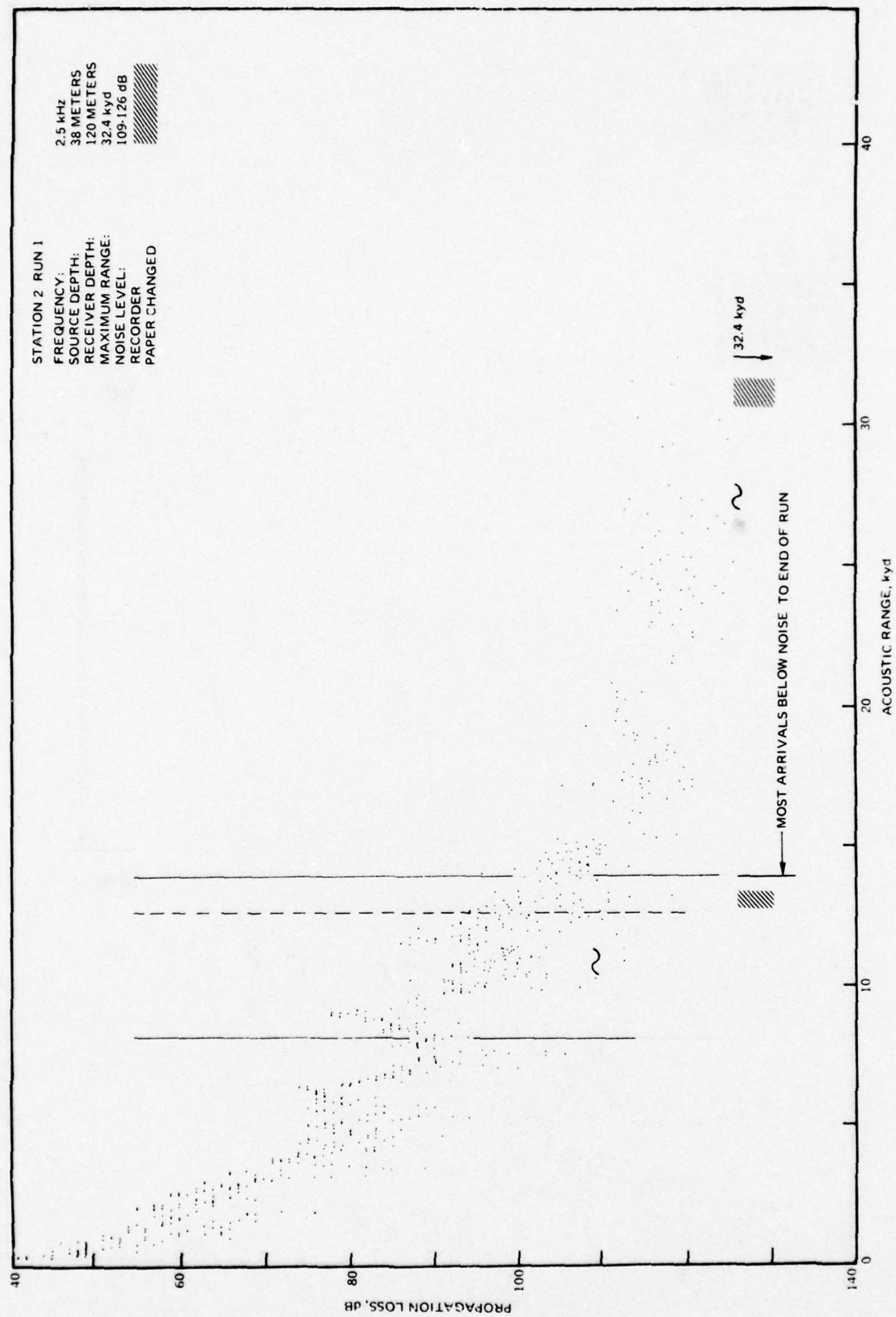
STATION 2 RUN 1
FREQUENCY: 1.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 120 METERS
MAXIMUM RANGE: 32.4 kyd
NOISE LEVEL: 107-118 dB
RECORDER PAPER CHANGED
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40
MOST ARRIVALS BELOW NOISE TO END OF RUN
32.4 kyd


STATION 2 RUN 1
FREQUENCY: 2.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 5 METERS
MAXIMUM RANGE: 32.4 kyd
NOISE LEVEL: 111-11
RECORDER
PAPER CHANGED
32.4 kyd
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40


STATION 2 RUN 1
FREQUENCY: 2.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 19 METERS
MAXIMUM RANGE: 32.4 kyd
NOISE LEVEL: 109-120 dB
RECORDER PAPER CHANGED
PROPAGATION LOSS, dB
ACOUSTIC RANGE, kyd
MOST ARRIVALS BELOW NOISE
32.4 kyd
40
60
80
100
120
140
0
10
20
30
40


STATION 2 RUN 1
FREQUENCY: 2.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 47 METERS
MAXIMUM RANGE: 32.4 kyd
NOISE LEVEL: 111-125 dB
RECORDER PAPER CHANGED
31.5 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40


STATION 2 RUN 1
FREQUENCY: 2.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 77 METERS
MAXIMUM RANGE: 32.4 kyd
NOISE LEVEL: 111-122 dB
RECORDER PAPER CHANGED
32.4 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40

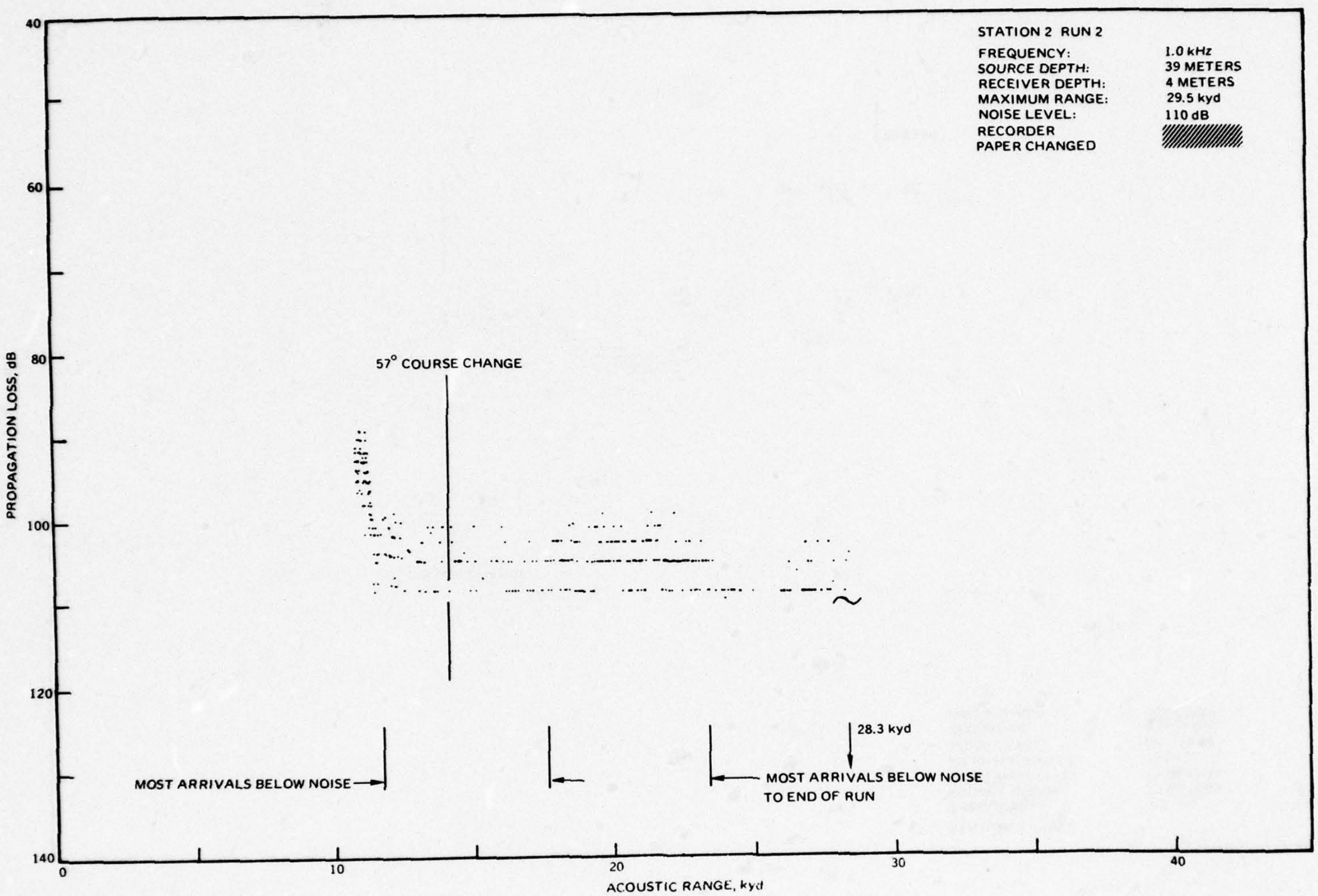


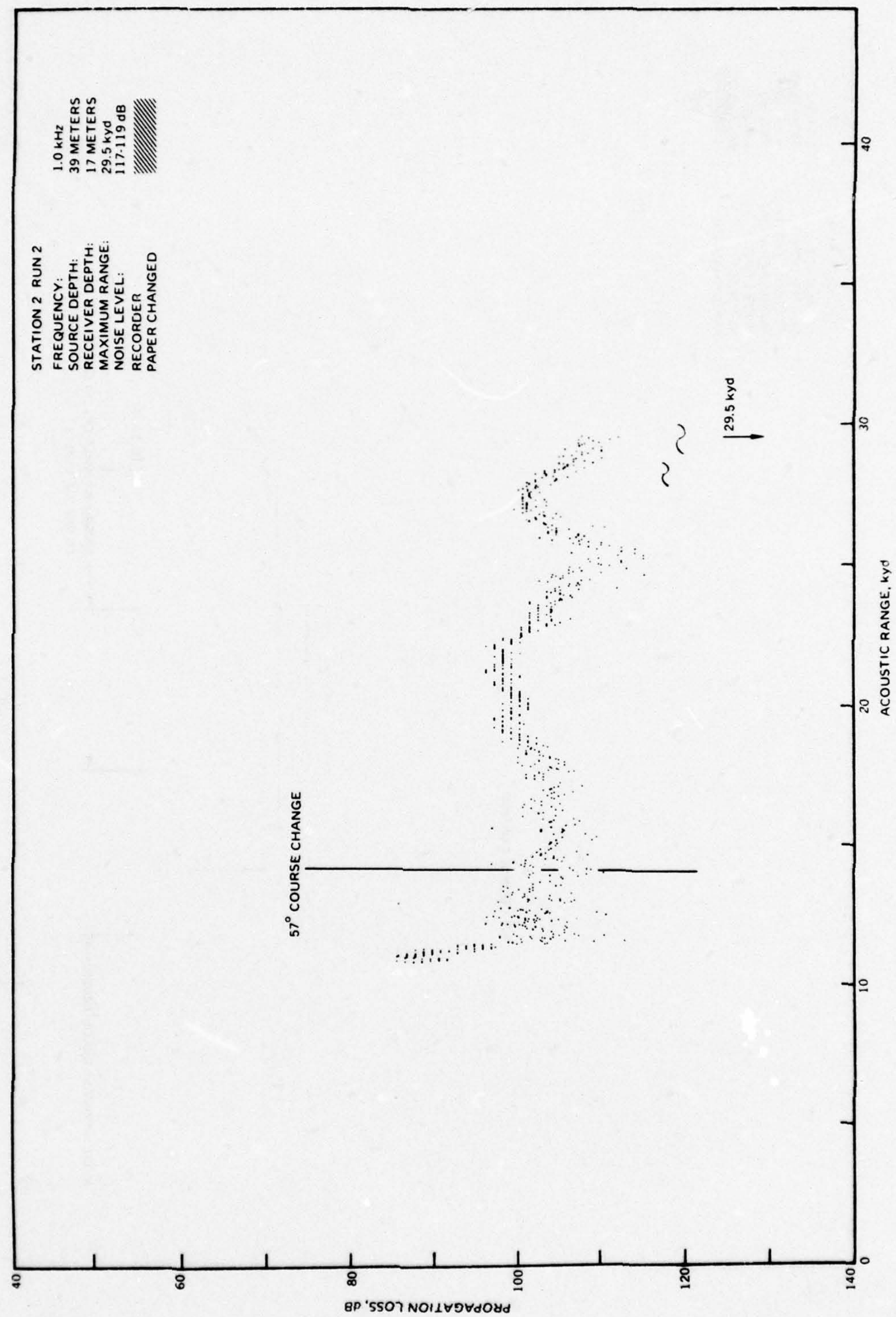
STATION 2 RUN 1
FREQUENCY: 2.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 120 METERS
MAXIMUM RANGE: 32.4 kyd
NOISE LEVEL: 109-126 dB
RECORDER
PAPER CHANGED
32.4 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
40
60
80
100
140
ACOUSTIC RANGE, kyd
0
10
20
30
40

