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THESIS

USE OF HISTORICAL SALINITY DATA IN THE
COMPUTATION OF DEPTH CORRECTIONS
DUE TO VARIATIONS IN SOUND SPEED

by

Luis Maria Cabral Leal de Faria

September 1980

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determined salinity can be used in the computation of the
depth corrections without exceeding the accuracy limits.
Two single values of salinity were found to be sufficient to
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Use of Historical Salinity Data in the Computation
of Depth Corrections Due to Variations in Sound Speed

by

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Lieutenant Junior Grade, Portuguese Navy
Portuguese Naval Academy, 1976

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Six different methods for averaging historical salinity values were studied for their applicability in the determination of depth corrections due to sound speed variations. The averaging techniques range in complexity from the use of a single value of salinity throughout the entire water column to the use of a historical salinity average profile corrected for the surface salinity. Results show that historically determined salinity can be used in the computation of the depth corrections without exceeding the accuracy limits. Two single values of salinity were found to be sufficient to cover the West Coast of the United States: 31 $\%_0$, applicable north of 40°N, and 33 $\%_0$, for use south of that latitude.

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I. INTRODUCTION

A. THE ECHOSOUNDER

Despite the development of laser- and photobathymetry, the echosounder, or fathometer, is still the most commonly used method for the determination of depth in hydrography. The transducer emits a sound pulse which is reflected by the bottom and received back at the transducer. The time of travel of this sound pulse is divided by two and this value multiplied by the assumed speed of sound in sea-water,[1] thus giving the depth according to the expression $z = v\,t$ (distance = speed x time). This transformation is made either mechanically or electronically within the fathometer itself, and the result displayed is the nominal or fathometer depth beneath the transducer. This depth is not equal to the true depth, since the assumed sound speed generally does not equal the true speed of sound in sea-water, which varies throughout the water column. One example of an observed sound speed profile is presented in Figure 1. For determining the true depth, one must know the sound speed profile throughout the water column and apply it according to the following expression [Greenberg and Sweers, 1972]:

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[1] Although sound speed is the correct term, most hydrographic literature uses sound velocity instead.
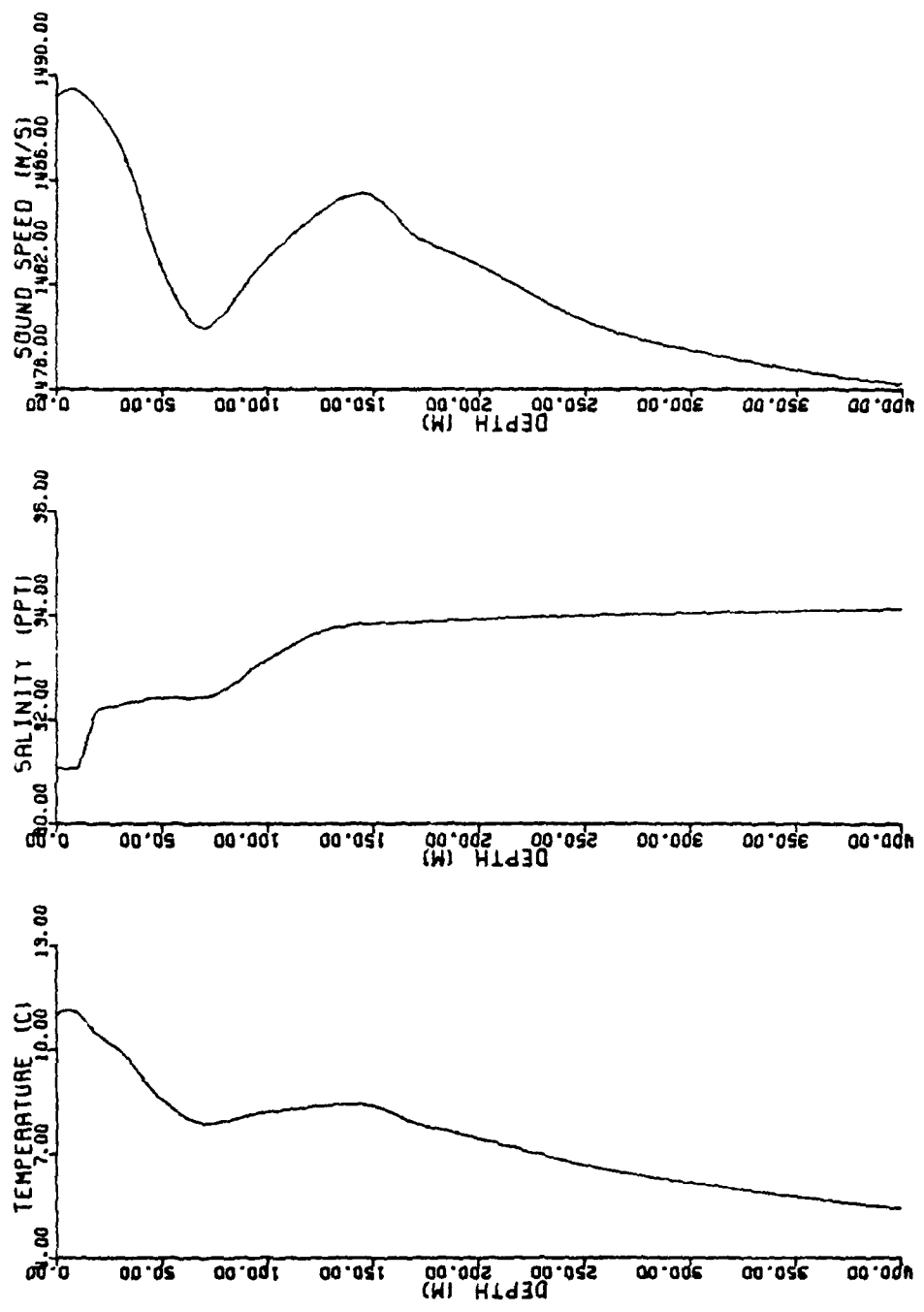
Figure 1.   Representative temperature, salinity and sound speed profiles.

$$z = \frac{1}{2} \int_0^{2\Delta t} v(z_t) \, dt$$

In this equation, $v(z_t)$ represents the sound speed at the depth z_t where the signal passes at the time t.

Some echosounders have the possibility of being set to different sound speeds, in order to represent as closely as possible the average speed of sound in the water column. In most cases, however, they are constructed with a calibrated speed of sound assumed in the device, usually 1463.04 or 1500 m/s (800 or 820 fathoms per second). The echosounders used by the National Ocean Survey (NOS) are calibrated for an assumed speed of sound of 1463.04 m/s which, according to Umbach [1976] is a value reasonably close to the sound speed in most waters surveyed. Corrections are then applied to the depths obtained by the fathometer in order to compensate for the use of a sound speed other than the one that actually affects the travel of the sound pulse.[2]

B. ACCURACY REQUIREMENTS

The International Hydrographic Bureau (IHB) established in 1968 the following requirements for accuracy of depth determination [International Hydrographic Bureau, 1968]:

---

[2] Although these are depth corrections, the term usually applied in hydrographic literature is sound velocity corrections.

