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SURFACE-DUCT SONAR MEASUREMENTS (SUDS I - 1972) OCEANOGRAPHIC M--ETC(U)
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Volume I: Instrumentation, Data Reduction Procedures, and Accuracy Analysis.

by

⑩ E. R. Anderson
Undersea Sciences Department

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R. B. GILCHRIST, CAPT, USN
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Technical Director

ADMINISTRATIVE STATEMENT

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 January 1976 and was approved for publication in March 1976.

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The SUDS I program was a coordinated and cooperative effort involving personnel from the Undersea Sciences Department and the Undersea Surveillance Department. Also participating in the oceanographic measurement program were personnel from the Lockheed Ocean Laboratory (Lockheed Missiles and Space Co., Inc.).

The Principal Investigator for the SUDS experiments was J. Cummins. P. G. Hansen and K. W. Nelson were the Senior Scientists for the oceanographic measurements program. D. P. Hamm was the Principal Investigator for the Lockheed Ocean Laboratory. The Lockheed Ocean Laboratory, with L. P. Coates as Program Manager, constructed the Teletherm buoy system, operated the system at sea, and provided the initial reduction of the data. The following assisted in a consulting and planning capacity: E. R. Anderson, P. A. Barakos, O. S. Lee, and W. F. Potter. Assisting in the preliminary data reduction and analysis was J. L. Thompson, an exchange scientists from Royal Australian Navy Research Laboratory, Sidney, Australia.

H. P. Bucker was the Scientist-in-Charge aboard the *DeSteiguer*, D. E. Good, the Scientist-in-Charge aboard the *Lee*, and P. A. Hanson, the Scientist-in-Charge aboard the *Cape*. Assisting with the oceanographic measurements at sea were: A. E. Diamond, H. L. Haskall, C. T. Smallenberger, and W. M. Woods. The assistance of the officers and men of the *DeSteiguer*, *Lee*, and *Cape* in making the oceanographic measurements program a success is acknowledged.

C. L. Barker and C. D. Curtis calibrated the Teletherm buoy sensors, K. W. Nelson, S. L. Speidel, and G. L. Crutcher assisted in the data reduction and computer aspects of the work, and O. S. Lee supervised the spectral analysis of the Waverider buoy measurements.

Additional acknowledgments are: Pacific Missile Range, Geophysics Division, Point Mugu, CA, which furnished the Datawell Waverider buoy system; Fleet Numerical Weather Central, Monterey, CA, which furnished the expendable bathythermograph probes; Fleet Weather Facility, San Diego, CA, which arranged for air-dropped expendable bathythermographs in the SUDS I areas prior to the ships moving from station 2 to station 3; the Naval Oceanographic Office, Pacific Support Group, San Diego, CA, which provided personnel to make environmental measurements and assistance aboard the *DeSteiguer*; and the Naval Electronics Laboratory Center, Communications Facilities Support Branch, which provided the shore-based portions of the ship-to-shore communications.

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During 9-24 February 1972 a series of 18 propagation loss experiments were conducted in three deep-water areas located southwest of San Diego, California. These measurements were designed to measure near-surface continuous wave (CW) pulse propagation losses and propagation losses for explosive sources out to ranges of 45 kyd and to obtain detailed supporting environmental measurements. Measurements were made at CW frequencies of 0.4, 1.0, 1.5, 2.5, 3.5, and 5.0 kHz. The explosive measurements were analyzed at 0.40, 0.63, 1.00, 1.60, 2.50, 3.15, 5.00, and 10.00 kHz.

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This is the third in a series of three NUC Technical Papers reporting the results of these measurements. This report contains the supporting environmental measurements made during the four acoustic stations. It consists of five volumes. Volume I discusses the instrumentation used to make the required environmental measurements, the data reduction procedures, an accuracy analysis of the final measurements, and the method of reconstruction of the experiment track charts. Volumes II–V contain the environmental measurements applicable to each propagation loss run.

SUMMARY

Develop a data base by obtaining near-surface acoustic propagation loss measurements complete with relevant supporting environmental measurements.

Specifically, the SUDS I experiments were designed to measure near-surface continuous-wave (CW) pulse propagation losses and propagation losses for explosive sources out to ranges of about 45 kyd and to obtain detailed supporting environmental measurements in three deep-water areas off the west coast of southern California. This study presents the oceanographic measurements made in support of the propagation loss measurements. This report consists of five volumes. Volume I discusses the instrumentation used to make the required environmental measurements, the data reduction procedures, an accuracy analysis of the final measurements, and the method of reconstruction of the experiment track charts. Volumes II-V contain the environmental measurements applicable to each acoustic station.

CONTENTS

FIGURES

TABLES

INTRODUCTION

From 9 to 24 February, 1972, the Naval Undersea Center conducted, at 4 acoustic stations, a series of 18 propagation-loss experiments in 3 deep-water areas off the west coast of Southern California. These experiments are known as the SUrface Duct Sonar Measurements (SUDS I - 1972). Figure 1 shows the locations of the experimental areas and the tracks of the source ship. Acoustic station 1 was conducted in area A, station 2 in area B, and stations 3 and 4 in area C. At each acoustic station either four or five propagation loss runs were made. During these experiments, propagation losses in near-surface propagation paths (direct, surface channel, and depressed channel) were made as a function of range out to ranges of 25.0 kyd to 43.7 kyd.

This is the third in a series of three NUC Technical Papers reporting on the propagation loss and supporting environmental measurements made during these experiments. The first report (Ref. 1) discusses the propagation loss and environmental measurements. The second (Ref. 2) is a propagation loss data report. It discusses the acoustic instrumentation and data reduction procedures and contains plots of the propagation loss measurements. The present report contains the supporting environmental measurements made during the four acoustic stations.[*] It consists of five volumes. Volume I discusses the instrumentation used to make the required environmental measurements, the data reduction procedures, an accuracy analysis of the final measurements, and the method of reconstruction of the experiment track charts. Volumes II-V contain the environmental measurements applicable to each propagation loss run.

The following oceanographic parameters were measured: temperature, salinity, and sound speed as a function of depth, and surface roughness and wind speed as a function of time. Hydrographic casts were used to measure temperature and salinity at discrete depths from the surface to bottom. A Plessey Environmental Systems 9040-4C STD/SV[**] Profiling System was used to simultaneously measure temperature, salinity, and sound speed as continuous functions of depth from the surface to the bottom. A Sippican Corporation R-603 XBT System[†] was used to measure temperature as a continuous function of depth from the surface to 450 m. A thermistor chain, consisting of 44 thermistors spaced 5.6 m apart, was used to measure a vertical temperature profile every 10 sec from the surface to 242 m along the track of the source ship. A Lockheed Teletherm buoy line consisting of 10 buoys tethered 1 nm apart was used to simultaneously measure 10 temperature profiles, at 10 equally spaced depths from the surfact to 125 m, every 10 sec. Surface roughness was measured by a Datawell Waverider buoy, with supplementary measurements made using a wave staff and stereo photographs of the sea surface. The ships' logs were used to obtain measurements of wind speed and direction and sea state.

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[*] *In this paper both* measured *and* computed *sound speeds are reported. The measured sound speeds are measured by a Plessey Environmental Systems sound velocimeter and the computed sound speeds are obtained from Anderson's sound-speed equation (Ref. 6). Discussions of sound-speed distributions present during the propagation loss measurements are based on the computed sound speeds.*

[**] *Salinity Temperature Depth/Sound Velocimeter.*

[†] *EXpendable BathyThermograph.*

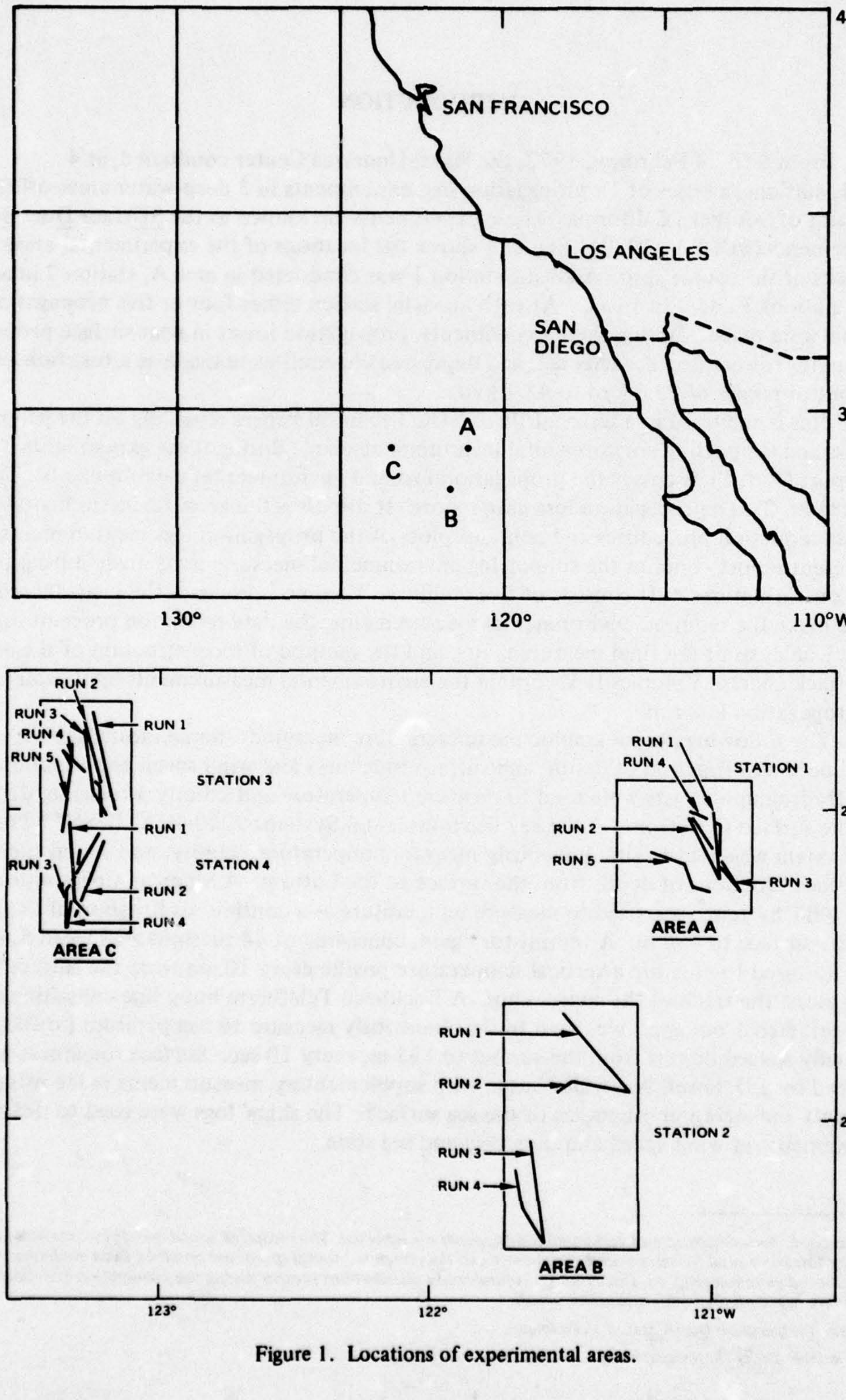

Figure 1. Locations of experimental areas.

Figure 2 contains schematic temperature and sound-speed profiles. This figure illustrates the following terms which will be used in the discussions to follow:

Isothermal layer: A layer, starting at the surface, in which the temperature gradients are more positive than –0.3°F/100 ft (–0.56°C/100 m).*

Surface layer depth: The depth of the top of the main thermocline.

Surface channel: A layer, starting at the surface, where the sound-speed gradient is positive and near linear.

Depressed channel axis: The depth within the surface layer where the sound speed has a relative minimum.

Refractive channel axis: The depth below the surface layer and in the main thermocline where the sound speed has minimum.

Deep channel axis: The depth of a sound-speed minimum below which the sound speed is an increasing function of depth.

Participating in these experiments were the *USNS S. P. Lee* (TAG-192), the *USNS DeSteiguer* (T-AGOR-12), and the *R/V Cape*. The *Lee* was the source ship, the *DeSteiguer* the receiver ship, and the *Cape* operated and monitored environmental sensors, including the line of temperature buoys and the Datawell Waverider buoy. A summary of preliminary results has been reported by Cummins (Ref. 3). The data contained in this report supercede the data reported in Ref. 3.

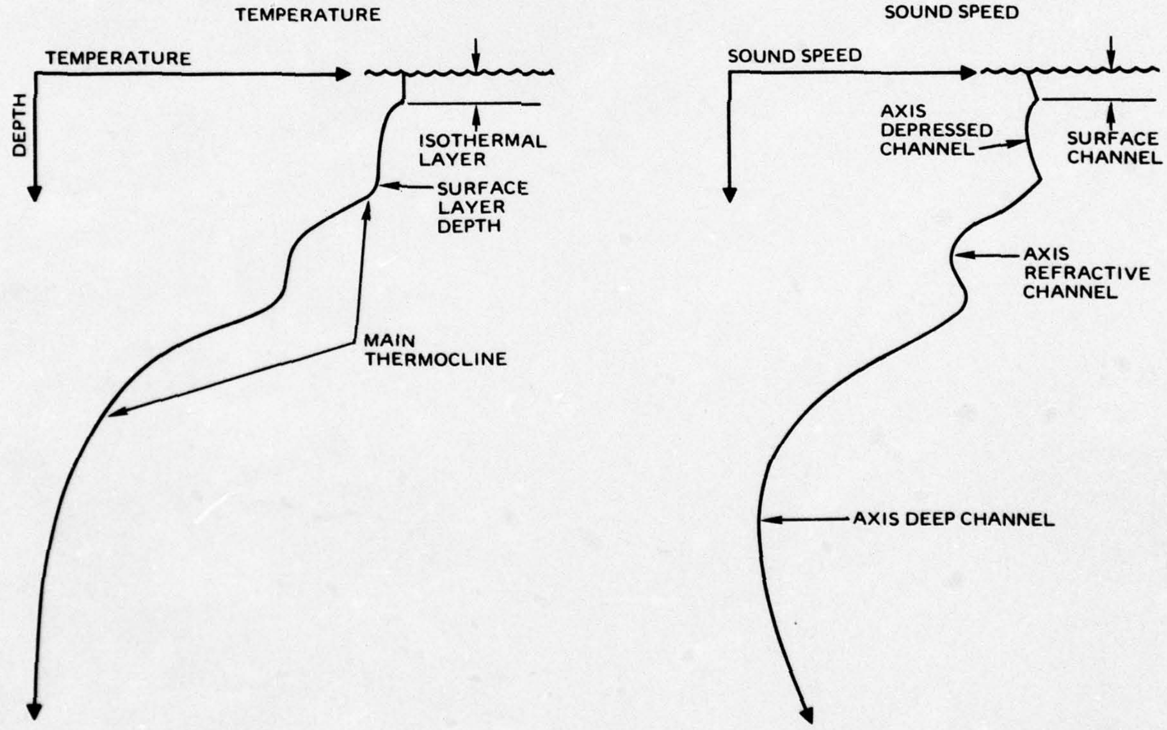

Figure 2. Schematic temperature and sound-speed profiles.