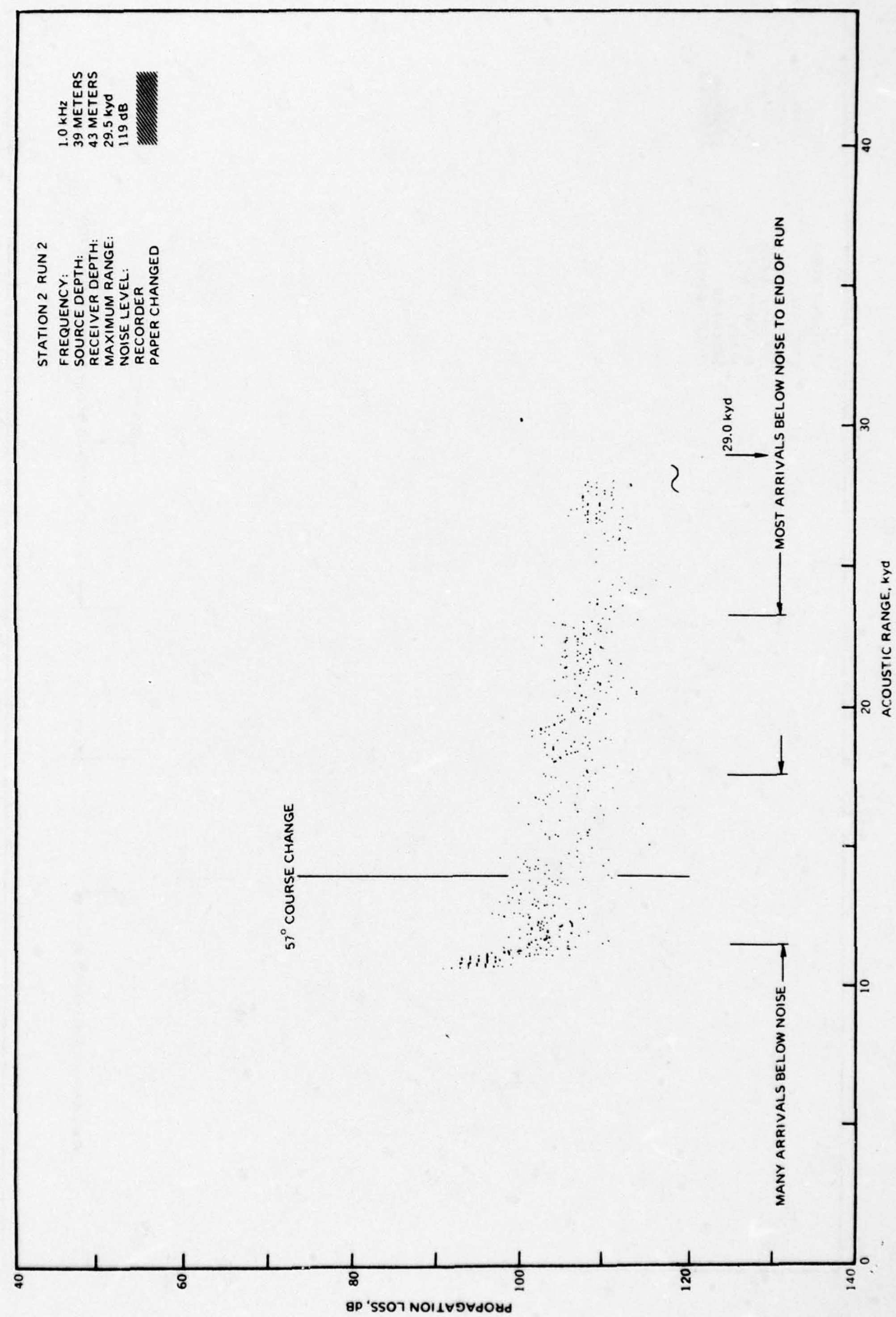
APPENDIX B

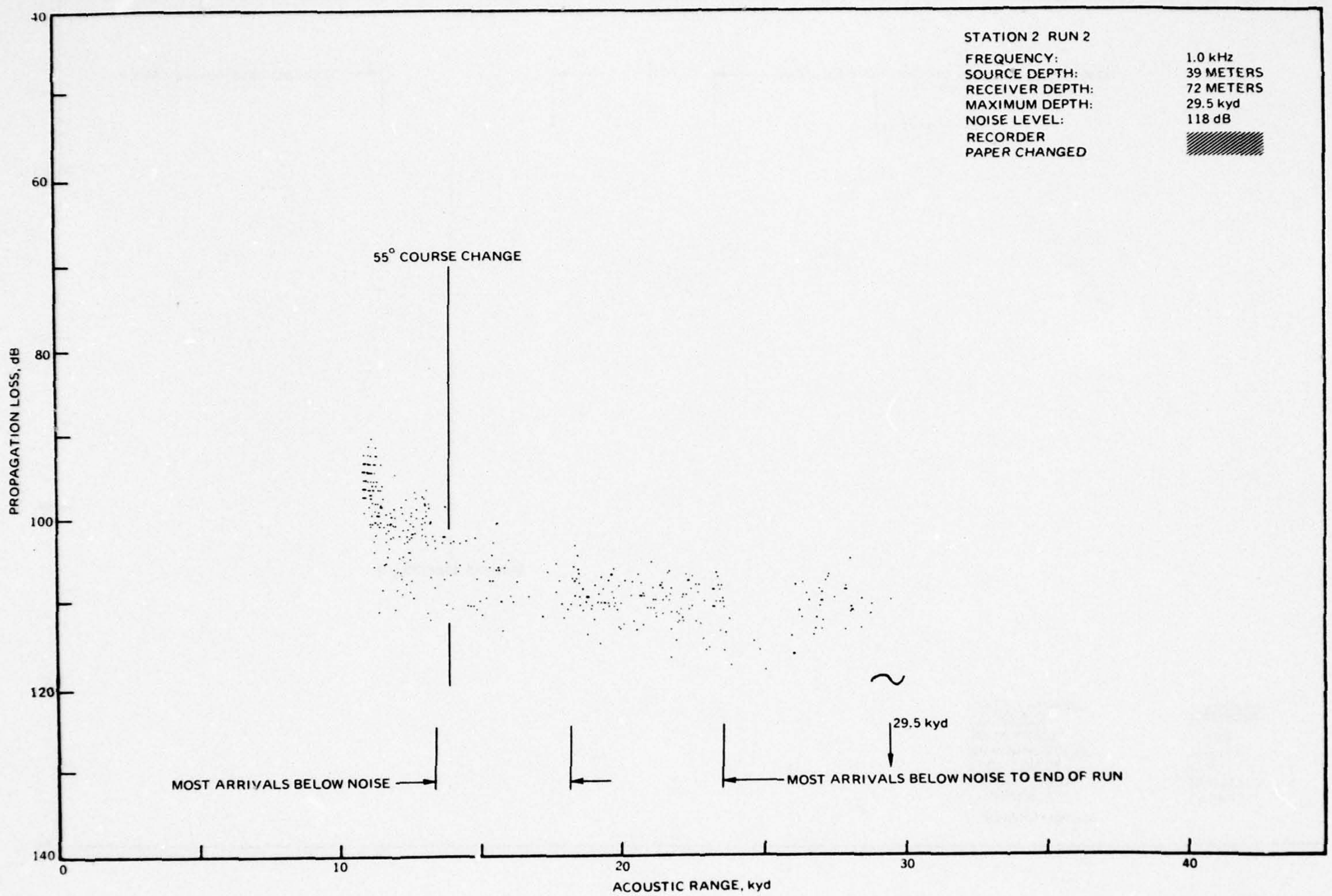
STATION 2 RUN 2

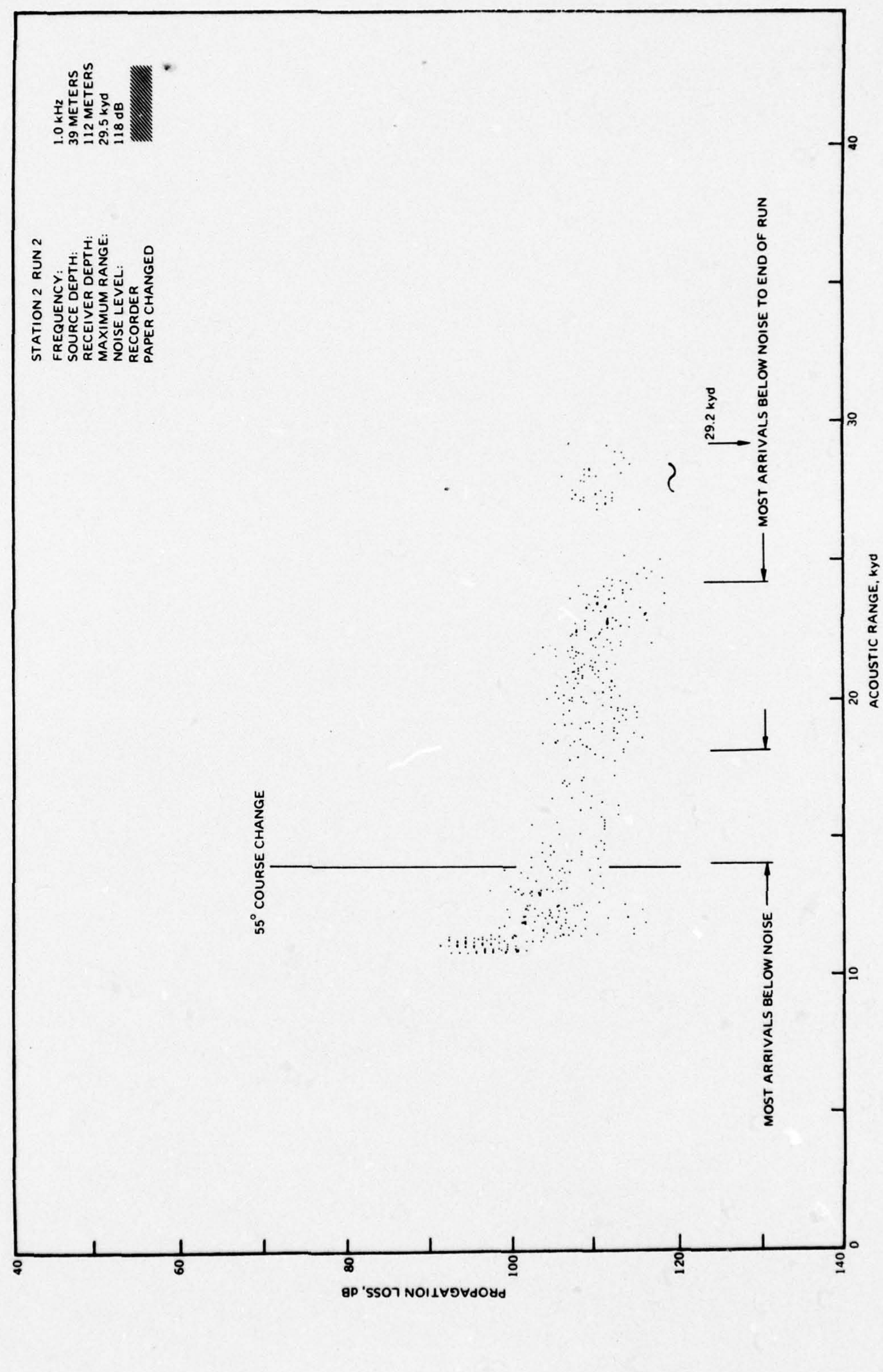
PROPAGATION LOSS VERSUS ACOUSTIC RANGE PLOTS


STATION 2 RUN 2
FREQUENCY: 1.0 kHz
SOURCE DEPTH: 39 METERS
RECEIVER DEPTH: 4 METERS
MAXIMUM RANGE: 29.5 kyd
NOISE LEVEL: 110 dB
RECORDER PAPER CHANGED
57° COURSE CHANGE
MOST ARRIVALS BELOW NOISE
28.3 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
40
60
80
100
120
140
0
10
20
30
40
ACOUSTIC RANGE, kyd


STATION 2 RUN 2
FREQUENCY: 1.0 kHz
SOURCE DEPTH: 39 METERS
RECEIVER DEPTH: 17 METERS
MAXIMUM RANGE: 29.5 kyd
NOISE LEVEL: 117-119 dB
RECORDER PAPER CHANGED
57° COURSE CHANGE
29.5 kyd
PROPAGATION LOSS, dB
ACOUSTIC RANGE, kyd
40
60
80
100
120
140
0
10
20
30
40


STATION 2 RUN 2
FREQUENCY: 1.0 kHz
SOURCE DEPTH: 39 METERS
RECEIVER DEPTH: 43 METERS
MAXIMUM RANGE: 29.5 kyd
NOISE LEVEL: 119 dB
RECORDER PAPER CHANGED
57° COURSE CHANGE
29.0 kyd
MANY ARRIVALS BELOW NOISE
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
ACOUSTIC RANGE, kyd
40
60
80
100
120
140
0
10
20
30
40