Depth Range	Accuracy Requirement
0-11 fathoms (0 - 20 m)	1.0 ft
11-55 fathoms (20 - 100 m)	3.0 ft
deeper than 55 fathoms	1% of the depth

The above standards represent the maximum allowable error in
the measurement of depth due to all sources, including the
variations of sound speed within the water column. When con-
sidering errors due to sound speed alone, no errors can be
equal to or exceed 0.25% of the depth, which means that the
mean sound speed must be known to within ±4 m/s [Umbach, 1976].
The standards mentioned above apply only to conventional echo-
sounding systems, in which the sound pulse beam is vertical.
Other systems, applying oblique acoustic paths, require higher
accuracy standards.

C. SPEED OF SOUND IN THE SEA

Speed of sound in a fluid depends on the density (ρ), and
compressibility (k) of the fluid and the ratio between the
specific heats of the fluid at constant pressure and at con-
stant volume (γ), according to the following expression
[Sverdrup, Johnson and Fleming, 1942; Bowditch, 1972]:

$$v = \sqrt{\frac{\gamma}{\rho k}}$$

As these parameters depend on temperature, salinity and
pressure (which depends on depth), it is more convenient

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to measure these properties instead, and compute the sound speed from them.

Different expressions have been developed empirically by Kuwahara [1939], Del Grosso [1950], Wilson [1960a, b], Leroy [1969] and, more recently, Clay and Medwin [1977]. Mackenzie [1960] compared several of these formulas, which showed differences between them of less than 3 m/s, or 0.2% at zero depth [Urick, 1975]. Speeds used for depth corrections in NOS are calculated using Wilson's equation [1960b], which is described in Appendix A. This equation is the most commonly accepted formula due to its large range of applicability and its relative accuracy (0.30 m/s standard deviation) [Wilson, 1960b, 1962].

D. TRADITIONAL METHODS FOR DETERMINING DEPTH CORRECTIONS

Several different procedures can be used to determine the depth corrections, or correctors, to be applied to echo-soundings. These corrections can either be found directly or by knowing the sound speed profile. The sound speed can either be measured directly (direct comparison systems) or computed after the determination of some characteristics of the water column, as stated above (oceanographic and limno-logic determination). Some of the different procedures are described below:

1. Direct Comparison Systems

The depth recorded by the echosounder is compared to the actual depth indicated by the leadline or the depth

at which the bar is lowered. Because these are comparative methods, not only are sound speed variations included in the results but also instrument errors [Umbach, 1976]. Both methods are limited to shallow depths and good weather conditions.

a. Leadline Comparison (Vertical Cast)

The leadline is lowered to the bottom at several depths over a range which should be at least as great as that likely to be encountered in the survey area [The Hydrographer of the Navy, 1969]. Several readings are taken from the fathometer at each depth, and all are plotted individually in order to eliminate random errors. In areas where launch hydrography joins or overlaps ship hydrography, it is of particular importance to use this method on both ships and launches in order to resolve possible discrepancies in the soundings [Umbach, 1976]. This method is limited to calm seas, shallow depths, and areas of hard bottom for accurate readings.

b. Bar Check

The depth of a bar indicated by the echosounder is compared to the known depth at which the bar is lowered below the transducer. The procedure is used at several depths and the readings are taken both when the bar is lowered and when it is raised. Since the bar is handled over the side, this method is usually limited to small vessels and shallow depths, although it is sometimes performed mechanically on

large vessels. The depth limitation still holds, however,
due to difficulties in maintaining vertical lowering lines
and in keeping the bar within the beam of the transducer.
This procedure should only be used in calm seas with light
winds and no strong current.

2. Direct Measurement of Sound Speed

Sound speed can be measured directly by lowering a
sound velocimeter to various depths and recording the speeds
indicated. Although accuracies obtained by this method
can be of the order of a few tenths of a meter per second
[Ulonska, 1972], sound velocimeters are not generally used
because they are very expensive instruments [Calder, 1975].

3. Measurements of Salinity, Temperature and Depth

These parameters can be determined by direct meas-
urement either with Nansen casts (temperature and salinity
at specific depths) or with continuous sampling instruments
which measure salinity (or conductivity), temperature and
depth (STD or CTD). The latter instruments can also be of
an expendable type. Sound speed at various depths is then
computed using an equation relating salinity, temperature
and depth (pressure) to sound speed, such as Wilson's equa-
tion [1960b], or they can be extracted from tables, wherein
sound speed is tabulated for different values of temperature,
pressure and salinity [Heck and Service, 1924; Matthews,
1927, 1939; Kuwahara, 1939].

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4. Historical Tables or Atlases

Sound speed or salinity and temperature data have been tabulated for various areas and seasons. Matthews' tables [1939] provide corrections to be applied to the depths obtained with fathometers calibrated to a sound speed of 1463 or 1500 m/s. These depth corrections are given as a function of nominal depth and are tabulated for 52 different oceanic areas identified by Matthews [Greenberg and Sweers, 1972]. This method is not used by NOS but it is used in some countries for depths exceeding 200 m. For example, this is the only method which Australia uses for determining corrections in water depths of more than 200 m [Compton, 1980].

E. THE LAYER METHOD

1. Options

In addition to the above techniques to establish the depth correction, yet another more sophisticated method is in widespread use--the "summation of layers" method [Umbach, 1976]. This method is applicable when the sound speed is determined either by direct measurement or by computation from the depth, temperature and salinity parameters of the water column. This method can be applied in two ways, which are described in the "Hydroplot/Hydrolog Systems Manual"[3] [Wallace, 1971]:

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[3] The Hydroplot/Hydrolog system is an automated data aquisition and processing system in use by NOS, respectively with and without a plotting capability. A description of this system is given in the Hydrographic Manual, Fourth Ed. [Umbach, 1976].

a. Curve-fit Method

The water column is partitioned into layers of varying thickness which are predetermined by the operator. Layer mid-depths are then computed and the sound speed at those depths interpolated either graphically or mathematically from a curve passed through the points at which the sound speed has been computed.

b. No-curve-fit Method

The water column is partitioned as above but the depths at which the observations have been made are considered as the mid-depths, the boundaries between layers being defined as half-way between two successive observations of the cast. One example illustrating the no-curve-fit method is shown in Figure 2.

2. Computation of the Depth Corrections

a. Layer Sound Speed

For each layer a sound speed is determined for the corresponding mid-depth by any of the methods described above. This value of sound speed is assumed to apply throughout the entire layer.