***This is the AMOS propagation loss model definition of an isothermal layer. It is the oceanographic equivalent to the acoustic surface channel since such temperature gradients (assuming constant salinity) result in positive sound-speed gradients because of the effect of pressure.**

INSTRUMENTATION

HYDROGRAPHIC CASTS

The hydrographic cast is an internationally standarized technique to obtain measurements of temperature and salinity at discrete depths from the surface to the bottom. Description of the instrumentation may be found in any physical oceanography textbook. The generally accepted overall accuracy of the technique is:

temperature:	±0.02°C
salinity:	±0.02 ppt
depth:	±5 m for depths <1000 m
	±0.5% for depths >1000 m

PLESSEY ENVIRONMENTAL SYSTEMS STD/SV PROFILING SYSTEM

Simultaneous salinity, temperature, depth, and sound-speed measurements were obtained using a Plessey Environmental Systems 9040-4C profiling system. The Plessey system provides both an analog and digital output. The analog output is a continuous trace of the measured variables as functions of depth and the digital record is on magnetic tape, with a sample rate of 0.2 sec for each measured variable. According to Plessey, the range of measurement and the overall system error for the STD/SV system is:

salinity:	30 to 40 ppt	±0.02 ppt
temperature:	–2 to 36°C	±0.02°C
sound speed:	1400 to 1600 m/sec	±0.30 m/sec
depth:	0 to 500 m	±4.0 m
	500 to 6000 m	±6.0 m

The manufacturer checked the calibration of the system prior to departure. The calibration report gave the following total system errors:

salinity:	±0.011 ppt
temperature:	±0.011°C
sound speed:	±0.15 m/sec*
depth:	±4.2 m

SIPPICAN XBT SYSTEM

Temperature measurements as a function of depth were obtained using a Sippican Corporation R-603 XBT system. The output of this system is an analog record of

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******The sound velocimeter was calibrated in distilled water using a fifth-degree polynomial fit to Del Grosso's distilled-water sound-speed measurements (Ref. 4). The total system error was obtained by comparison at six temperatures with Del Grosso's distilled-water equation.*

temperature as a function of depth to a maximum depth of 460 m. According to Sippican, the range of measurement and the system accuracy for the XBT system is:

temperature:	−1.7 to 35.6°C	±0.2°C
depth:	0 to 230 m	±4.6 m
	230 to 460 m	±2.0%

THERMISTOR CHAIN

The thermistor chain is a towed device used for measuring temperature from the surface to a maximum depth of 242 m. It consists of 44 thermistors, spaced 5.6 m apart, . plus shipboard equipment consisting of a winch and the necessary electronics for recording the temperature as measured by the 44 thermistors. The instrument is designed to measure a vertical temperature profile every 10 sec with an estimated accuracy of about ±0.1°C. At a 3-knot towing speed this results in a vertical temperature profile every 17 yd. Additionally, a depth sensor records the depth of the deepest thermistor. The towed configuration of the chain is a modified catenary whose shape is a function of towing speed. By knowing the towing speed and the maximum depth, the depth of each sensor may be computed. The system provides both an analog and a digital output. The analog output is a contour chart showing interpolated integer isotherms as a function of depth and range, and the digital record is a magnetic tape containing the output of each vertical scan of the temperature and depth sensor.

LOCKHEED TELETHERM BUOY SYSTEM

A line of 10 Lockheed Model 9-TB-10T Teletherm buoys was used to measure temperature profiles. The 10 buoys were tethered 1 nm apart, forming a 9-mile-long line. The plan was to deploy these buoys in a line from the vicinity of the receiving ship in the direction of the planned propagation path. This procedure would provide 10 simultaneous temperature profiles along the first 18 kyd of the propagation run. Each buoy measured temperatures, using thermistor beads as sensors, at 10 equally spaced depths from the surface to 125 m. A complete temperature profile was measured every 10 sec for each buoy. The data were transmitted via a radio link to the *Cape* and recorded on magnetic tape in digital format. According to the manufacturer the overall system accuracy is 0.034°C. No depth sensor was included in the system. Details of the system are reported in Ref. 5.

DATAWELL WAVERIDER BUOY SYSTEM

The Datawell Waverider buoy system was used to obtain a measure of sea-surface roughness. The system, manufactured by the Datawell Laboratory for Instrumentation, a Netherlands company, measures wave height versus time in both analog and digital formats. The system consists of a telemetering buoy employing accelerometers to sense sea-surface variations and shipboard receiving and recording equipment. According to the manufacturer the system will measure waves of 1.25- to 16.7-sec periods with an accuracy of about 3 percent for waves up to a maximum wave height of 20 m.

ACOUSTIC EXPERIMENT TRACK CHARTS

Satellite navigation, celestial navigation, and dead reckoning were employed for absolute positioning, while radar ranges and bearings and acoustic ranges were used for relative positioning. The experimental plan required each ship to maintain a position-fix log, a maneuvering log, and a radar range and bearing log during all propagation loss runs. The satellite fixes gave the most accurate absolute positions and the acoustic ranges gave the most accurate relative range determinations. All positions were adjusted to these measurements. Only the *Lee* was equipped with a satellite navigation system. The first step in the reconstruction of the experimental geometry was to determine the position of the *Lee* during each of the experimental runs and for periods between runs when environmental data were being taken. The satellite fixes were plotted and the maneuvering log courses and speeds used to determine the position of the *Lee*, both back and forward in time, relative to the satellite fixes. Celestial fixes were sometimes used in the absence of satellite fixes. Because of a marked and variable drift from the northwest due to currents and wind, it was often necessary to adjust the track so that the track would agree reasonably well with the satellite fixes. In some cases it was necessary to revert to the use of dead reckoning only. In these cases the absolute positioning of the *Lee* is uncertain, with the uncertainty increasing as a function of time since the last satellite fix. There were times when because of drifting, when hove to, or when frequent course and speed changes were made, it was impossible to reconstruct the *Lee's* track. This was particularly true between the conclusion of the station 1 experiments on 12 February 1400 LST* and the beginning of the station 2 experiments on 14 February 1822 LST. In these cases, arbitrary straight-line interpolation between satellite fixes was used in the reconstruction.

The second step in the reconstruction process was to determine the position of the *DeSteiguer*, and the *Cape* with respect to the *Lee*. During each run the *Lee*, *DeSteiguer*, and *Cape* took radar range and bearing measurements on each other every 20 min. Figure 3 is a plot of the *Lee* radar range to the *DeSteiguer* versus the *DeSteiguer* radar range to the *Lee* for a selected set of 65 couplets measured between 11 and 23 February, 1972. If the two radars were in agreement, the plotted points would lie on the dashed line. The solid line is a least-square fit of a straight line to the data points. The standard deviation of the data points about the regression line is 680 yd. It is obvious that the two radars differ systematically in the range measurements. During the acoustic experiments, ranges between the *Lee* and the *DeSteiguer* were measured acoustically. Acoustic ranges were determined by measuring the time difference in arrivals at the receiver ship of an acoustic signal and a radio signal generated simultaneously by the source ship. This time difference multiplied by the average sound speed over the propagation path is the range between the source and receiver. Figure 4 is a plot of the *DeSteiguer* radar range to the *Lee* versus the acoustic range between the *Lee* and *DeSteiguer*. The acoustic range measurements were made within ±2 min of the same time as the radar range measurements. The straight line is a least-square fit to the measurements. The standard deviation of the measurements about the regression line is 480 yd.

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*Local Standard Time.

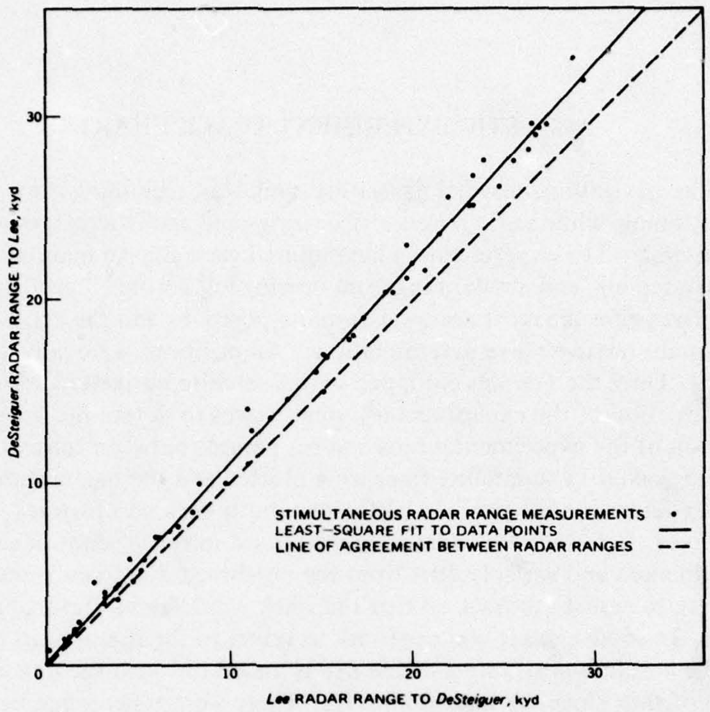

Figure 3. Relationship between *Lee* and *DeSteiguer* radar ranges.

The agreement between the independently determined ranges is obvious. Figure 5 compares the *Cape* radar range measurements to the *DeSteiguer* versus the *DeSteiguer* radar range measurements to the *Cape*. The straight line is a least-square fit to the data points. The standard deviation of the measurements about regression is 1.4 kyd. The standard deviation is considerably larger than that obtained in the previous comparisons and is caused by the two compensating comparisons made at *Cape* ranges of about 10.0 and 13.4 kyd. The agreement between the *Cape* and *DeSteiguer* radar ranges is obvious. Based on the data presented in Figure 4 and 5 it was concluded that the *Lee* radar ranges are in error. The *Lee* ranges can be corrected to agree with the *DeSteiguer* ranges by using the linear relationship shown on Fig. 3. Figure 6 compares the *DeSteiguer* radar bearings on the *Lee* with *Lee* radar reciprocal bearings on the *DeSteiguer.* The straight line is a least-square fit to the data points, and the standard deviation of the measurements about regression is 3 degrees. Again, the agreement in bearing measurement is obvious. The relative position of *Lee* and *Cape* to *DeSteiguer* was determined using the *DeSteiguer* range and bearing on the *Lee* and *Cape.* During times when the *DeSteiguer* measurements to the *Lee* were missing, the *Lee* ranges, corrected using the relationship shown on Fig. 3, and bearings were used to fix the *Lee* position. All the relative positions of *Lee* and *Cape,* thus, are consistent with the acoustic range determinations and the *Lee* radar bearings.

During the course of the second deployment of the thermistor buoy line, 19 February 1800 LST to 23 February 1140 LST, the *Cape* made frequent range and bearing measurements on buoy 1, 4, and 8; and from 20 February 1350 LST to 23 February 0400 LST, measurements were made on all eight buoys. The third step in the reconstruction of the experimental tracks was to use these data to locate the position of the buoy line with respect to the *Cape.*

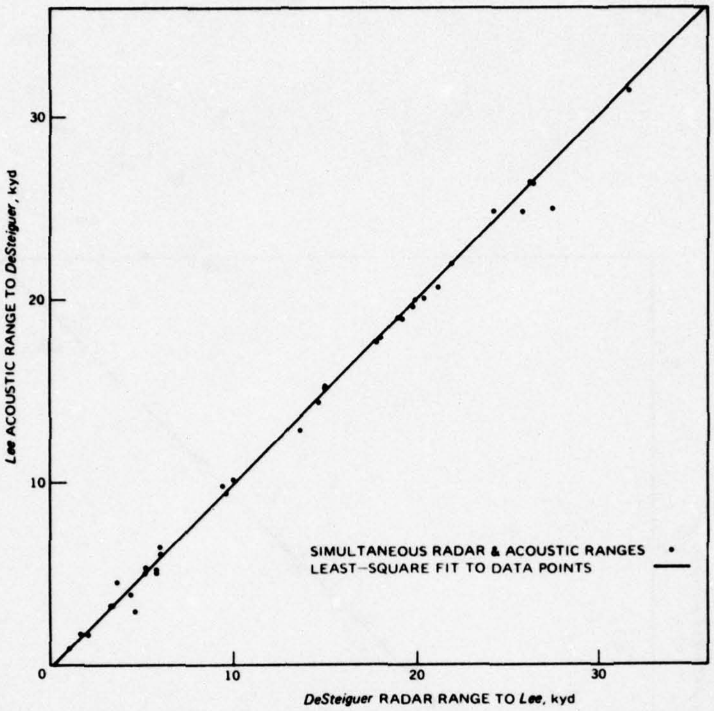

Figure 4. Relationship between *DeSteiguer's* radar range and the acoustic range.