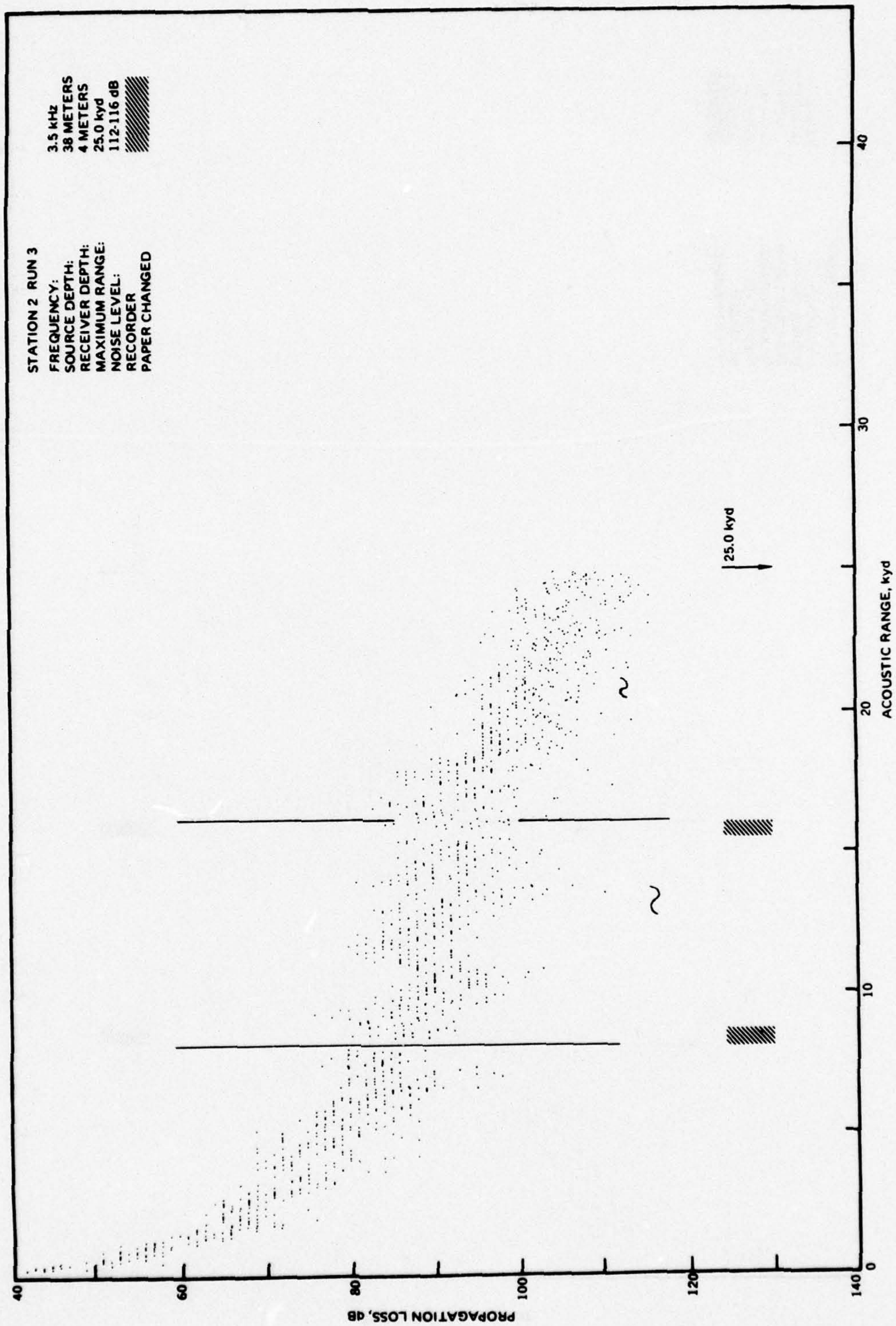

STATION 2 RUN 2
FREQUENCY: 1.0 kHz
SOURCE DEPTH: 39 METERS
RECEIVER DEPTH: 72 METERS
MAXIMUM DEPTH: 29.5 kyd
NOISE LEVEL: 118 dB
RECORDER PAPER CHANGED
55° COURSE CHANGE
29.5 kyd
MOST ARRIVALS BELOW NOISE
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
40
60
80
100
120
140
0
10
20
30
40
ACOUSTIC RANGE, kyd

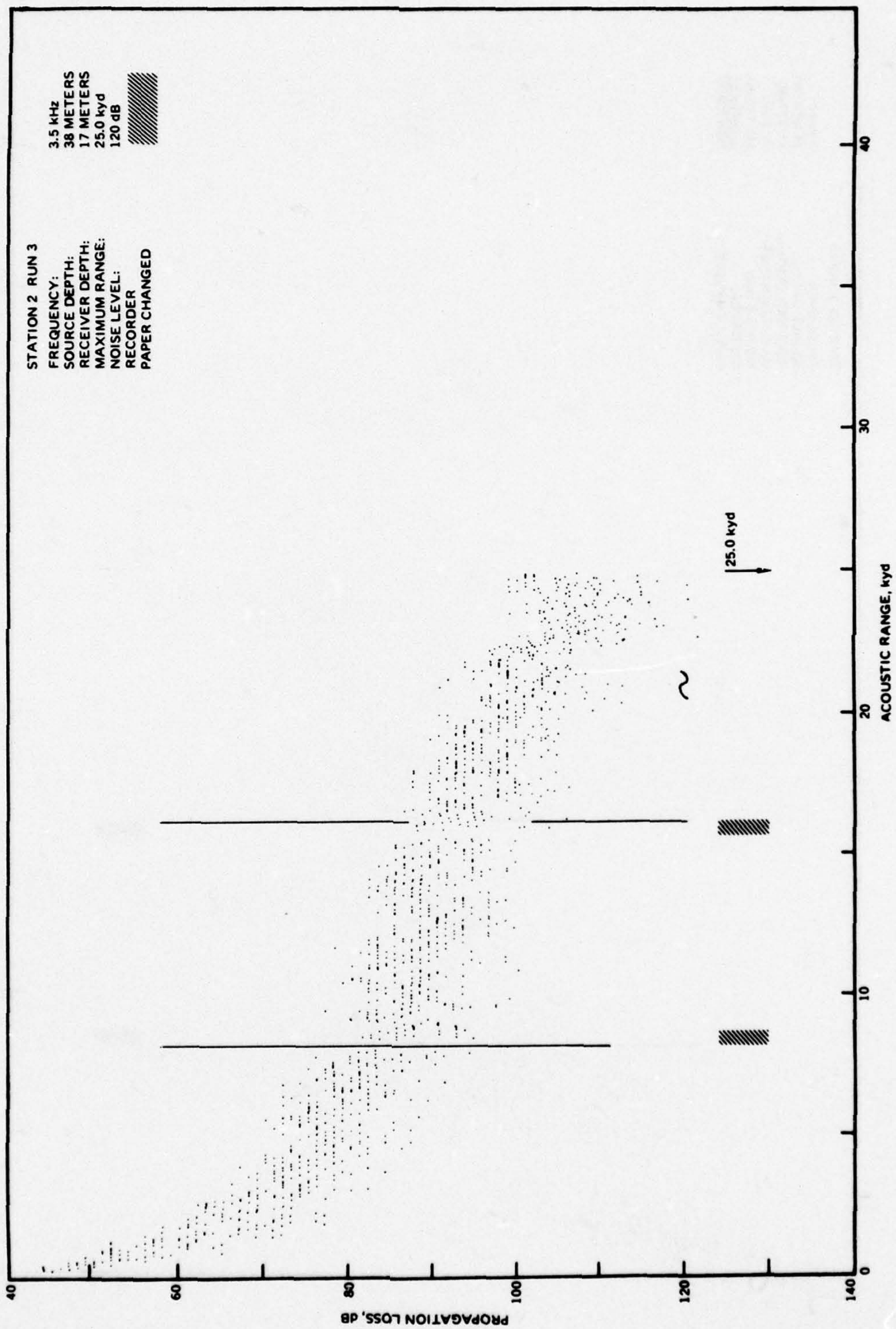

STATION 2 RUN 2
FREQUENCY: 1.0 kHz
SOURCE DEPTH: 39 METERS
RECEIVER DEPTH: 112 METERS
MAXIMUM RANGE: 29.5 kyd
NOISE LEVEL: 118 dB
RECORDER PAPER CHANGED
55° COURSE CHANGE
29.2 kyd
MOST ARRIVALS BELOW NOISE
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40