b. Layer Factor

A factor is computed for each layer, based on the sound speed for which the instrument is calibrated, using the following expression [Umbach, 1976]:

$$\text{factor}_i = \frac{A_i - C}{C}$$

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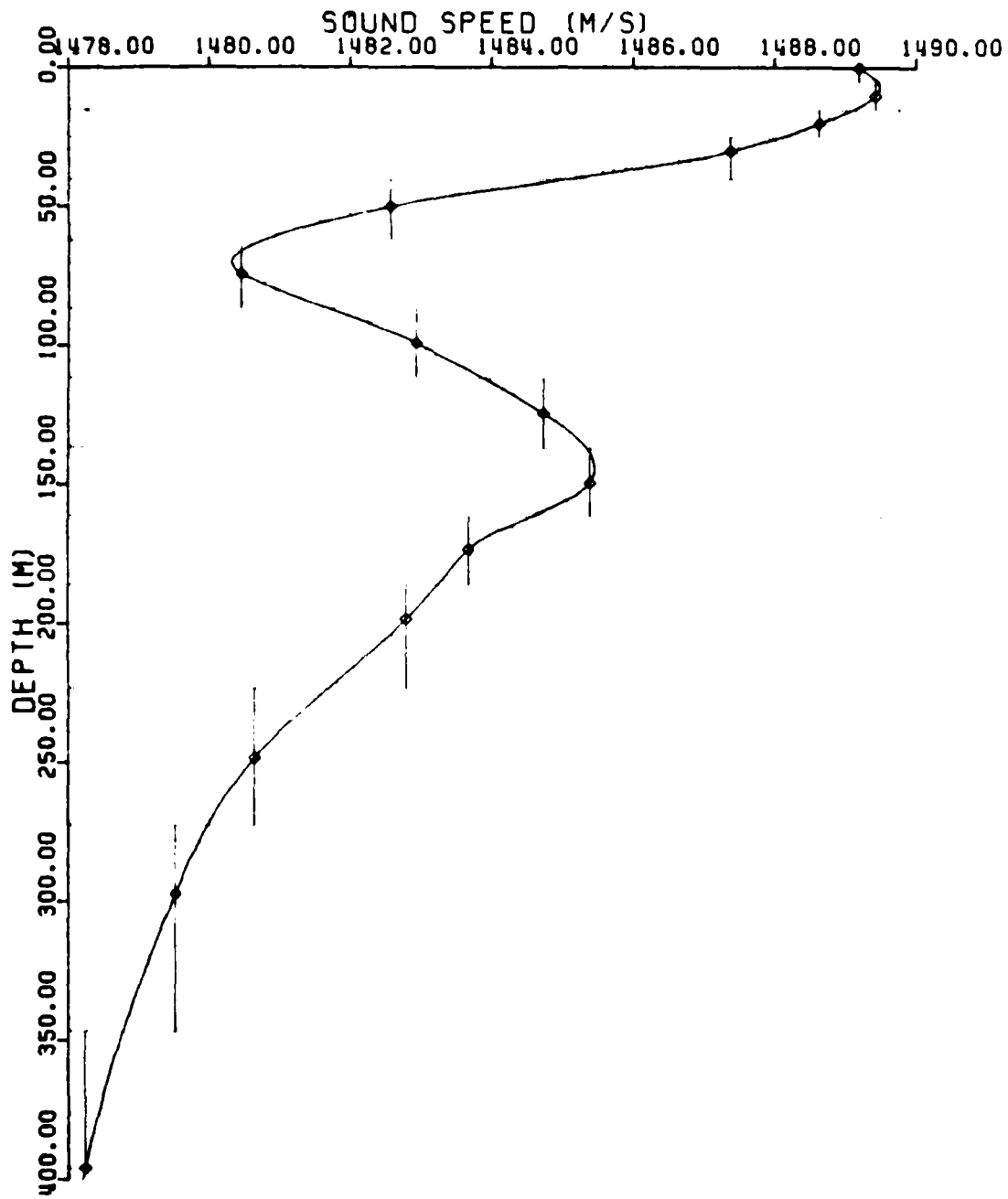
Figure 2.   Layer distribution for the no-curve-fit
option of the layer method.

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where A_i is the actual sound speed for the i-th layer which has been determined for the corresponding mid-depth (see preceding paragraph), and C is the assumed sound speed of the instrument.

c. Layer Correction

The above factor is multiplied by the layer thickness, Δz_i (the difference between the depth at the bottom and at the top of the layer) in order to obtain the correction to the depth (LC_i) due to the variation in sound speed of that layer:

$$LC_i = factor_i \times \Delta z_i$$

The water column above the transducer is eliminated when determining the corrections for the upper layer.

d. Bottom-of-layer Correction

The layer corrections are added from the surface downward in order to obtain the total correction at the bottom of each layer:

$$C_i = \sum_{j=1}^{i} LC_j$$

where C_i is the correction at the bottom of the i-th layer.

e. Fathometer Depth Correction Table

The above corrections correspond to the true depth of the bottom of each layer. To obtain the fathometer depth to which these corrections will apply, one must sub-tract the correction (C_i) from the true depth of the bottom

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of the corresponding layer (z_i):

$$C_{FD_i} = z_i - C_i$$

where C_{FD_i} is the fathometer depth corresponding to the i-th
layer.

  f. Correction Curve

    The values of the corrections are plotted against
the fathometer depth. A curve is drawn to fit these depth-
correction pairs. From this curve the depth correction appli-
cable to any reading of the fathometer (within the range for
which the curve has been computed) can be obtained. An example
of such a curve, for which a transducer at zero depth has been
considered, is shown in Figure 3.

F. VARIATION OF THE PARAMETERS

  The variation of sound speed with depth, temperature
and salinity depends on the initial conditions of these par-
ameters. For a temperature of 14°C, salinity of 34 ‰ and at
zero depth (sound speed under these conditions is 1502.94 m/s)
an increase of one degree in temperature will increase sound
speed by about 4.5 m/s; an increase of 1 ‰ in salinity will
increase the sound speed by about 1.3 m/s; an increase in
depth of 100 m (about 10 atmospheres in pressure) will in-
crease sound speed by about 1.7 m/s [Urick, 1975]. Latitude
also has some influence, since pressure increases from the
equator to the poles because of the increase of the gravita-
tional attraction. This influence, however, is very small
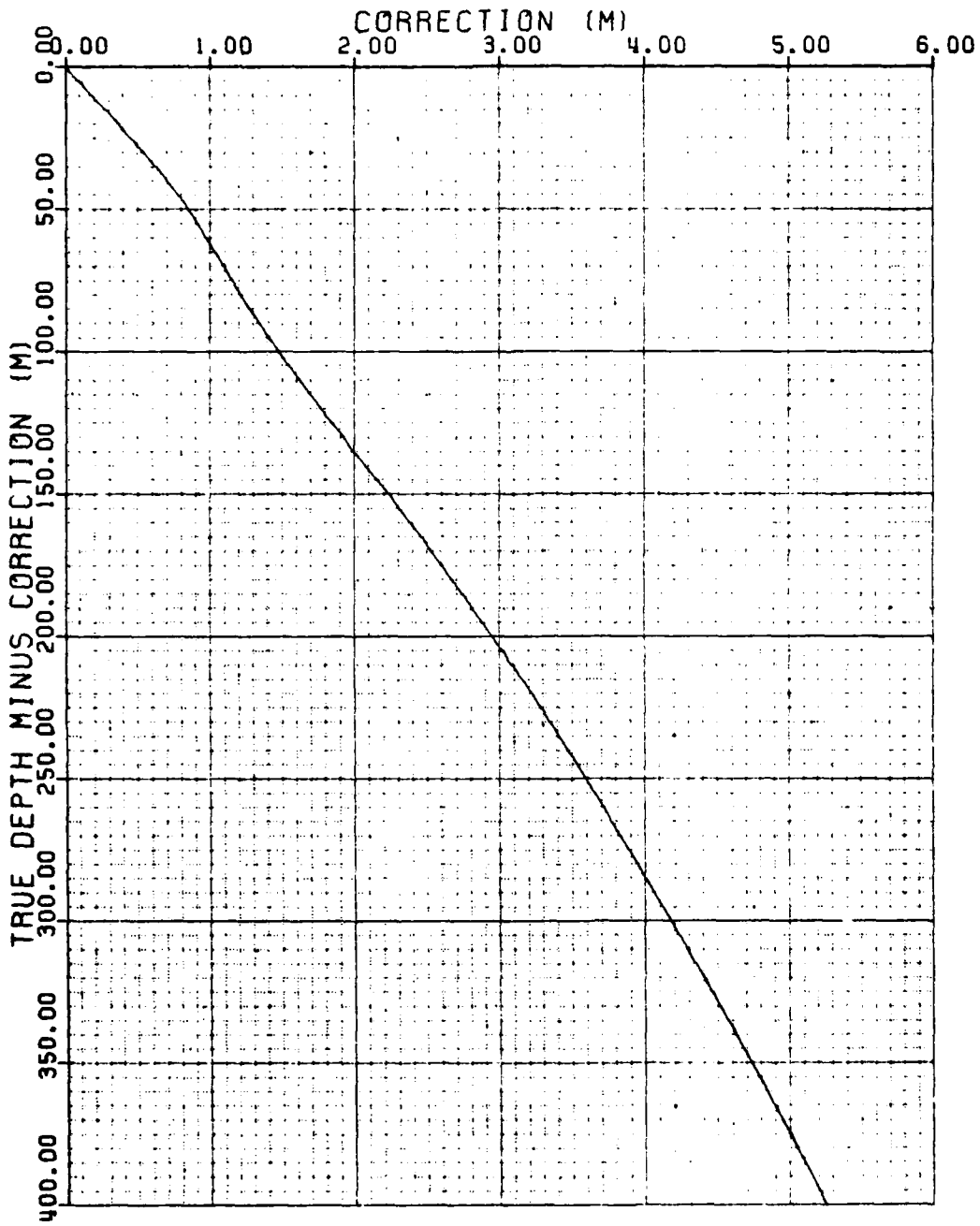
Figure 3. Depth correction diagram.