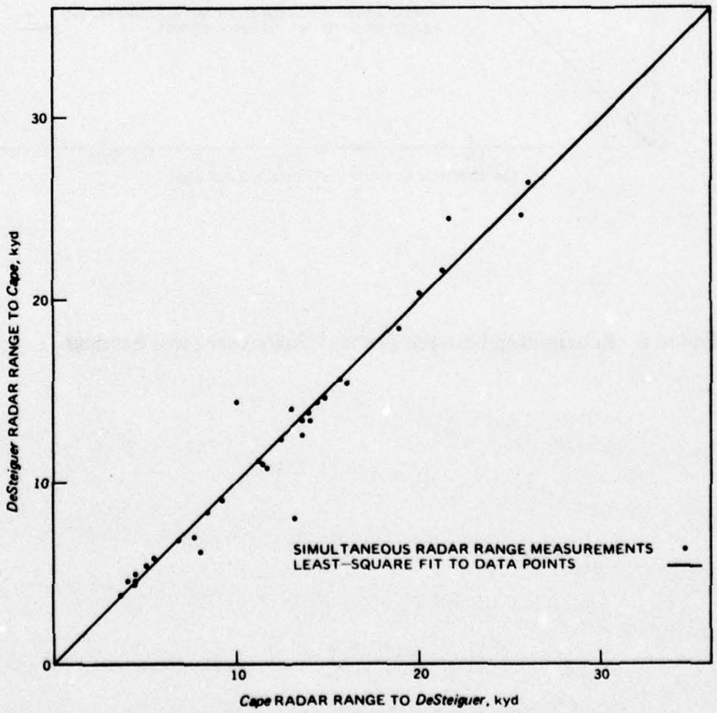

Figure 5. Relationship between *DeSteiguer* and *Cape* radar ranges.

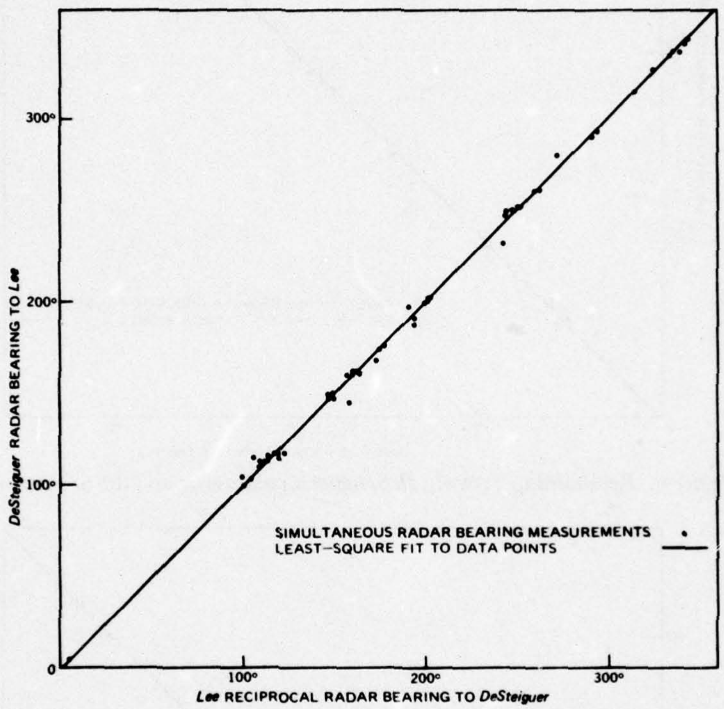

Figure 6. Relationship between *Lee* and *DeSteiguer* radar bearings.

DATA REDUCTION AND ANALYSIS

HYDROGRAPHIC CAST MEASUREMENTS

Hydrographic cast measurements of temperature, salinity, and depth were made at 13 locations by means of internationally accepted instrumentation, observational procedures, and data reduction techniques. These measurements are the primary measurements of temperature, salinity, and depth. In the analysis they are the standard for comparison of other measurements of these parameters using other instrumentation. Locations of these measurements are shown in Fig. 7 by the symbol (+). Pertinent information is summarized in Table 1. The time shown in Table 1 is the messenger release time in local standard time (LST).

The observed and interpolated values of temperature and salinity at the measured and standard hydrographic cast depths, as well as supporting information, are tabulated in Appendix A. Following generally accepted procedures, casts 2 and 3 and casts 7 and 8 are combined to form two sets of measurements extending from the surface to 1783 and 4010 m, respectively. The other deep cast, cast 4, contains measurements to 3341 m; however, no measurements were made between the surface and 181 m. Hydrographic casts 1, 2, 3, 4, and 9 were made in area A and 6, 7, 8, 11, 12, and 13 were made in area C. No hydrographic casts were made in area B.

STD/SV MEASUREMENTS

Measurements of salinity, temperature, and sound speed as functions of depth were made at the 12 locations shown in Fig. 7 by the symbol (▲) using a Plessey Environmental Systems 9040-4C profiling system. Measurements were recorded in both a digital and analog format. The digital output was recorded on magnetic tape using a 0.2-sec sampling rate. Pertinent information for the profiles is summarized in Table 2. The time shown is the start of the down profile and is in local standard time. The "D" or "U" indicates whether the measurements were made on the down or up profiling.

Plessey checked the sound velocimeter's calibration at atmospheric pressure for six temperatures in distilled water and seawater (salinity 33.15 ppt). Figure 8 presents the results of these calibration checks, which employed sound-speed equations based on Wilson's laboratory sound-speed measurements. The distilled water standard was a fifth-degree polynomial fitted to Wilson's atmospheric pressure laboratory sound-speed measurements (Ref. 4). The seawater standard was Anderson's sound-speed equation (Ref. 6). The solid lines are least-square fits of first- or second-degree polynomials to the differences between the measured and computed sound speeds for the distilled water (·) and seawater (+) calibration checks. The calibration checks in distilled water and seawater do not agree. The reason for this is not known. An arbitrary decision as to which calibration correction should be used must be made. Since the sound-speed measurements are made in seawater it seems reasonable that the seawater calibration correction be used. The seawater sound-speed calibration shown in Fig. 8 was applied to all of the measured sound speeds. As previously noted the calibration checks for salinity, temperature, and depth were within the system's designed accuracies, so no calibration corrections were applied to these measurements.

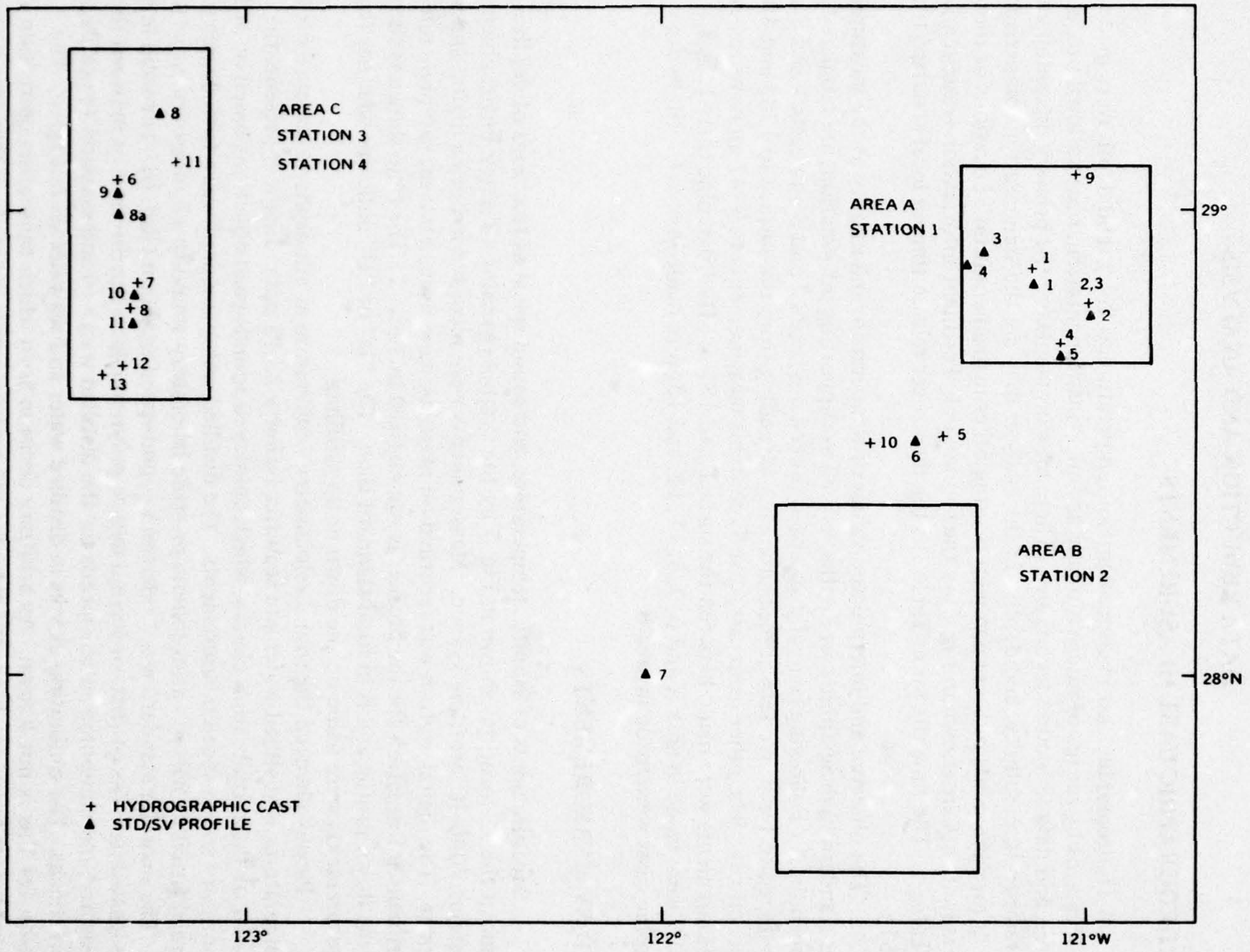

Figure 7. Locations of hydrographic casts and STD/SV measurements.

Table 1. Summary of Hydrographic Cast Measurements.

Hydrographic Cast Number	Ship	Date Feb. 1972	Time	Maximum Depth, m
1	*Lee*	9	1133	306
2	*Lee*	10	1328	496
3	*Lee*	10	2010	1783
4	*Lee*	12	1930	3341
5	*Lee*	13	1621	306
6	*Lee*	21	2143	505
7	*Lee*	23	0910	495
8	*Lee*	23	1303	4010
9	*DeSteiguer*	9	1219	448
10	*DeSteiguer*	14	1715	407
11	*DeSteiguer*	19	1408	502
12	*DeSteiguer*	22	1510	503
13	*DeSteiguer*	23	0645	504

Table 2. Summary of STD/SV Measurements.

STD/SV Number	Date Feb. 1972	Time	Maximum Depth, m
1D	9	1735	855
2D	10	1415	3542
3D	12	0415	312
4D	12	0610	3784
5D	12	2020	3653
6D	13	1815	2011
7D	16	0940	1527
8D	19	1205	1517
8aD	21	1615	2045
9U	21	2220	628
10D	23	0945	529
11D	23	1600	3789

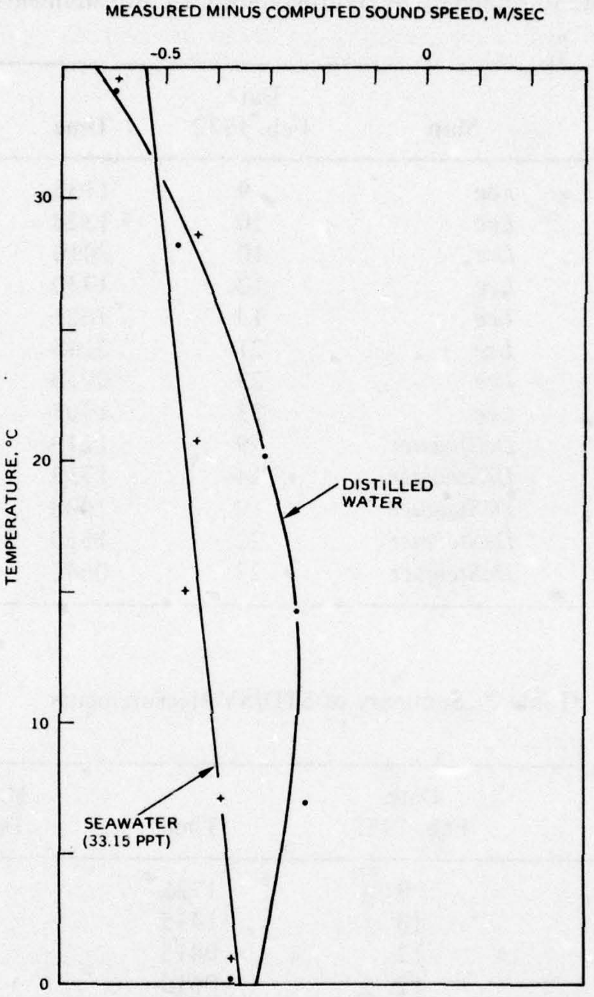

Figure 8. Sound velocimeter calibrations.

Data Reduction Procedures

The digital data, recorded on magnetic tape, were used as the measured salinity, temperature, sound speed, and depth. The first step in the data reduction procedure was to plot temperature, salinity, and sound speed as a function of depth for all digitially recorded measurements made on the down profiling. The set of measurements made on the down profiling was used for all profiles except profile 9, for which the up profile measurements was used. Additionally, a listing of the measurements was made. An inspection of the plotted data showed that for some depth intervals, no data were recorded. However, since these depth intervals were small, it was found that interpolation could be used without any significant loss of accuracy.

The STD/SV system uses a pressure sensor to obtain depth information. The hydrostatic pressure equation is used to convert pressure to depth. This conversion requires values for the mean density of the water column from the surface to the depth in question and a value for the acceleration of gravity. Both of these vary with location, and the mean density varies with time. The STD/SV system assumes a near-surface density appropriate to low-salinity near-surface water and uses the standard value for the acceleration of gravity. Thus, all depths recorded by the STD/SV system, except for the surface, are systematically in error. For the SUDS I measurements, the depths are corrected for the mean density found in the northeast Pacific Ocean using data compiled by Bialec (Ref. 7). The internationally adopted standard value for the acceleration of gravity is used since it can be shown that gravity corrections for latitude and depth are less than 1 m at 5000 m. The depth correction is zero at the surface, 4 m at 1000 m, 13 m at 2000 m, 26 m at 3000 m, and 44 m at 4000 m. Neglect of this correction seriously biases measured deep-water gradients of any property.

The primary purpose for the STD/SV measurements is to support the interpretation of the acoustic experimental data acquired during the SUDS I experiments. Previous work indicated that this purpose could be fulfilled by using data at standard hydrographic cast depths from the surface to 2000 m and from that depth to the bottom in 500-m increments. The second step in the data reduction procedure was to determine the digital depths equivalent to the standard depths and tabulate the digitally recorded values of salinity, temperature, and sound speed for these depths. The measured values were obtained from the computer listings of the digital measurements. For those standard depths at which the digital measurements were missing, values were interpolated from the plotted data. In addition, sound speeds were tabulated at special depths, such as, mixed layer depth, maxima, and minima.