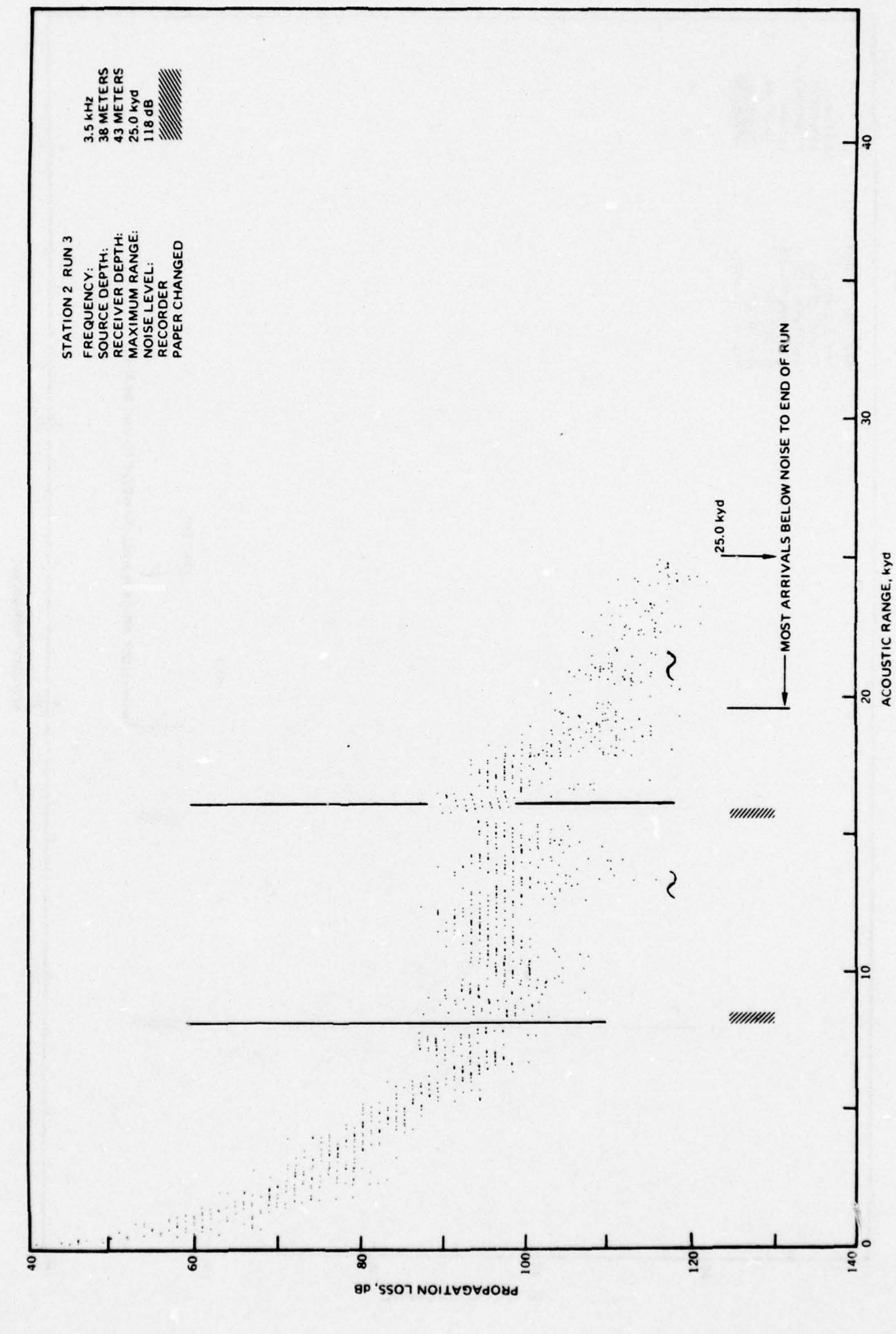
APPENDIX C

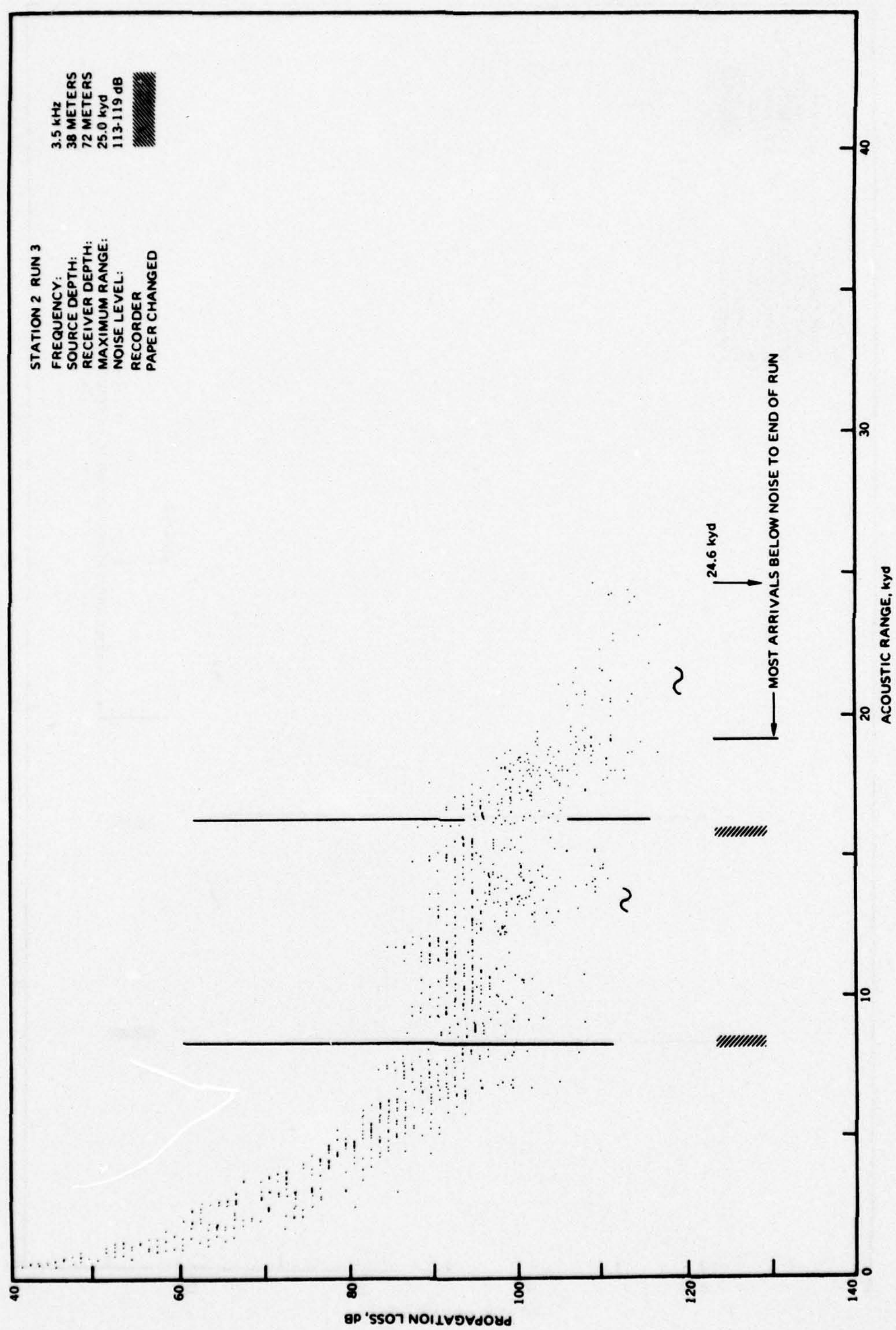
STATION 2 RUN 3

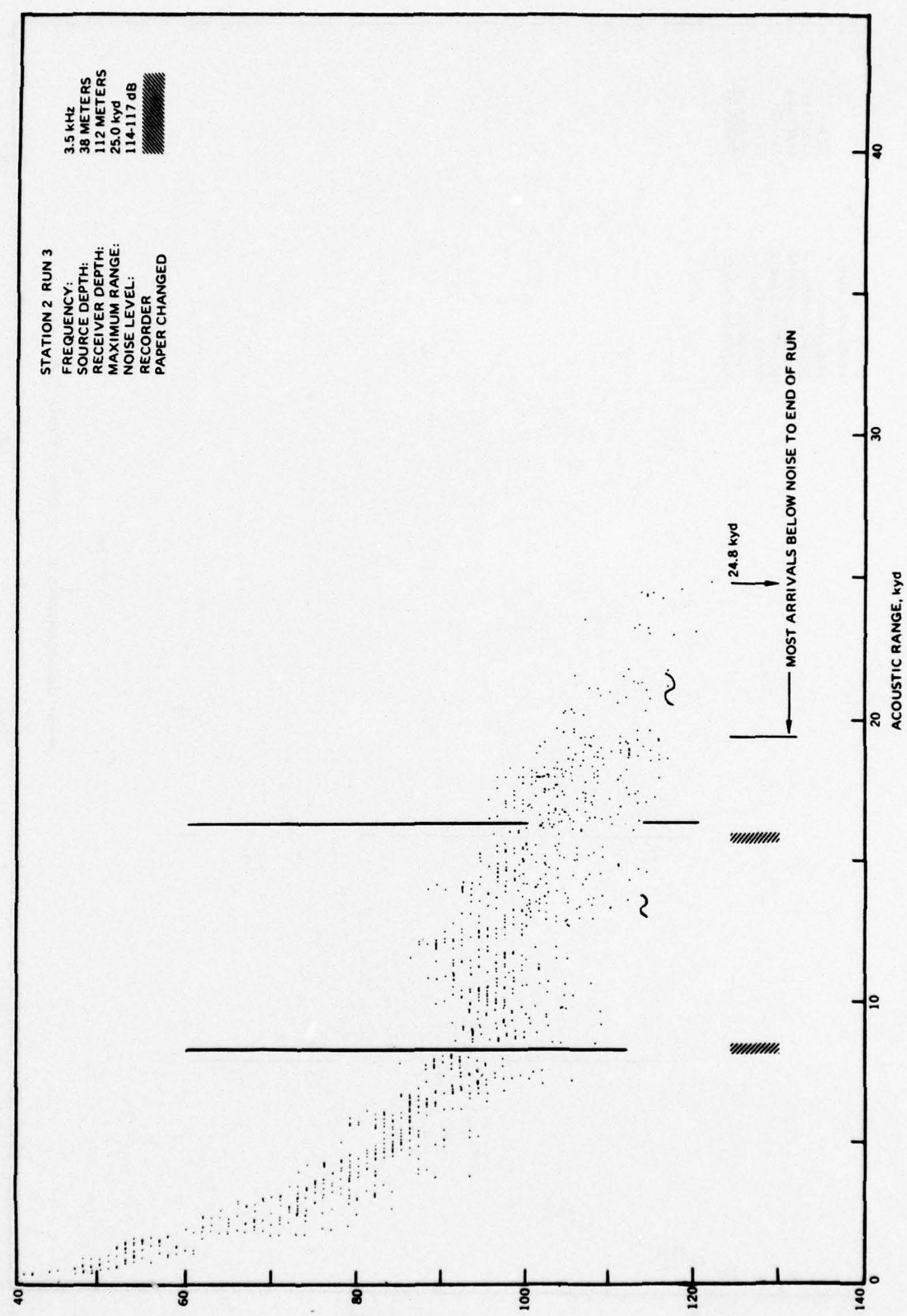
PROPAGATION LOSS VERSUS ACOUSTIC RANGE PLOTS

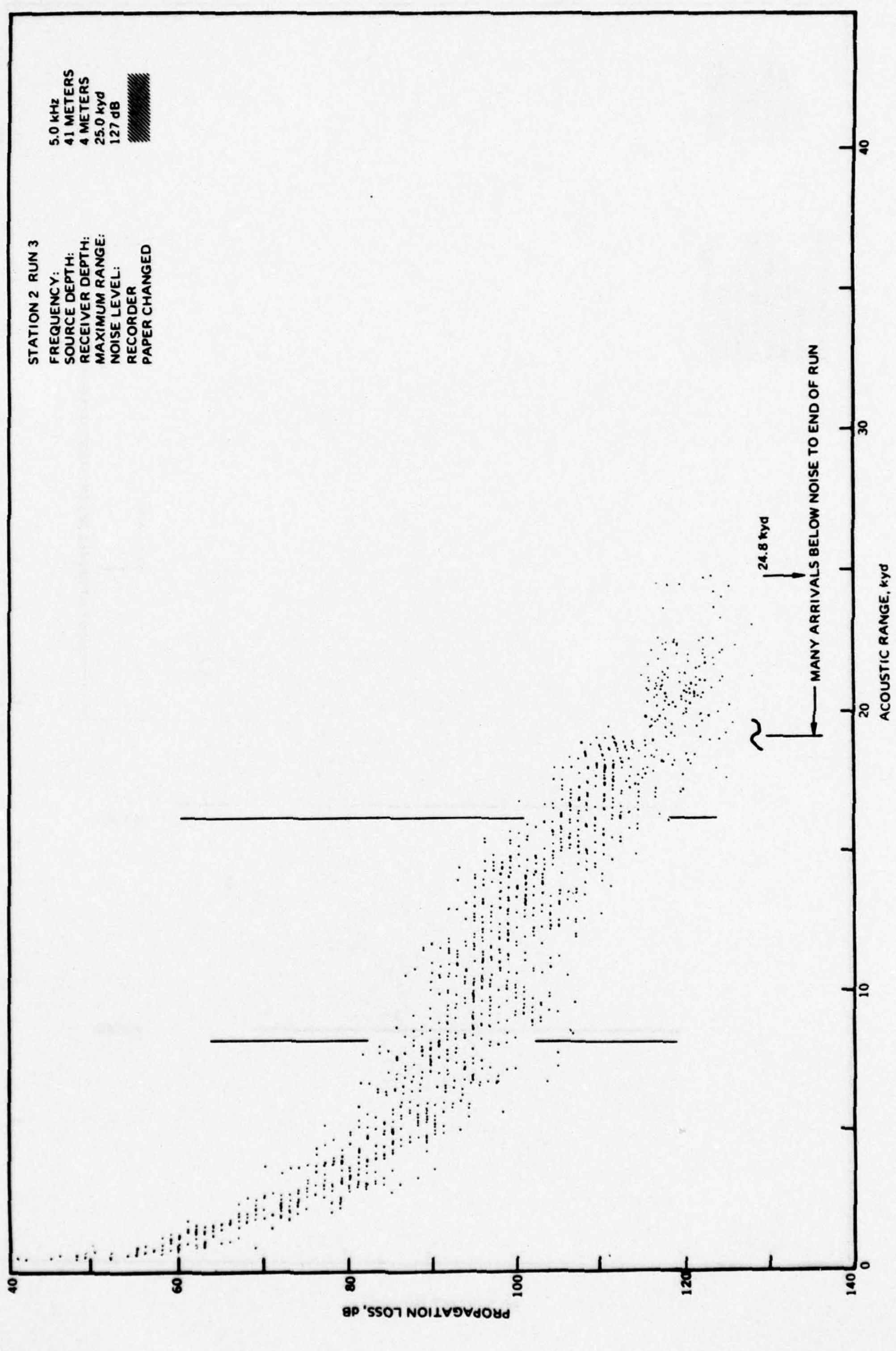

STATION 2 RUN 3
FREQUENCY: 3.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 4 METERS
MAXIMUM RANGE: 25.0 kyd
NOISE LEVEL: 112-116 dB
RECORDER
PAPER CHANGED
25.0 kyd
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40

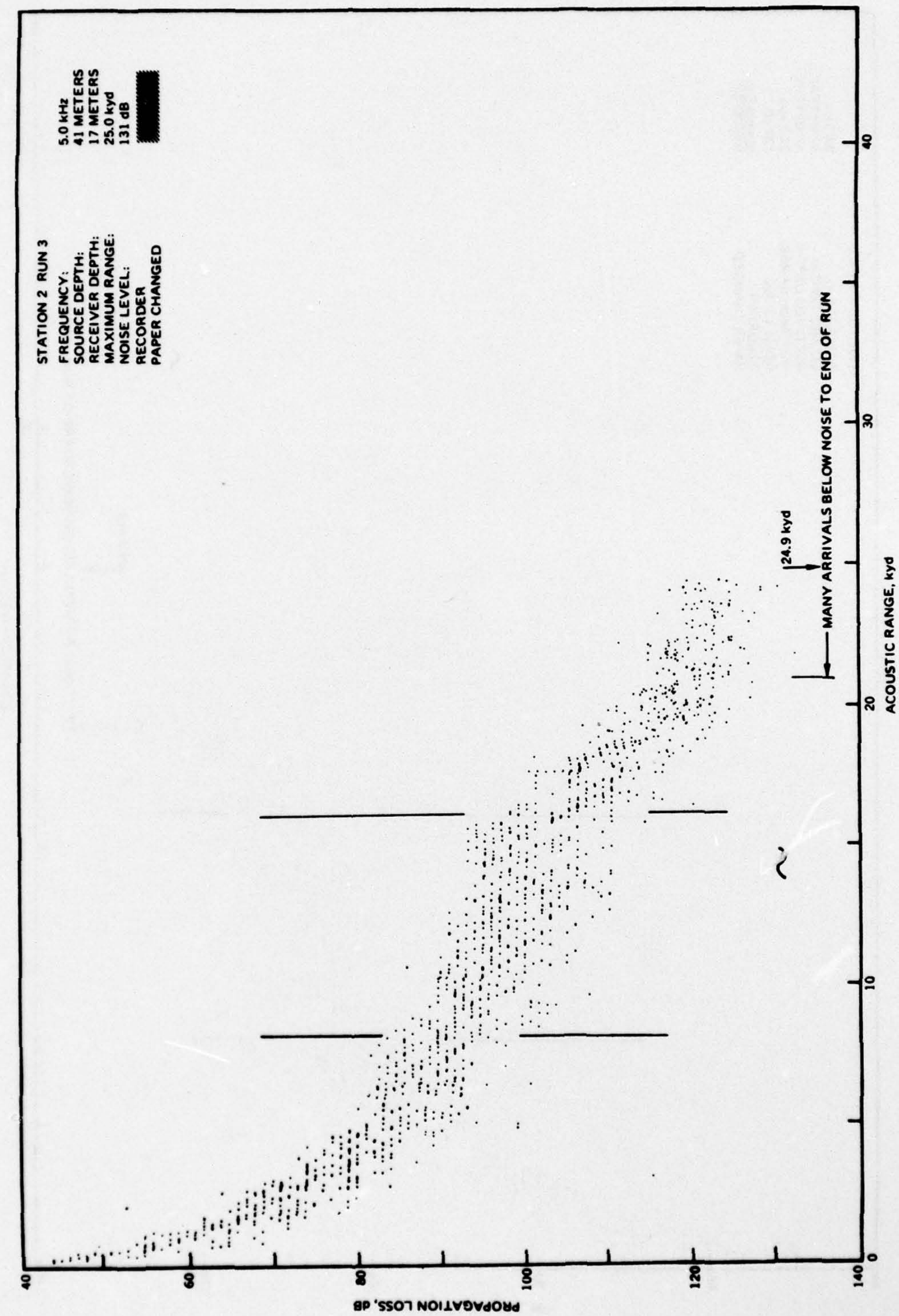

STATION 2 RUN 3
FREQUENCY: 3.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 17 METERS
MAXIMUM RANGE: 25.0 kyd
NOISE LEVEL: 120 dB
RECORDER PAPER CHANGED
25.0 kyd
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40