and can be ignored. An example of the variation of sound speed with temperature, salinity and depth is shown in Figure 1.

Temperature is the parameter that has the largest influence on sound speed. Also, it shows more variability with time. Umbach [1976] states that, for the sound speed to be accurate to within ±4 m/s, temperature and salinity must be determined with an accuracy of ±1°C and 1 %00, respectively. However, recent studies have been performed by the Testing Division, Office of Marine Technology (OMT), NOAA, regarding the influence of the different parameters on sound speed. These studies show that if temperatures can be determined with an accuracy of ±.1°C, the salinity accuracy need only be within ± 3%00 to still meet the requisite accuracy standards [Bivins, 1976].

G. USE OF HISTORICAL INFORMATION

Historical information has been used for some time in the computation of depth corrections for echosoundings, but usually only for depths in excess of 200 m [Sherwood, 1974; Urick, 1975]. Yeager [1979] studied whether depth corrections of sufficient accuracy could be determined from historical salinity and temperature only. He chose an area which is representative of the near shore region along the East Coast of the United States. The historical sound speed data there indicated that the temporal and spatial variability of temperature exceeded the acceptable limits for sounding

corrections, thus precluding the use of historical data alone for correction determination. In his study he also concluded that, in that area (a little more than one degree square with depths less than 200 m) salinity values were sufficiently stable to allow acceptable depth corrections to be computed from historically derived salinity values combined with in situ temperature measurements.

In Australia data have been collected over the continental shelf since 1965 which show salinity to vary generally between 34.5 and 36 $^0/_{00}$, changing only slightly with depth down to 300 m [Calder, 1975]. At present, the Australian Hydrographic Service exclusively uses a value of 35 $^0/_{00}$ for the calculation of sound speed in depths less than 200 m [Compton, 1980].

H. OBJECTIVES

The purpose of this thesis is to analyze the possibility of using historical salinity data averages for a large area with in situ temperature measurements to compute depth corrections and still remain within the required accuracy limits. The historical salinity data were treated using several different techniques which increased in accuracy as more complex averaging schemes were used.

Temperature-salinity observations generally have to be made at least once a month and be of sufficient number to cover the entire area sounded [Umbach, 1976]. The use of

historical salinity data and XBT (expendable bathythermo-
graph) temperature information could save a significant
amount of time and money if results remain within the
accuracy standards. Also, since little time is needed for
each XBT observation, more frequent temperature measurements
could be made (both in time and space), thus increasing the
accuracy of the corrections used throughout the survey.

II. PROCEDURE AND METHODOLOGY

Some of the terms to be used in the following chapters are defined below:

Historical data: data resultant from some averaging scheme applied to previous observations in a large area.

Inferred data: data obtained from both historical and observed salinities, used to represent the data for a large region. It has not been measured, and consists of a single value.

Station: group of measurements taken at a particular time in a particular location. Each station consists of several observations taken over a given depth interval.

Observation: measurement taken at a particular depth in one station.

True correction: depth correction resultant from the application of the observed data.

Estimated correction: depth correction for which the computation of some historical data were used.

Error: difference between the estimated and true corrections.

Percentage of error: division of the error by the depth over which the correction applies.

A. STUDY AREA

The area selected for this study was the continental shelf region of the West Coast of the United States, extending off-shore generally to depths of about 1500 m. The study area can be seen in Figure 4. This area was chosen on the basis of several factors:
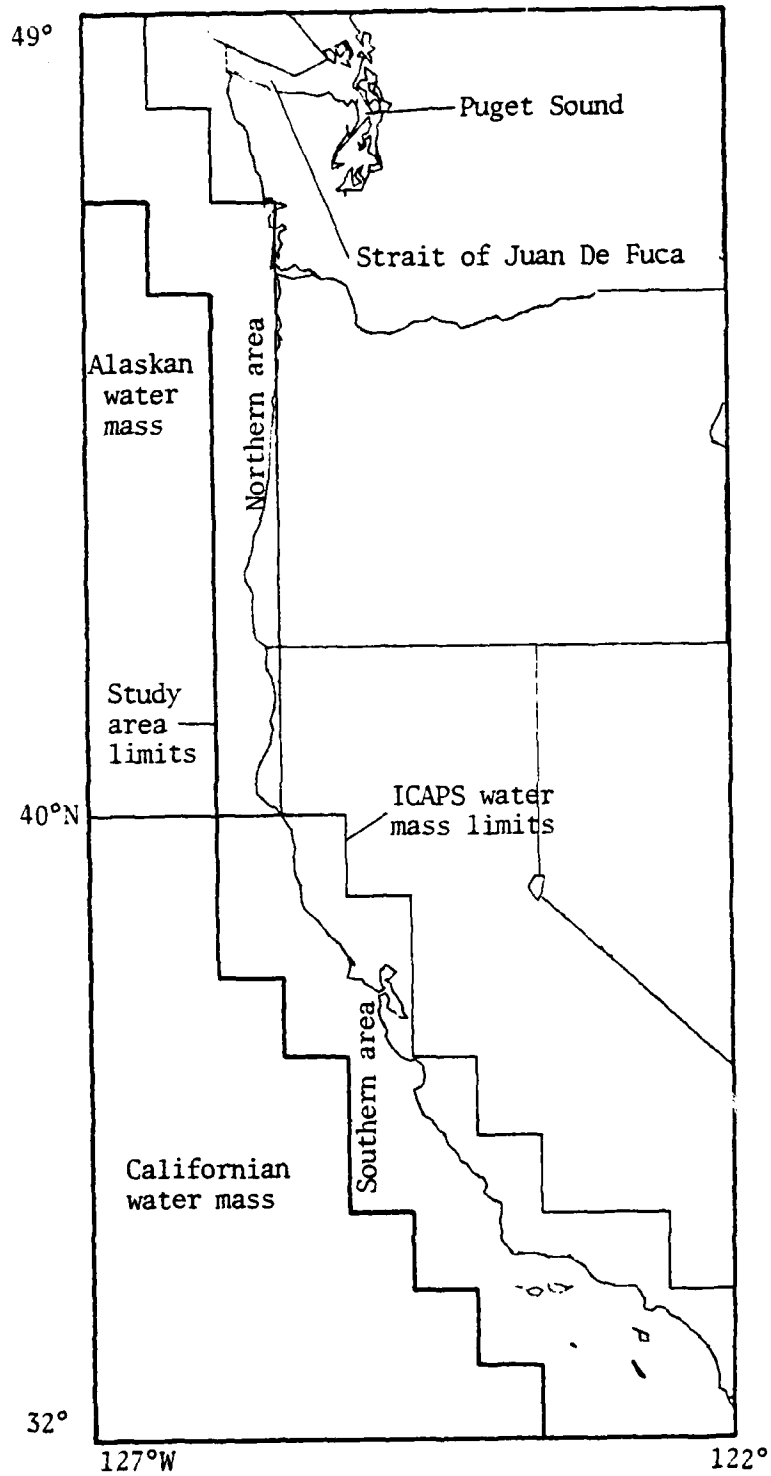
Figure 4. Study area, showing the inshore limits of the
Alaskan and Californian water masses.