In Situ Accuracy Checks

The original planned observational program included independent measurements of temperature, salinity, and depth utilizing hydrographic cast measurements. Hydrographic casts 2, 3, 4, 6, 7, and 8 were taken close enough in time and space to the STD/SV measurements to obtain useful comparisons. Reversing thermometers and sampling bottles attached to the STD/SV cable just above the sensor unit were also used to obtain temperature, salinity, and depth measurements at the maximum depth of selected STD/SV profiles. Attempts were made on 7 of the 12 STD/SV profiles. Satisfactory measurements were obtained on 2 of the 7 attempts. In addition, an attempt was made to obtain temperature and salinity measurements at several depths on STD/SV 6 by attaching a rosette sampler just above the sensor unit. This attempt failed to produce any useful information.

Table 3 summarizes the maximum-depth accuracy checks. The two successful comparisons were obtained on STD/SV 8aD and 11D. On each STD/SV measurement two hydrographic cast sampling bottles, one above the other, with three thermometers on each bottle were used. Of the six thermometers, three were protected and three were unprotected thermometers, resulting in a total of three independent depth measurements. The agreement between the two independent depth determinations is obvious. The manufacturer gives an accuracy of ±6 m for the depth sensor used in this system, and the generally accepted thermometric depth accuracy is ±0.5 percent.

Temperature accuracy checks were obtained on six hydrographic casts and at the maximum depth on two STD/SV profiles. Table 4 and Fig. 9 summarize the results of a comparison between temperatures measured by the STD/SV system and the hydrographic cast system. Figure 9 is a plot of the average difference (•) between the temperature measured by the STD/SV system and that measured by reversing thermometers as a function of the depth. The bar shows one standard deviation of the average. The left figure shows

Table 3. Comparison of STD/SV Depths with Those Obtained from Reversing Thermometers.

	Depth, m		
Profile	STD/SV	Thermometric	Difference
8aD	2042	2039	+3
		2043	–1
		2044	–2
11D	3777	3782	–5
		3785	–8
		3778	–1

Table 4. Comparison of STD/SV and Reversing Thermometer Temperatures at Maximum Profile Depth.

	Temperature, °C		
Profile	STD/SV	Reversing Thermometer	Difference
8aD	2.04	2.05	–0.01
		2.06	–0.02
		2.05	–0.01
22D	1.50	1.52	–0.02
		1.54	–0.04
		1.53	–0.03

the difference from the surface to 300 m and the right figure shows the difference for depths greater than or equal to 300 m. The differences contained in Table 4 are shown by the (+) symbol. For depths greater than 2000 m the STD/SV gives temperatures that are consistently about 0.02°C lower than the hydrographic cast temperature measurements. Thus, 0.02°C is added to all STD/SV temperature measurements to bring them into agreement with those measured by the hydrographic cast.

Salinity accuracy checks were obtained on six hydrographic casts and at the maximum depth on two STD/SV profiles. Table 5 and Fig. 10 summarize the results, using the same format used for Fig. 8. Figure 10 shows that at all depths the STD/SV measured higher salinity than the hydrographic cast, with the difference being a function of depth from the surface to 1000 m. For depths greater than 1000 m the average difference is a constant difference of 0.06 ppt. A similar depth bias has been reported utilizing similar STD/SV systems (for example, Ref. 8). The solid line is a visually determined average correction. This correction was applied to all STD/SV salinity measurements.

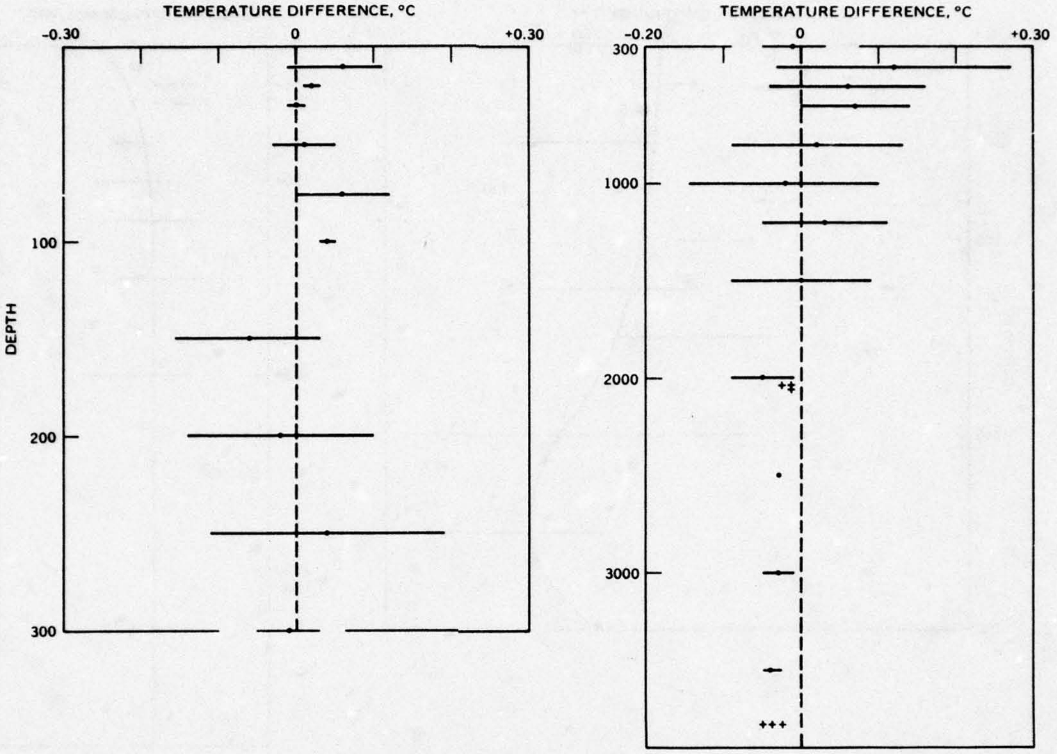

Figure 9. Temperature differences between STD/SV and hydrographic cast measurements.

Table 5. Comparison of STD/SV and Sampling Bottle Salinities at Maximum Profile Depth.

	Salinity, ppt		
Profile	STD/SV	Sampling Bottle	Difference
8aD	34.69	34.60	0.09
		34.64	0.05
11D	34.72	34.67	0.05
		34.66	0.06

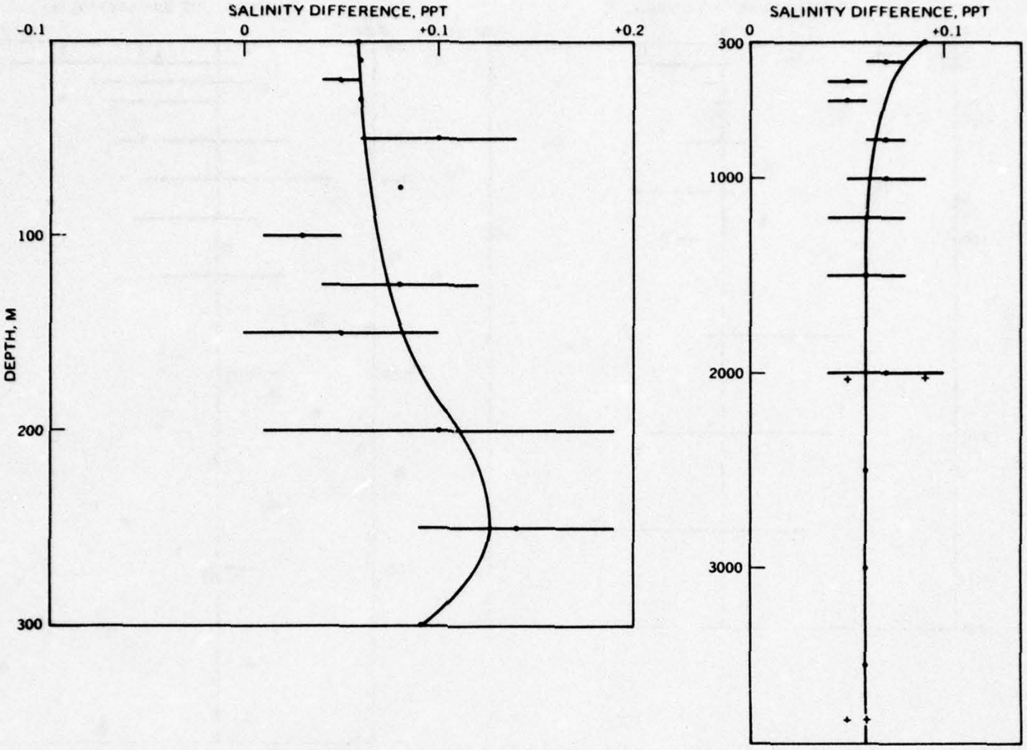

Figure 10. Salinity difference between STD/SV and hydrographic cast measurements.

XBT MEASUREMENTS

A total of 462 XBT temperature profiles, from the surface to 450 m, were attempted in the areas where the acoustic experiments were conducted. Table 6 summarizes the number of XBT records made by each ship in each of the operating areas.

Table 6. Number of XBT Records

Ship	Area A	Area B	Area C
Lee	89	66	104
DeSteiguer	49	21	50
Cape	19	18	46
	157	105	200

XBT Data Processing

A visual examination of the XBT records sufficed to detect the XBT records that were catastrophic failures (no usable temperature measurements) and those that were partial failures (usable temperature measurements did not extend to 450 m). Table 7 summarizes the number and percent of theXBTs that were catastrophic and partial failures by area for each research ship. Out of a total of 462 recorded XBT profile attempts 52 (11.3 percent) and 25 (5.4 percent) were catastrophic or partial failures, respectively. Eliminating the 52 catastrophic failures left 410 visually acceptable XBT temperature profiles.

Table 7. Summary of XBT Record Failures and Partial Failures.

Area	*Lee*		*DeSteiguer*		*Cape*	
	number	percent	number	percent	number	percent
CATASTROPHIC FAILURES						
A	10	11.2	2	4.1	0	0.0
B	8	12.1	5	23.8	2	11.1
C	13	12.5	4	8.0	8	17.4
Total	31	12.0	11	9.2	10	12.0
PARTIAL FAILURES						
A	3	3.4	3	6.1	0	0.0
B	9	13.6	1	4.8	2	11.1
C	2	1.9	4	8.0	1	2.2
Total	14	5.4	8	6.7	3	3.6

The XBT analog records contain a calibration mark at 16.7°C. The calibration of each of the visually acceptable XBT records was checked and any required corrections were noted and applied to all subsequent temperature determinations. Additionally, any depth offsets were noted and applied. The records were then read, corrected, and recorded at the standard hydrographic cast depths. Since the acoustic experiments were concerned with propagation in near-surface acoustic propagation paths, special attention was paid to reading and recording temperatures at additional depths where temperature gradient changes were observed.

Previous comparisons of XBT temperature measurements with simultaneous and independent temperature measurements made using hydrographic cast and STD/SV systems show that some visually acceptable XBT profiles result in temperatures that are higher than those made by the hydrographic cast and/or STD/SV systems (Ref. 8). Since the observed difference is an increasing function of depth, the acceptance and use of such measurements results in a systematic biasing of the vertical temperature gradient.

To detect XBT profiles that might possibly contain such gradient biasing errors, the 200-m and 400-m measurements were used. For each ship and each area, the average the temperature and standard deviation were obtained for these two depths. If, for a given XBT, both the 200-m and 400-m temperatures were within three standard deviations of the average temperature, the XBT record was considered to be correct. If the temperature at either depth was greater than or equal to three standard deviations of the average temperature, the profile was considered in error and eliminated from further analysis. A total of 9 out of the 410 visually acceptable XBT records (2.2 percent) failed to meet this criterion.

Table 8 summarizes the number of acceptable XBT records. Also shown is the percent of those attempted that were considered to be acceptable. Out of a total of 462 attempted XBTs, 401, or 86.8 percent, were considered acceptable.

Table 8. Number of Acceptable XBT Records.

Area	*Lee*		*DeSteiguer*		*Cape*	
	number	percent	number	percent	number	percent
A	76	85.4	46	93.4	18	94.7
B	57	86.4	16	76.2	16	88.9
C	89	85.6	45	90.0	38	82.6
Total	222	85.7	107	89.2	72	86.7

The final accuracy check was to compare the XBT 200-m and 400-m temperatures with the average STD/SV and hydrographic cast 200-m and 400-m average temperatures. Two of the 401 XBTs failed to meet the criterion of not exceeding plus or minus three standard deviations of the average hydrographic cast and STD/SV temperature at 200 m and 400 m. In addition, one XBT could not be used since the time was not recorded on the trace. Thus, out of the original 462 XBT profiles, 399 (86.4 percent) were finally accepted as being accurate temperature profiles.

Comparison of XBT Systems

Temperature measurements at 200 m and 400 m were used to determine if the three XBT systems were in agreement. Table 9 presents the differences, at 200 m and 400 m, between the average temperature measured on the *Lee* XBT system and those measured on the *DeSteiguer* and *Cape* XBT systems, respectively. Differences are shown for each area. An examination of these differences shows agreement between the *Lee* and *Cape* XBT systems, while the *DeSteiguer* system is consistently measuring a temperature that is lower than that measured on the *Lee* system. The average of the six average differences is –0.28°C for the *DeSteiguer* and –0.01°C for the *Cape*. It is concluded that 0.3°C should be added to the *DeSteiguer* XBT temperature measurements to bring them into agreement with those measured on the *Lee* and *Cape*.

Comparison of Hydrographic Cast-STD/SV and XBT Temperatures

Table 10 compares the average XBT temperatures measured in areas A and C with the average hydrographic cast (HC) and STD/SV temperatures measured in these same areas. No comparison can be made with the XBTs recorded in area B since no hydrographic casts or STD/SVs were made in that area. Comparisons are made at seven selected depths below the thermocline. Shown in Table 8 are the averages, standard deviations, and differences. All differences are less than one standard deviation of the XBT average, with the differences being less than 0.1°C for all comparisons deeper than 200 m.

Nine hydrographic casts and STD/SVs were made within 45 min of the time nine XBT temperature profiles were recorded. Figure 11 presents comparisons of these nine pairs

Table 9. XBT System Temperature Comparison (°C).