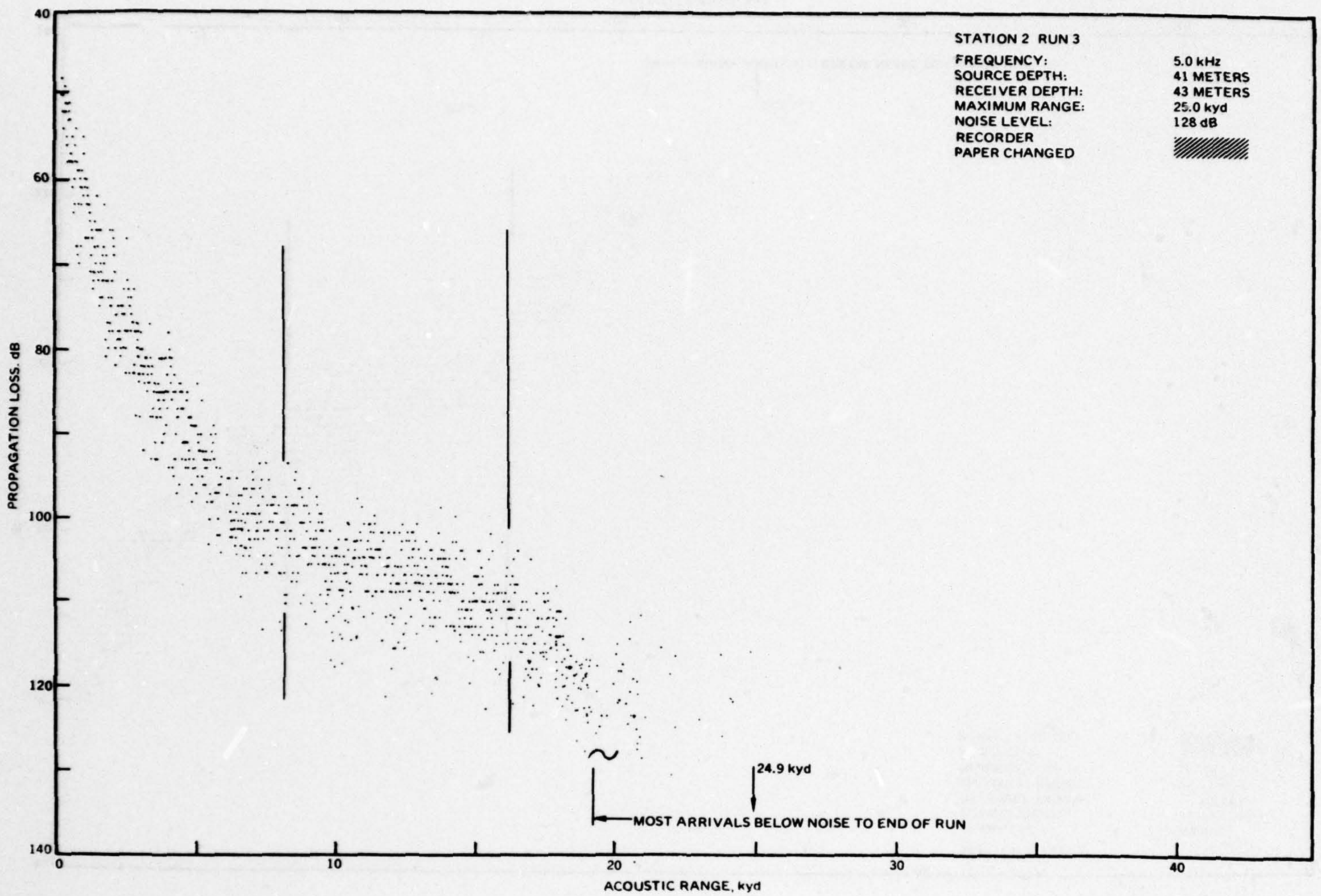

STATION 2 RUN 3
FREQUENCY: 3.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 43 METERS
MAXIMUM RANGE: 25.0 kyd
NOISE LEVEL: 118 dB
RECORDER PAPER CHANGED
25.0 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
ACOUSTIC RANGE, kyd
PROPAGATION LOSS, dB
0
10
20
30
40
60
80
100
120
140

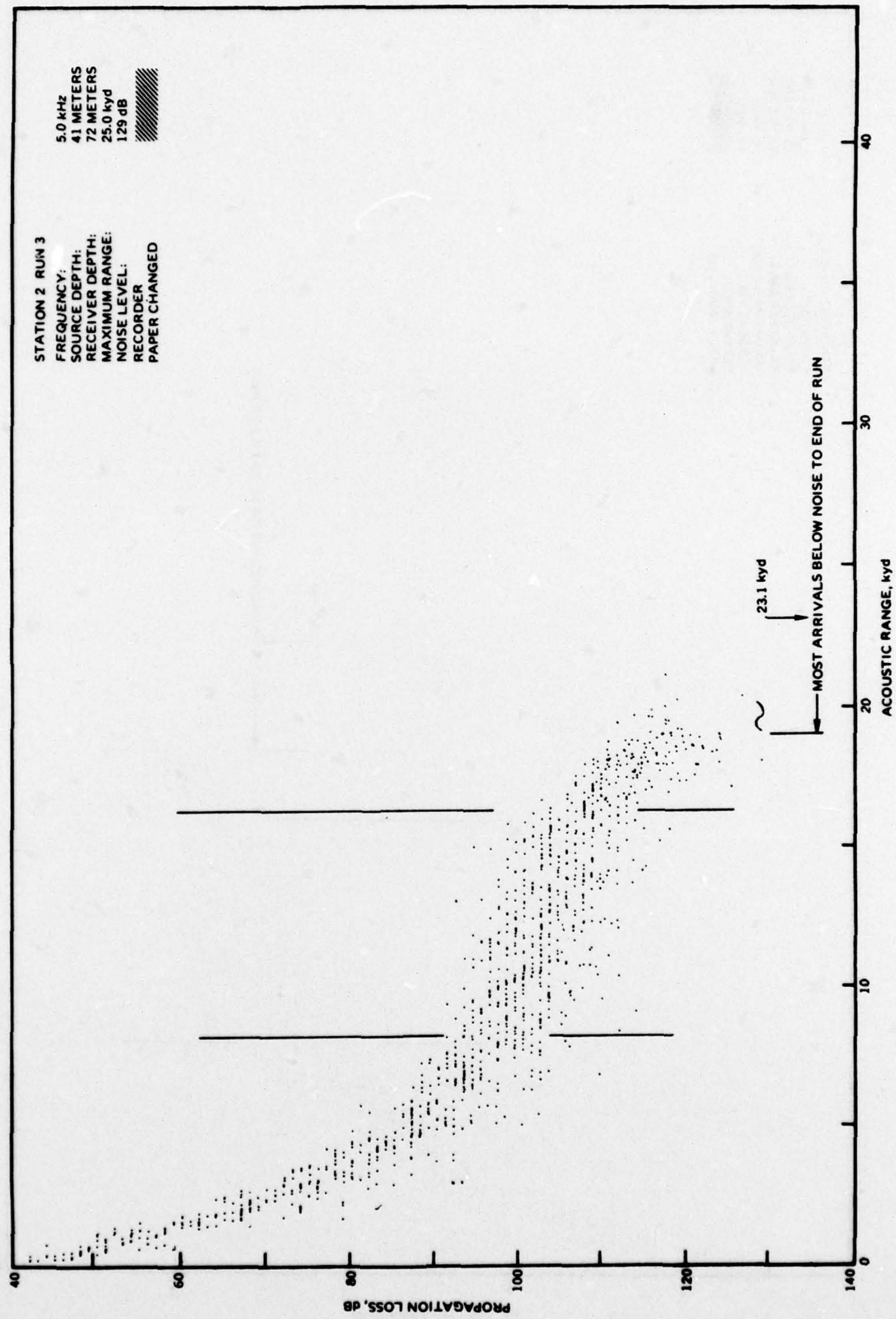

STATION 2 RUN 3
FREQUENCY: 3.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 72 METERS
MAXIMUM RANGE: 25.0 kyd
NOISE LEVEL: 113-119 dB
RECORDER PAPER CHANGED
24.6 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40

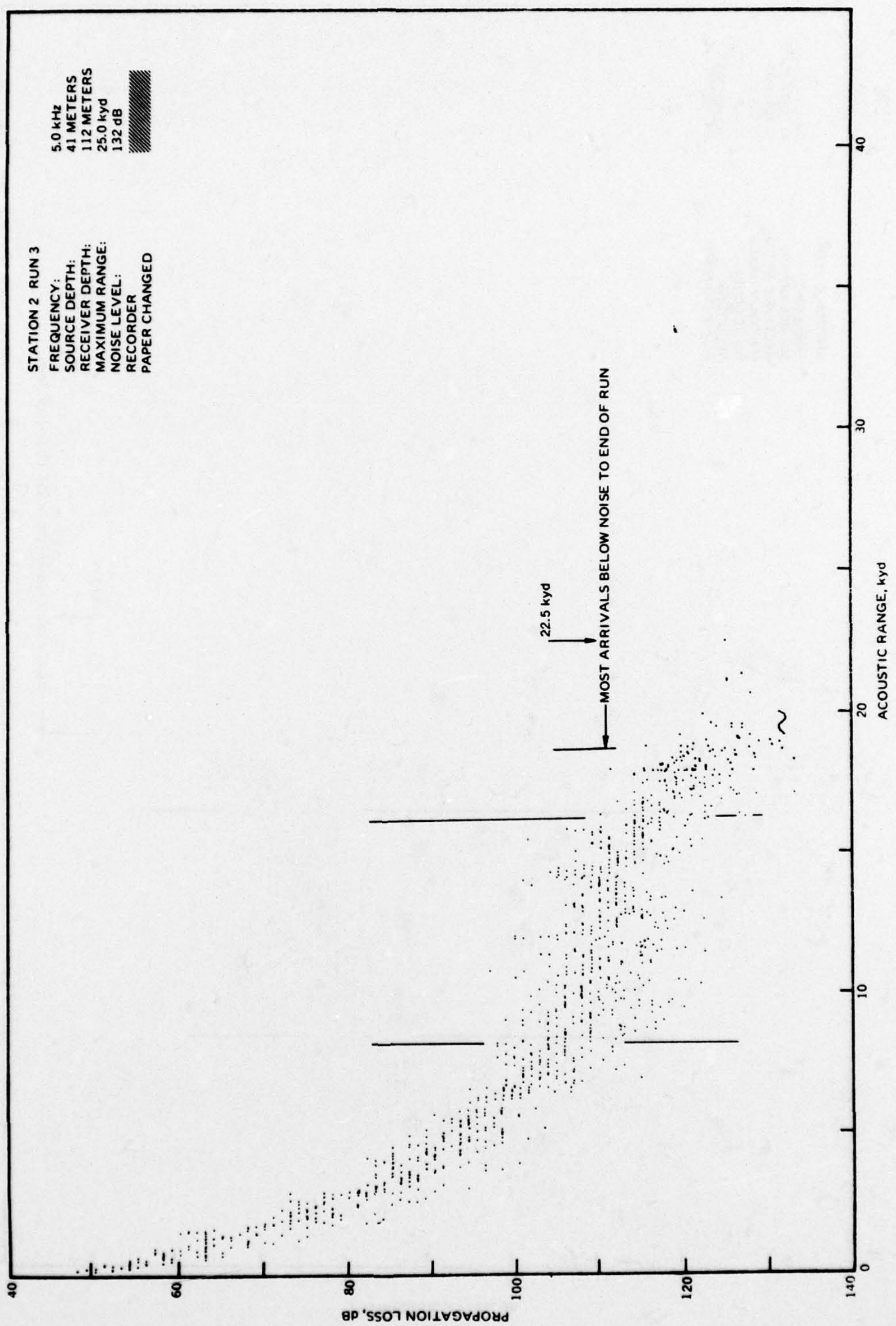

STATION 2 RUN 3
FREQUENCY: 3.5 kHz
SOURCE DEPTH: 38 METERS
RECEIVER DEPTH: 112 METERS
MAXIMUM RANGE: 25.0 kyd
NOISE LEVEL: 114-117 dB
RECORDER PAPER CHANGED
24.8 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
ACOUSTIC RANGE, kyd
0
10
20
30
40
PROPAGATION LOSS, dB
40
60
80
100
120
140


STATION 2 RUN 3
FREQUENCY: 5.0 kHz
SOURCE DEPTH: 41 METERS
RECEIVER DEPTH: 4 METERS
MAXIMUM RANGE: 25.0 kyd
NOISE LEVEL: 127 dB
RECORDER
PAPER CHANGED
24.8 kyd
MANY ARRIVALS BELOW NOISE TO END OF RUN
ACOUSTIC RANGE, kyd
PROPAGATION LOSS, dB
0
10
20
30
40
40
60
80
100
120
140


STATION 2 RUN 3
FREQUENCY: 5.0 kHz
SOURCE DEPTH: 41 METERS
RECEIVER DEPTH: 17 METERS
MAXIMUM RANGE: 25.0 kyd
NOISE LEVEL: 131 dB
RECORDER
PAPER CHANGED
24.9 kyd
MANY ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40


STATION 2 RUN 3
FREQUENCY: 5.0 kHz
SOURCE DEPTH: 41 METERS
RECEIVER DEPTH: 43 METERS
MAXIMUM RANGE: 25.0 kyd
NOISE LEVEL: 128 dB
RECORDER
PAPER CHANGED
24.9 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
40
60
80
100
120
140
0
10
20
30
40
ACOUSTIC RANGE, kyd


STATION 2 RUN 3
FREQUENCY: 5.0 kHz
SOURCE DEPTH: 41 METERS
RECEIVER DEPTH: 72 METERS
MAXIMUM RANGE: 25.0 kyd
NOISE LEVEL: 129 dB
RECORDER
PAPER CHANGED
23.1 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40