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1. It represents a fairly large area wherein a considerable amount of data were available. For the purpose of this study, a large area was desired to generalize the applicability of the results.

2. Most hydrographic surveys are conducted over the continental shelf region.

3. The area was well suited for acquisition of historical data, as will be seen later in this chapter.

4. The extension to 1500 m depths guaranteed that all shelf features, including submarine canyons, would be considered.

The study area was subdivided into three sub-areas: Northern, Southern and Strait of Juan De Fuca and Puget Sound. This latter area was considered separately because of its particular salinity characteristics. The North-South division of the Pacific Ocean waters along latitude 40°N corresponds to the separation of the two different water masses considered in the historical salinity file.

B. DATA SOURCES AND TREATMENT OF DATA

1. Historical Data

Historical data for this study were obtained through the PROFIL subroutine of the Integrated Command ASW Prediction System (ICAPS). The ICAPS water mass history file was developed by the U.S. Naval Oceanographic Office (NAVOCEANO) and contains historical information on the water masses of

the Northern Hemisphere and Indian Ocean [Department of the Navy, 1978]. Each ocean is divided into several areas and subareas. In each of these subareas up to five different water masses may be included. Figure 5 shows the North Pacific Ocean, Pacific Area A divisions and the water masses present in Area A. The water mass files are also grouped seasonally: winter (January through March), spring (April through June), summer (July through September), fall (October through December).

Within the study area the ICAPS water mass file consists of only two water masses: Alaskan water (north of 40°N and Californian water (south of 40°N). These are shown in Figure 5(b). The inshore limits of these water masses are shown in Figure 4. The Alaskan water mass was used for the near shore area off Washington, although this area is not included in either of the two water masses.

For ICAPS data retrieval and processing, several different program modules are available [Chace, 1979]. In this study only the PROFIL subroutine was used. One of the outputs of PROFIL is historical salinity. It was used to obtain information for each area during all four seasons. The salinity profiles from these eight runs were punched onto cards and are shown in Table I.

2. Observed Data

The main source of observed data was the Fleet Numerical Oceanography Center (FNOC) file entitled MOODS (Master
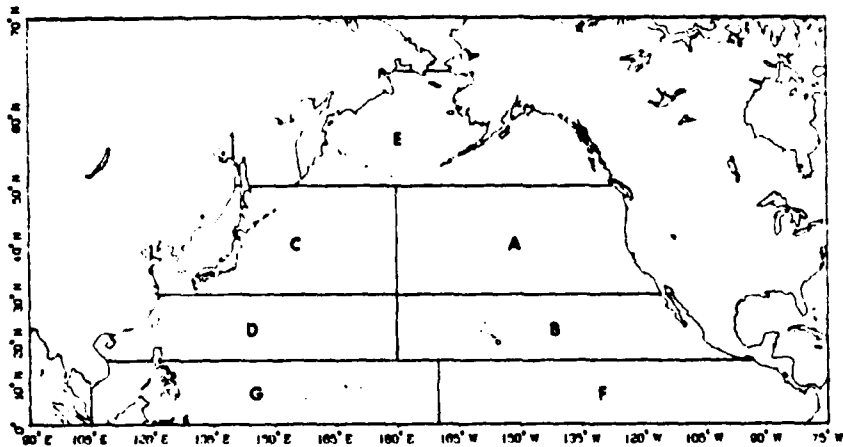
Figure 5(a)
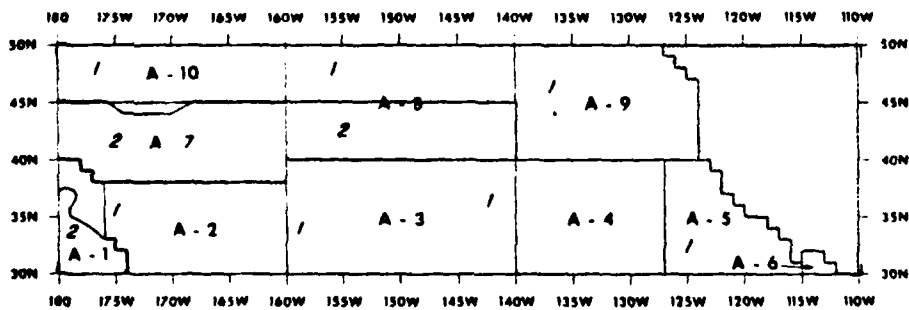
Figure 5(b)

Region	Water Mass Name	T200 (°C) Min	Max	DT (°C) Min	Max	Position	Freq. (%)
A1	TRANSITION	7	13			1	35
	KUROSHIO	13	19			2	65
A2	FAST TRANSITION	10	16			1	100
A3	NORPAC	7	12			1	43
	FAST TRANSITION	12	16			2	57
A4	CALIFORNIAN	5	11			1	60
	FAST TRANSITION	11	19			2	40
A5	CALIFORNIAN	5	11			1	100
A6	GULF OF CALIFORNIA	10	18			1	100
A7	ALEUTIAN	0	7			1	8
	NORPAC	7	12			2	92
A8	ALASKAN	0	7			1	46
	NORPAC	7	12			2	54
A9	ALASKAN	0	9			1	100
A10	ALEUTIAN	0	9			1	100

Figure 5(c)

Figure 5(a) North Pacific Ocean locator chart, (b) Pacific area A, and (c) Pacific area A water masses, as defined in the ICAPS history file.