Area	*DeSteiguer*	*Cape*
200 Meters		
A	–0.37	–0.06
B	–0.21	+0.11
C	–0.32	–0.07
400 Meters		
A	–0.37	–0.05
B	–0.16	+0.14
C	–0.27	–0.13

Table 10. Comparison of Average HC – STD/SV Temperatures with Average XBT Temperatures (°C).

Depth,	HC – STD/SV			XBT			
m	n	$\overline{T}$	σ	n	$\overline{T}$	σ	Difference
AREA A							
100	8	12.52	0.71	139	12.82	0.63	0.30
125	8	10.96	0.31	139	11.30	0.43	0.34
150	8	10.52	0.12	139	10.67	0.24	0.15
200	9	10.27	0.12	139	10.28	0.19	0.01
250	9	9.84	0.11	137	9.86	0.21	0.02
300	8	9.45	0.19	135	9.38	0.27	–0.07
400	7	8.31	0.30	133	8.30	0.33	–0.01
AREA C							
100	10	14.55	0.28	169	14.55	0.32	0.00
125	7	13.47	0.29	169	13.29	0.46	–0.18
150	10	11.83	0.47	168	11.88	0.54	0.05
200	10	9.76	0.19	168	9.78	0.26	0.02
250	10	8.74	0.12	168	8.75	0.24	0.01
300	10	7.87	0.10	167	7.88	0.21	0.01
400	10	6.62	0.09	163	6.67	0.19	0.05

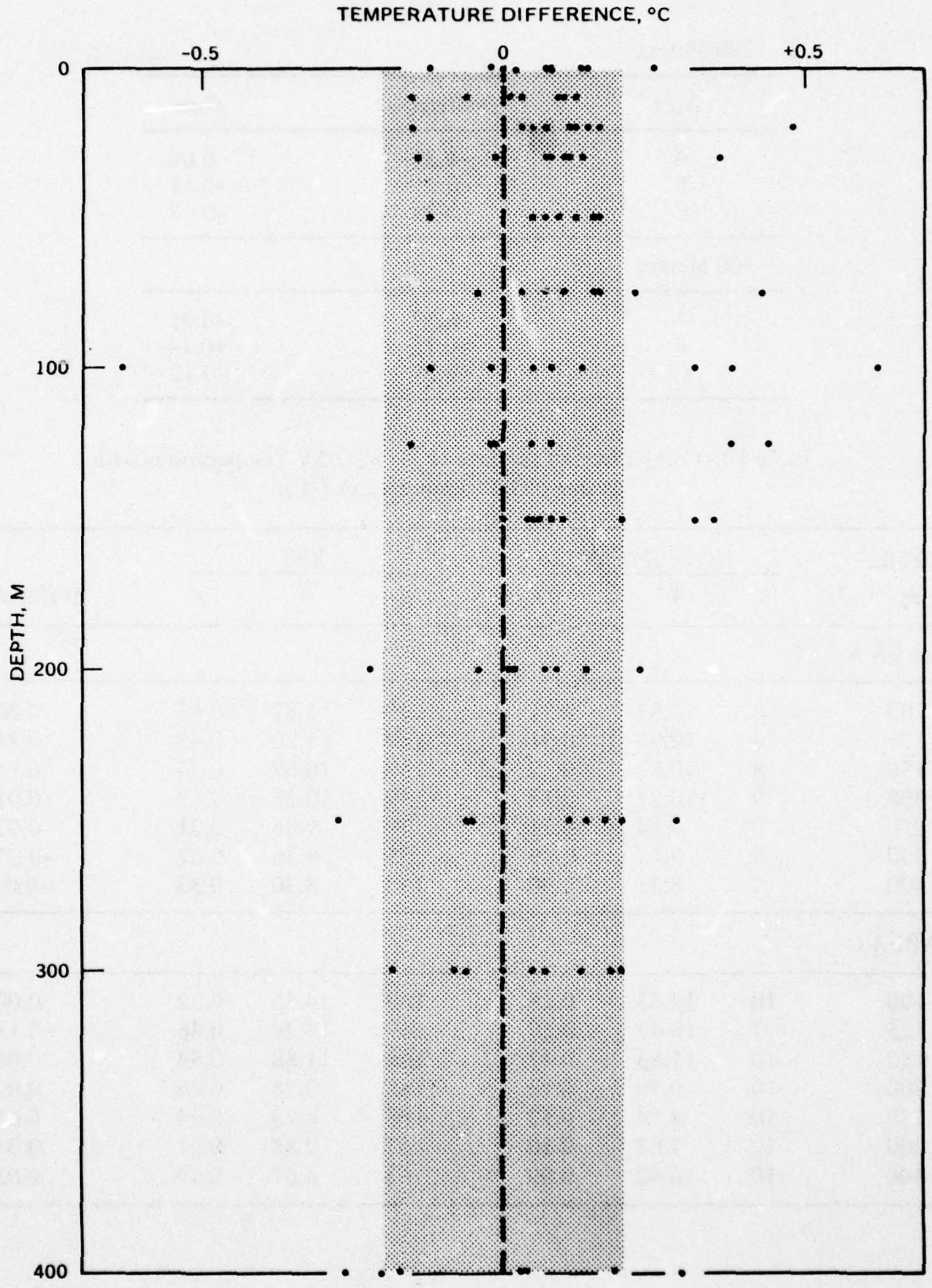

Figure 11. Difference between XBT and hydrographic cast of STD/SV temperatures measured less than 45 min apart.

of observations. Shown are the differences between the XBT and the hydrographic cast or STD/SV temperatures at 13 selected depths from the surface to 400 m. The shaded band contains temperatures and the hydrographic cast or STD/SV temperatures at 13 selected depths from the surface to 400 m. The shaded band contains all differences less than or equal to ±0.2°C, the manufacturer's specified accuracy of the XBT system. Out of a total of 114 differences, 94 (82.5 percent) were less than ±0.2°C. In general, the larger differences are associated with depths where the temperature gradients are the greatest. The average difference was +0.08°C, with 87 (76.3 percent) being positive and 27 (23.7 percent) negative. This suggests that the XBT system measures a higher temperature than the hydrographic cast or STD/SV. This tendency has been observed in other temperature measurement programs involving the XBT system (unpublished data).

SUMMARY

The following summarizes the results of the accuracy analysis of 462 XBT temperature profiles made during the SUDS I acoustic experiments:

Number XBT		Percent
462	profiles recorded	100.0
52	catastrophic failures	11.3
9	failed $\overline{T}(XBT) \pm 3\sigma$ criterion at 200 m and 400 m	2.2
2	failed $\overline{T}(HC\text{-}STD/SV) \pm 3\sigma$ criterion at 200 m and 400 m	0.5
399	acceptable XBT profiles	86.4

In addition, there was a tendency for the XBT system to record temperatures slightly higher than the actual temperature.

THERMISTOR CHAIN MEASUREMENTS

The thermistor chain was used to obtain temperature profiles from the surface to 242 m along the track of the source ship. Measurements were obtained for all propagation loss runs. Unfortunately, during the SUDS I experiments the thermistor chain's depth sensor was inoperative. As a result, the sensor depths have to be determined inferentially from comparisons with temperatures measured by other systems. For all experiments, except station 1 run 5, the towing speed was 3 knots. For the station 1 run 5 experiment the towing speed was 6 knots. It was hoped at the slow 3-knot towing speed the chain would be vertical in the water, with the deepest sensor at a depth of 242 m. This section evaluates the accuracy of the chain temperature measurements by comparison with temperatures measured by the STD/SV system and determines the maximum depth of measurement from comparisons with average hydrographic cast and STD/SV temperatures.

TEMPERATURE ACCURACY CHECKS

Between runs 4 and 5 of station 1, temperatures were measured simultaneously by the thermistor chain hanging vertically in the water (zero tow speed) and the STD/SV system. STD/SV 3 was made to a depth of 312 m in 10 min, starting at 0415 LST on 12 February 1972. During the period 0418-0425 LST the chain made 45 scans of its sensors. Figure 12 summarizes the results of a comparison between these two sets of measurements. The left-hand figure is a plot of the average thermistor chain temperatures as a function of depth, and the right-hand figure shows the differences between the average thermistor chain measurements and the STD/SV 3 temperature measurements at the same depths. The shaded area contains all differences less than or equal to ±0.03°C. Two features are of interest. One is the relatively large differences centered at a depth of 100 m. These differences are related to the strong negative temperature gradients observed between 80 and 135 m. A small change in depth changes the temperature considerably. For example, the temperature difference of –0.46°C at 100 m can be accounted for by a depth change of 2 m. The second feature is that from the surface to 80 m and from 135 m to 242 m, where the temperature gradients are small, all but three of the differences are positive, i.e., the thermistor chain measures a temperature higher than the STD/SV system. The average difference for these two layers is 0.03°C. Thus, all thermistor chain measurements should be reduced by 0.03°C to bring them into agreement with the hydrographic cast and STD/SV measurements.

Depth Accuracy Checks

To obtain information on the sensor depths when towing at 3 knots, the average hydrographic cast and STD/SV temperatures made in area A and area C were compared with the average temperatures measured by the thermistor chain for all acoustic runs made in these two areas. The results of this comparison are summarized in Fig. 13. The solid curve connects the average hydrographic cast and STD/SV temperatures at standard depths with the horizontal bar connecting the lowest and highest temperatures observed at the indicated depth. The dots are the average thermistor chain temperatures for each of the 44 sensors. The comparisons for the area C measurements suggest agreement, on the average, between the hydrographic cast and STD/SV measurements and the thermistor chain. The area A comparisons show good agreement for depths greater than or equal to 150 m, with the average thermistor chain measurements being higher than the hydrographic cast and STD/SV average measurements at shallower depths. However, all average thermistor chain measurements fall within the hydrographic cast and STD/SV measured range of temperatures. In the vicinity of the thermocline good agreement would be observed if all thermistors were at a depth about 10 m shallower than assumed. For this to occur the deepest thermistor would have to be about 18 m shallower than the 242-m maximum depth. Experience in towing the chain suggests that this amount of shoaling could not occur at a 3-knot towing speed. Since these data show no consistent evidence of shoaling at the 3-knot towing speed, it is assumed that the chain is being towed nearly vertically, with the deepest sensor very close to 242 m.

Figure 14 summarizes the comparison of the average hydrographic cast and STD/SV temperature measurements made in area A with the average temperature measured by the thermistor chain for the 6-knot tow made during station 1 run 5. The format is the same as for Fig. 13. In the left-hand figure the chain's sensor depths are uncorrected (deepest

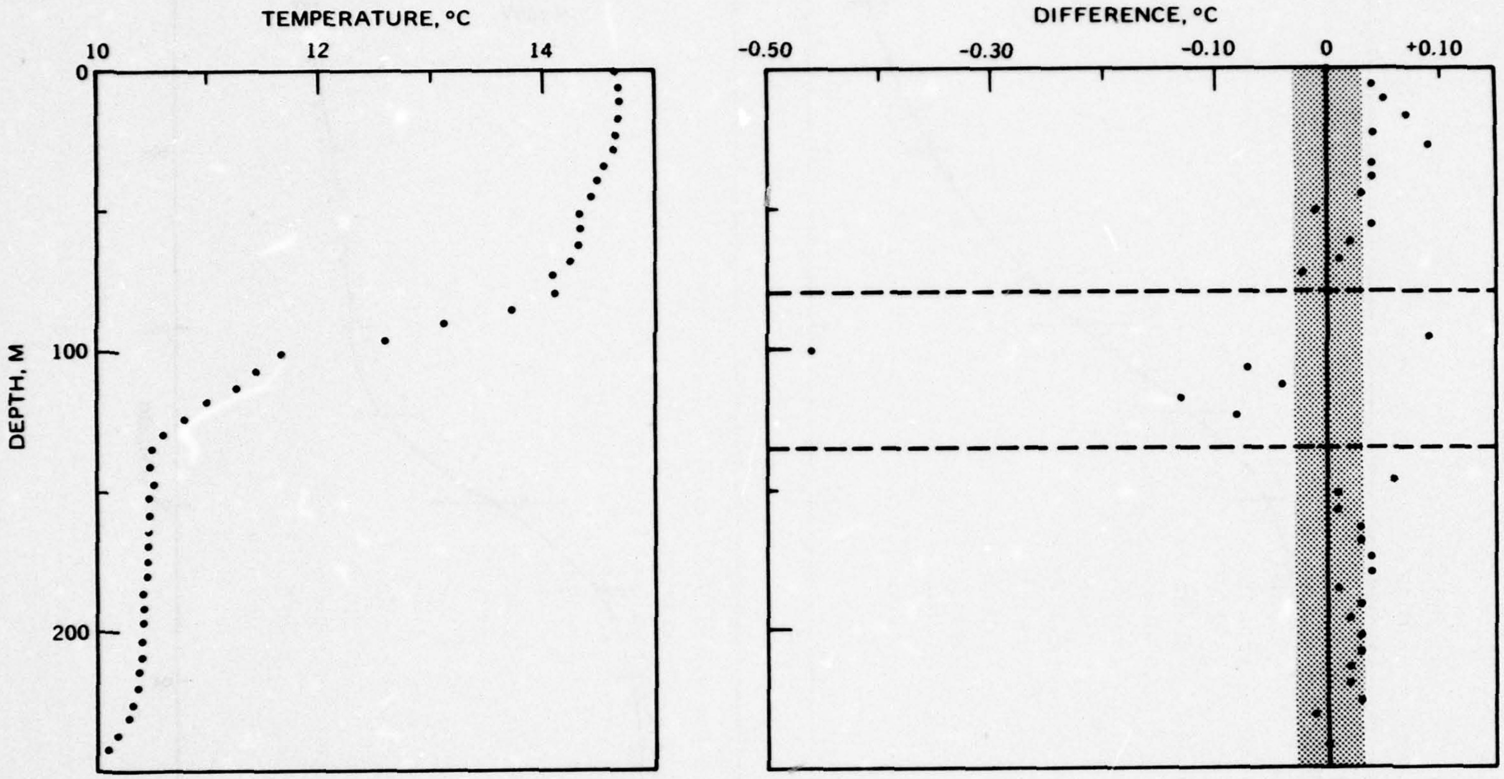

Figure 12. Comparison of temperatures measured simultaneously by the thermistor chain and the STD/SV system. A positive difference indicates the thermistor chain is measuring temperature higher than the STD/SV system.