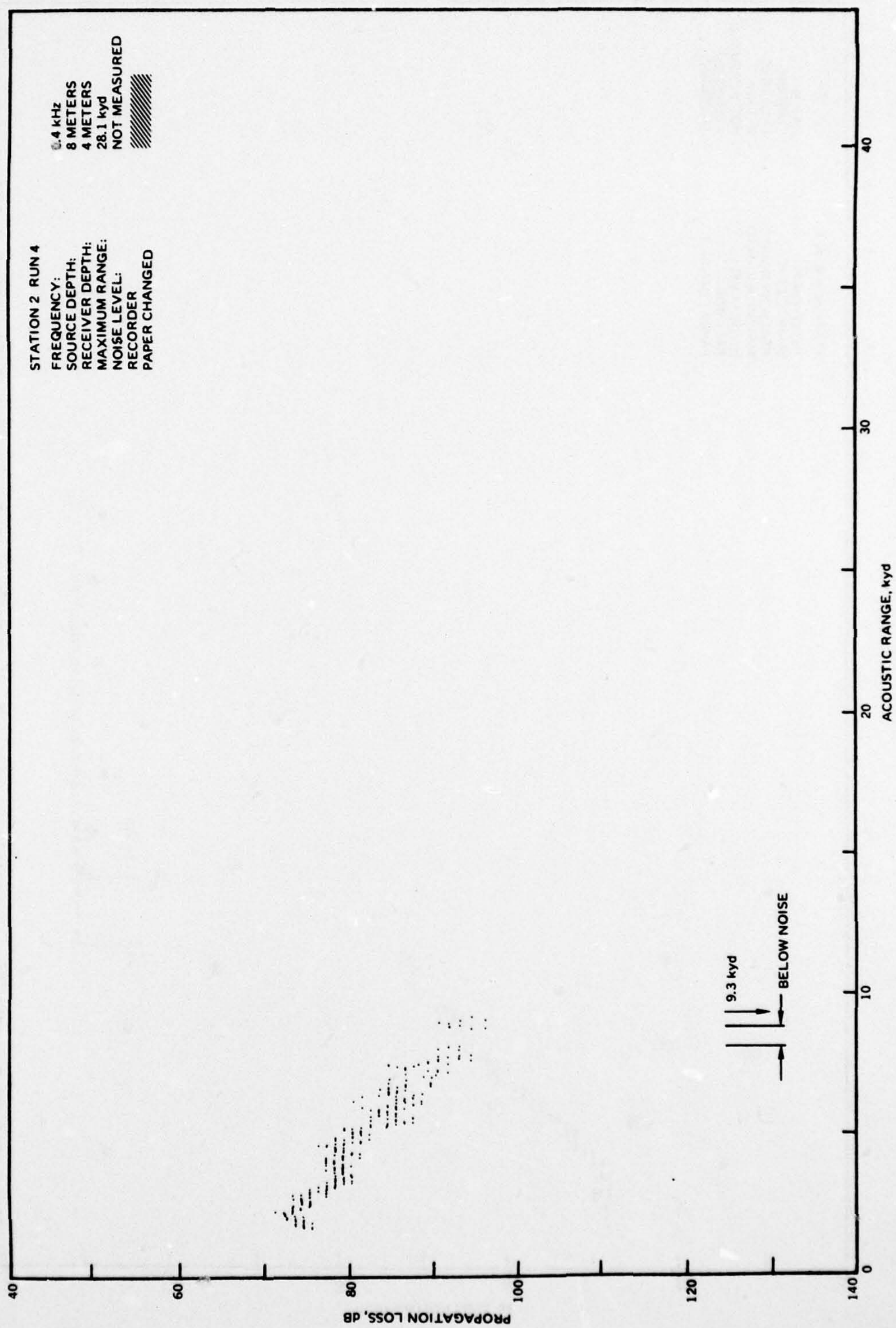


STATION 2 RUN 3
FREQUENCY: 5.0 kHz
SOURCE DEPTH: 41 METERS
RECEIVER DEPTH: 112 METERS
MAXIMUM RANGE: 25.0 kyd
NOISE LEVEL: 132 dB
RECORDER
PAPER CHANGED
22.5 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
ACOUSTIC RANGE, kyd
40
60
80
100
120
140
0
10
20
30
40

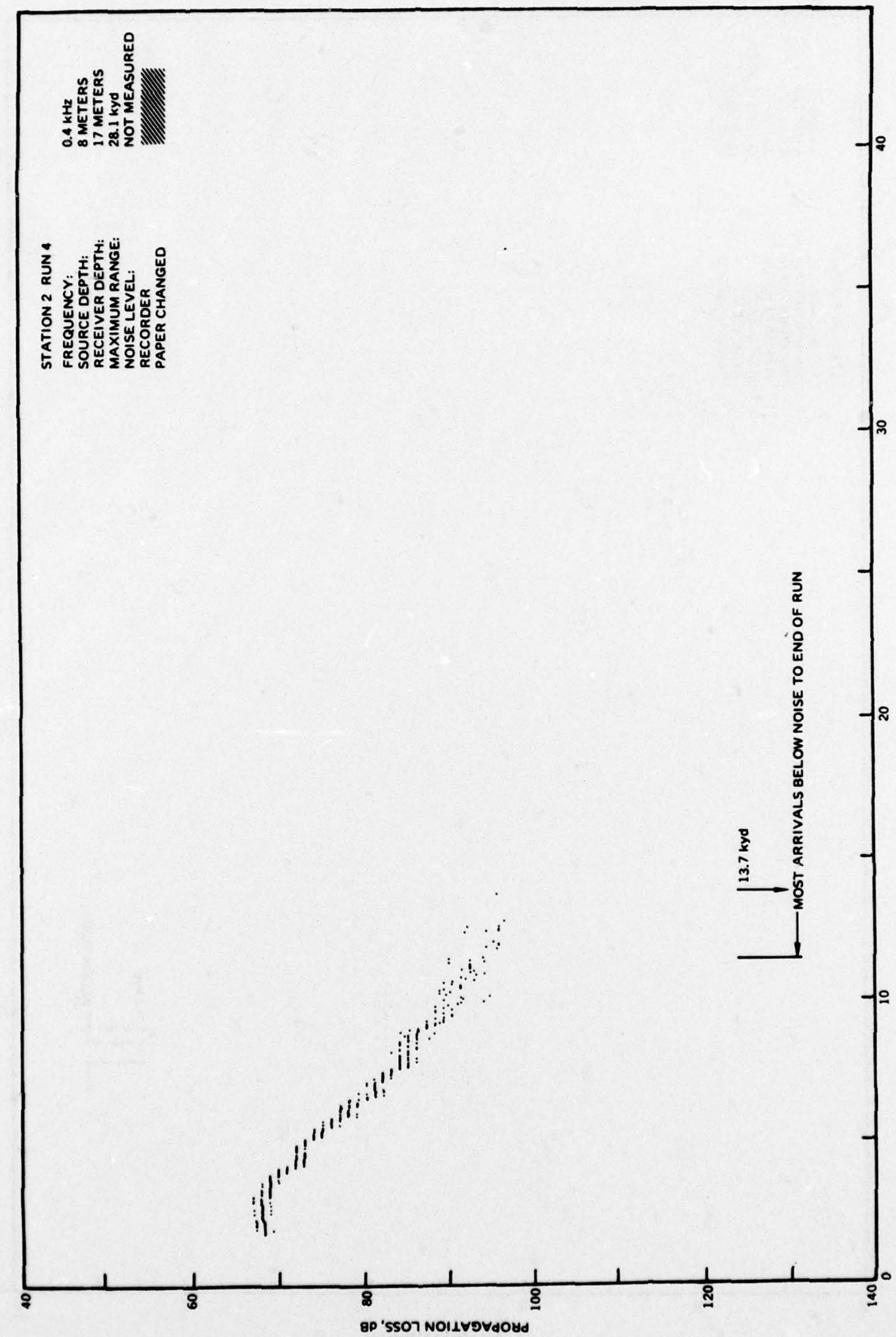
APPENDIX D

STATION 2 RUN 4

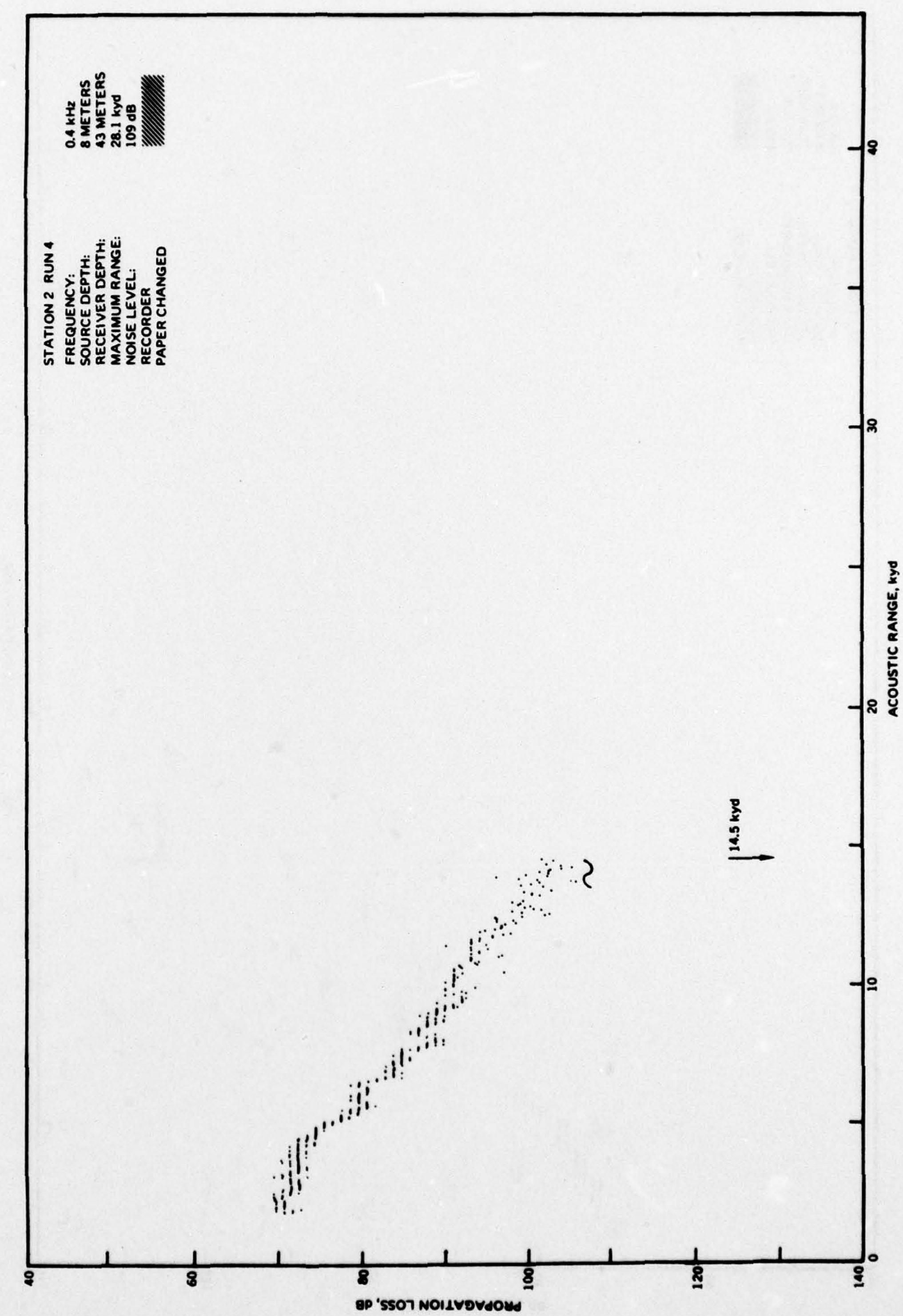
PROPAGATION LOSS VERSUS ACOUSTIC RANGE PLOTS