TABLE I

HISTORICAL SALINITY FOR THE WEST COAST
OF THE UNITED STATES, FROM ICAPS

Oceanographic Observation Data Set). Some additional data
were obtained from the Pacific Marine Center (PMC), NOAA,
Seattle, Washington. The MOODS file contains data from sea
water observations all over the world. Different types of
observations are included: STD, CTD, Nansen cast, BT or XBT,
and others. Each station contains the geographical location,
date, time and a code for the ship/agency that made the ob-
servation. Temperature, salinity, sound speed, oxygen con-
centration or other properties are also provided depending
on the type of observation. The depth interval between
observations for different stations is not standardized.

The time interval chosen for the study was the ten
year period from 1964 to 1973. A more recent period was not
chosen because a very large percentage of the recent data is
from XBT observations, which does not provide salinity infor-
mation.

A direct extract from the MOODS file was not readily
usable on the Naval Postgraduate School computer since the
MOODS data are stored with a variable block size. A nine
track tape, 1600 bits per inch, constant block size, was then
prepared at FNOC which contained temperature and salinity for
depths standardized to 0, 30, 60, 90, 120, 150, 175, 200, 250
and 300 m. Values in excess of 300 m were not given, even if
they had existed in the original data. In the meantime, some
data were punched onto cards, extracted from a printout ob-
tained from the original data. Since this data set had a

better profile definition, especially useful for the inter-
mediate values between the surface and 30 m, it was decided
to use this punched data in substitution for the correspond-
ing stations on the tape.

A total of 3459 stations were analyzed, with the
distribution shown in Table II. For each of these stations
a depth correction was calculated based on the procedures
outlined in the previous chapter. Such corrections are con-
sidered true depth corrections and are the values against
which the estimated depth corrections (based on some mean
historical salinity value) must be compared.

TABLE II

DISTRIBUTION OF THE STATIONS BY AREA AND SEASON

	Winter	Spring	Summer	Fall	Total
North	248	679	643	195	1765
South	450	350	229	193	1222
Puget Sound/ Strait of Juan De Fuca	127	149	100	96	472
Total					3459

Appendix B shows all the station locations for each
area and season. Multiple occupations of a station may have
been made which are not indicated by these figures.

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C. DATA ANALYSIS

   1. Salinity

        From the ICAPS data file, mean salinity values were
computed from the surface to a given depth, for each area
and season. This mean was determined not only for the depth
of each given value of historical salinity (Table I) but also
for the mid-depths between two successive values. Table III
contains the values obtained. These data were then used to
establish a variety of historical salinity averages to be
described below.

        Estimated depth corrections were then determined for
each station using the observed temperature and an historical
salinity value derived from one of four different methods:

        a. Gross Historical Salinity Average (Method 1)

        This method uses a single value of salinity
throughout the entire water column. This salinity value
was determined by averaging the historical salinity data
from the surface to 200, 1000 or 3000 m. The choice of the
depth depended on whether the deepest depth for the station
was less than 200, between 200 m and 3000 m, or greater than
3000 m.

        b. Fine Historical Salinity Average (Method 2)

        This method was similar to the previous one
except that, instead of three possible values for salinity,
ten possible values were considered: averages from the sur-
face to 50, 100, 150, 200, 300, 500, 750, 1000, 1500 and

TABLE III

HISTORICAL SALINITY AVERAGES FOR THE
WEST COAST OF THE UNITED STATES

Z	SOUTH (<40 N)				NORTH (>40 N)			
	W	S	S	F	W	S	S	F
0.0	33.350	33.360	33.400	33.400	32.480	32.240	32.140	32.360
5.0	33.350	33.360	33.400	33.400	32.460	32.240	32.140	32.360
10.0	33.350	33.360	33.395	33.400	32.465	32.260	32.170	32.360
15.0	33.350	33.360	33.393	33.400	32.467	32.267	32.180	32.360
20.0	33.350	33.360	33.390	33.400	32.492	32.302	32.245	32.367
25.0	33.350	33.360	33.388	33.400	32.496	32.324	32.254	32.373
30.0	33.352	33.362	33.385	33.398	32.502	32.352	32.307	32.383
40.0	33.354	33.364	33.381	33.316	32.509	32.386	32.353	32.397
50.0	33.359	33.373	33.379	33.319	32.523	32.427	32.424	32.448
62.5	33.363	33.383	33.377	33.363	32.534	32.460	32.475	32.488
75.0	33.374	33.397	33.393	33.396	32.592	32.520	32.519	32.564
87.5	33.382	33.409	33.404	33.405	32.616	32.584	32.535	32.617
100.0	33.400	33.433	33.428	33.429	32.690	32.641	32.652	32.664
112.5	33.420	33.451	33.447	33.448	32.748	32.702	32.704	32.754
125.0	33.447	33.479	33.476	33.476	32.865	32.762	32.775	32.826
137.5	33.469	33.502	33.499	33.501	32.908	32.847	32.532	32.896
150.0	33.498	33.531	33.527	33.531	32.958	32.919	32.900	32.952
175.0	33.544	33.576	33.572	33.576	33.066	33.032	33.005	33.056
200.0	33.601	33.632	33.627	33.632	33.165	33.134	33.113	33.154
225.0	33.645	33.675	33.669	33.674	33.245	33.224	33.197	33.239
250.0	33.690	33.716	33.711	33.717	33.315	33.294	33.271	33.308
275.0	33.726	33.750	33.746	33.752	33.375	33.363	33.331	33.365
300.0	33.760	33.783	33.778	33.784	33.425	33.404	33.383	33.414
350.0	33.813	33.834	33.830	33.835	33.502	33.485	33.465	33.492
400.0	33.861	33.880	33.876	33.882	33.566	33.553	33.536	33.553
450.0	33.855	33.915	33.912	33.918	33.620	33.606	33.591	33.609
500.0	33.924	33.950	33.946	33.953	33.668	33.657	33.642	33.657
550.0	33.963	33.978	33.974	33.912	33.707	33.678	33.633	33.697
600.0	33.991	34.005	34.001	34.009	33.746	33.714	33.735	33.736
750.0	34.053	34.064	34.051	34.070	33.793	33.766	33.815	33.823
800.0	34.074	34.084	34.081	34.010	33.862	33.857	33.840	33.853
900.0	34.110	34.118	34.116	34.125	33.911	33.907	33.347	33.502
1000.0	34.145	34.152	34.150	34.159	33.959	33.956	33.945	33.951
1100.0	34.174	34.180	34.178	34.187	33.998	33.997	33.946	33.991
1200.0	34.201	34.207	34.206	34.214	34.036	34.134	34.025	34.029
1350.0	34.234	34.239	34.240	34.247	34.082	34.081	34.072	34.075
1500.0	34.266	34.271	34.271	34.277	34.126	34.124	34.115	34.120
1750.0	34.306	34.310	34.311	34.316	34.182	34.181	34.172	34.178
2000.0	34.343	34.347	34.348	34.352	34.233	34.232	34.224	34.229
2250.0	34.372	34.375	34.377	34.379	34.273	34.272	34.265	34.269
2500.0	34.398	34.401	34.403	34.404	34.306	34.303	34.301	34.305
2750.0	34.420	34.423	34.425	34.425	34.337	34.337	34.331	34.335
3000.0	34.440	34.442	34.444	34.444	34.363	34.363	34.358	34.361

3000 m depth. As before, the depth greater than or equal to the deepest depth observed was chosen. For example, if the depth were 250 m, the salinity average would be the one corresponding to the 300 m water column.

c. Historical Salinity Curve (Method 3)

The value from the historical salinity curve, which corresponded to a given depth, was obtained by interpolation from the existing values extracted from the ICAPS file.

d. Adjusted Historical Salinity Curve (Method 4)

Since the salinity value observed at the sea surface can sometimes deviate considerably from the historical surface value, an alternative to the historical salinity curve was considered. A linear adjustment was made to this curve so that the surface value would equal the observed salinity value, and the value at 30 m would equal the historical data (ICAPS) at that depth. Below 30 m the historical curve was used.