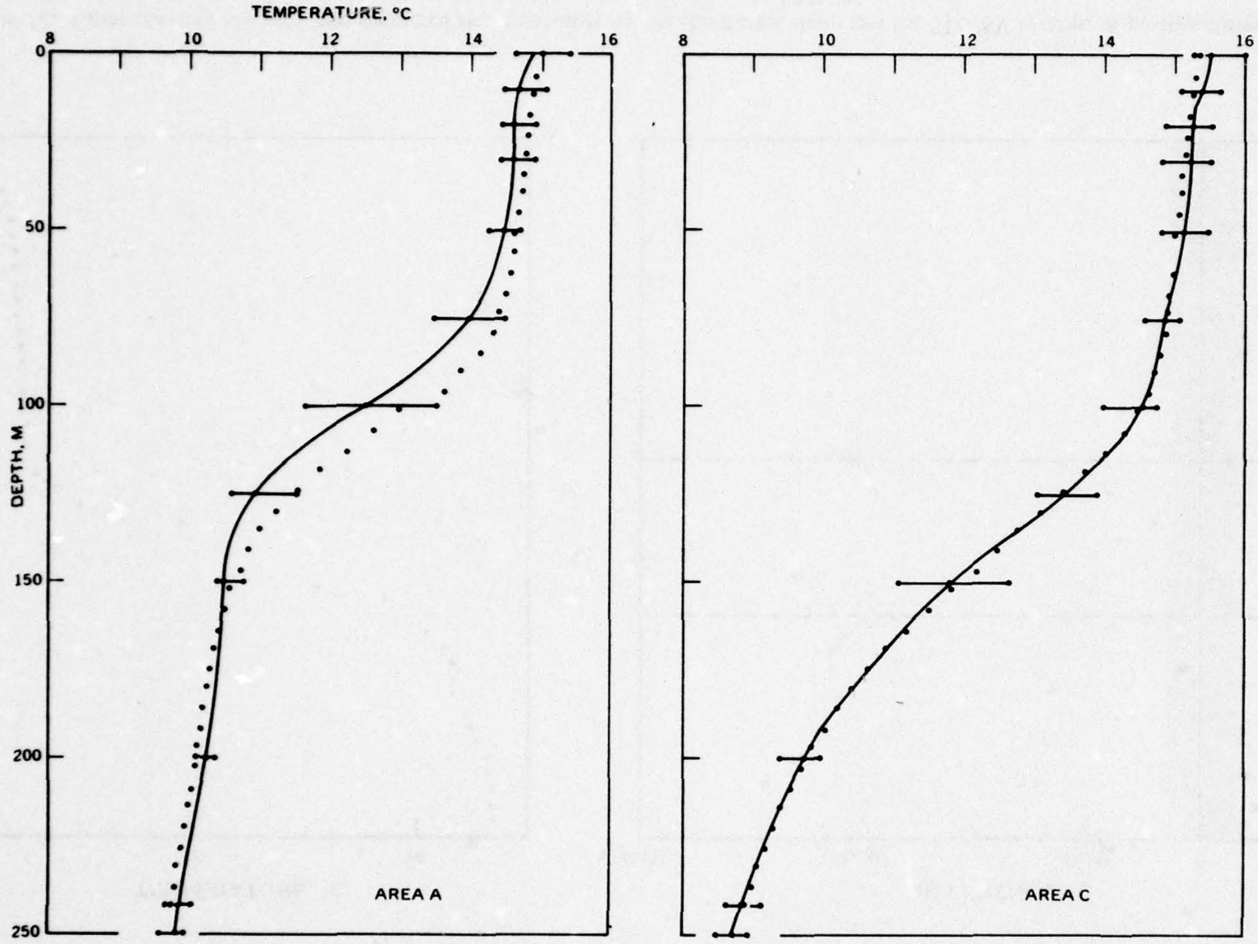

Figure 13. Comparison between average hydrographic cast and STD/SV temperatures with average thermistor chain temperatures for 3-knot tows in Area A and Area C. Solid curve connects the average hydrographic cast and STD/SV temperatures. Horizontal bar indicates the lowest and highest measured temperature.

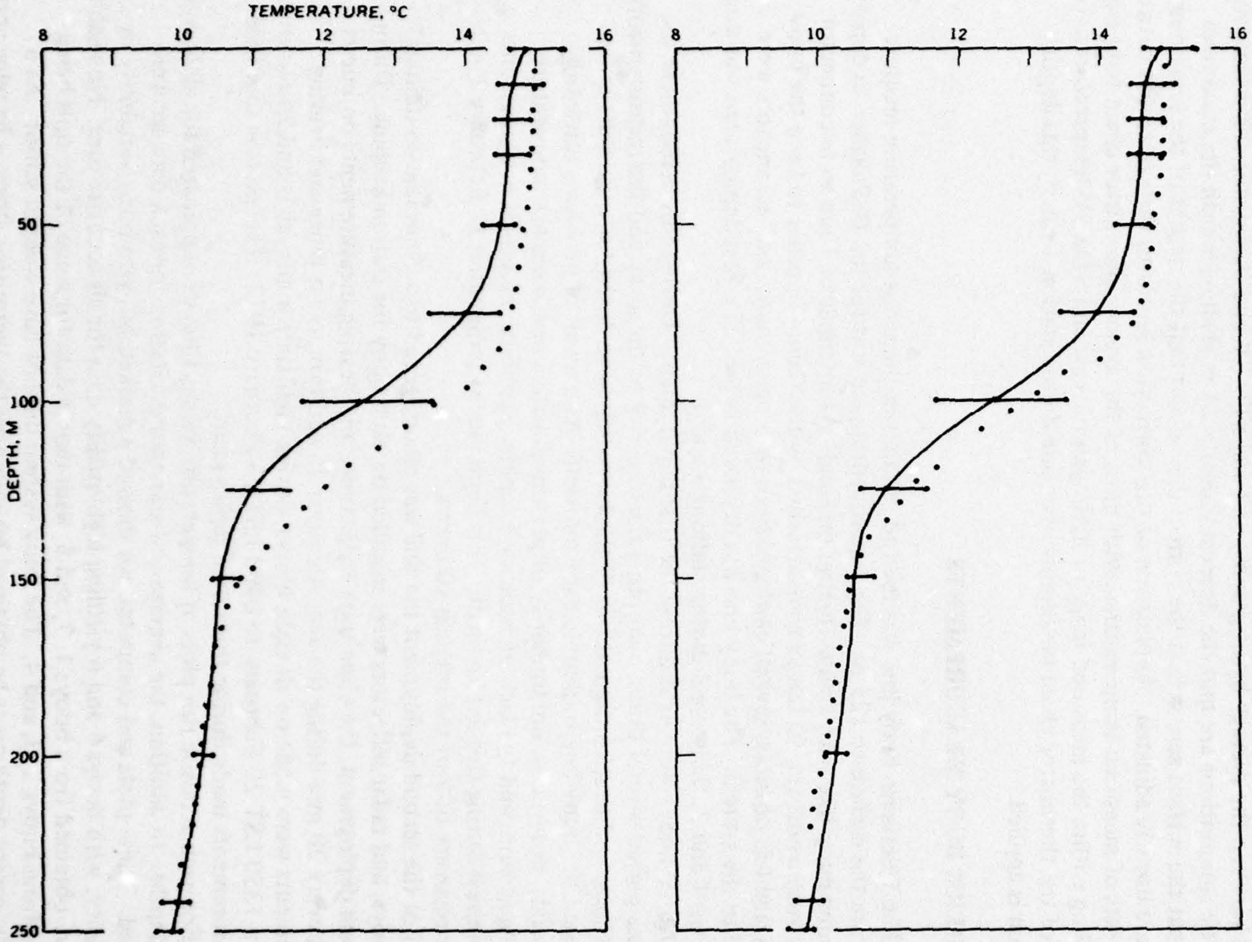

Figure 14. Comparison between average hydrographic cast and STD/SV temperatures for Area A with average thermistor chain temperatures for 6-knot tow during station 1 run 5 experiments. Solid line connects the average hydrographic cast and STD/SV temperatures. Horizontal bar indicates the lowest and highest measured temperatures.

sensor at 242 m). For the depth interval 20 to 150 m, the average chain temperatures are all higher than the highest recorded hydrographic cast and STD/SV temperature measurements. At a tow speed of 6 knots, a commonly used tow speed, experience indicates that the depth of the 242-m thermistor is about 221 m. The right-hand figure shows the relationship between the average hydrographic cast and STD/SV and thermistor chain temperatures. The assumptions are that the deepest sensor is 21 m shallower than the maximum depth, that the surface sensor is at the correct depth, and that the depths of the remaining sensors are linearly adjusted. Application of this correction improves the agreement between the two sets of measured temperatures, with most of the average thermistor chain temperatures falling within the measured range of hydrographic cast and STD/SV temperatures. In any use of the thermistor chain measurements made during station 1 run 5, this depth correction is applied.

TELETHERM BUOY MEASUREMENTS

The Teletherm buoy line was used to obtain simultaneous temperature measurements from the surface to 125 m. The experimental plan was for the *DeSteiguer* to deploy a 9-nm-long buoy line with a large float at one end. At intervals of 1 nm were connector shackles onto which the 10 buoys were attached by the *Cape*. In order to keep the buoy line as straight as possible, several configurations of drogue chutes and sea anchors were attached to the system. The buoy line was deployed twice. The first deployment was during stations 1 and 2, the second during stations 3 and 4.

All 10 buoys were used during the first deployment. During this deployment the tether line parted several times, disrupting the integrity of the array and the measurements. Several times nonlinear configurations of the buoy line were noted. A wind shift at one time caused the buoy line to double back on itself. As a result of problems caused by strong winds, heavy seas, unfamiliarity of personnel with a new complex temperature measuring system, and the lack of a station-keeping capability, no useful measurements were obtained during this deployment. This deployment terminated 17 February 1972 with the recovery of 9 of the original 10 buoys.

For the second deployment the line was reconfigured to a 7-nm line containing eight buoys, and radar reflectors were installed on each buoy for station keeping. During the second deployment, the *Cape* took radar range and bearing measurements on buoys 1, 4, and 8 every 20 min during the acoustic runs. In addition, radar range and bearing measurements were made on all eight buoys, during nighttime hours, at 1- and 2-hour intervals from 1350 LST 20 February to 0400 LST 23 February 1972. This section discusses the measurements made during this latter deployment.

For each acoustic run plots of temperature versus time were prepared for all buoys and all depths. In addition, the average and standard devitation for each data set were computed. These plots and computations showed a marked buoy-to-buoy variability in data quality, with buoys 5 and 6 yielding high-quality data for all acoustic runs. No usable data were obtained from buoys 1, 7, and 8, with usable data for some of the runs being obtained from buoys 2, 3, and 4. The buoy system did not have a depth sensor. As a result, the sensor depth must be obtained by assuming the thermistor string is hanging vertically in the water, with sensors equally spaced from the surface to 125 m. This assumption is probably valid under calm or near-calm wind conditions but invalid when the wind is blowing, which causes the system to drift through the water and produces shoaling of all sensors. To check this assumption, 19 XBTs, taken with 1 nm of a buoy, were compared with the buoy measurements made at the same time as the XBT measurements. The average differences at eight selected depths were:

0 m	0.1°C	50 m	0.1°C
10	0.1	75	0.0
20	0.1	100	0.2
30	0.2	125	0.8

Since the depth of the top of the main thermocline was 80 to 100 m, good agreement would be expected from the surface to about 100 m. The above data show the buoys to be giving, on the average, temperatures about 0.1°C higher than the XBTs. The 125-m sensor was located in the thermocline. On the average, this sensor measured temperatures 0.8°C higher than the XBTs. Of the 19 comparisons at this depth, only 2 were negative. The differences varied from –0.4°C to 2.4°C with six of the differences being greater than 1.0°C. This suggests that the buoy sensors are at a depth shallower than assumed. Since the amount of shoaling is variable, being a function of wind and water current effects, it was not possible to correct the assumed depths. Consequently, only the measurements made in the mixed layer, where vertical gradients are small or nonexistent, are valid. The primary value of these measurements is as an indicator of temporal temperature stability in the mixed layer.

DATAWELL WAVERIDER BUOY MEASUREMENTS

The Waverider buoy measures the frequency of sea-surface waves from 0.06 to 0.8 Hz, equivalent to 1.25- to 16.7-sec wave periods, with an accuracy of 3 percent. The measurement rate is 120/min. In 1969 the Nearshore Processes Group at Scripps Institution of Oceanography made measurements with two Datawell Waverider buoys simultaneous with measurements from another wave-height sensor that they had some faith in. They concluded: "the buoys they used measured nearshore waves with sufficient accuracy and precision to allow an energy spectrum to be calculated which is statistically valid between 0.055 Hz and 1.0 Hz. However, the response . . . is not reliable for frequencies less than about 0.055 Hz . . . " (personal communication to K. W. Nelson).

During the first deployment of the Teletherm buoy line, the Waverider buoy was attached to Teletherm buoy 5 and during the second deployment to Teletherm buoy 4. The measurements were telemetered to the *Lee* and recorded on magnetic tape. Complete measurement sets (no breaks in sampling) were obtained for station 1 runs 2, 3, 4, and 5; station 3 run 2; and station 4 runs 1 and 4. Incomplete sets were obtained for station 3 runs 1, 4, and 5 and station 4 runs 2 and 3. No measurements were obtained for station 2 and station 3 run 3. During station 1 the Waverider buoy was attached to the Teletherm buoy line from a ring on the bottom of the Waverider buoy. This method of attachment could cause the buoy to be tilted during periods of high wind speeds. For the station 3 and 4 measurements, the buoy was attached from a ring on the side of the Waverider buoy, thereby eliminating the possibility of tilting.

At the present time the sea-surface roughness parameter most useful as an input to acoustic models is the standard deviation of the time average of the measurements. After experimenting with averaging times up to 30 min it was arbitrarily decided that a 3-min averaging time would preserve enough detail for most current applications. Thus, for each acoustic run in which Waverider buoy measurements were made, a table of standard deviations of 3-min averages was generated together with the standard deviation of the entire set of measurements made during the run. Three plots were prepared to summarize the data: (a) standard deviation as a function of time, (b) histogram of the standard deviations, and (c) an ogive of the standard deviations.