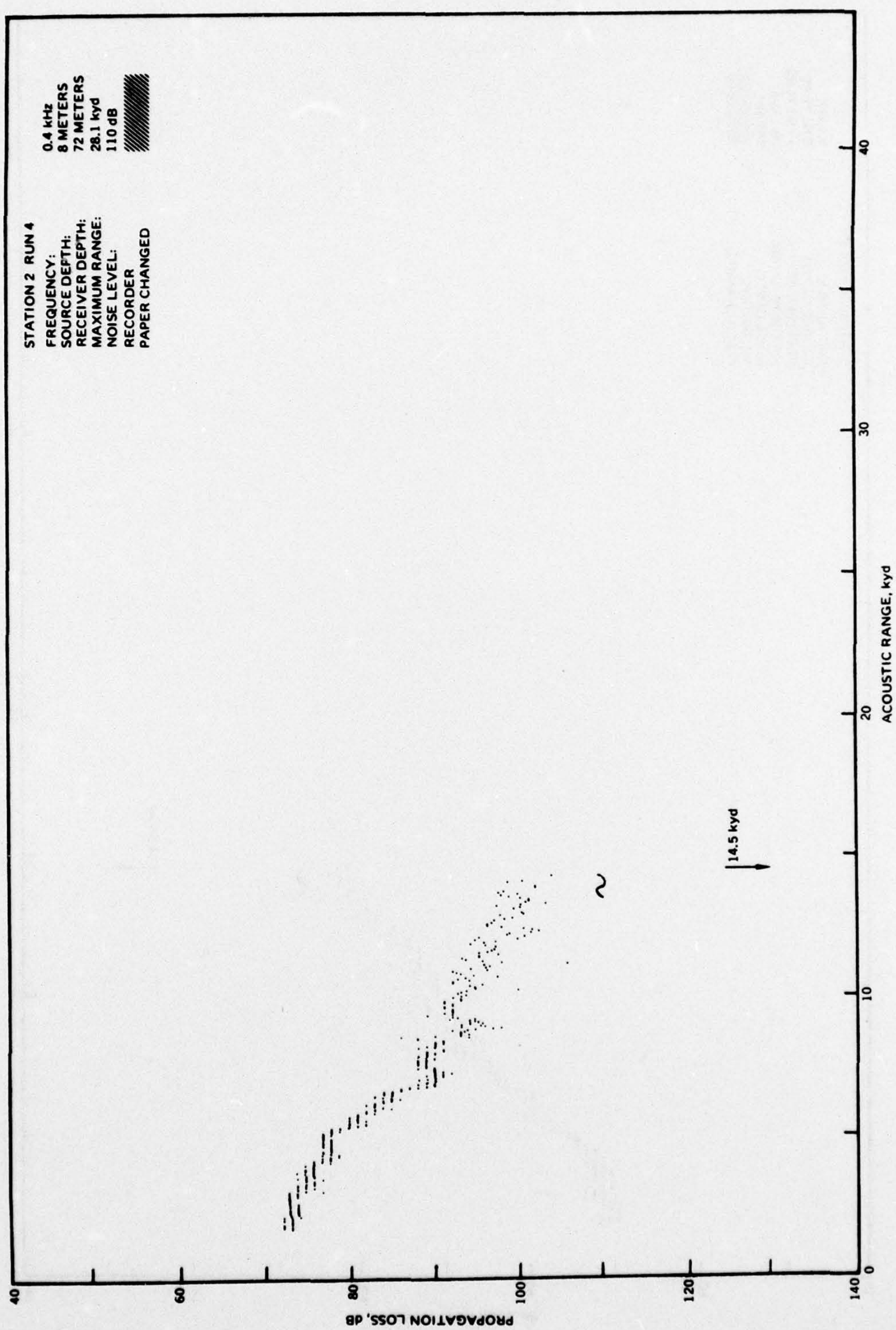


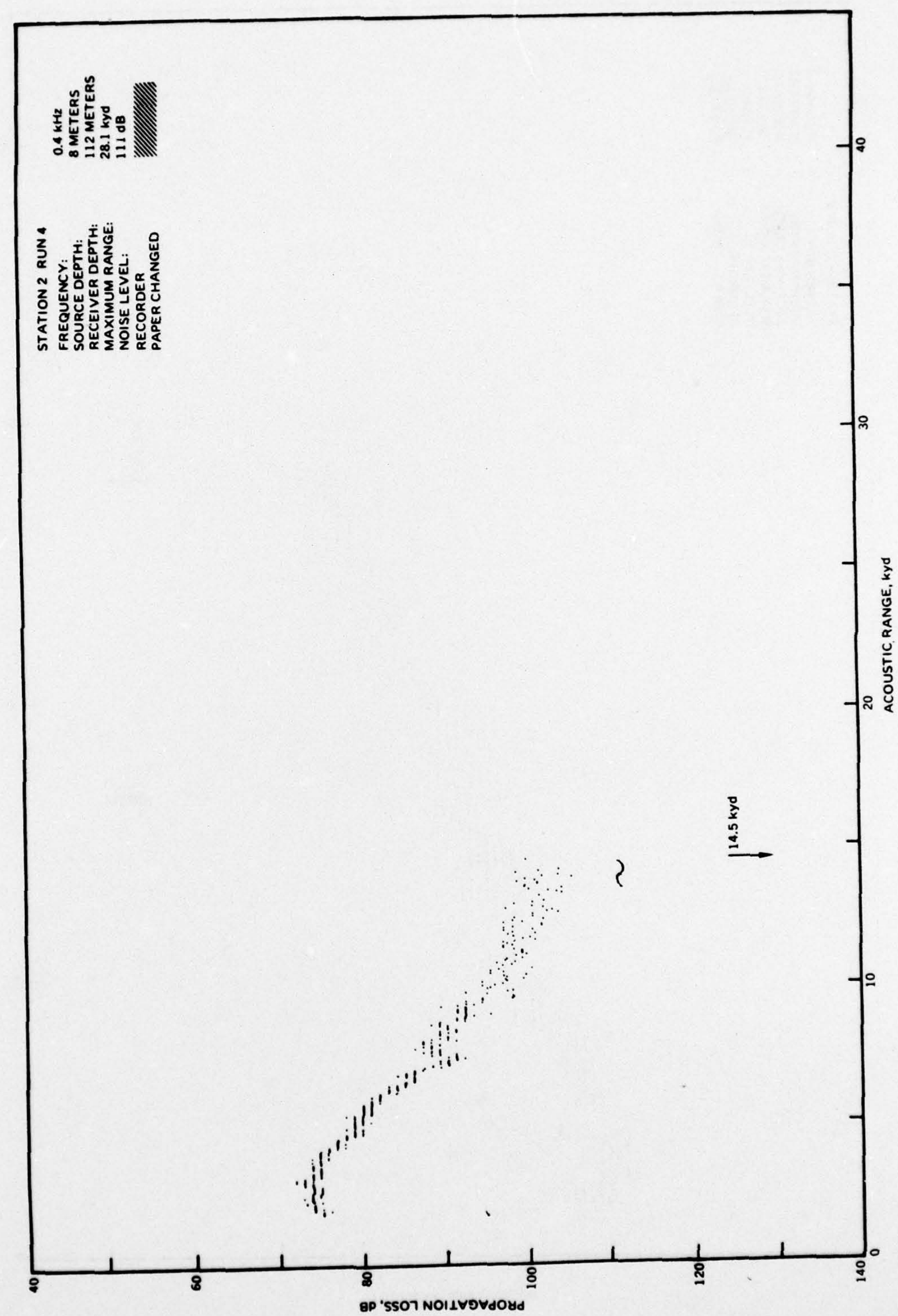
STATION 2 RUN 4
FREQUENCY: .4 kHz
SOURCE DEPTH: 8 METERS
RECEIVER DEPTH: 4 METERS
MAXIMUM RANGE: 28.1 kyd
NOISE LEVEL: NOT MEASURED
RECORDER PAPER CHANGED
9.3 kyd
BELOW NOISE
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40



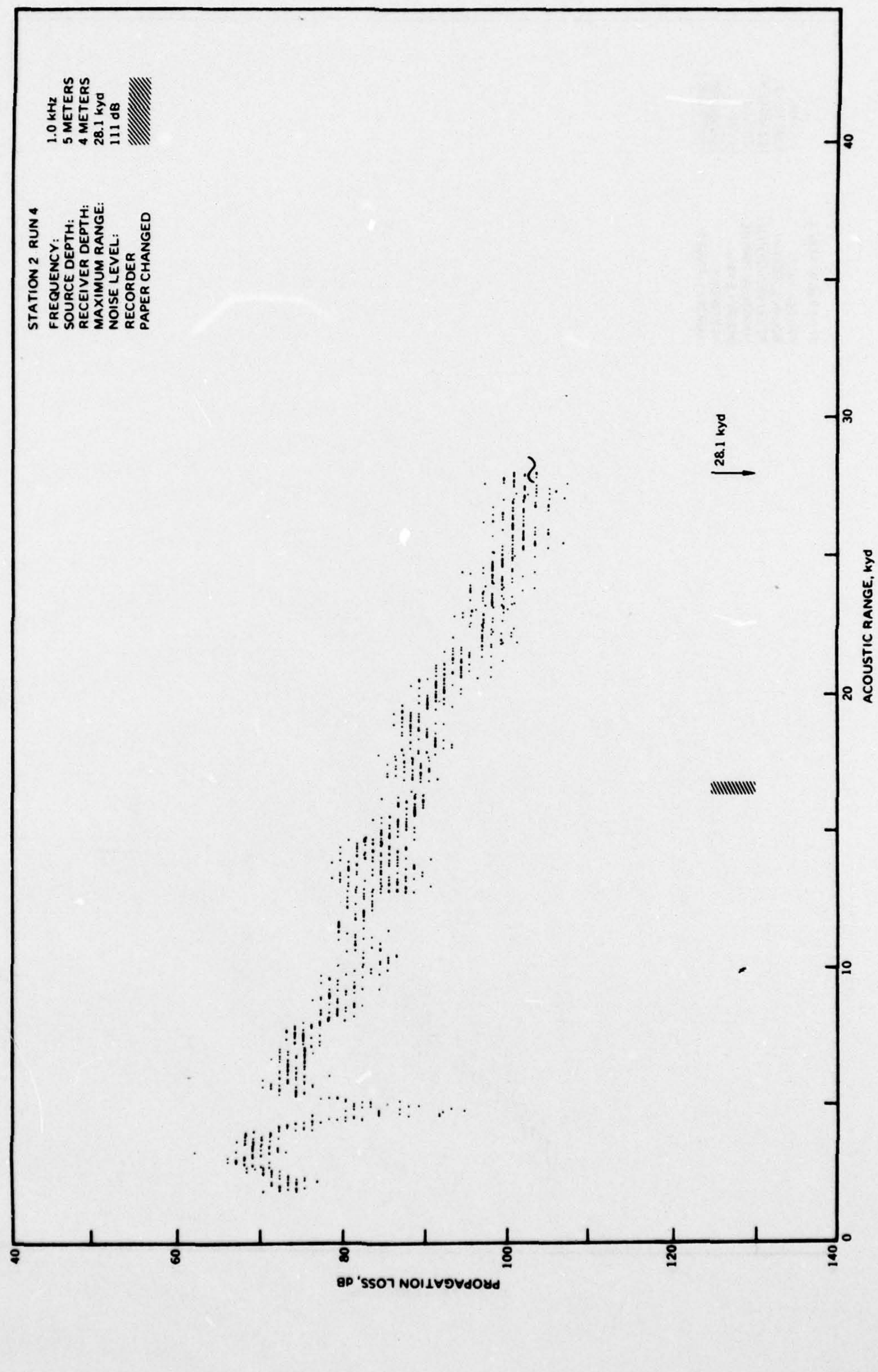
STATION 2 RUN 4
FREQUENCY: 0.4 kHz
SOURCE DEPTH: 8 METERS
RECEIVER DEPTH: 17 METERS
MAXIMUM RANGE: 28.1 kyd
NOISE LEVEL: NOT MEASURED
RECORDER PAPER CHANGED
13.7 kyd
MOST ARRIVALS BELOW NOISE TO END OF RUN
PROPAGATION LOSS, dB
40
60
80
100
120
140
0
10
20
30
40

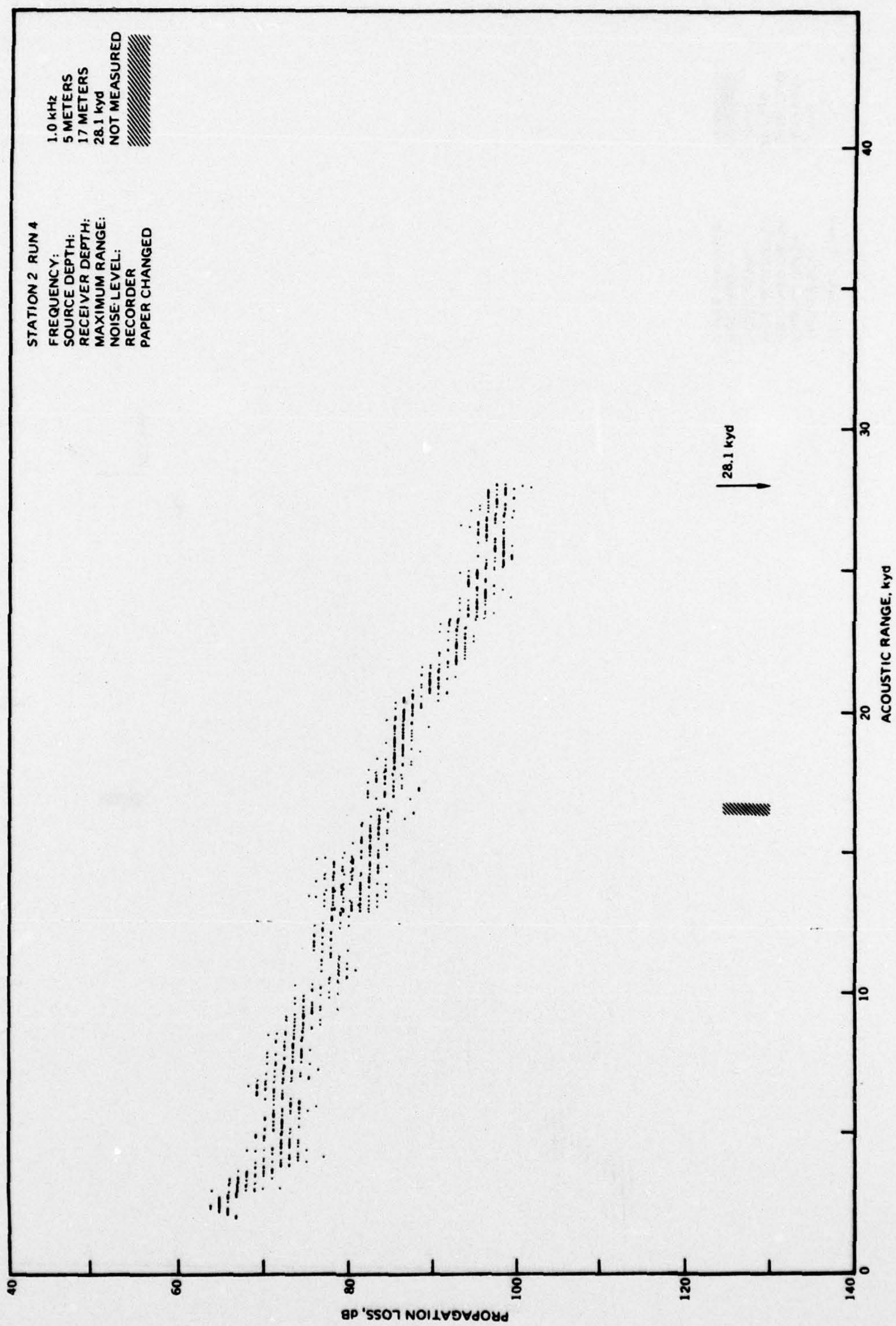

STATION 2 RUN 4
FREQUENCY: 0.4 kHz
SOURCE DEPTH: 8 METERS
RECEIVER DEPTH: 43 METERS
MAXIMUM RANGE: 28.1 kyd
NOISE LEVEL: 109 dB
RECORDER PAPER CHANGED
14.5 kyd
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40