Salinity values illustrating these first four methods as applied to a particular station are shown in Figure 6. In light of the results obtained using these four methods, two new approaches were taken:

e. Inferred Value (Method 5)

A single value of salinity was used for each area, independent of season and depth. This value, which was inferred from both the historical data and the actual observations, was judged to represent average conditions for the area.

37
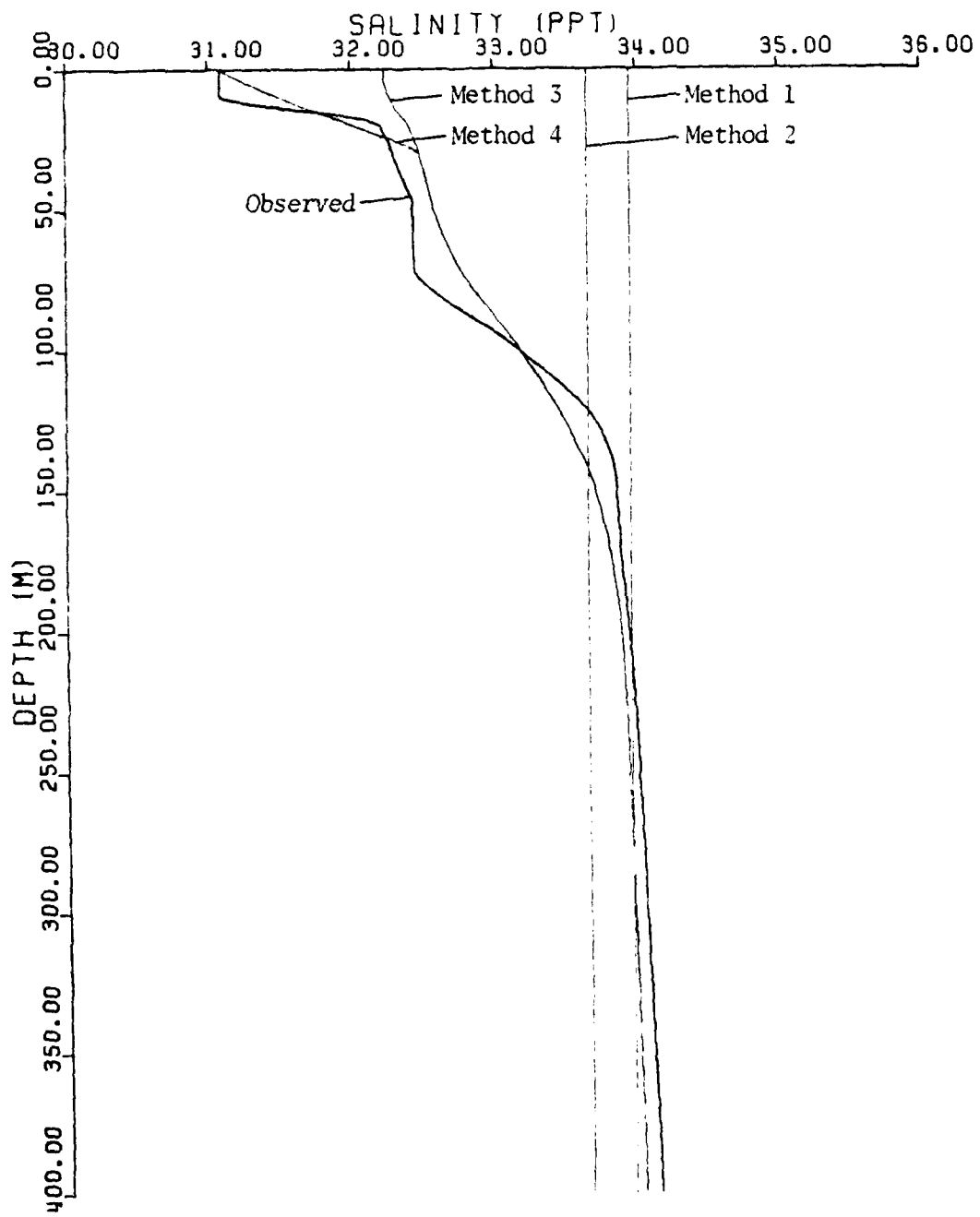
Figure 6. Historical salinity derived from ICAPS.

f. Inferred Value With Observed Surface Salinity
    (Method 6)

This method is similar to the previous method, except that the salinity which is applied to the first layer is the observed surface salinity. This method is also similar to method 4, except it only uses one value of salinity throughout the column for depths other than the surface.

2. Corrections

Each of the six methods was applied as in a normal survey. Estimated depth corrections were computed for each layer using the no-curve-fit method, i.e., the depth of the observed temperature was used as the mid-depth for the layer. The procedures indicated in section I.E. were followed using steps a to d:

(a) Estimated sound speed for each layer.

(b) Computation of the corresponding factor.

(c) Layer correction.

(d) Bottom of layer correction

The correction curves for the observed temperature and salinity values and those based upon each of the first four methods are shown in Figure 7. The estimated correction at the bottom of each layer was compared to the "true" correction which was obtained using the observed salinity.