A more detailed analysis of the measurements was made employing fast Fourier Transform techniques (Ref. 9). These calculations generate a table of variance (standard deviation squared) as a function of wave frequency (reciprocal of the wave period). In order to determine if any change in surface roughness occurred during the acoustic run, the data were subdivided into periods approximately 1 hour in length. The spectra for these 1-hour samples were computed and examined. If no significant time changes were noted, the spectra were ensemble averaged into a single spectrum. The final data were summarized in a plot of standard deviation versus wave period. This type of analysis is useful in that it determines the wave periods in which most of the surface roughness (variance) is concentrated.

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APPENDIX A

HYDROGRAPHIC CAST MEASUREMENTS

SUDS I – 1 USNS *Lee*; 9 February 1972; 1133 LST; 28°51.9′N, 121°7.3′W; sounding, 2300 fm; wind 200°T, 2 knots; weather, partly cloudy; sea, ripples; wire angle 0°.

OBSERVED			INTERPOLATED		
Z, m	T, °C	S ppt	Z, m	T, °C	S ppt
0	14.72	33.40	0	14.72	33.40
10	14.47	33.41	10	14.47	33.40
20	14.45	33.45	20	14.45	33.40
30	14.43	33.43	30	14.43	33.40
50	–	33.40	50	14.24	33.40
75	13.47	33.40	75	13.47	33.40
100	11.68	33.54	100	11.68	33.54
150	10.45	34.03	125	10.66	33.81
200	10.41	34.16	150	10.45	34.03
252	–	34.29	200	10.41	34.20
306	9.43	34.39	250	9.96	34.31
			300	9.68	34.36

SUDS I – 2 & 3 USNS *Lee*; 10 February 1972; 1328, 2010 LST; 28°47.2′N, 120°59.3′W; sounding 2220 fm; wind 110°T to 160°T, 2 to 8 knots; weather, partly cloudy; sea 110°T to 160°T, 1 ft; wire angles 0°, 30°.

OBSERVED			INTERPOLATED		
Z, m	T, °C	S ppt	Z, m	T, °C	S ppt
0	15.05	33.49	0	15.05	33.49
10	14.58	33.48	10	14.58	33.48
20	14.51	33.50	20	14.51	33.50
30	14.50	33.48	30	14.50	33.48
49	14.46	33.42	50	14.44	33.41
74	13.85	33.41	75	13.80	33.42
99	12.16	33.51	100	12.10	33.52
148	10.54	33.91	125	11.00	33.72
197	10.16	34.15	150	10.50	33.92
296	9.39	34.35	200	10.14	34.16
396	8.09	34.35	250	9.82	34.28
496	7.02	–	300	9.32	34.36
			400	8.04	34.35
0	14.83	33.51	500	7.07	34.34
180	–	34.12	600	6.22	34.35
454	7.62	34.34	800	4.94	34.41
911	4.48	34.44	1000	4.20	34.46
1368	3.27	34.54	1200	3.62	34.50
1783	2.38	34.59	1500	2.98	34.55

SUDS I – 4 USNS *Lee*; 12 February 1972; 1930 LST; 28°41.8′N, 121°3.6′W; sounding, missing; wind 350°T, 23 knots; weather, partly coudly; sea, 350°T, 5 ft; wire angle 25°.

OBSERVED			INTERPOLATED		
Z, m	T, °C	S ppt	Z, m	T, °C	S ppt
0	15.40	–	0	15.40	–
181	10.32	33.98	200	10.13	34.05
359	8.45	34.31	250	9.60	34.18
534	6.73	34.35	300	9.08	34.25
707	5.54	34.39	400	8.01	34.32
874	4.70	34.43	500	7.04	34.35
1043	4.13	34.46	600	6.22	34.37
1295	3.40	34.53	800	5.11	34.40
1713	2.51	34.58	1000	4.30	34.45
2125	2.01	34.62	1200	3.67	34.50
2535	1.76	34.63*	1500	2.94	34.57
2940	1.62	34.61*	2000	2.14	34.61
3341	1.59	34.63*	2500	1.79	34.63*
			3000	1.62	34.61*
			3500	*(1.58)*	*34.62**

*salinity doubtful

SUDS I – 5 USNS *Lee*; 13 February 1972; 1621 LST; 28°29.7′N, 121°20.2′W; sounding, missing; 0°T, 15 knots; weather, partly cloudy; sea, 0°T, 3 ft; wire angle 15°.

OBSERVED			INTERPOLATED		
Z, m	T, °C	S ppt	Z, m	T, °C	S ppt
0	14.98	33.39	0	14.98	33.39
10	14.80	33.39	10	14.80	33.39
20	14.65	33.39	20	14.65	33.39
31	14.54	33.38	30	14.54	33.38
51	14.42	33.37	50	14.42	33.37
77	14.09	33.33	75	14.12	33.33
102	13.23	33.38	100	13.34	33.37
153	10.50	33.76	125	11.92	33.52
204	10.20	34.13	150	10.62	33.73
255	9.90	34.22	200	10.20	34.12
306	8.97	34.37	250	9.94	34.24
			300	9.10	34.35

SUDS I – 6 USNS *Lee*; 21 February 1972; 2143 LST; 29°2.0′N, 123°19.0′W; sounding, missing; wind 10° T, 5 knots; weather, partly cloudy; sea, 10°T, 1 ft; wire angle 0°.

OBSERVED			INTERPOLATED		
Z, m	T, °C	S ppt	Z, m	T, °C	S ppt
0	15.52	–	0	15.52	–
10	15.27	–	10	15.27	–
20	15.03	–	20	15.03	–
30	14.99	–	30	14.99	–
51	14.95	–	50	14.95	–
76	14.57	–	75	14.58	–
101	14.14	–	100	14.15	–
152	11.78	–	125	13.32	–
202	9.39	–	150	11.80	–
303	7.69	–	200	9.43	–
403	6.45	–	250	8.51	–
504	5.77	–	300	7.72	–
			400	6.47	–
			500	5.77	–

SUDS I – 7 & 8 USNS *Lee*; 23 February 1972; 0910, 1303 LST; 28°50.3′N, 123°16.2′W and 28°47.4′N, 123°15.9′W; sounding, missing; wind 40°T, 6 – 15 knots; weather, overcast, sea 40°T, 1 ft; wire angle, 15°, 6°.

OBSERVED

Z, m	T, °C	S ppt
0	15.50	33.60
10	15.42	33.61
19	15.38	33.62
29	15.34	33.62
48	–	33.59
72	15.01	33.60
97	14.77	33.59
146	12.15	33.48
196	10.17	–
295	7.97	–
395	6.66	–
495	5.97	–
0	15.67	33.60
204	9.82	33.74
401	6.49	34.10
600	5.27	34.30
794	4.44	34.42
989	3.90	34.49
1186	3.35	34.53
1486	2.73	34.58
1994	2.06	34.63
2500	1.80	34.65
3007	1.62	34.66
3509	1.54	34.67
4010	1.54	34.69

INTERPOLATED

Z, m	T, °C	S ppt
0	15.50	33.60
10	15.42	33.61
20	15.38	33.62
30	15.34	33.62
50	15.21	33.59
75	15.01	33.60
100	14.70	33.58
125	13.34	33.48
150	11.95	33.49
200	10.00	33.73
250	8.80	33.83
300	7.90	33.94
400	6.57	34.10
500	5.90	34.22
600	5.27	34.30
800	4.43	34.42
1000	3.82	34.49
1200	3.32	34.54
1500	2.72	34.58
2000	2.06	34.63
2500	1.80	34.65
3000	1.63	34.66
3500	1.54	34.67
4000	1.54	34.69

SUDS I – 9 USNS *DeSteiguer*; 9 February 1972; 1219 LST; 29°4.0'N, 121°2.2'W; sounding, missing; wind 190°T, 5 knots; weather, partly cloudy; sea, ripples; wire angle, unknown.

OBSERVED			INTERPOLATED		
Z, m	T, °C	S, ppt	Z, m	T, °C	S ppt
0	14.82	33.52	0	14.82	33.52
10	14.68	33.51	10	14.68	33.51
20	14.66	33.51	20	14.66	33.51
30	14.64	33.50	30	14.64	33.50
39	14.64	33.50	50	14.66	33.50
49	14.65	33.49	75	14.50	33.50
74	14.54	33.50	100	13.02	33.45
98	13.14	33.44	125	11.25	33.65
148	10.54	33.84	150	10.52	33.85
198	10.18	33.11	200	10.17	34.13
247	9.93	–	250	9.90	34.27
289	9.54	34.34	300	9.44	34.35
397	8.54	34.36	400	8.50	34.36
448	7.97	34.33			

SUDS I – 10 USNS *DeSteiguer*; 14 February 1972; 1715 LST; 28°30.0'N, 121°30.0'W; sounding, missing; wind, 345°T, 18 knots; weather, partly cloudy; sea 345°T, 3 ft; wire angle, unknown.

OBSERVED			INTERPOLATED		
Z, m	T, °C	S, ppt	Z, m	T, °C	S ppt
0	14.68	33.49	0	14.68	33.49
8	14.68	33.46	10	14.68	33.46
17	14.67	33.46	20	14.67	33.46
26	14.64	33.45	30	14.50	33.43
34	14.24	33.40	50	14.00	33.39
43	14.07	33.38	75	13.48	33.34
65	13.84	33.37	100	11.96	33.33
86	12.70	33.30	125	10.90	33.53
130	10.77	33.56	150	10.20	33.70
173	9.66	33.79	200	9.18	33.86
216	8.94	–	250	8.50	33.96
260	8.40	33.98	300	8.13	34.06
353	7.82	34.15	400	7.43	34.23
407	7.34	34.24			

SUDS I – 11 USNS *DeSteiguer*; 19 February 1972; 1408 LST; 29°6.0'N, 123°10.0'W; sounding, missing; wind, light airs; weather, overcast, sea, calm; wire angle, unknown.

OBSERVED			INTERPOLATED		
Z, m	T, °C	S, ppt	Z, m	T, °C	S, ppt
0	15.35	33.57	0	15.35	33.57
10	15.10	33.56	10	15.10	33.56
20	14.89	33.55	20	14.89	33.55
30	14.83	33.55	30	14.83	33.55
40	14.82	33.55	50	14.82	33.55
50	14.82	33.55	75	14.80	33.55
76	14.79	33.56	100	14.54	33.52
101	14.52	33.52	125	–	33.51
151	11.67	33.56	150	11.70	33.56
201	9.76	33.82	200	9.80	33.81
252	8.72	33.98	250	8.77	33.98
302	7.90	33.99	300	7.93	33.99
402	6.60	34.10	400	6.63	34.10
502	5.94	34.21	500	5.96	34.21

SUDS I – 12 USNS *DeSteiguer*; 22 February 1972; 1510 LST; 28°40.0'N, 123°17.5'W; sounding, missing; wind, 30°T, 8 knots; weather, overcast, sea, 30°T, 1 ft; wire angle, unknown.

OBSERVED			INTERPOLATED		
Z, m	T, °C	S, ppt	Z, m	T, °C	S, ppt
0	16.02	33.65	0	16.02	33.65
10	–	33.64	10	15.66	33.64
20	15.54	33.64	20	15.54	33.64
30	15.51	33.64	30	15.52	33.64
41	15.48	33.64	50	15.48	33.65
51	15.48	33.63	75	15.09	33.59
76	15.08	33.59	100	13.99	33.52
101	13.95	33.52	125	–	33.49
152	11.03	33.54	150	11.10	33.53
202	9.54	33.80	200	9.59	33.79
253	8.62	33.81	250	8.68	33.80
303	7.78	34.06	300	7.83	34.05
403	6.48	34.11	400	6.50	34.11
503	5.88	34.20	500	5.90	34.19

SUDS I – 13 USNS *DeSteiguer*; 23 February 1972; 0645 LST; 28°38.5′N, 123°20.0′W; sounding, missing; wind, 25°T, 10 knots; weather, overcast; sea, 25°T, 1 ft; wire angle, unknown.

OBSERVED			INTERPOLATED		
Z, m	T, °C	S, ppt	Z, m	T, °C	S, ppt
0	15.45	33.61	0	15.45	33.61
10	15.48	33.61	10	15.48	33.61
20	15.48	33.61	20	15.48	33.61
30	15.44	33.60	30	15.44	33.60
41	15.32	33.60	50	15.32	33.60
51	15.32	33.60	75	15.04	33.59
76	15.03	33.59	100	14.72	33.57
100	14.72	33.57	125	–	33.45
152	11.15	33.55	150	11.20	33.55
203	9.84	33.74	200	9.92	33.73
253	8.87	33.95	250	8.97	33.97
304	7.95	34.02	300	8.00	34.01
404	6.66	34.10	400	6.70	34.10
504	5.80	34.19	500	5.83	34.18

APPENDIX B

STD/SV MEASUREMENTS AND COMPUTED SOUND SPEEDS

The following abbreviations are used:

SC	surface sound channel
DC	depressed channel axis
MAX	maximum
RC	refractive channel axis
AXIS	deep channel axis

PROFILE NO. 1D

Latitude 28°50′N
Longitude 121°7.3′W

Date 9 February 1972
Time 1735 LST

Depth, m	Temperature, °C	Salinity, ppt	Sound Speed, m/sec	
			Measured	Computed
0	14.78	33.46	1504.6	1504.5
10	14.61	33.46	04.2	04.1
20	14.58	33.46	04.2	04.2
30	14.49	33.46	04.0	04.1
50	14.41	33.51	04.2	04.2
75	13.65	33.45	02.2	02.1
100	11.98	33.37	1496.4	1496.8
125	10.62	33.89	93.0	93.1
150	10.44	34.01	93.0	93.0
200	10.36	34.12	93.7	93.7
250	9.86	34.20	92.7	92.8
300	9.63	34.31	92.9	92.9
400	8.66	34.33	90.9	91.0
500	7.49	34.31	88.1	88.2
600	6.66	34.28	86.5	86.5
800	5.15	34.38	83.9	84.0
855	4.71	34.41	83.0	83.1