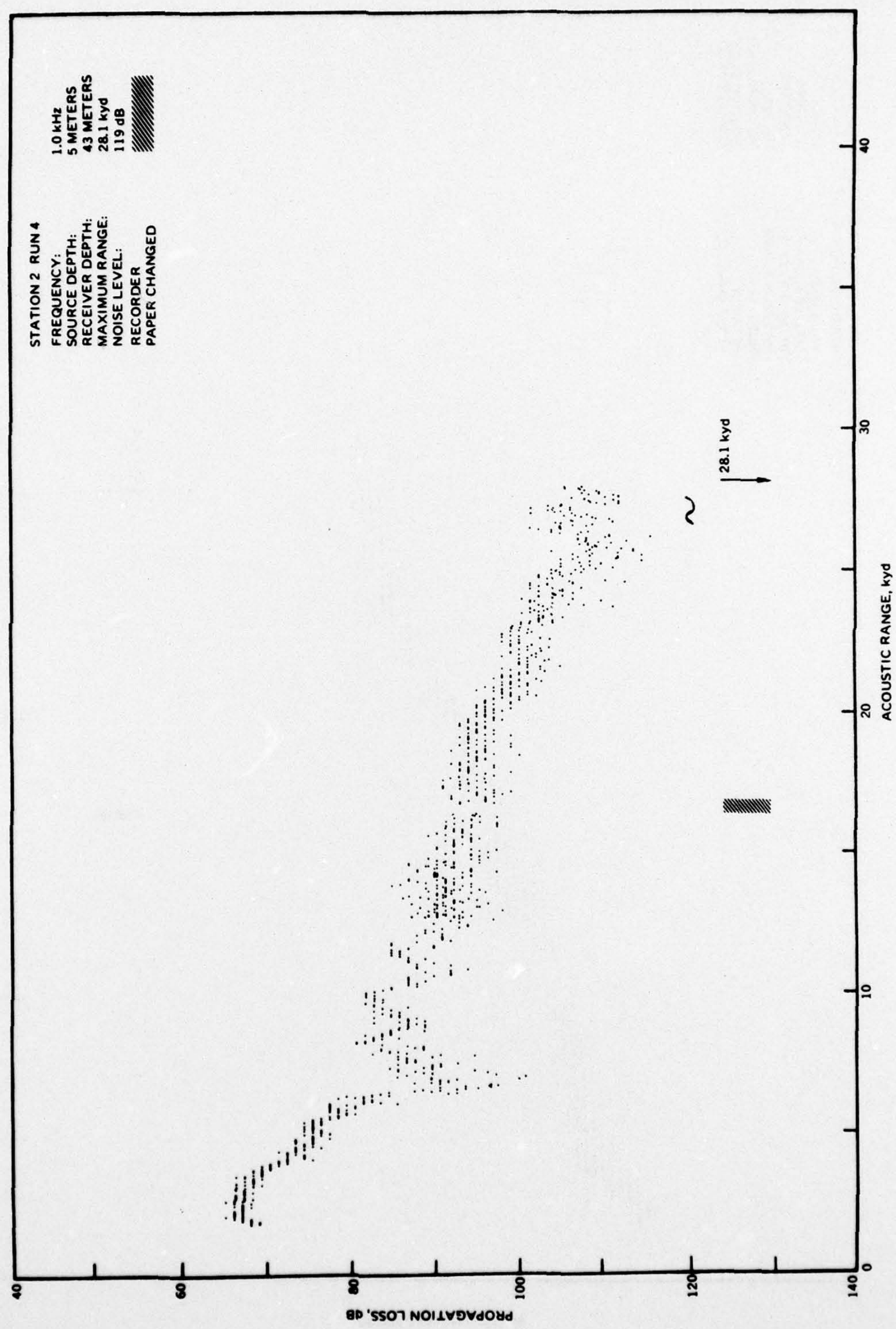

STATION 2 RUN 4
FREQUENCY: 0.4 kHz
SOURCE DEPTH: 8 METERS
RECEIVER DEPTH: 72 METERS
MAXIMUM RANGE: 28.1 kyd
NOISE LEVEL: 110 dB
RECORDER PAPER CHANGED
14.5 kyd
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40

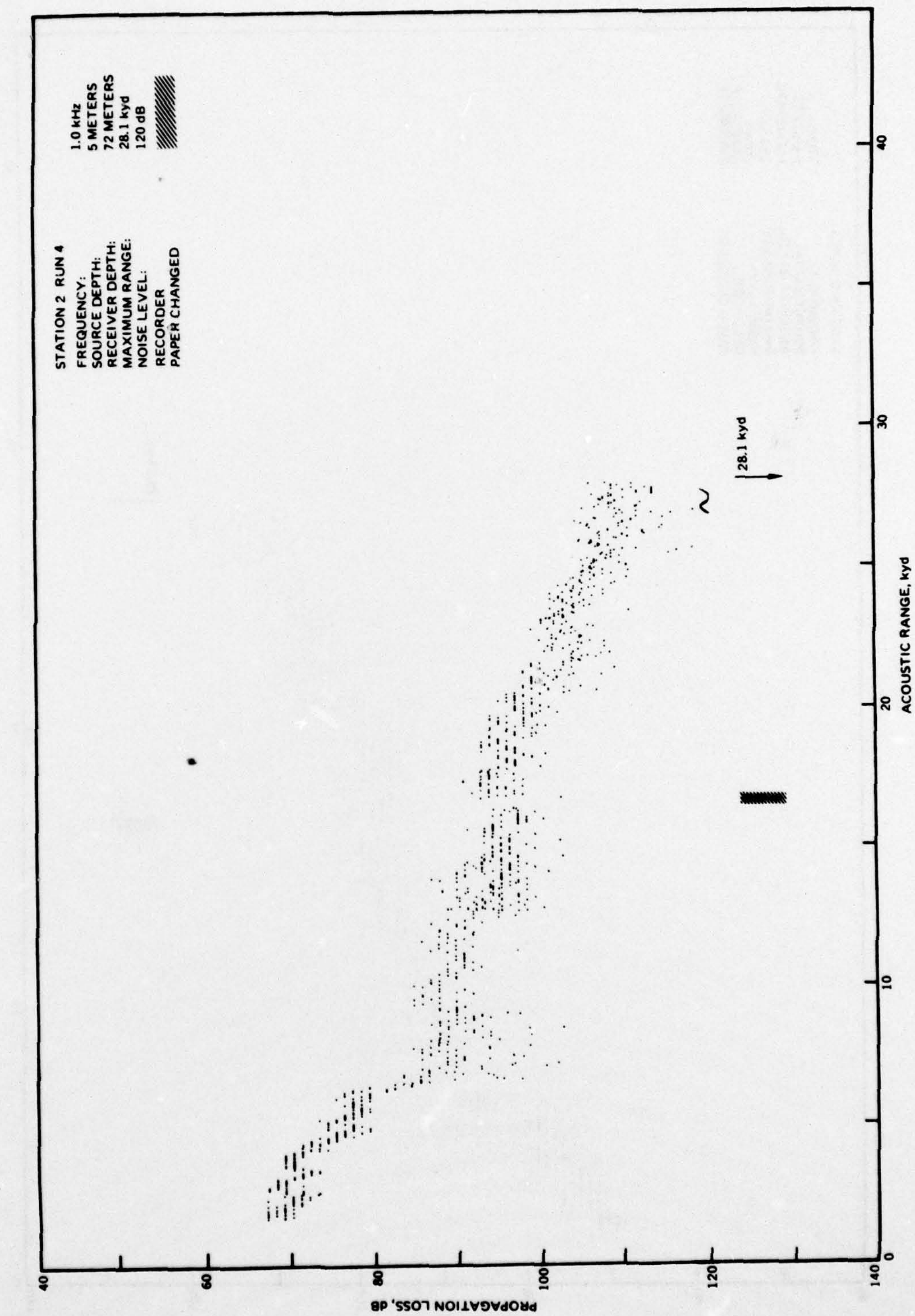


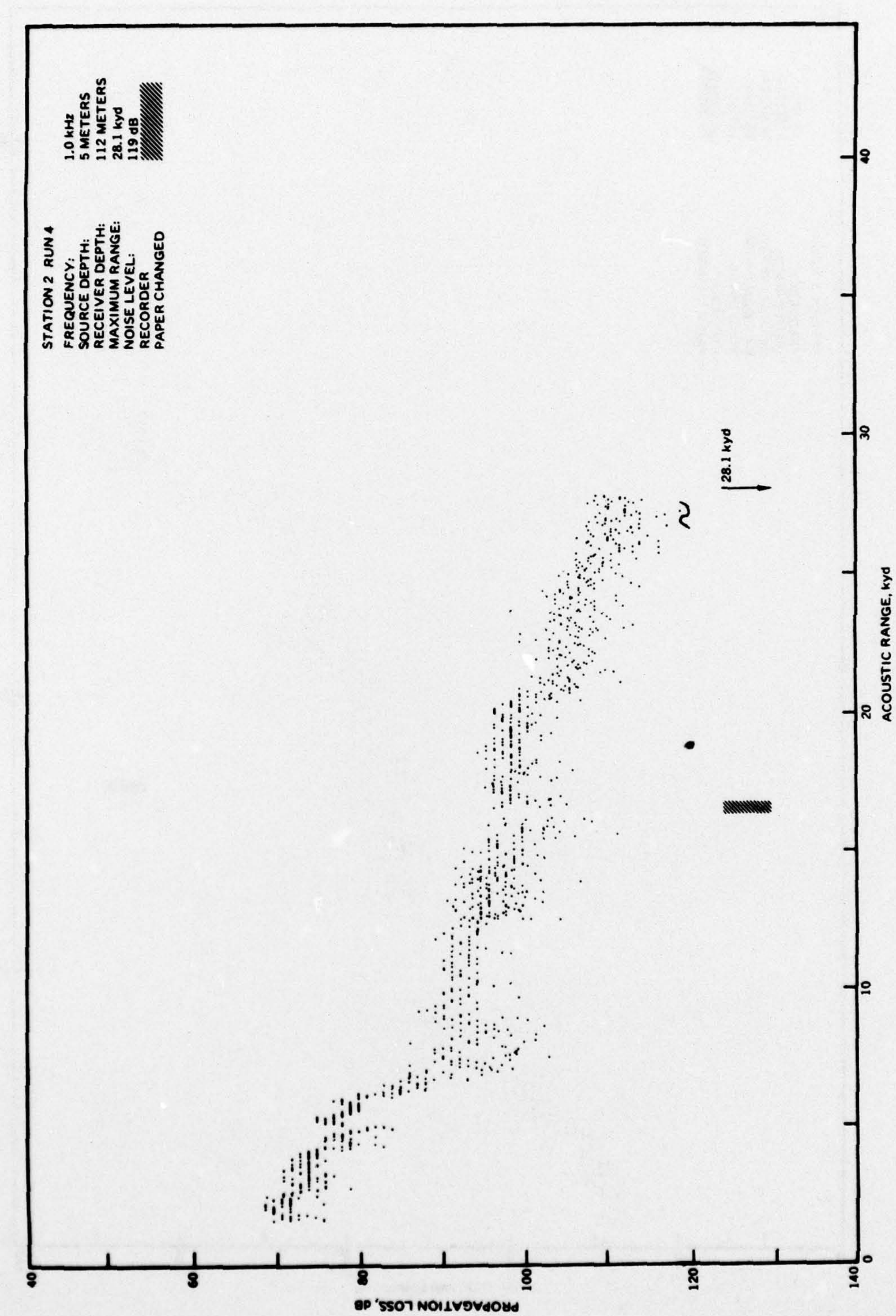
STATION 2 RUN 4
FREQUENCY: 0.4 kHz
SOURCE DEPTH: 8 METERS
RECEIVER DEPTH: 112 METERS
MAXIMUM RANGE: 28.1 kyd
NOISE LEVEL: 111 dB
RECORDER PAPER CHANGED
14.5 kyd
PROPAGATION LOSS, dB
40
60
80
100
120
140
0
10
20
30
40
ACOUSTIC RANGE, kyd


STATION 2 RUN 4
FREQUENCY: 1.0 kHz
SOURCE DEPTH: 5 METERS
RECEIVER DEPTH: 4 METERS
MAXIMUM RANGE: 28.1 kyd
NOISE LEVEL: 111 dB
RECORDER PAPER CHANGED
28.1 kyd
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40


STATION 2 RUN 4
FREQUENCY: 1.0 kHz
SOURCE DEPTH: 5 METERS
RECEIVER DEPTH: 17 METERS
MAXIMUM RANGE: 28.1 kyd
NOISE LEVEL: NOT MEASURED
RECORDER
PAPER CHANGED
28.1 kyd
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40


STATION 2 RUN 4
FREQUENCY: 1.0 kHz
SOURCE DEPTH: 5 METERS
RECEIVER DEPTH: 43 METERS
MAXIMUM RANGE: 28.1 kyd
NOISE LEVEL: 119 dB
RECORDER PAPER CHANGED
28.1 kyd
PROPAGATION LOSS, dB
ACOUSTIC RANGE, kyd
40
60
80
100
120
140
0
10
20
30
40


STATION 2 RUN 4
FREQUENCY: 1.0 kHz
SOURCE DEPTH: 5 METERS
RECEIVER DEPTH: 72 METERS
MAXIMUM RANGE: 28.1 kyd
NOISE LEVEL: 120 dB
RECORDER PAPER CHANGED
28.1 kyd
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40


STATION 2 RUN 4
FREQUENCY: 1.0 kHz
SOURCE DEPTH: 5 METERS
RECEIVER DEPTH: 112 METERS
MAXIMUM RANGE: 28.1 kyd
NOISE LEVEL: 119 dB
RECORDER
PAPER CHANGED
28.1 kyd
PROPAGATION LOSS, dB
40
60
80
100
120
140
ACOUSTIC RANGE, kyd
0
10
20
30
40