SC	0	1504.6
RC	132	1492.8
MAX	200	1494.0
RC	250	1492.7
MAX	300	1492.8

PROFILE NO. 2D

Latitude 29°47.2′N
Longitude 120°59.3′W

Date 10 February 1972
Time 1415 LST

Depth, m	Temperature, °C	Salinity, ppt	Sound Speed, m/sec	
			Measured	Computed
0	14.65	33.48	1504.2	1504.1
10	14.70	33.48	04.4	04.5
20	14.54	33.48	04.2	04.1
30	14.51	33.48	04.1	04.2
50	14.45	33.48	04.2	04.3
75	13.84	33.43	03.0	02.7
100	12.17	33.46	1497.1	1497.5
125	10.95	33.70	94.0	94.0
150	10.50	33.92	92.9	93.1
200	10.14	34.11	92.8	92.9
250	9.85	34.23	92.9	92.8
300	9.38	34.32	92.0	92.0
400	8.37	34.34	89.8	89.9
500	7.31	34.34	87.4	87.5
600	6.35	34.34	85.3	85.4
800	5.06	34.41	83.5	83.6
1000	4.20	34.47	83.4	83.5
1200	3.69	34.51	84.6	84.8
1500	2.94	34.57	86.4	86.7
2000	2.13	34.62	91.6	91.7
2500	1.80	34.65	98.7	98.9
3000	1.63	34.66	1506.6	1506.8
3500	1.56	34.66	—	15.3
3542	1.56	34.66	—	16.0

SC	12	1504.6
DC	25	1504.0
MAX	50	1504.2
RC	175	1492.7
MAX	250	1492.9
AXIS	927	1483.0

PROFILE NO. 3D

Latitude	28°54.4′N	Date	12 February 1972
Longitude	121°14.5′W	Time	0415 LST

Depth, m	Temperature, °C	Salinity, ppt	Sound Speed, m/sec Measured	Sound Speed, m/sec Computed
0	14.63	33.49	1504.0	1504.1
10	14.61	33.49	04.2	04.2
20	14.59	33.49	04.3	04.3
30	14.50	33.48	04.1	04.1
50	14.33	33.45	03.8	03.9
75	14.07	33.42	03.3	03.4
100	12.23	33.36	1496.9	1497.6
125	10.85	33.83	93.6	93.8
150	10.46	34.06	93.0	93.1
200	10.39	34.14	93.8	93.8
250	9.96	34.23	93.2	93.2
300	9.56	34.36	92.7	92.7
312	9.50	34.37	—	92.7

SC	20	1504.3
RC	145	1493.0
MAX	220	1494.0

PROFILE NO. 4D

Latitude	28°52.7′N	Date	12 February 1972
Longitude	121°17.0′W	Time	0610 LST

Depth, m	Temperature, °C	Salinity, ppt	Sound Speed, m/sec	
			Measured	Computed
0	14.66	33.51	1504.2	1504.2
10	14.67	33.52	04.4	04.4
20	14.67	33.52	04.6	04.6
30	14.67	33.52	04.7	04.7
50	14.39	33.47	04.1	04.1
75	14.27	33.45	04.2	04.1
100	13.54	33.46	01.9	02.1
125	10.81	33.84	1493.5	1493.7
150	10.46	34.04	93.1	93.1
200	10.38	34.15	93.8	93.8
250	9.84	34.26	92.8	92.8
300	9.47	34.37	92.4	92.4
400	8.64	34.37	91.1	91.0
500	7.39	34.35	87.9	87.9
600	6.56	34.32	86.0	86.2
800	5.00	34.42	83.3	83.4
1000	4.18	34.48	83.2	83.4
1200	3.62	34.53	84.2	84.5
1500	2.92	34.57	86.4	86.6
2000	2.17	34.62	91.7	91.9
2500	1.80	34.65	98.6	98.9
3000	1.64	34.66	1506.6	1506.9
3500	1.57	34.67	—	15.3
3784	1.54	34.67	—	20.2

SC	35	1504.9
RC	130	1493.0
MAX	210	1493.8
AXIS	833	1483.2
MAX	927	1483.8
AXIS	966	1483.2

PROFILE NO. 5D

Latitude 28°41.2′N
Longitude 121°4.2′W

Date 12 February 1972
Time 2020 LST

	Depth, m	Temperature, °C	Salinity, ppt	Sound Speed, m/sec	
				Measured	Computed
	0	15.11	33.57	1505.7	1505.7
	10	15.08	33.55	05.7	05.8
	20	14.93	33.57	05.4	05.5
	30	14.92	33.58	05.5	05.6
	50	14.72	33.58	05.6	05.3
	75	14.22	33.53	04.6	04.0
	100	13.42	33.45	00.9	01.7
	125	11.56	33.44	1495.4	1495.8
	150	10.81	33.82	93.9	94.1
	200	10.25	34.14	93.2	93.3
	250	9.77	34.21	92.4	92.5
	300	—	34.27	—	—
	400	7.98	34.30	88.2	88.2
	500	7.03	34.33	86.3	86.4
	600	6.23	34.35	84.9	85.0
	800	5.03	34.42	83.3	83.5
	1000	4.18	34.48	83.2	83.4
	1200	3.64	34.52	84.3	84.6
	1500	2.92	34.57	86.4	86.6
	2000	2.09	34.64	91.4	91.6
	2500	1.78	34.66	98.6	98.8
	3000	1.63	34.67	1506.6	1506.8
	3500	1.57	34.67	—	15.3
	3652	1.55	34.67	—	17.9
SC	10			1505.7	
DC	12			1505.4	
MAX	62			1505.7	
AXIS	897			1483.0	

PROFILE NO. 6D*

Latitude	28°29.5′N	Date	13 February 1972
Longitude	121°23.6′W	Time	1815 LST

Depth, m	Temperature, °C	Salinity, ppt	Sound Speed, m/sec	
			Measured	Computed
0	14.79	33.51	1504.6	1504.6
10	14.79	33.51	04.8	04.8
20	14.77	33.51	04.9	04.9
30	14.67	33.50	04.8	04.7
50	14.37	33.48	04.1	04.1
75	14.17	33.43	03.8	03.8
100	13.59	33.40	02.4	02.2
125	11.52	33.49	1495.6	1495.7
150	10.52	33.69	92.4	92.9
200	10.09	34.11	92.6	92.7
250	9.44	34.17	91.1	91.2
300	8.80	34.24	89.6	89.8
400	7.71	34.30	87.4	87.4
500	6.82	34.33	85.5	85.6
600	6.02	34.36	83.9	84.0
800	4.92	34.44	83.0	83.1
1000	4.14	45.50	83.0	83.3
1200	3.61	34.53	84.2	84.4
1500	2.92	34.58	86.4	86.6
2000	2.13	34.64	91.6	91.7
2011	2.12	34.64	–	91.9

SC	20	1504.9
RC	148	1491.9
MAX	158	1493.0
RC	230	1490.3
MAX	240	1491.4
AXIS	882	1482.9

*Rosette sampler used

PROFILE NO. 7D

Latitude	28°0.7′N	Date	16 February 1972
Longitude	122°2.1′W	Time	0940 LST

Depth, m	Temperature, °C	Salinity, ppt	Sound Speed, m/sec	
			Measured	Computed
0	14.87	33.53	1504.9	1504.9
10	14.83	33.55	05.0	05.0
20	14.83	33.56	05.1	05.1
30	14.83	33.55	05.3	05.3
50	14.82	33.56	05.6	05.6
75	14.03	33.42	03.3	03.3
100	12.87	—	1496.5	—
125	11.60	—	95.1	—
150	10.39	33.67	92.4	1492.4
200	9.25	33.82	88.9	89.3
250	9.81	—	—	—
300	8.44	34.19	88.3	88.4
400	6.90	34.24	84.2	84.2
500	6.07	34.29	82.5	82.6
600	5.72	34.37	82.9	83.0
800	4.67	34.44	82.0	82.1
1000	4.02	34.49	82.5	82.8
1200	3.48	34.53	83.7	83.9
1500	2.82	34.58	86.1	86.2
1527	2.78	34.58	86.2	86.5

SC	58	1505.7
RC	100	1496.5
MAX	110	1497.0
RC	170	1490.0
MAX	180	1492.2
RC	210	1488.2
MAX	220	1491.1
AXIS	509	1482.1
MAX	530	1483.3
AXIS	778	1481.9

PROFILE NO. 8D

Latitude	29°12.0'N	Date	19 February 1972
Longitude	123°12.6'W	Time	1205 LST

Depth, m	Temperature, °C	Salinity, ppt	Sound Speed, m/sec Measured	Sound Speed, m/sec Computed
0	15.25	33.60	1506.0	1506.2
10	15.10	33.60	05.9	05.9
20	14.99	33.59	05.7	05.7
30	14.96	33.59	05.7	05.8
50	14.88	33.57	05.8	05.8
75	14.81	33.57	06.0	06.0
100	14.76	33.53	06.1	06.2
125	13.94	33.48	03.5	03.9
150	12.69	33.50	1499.9	00.2
200	9.91	33.71	91.6	1491.5
250	8.86	33.87	88.9	88.7
300	7.86	33.99	85.8	85.9
400	6.59	34.08	82.9	82.7
500	5.84	34.18	81.5	81.5
600	5.25	34.27	80.9	80.9
800	4.46	34.42	81.1	81.2
1000	3.85	34.48	81.9	82.0
1200	3.35	34.54	83.1	83.4
1500	2.77	34.60	85.7	86.0
1517	2.74	34.60	85.8	86.1

SC	0	1506.0
DC	18	1505.6
MAX	40	1505.8
DC	70	1505.7
MAX	95	1506.5
AXIS	624	1480.5

PROFILE NO. 8aD

Latitude 28°58.2′N
Longitude 123°18.4′W

Date 21 February 1972
Time 1615 LST

Depth, m	Temperature, °C	Salinity, ppt	Sound Speed, m/sec Measured	Sound Speed, m/sec Computed
0	15.66	33.60	1507.5	1507.5
10	15.59	33.60	07.1	07.4
20	15.32	33.58	06.5	06.7
30	15.27	33.60	06.5	06.7
50	15.13	33.61	06.6	06.6
75	14.82	33.54	05.9	06.0
100	14.42	33.49	04.9	05.0
125	13.72	33.53	03.0	03.2
150	12.28	33.51	1498.7	1498.8
200	9.87	33.66	91.2	91.3
250	8.73	33.86	88.1	88.2
300	7.97	33.95	86.3	86.3
400	6.71	34.06	83.1	83.2
500	5.95	34.15	81.8	81.9
600	5.46	34.26	81.7	81.8
800	4.50	34.40	81.2	81.3
1000	3.91	34.49	82.1	82.3
1200	3.41	34.53	83.4	83.6
1500	2.80	34.58	85.9	86.1
2000	2.09	34.63	91.4	91.5
2045	2.06	34.63	91.9	92.2

SC	0	1507.5
DC	35	1506.4
MAX	60	1506.7
AXIS	778	1481.0

PROFILE NO. 9U

Latitude	29° 1.6′N	Date	21 February 1972
Longitude	123° 19.0′W	Time	2220 LST

	Depth, m	Temperature, °C	Salinity, ppt	Sound Speed, m/sec	
				Measured	Computed
	0	15.37	33.59	1506.5	1506.6
	10	15.36	33.59	06.7	06.7
	20	15.07	33.57	05.9	05.9
	30	15.02	33.57	05.8	05.9
	50	14.95	33.56	05.9	06.0
	75	14.73	33.56	05.7	05.7
	100	14.22	33.57	04.3	04.5
	125	13.31	33.63	02.0	02.0
	150	11.65	33.61	1496.7	1496.8
	200	9.48	33.76	90.0	90.0
	250	8.69	33.89	88.1	88.1
	300	7.70	33.99	85.3	85.3
	400	6.67	34.07	83.0	83.0
	500	5.80	34.19	81.3	81.4
	600	5.40	34.30	81.5	81.6
	628	5.28	34.31	81.4	81.6
SC	15			1506.7	
DC	30			1505.8	
MAX	65			1506.0	

PROFILE NO. 10D

Latitude	28°49.7′N	Date	23 February 1972
Longitude	123°16.2′W	Time	0945 LST

	Depth, m	Temperature, °C	Salinity, ppt	Sound Speed, m/sec	
				Measured	Computed
	0	15.43	33.61	1506.8	1506.8
	10	15.42	33.61	06.8	06.9
	20	15.42	33.61	07.0	07.1
	30	15.35	33.62	07.0	07.0
	50	15.29	33.60	07.0	07.1
	75	15.05	33.61	06.8	06.8
	100	14.75	33.55	06.1	06.2
	125	13.61	33.51	02.8	02.8
	150	11.97	33.42	1497.4	1497.6
	200	9.83	33.66	91.2	91.2
	250	8.68	33.87	87.9	88.0
	300	7.88	33.97	85.8	96.0
	400	6.58	34.08	82.7	82.7
	500	5.97	34.18	82.0	82.1
	529	5.74	34.24	81.6	81.7
SC	50			1507.0	
DC	70			1506.4	
MAX	80			1506.8	

PROFILE NO. 11D

Latitude	28°45.2′N	Date	23 February 1972
Longitude	123°15.7′W	Time	1600 LST

Depth, m	Temperature, °C	Salinity, ppt	Sound Speed, m/sec	
			Measured	Computed
0	15.65	33.62	1507.4	1507.5
10	15.65	33.62	07.6	07.6
20	15.48	33.64	07.2	07.3
30	15.45	33.65	07.3	07.4
50	15.32	33.65	07.3	07.3
75	14.71	33.52	05.4	05.9
100	14.23	33.58	04.4	04.5
125	13.08	33.58	01.1	01.2
150	12.00	33.48	1497.6	1497.8
200	9.77	33.66	91.0	91.0
250	8.74	33.88	88.3	88.3
300	7.89	33.94	85.8	86.0
400	6.76	34.09	83.4	83.4
500	5.99	34.19	82.1	82.2
600	5.39	34.28	81.4	81.5
800	4.51	34.42	81.2	81.4
1000	3.93	34.49	82.2	82.4
1200	3.44	34.52	83.4	83.7
1500	2.85	34.57	86.0	86.3
2000	2.11	34.62	91.4	91.6
2500	1.80	34.65	—	98.9
3000	1.61	34.66	—	1506.7
3500	1.52	34.67	—	15.1
3789	1.52	34.66	—	20.2

SC	15	1507.6
DC	25	1507.1
MAX	30	1507.2
AXIS	667	1481.0