$$\text{Error}_i = \text{estimated correction}_i - \text{true correction}_i$$

The differences were divided by the depth, in order to obtain

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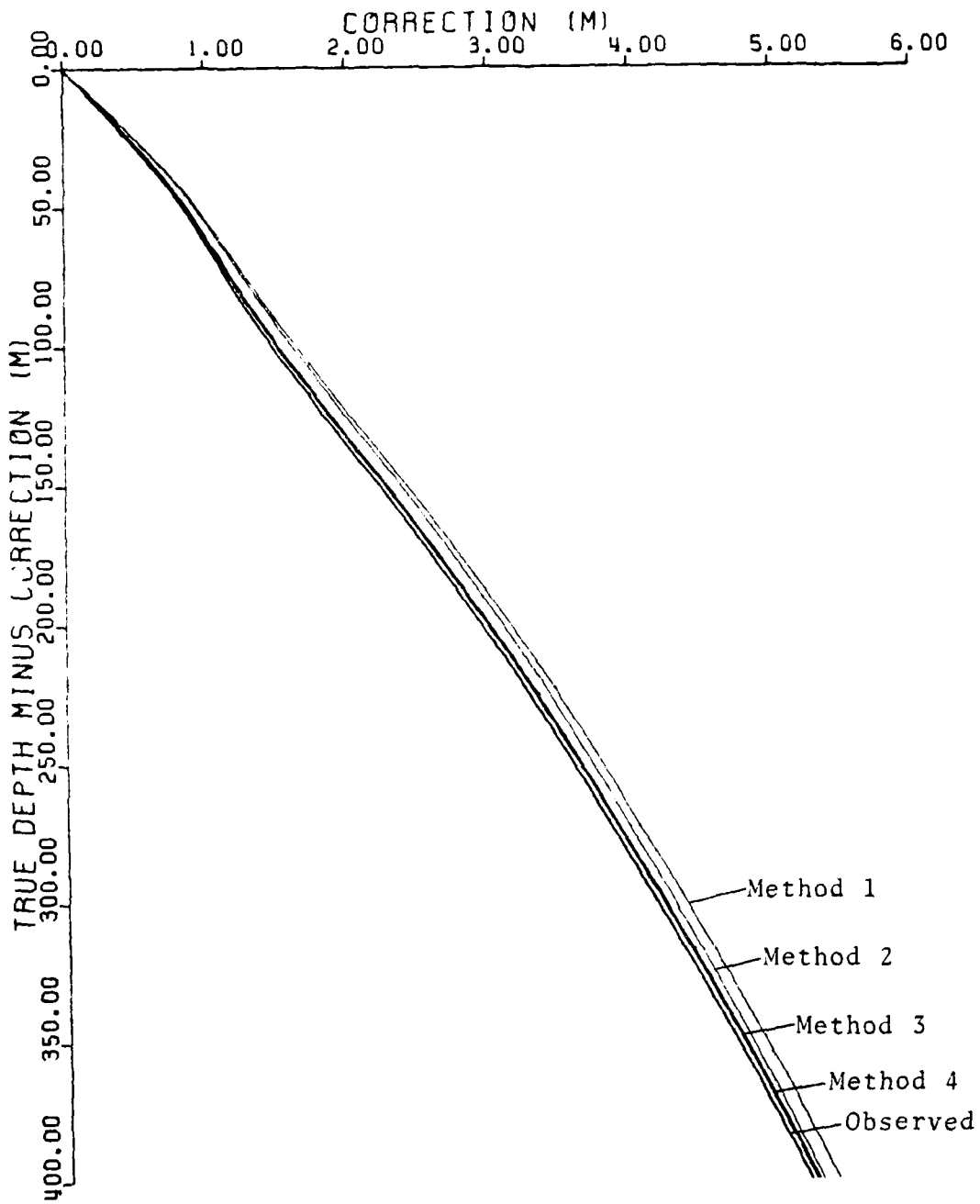
Figure 7. Correction curves for the first four methods.

the percentage of error for that particular depth:

$$\text{Percentage of error}_i = \frac{\text{Error}_i}{z_i}$$

where z_i is the depth of the bottom of the layer. If this value were greater than or equal to 0.25%, the method was considered unsuitable at that depth, since the accuracy requirements could not be met. The values compared were the corrections at the true depth at the bottom of each layer. In reality, the values at the fathometer depth (true depth minus correction) should have been compared. This was not done since the fathometer depths would probably be different for each error. However, the resultant error from this approximation is insignificant--of the order of a few millimeters (see Figure 8).

All the computations for the first four methods were executed sequentially in the same program, shown in Appendix C. This program was also used for the fifth and sixth methods. An output of this program for a particular station is shown in Figure 9. The meaning of the different headings is as follows:

SH1: gross historical salinity average (method 1)

SH2: fine historical salinity average (method 2)

Z : depth of the observation

ID : depth at the bottom of each layer

T : observed temperature

S : observed salinity

41
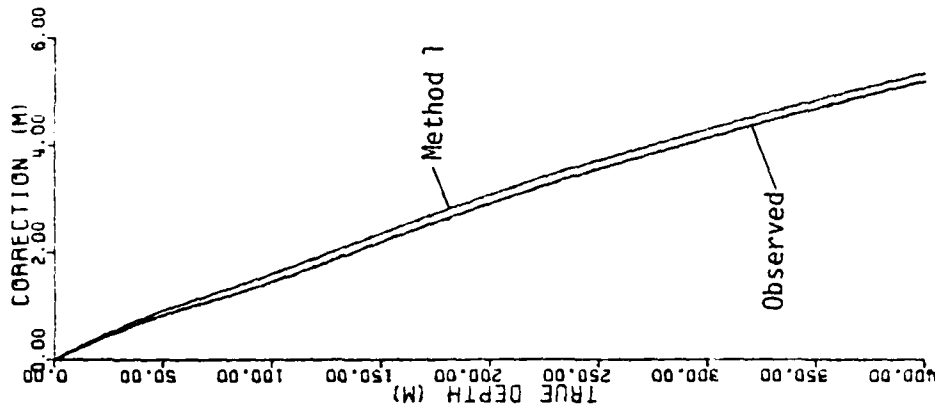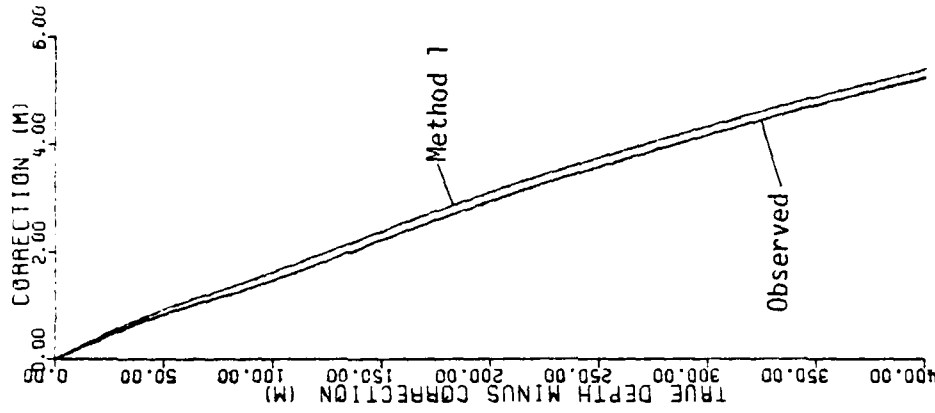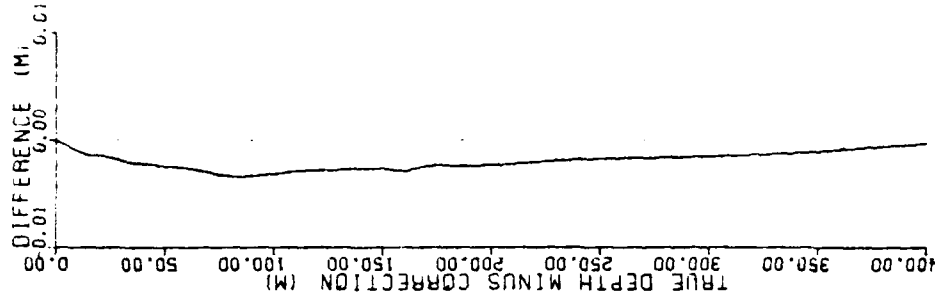
Figure 8(c)

Figure 8(b)

Figure 8(a)

Figure 8.   Depth corrections as a function of "true depth" (a) and
"true depth minus correction" (b) for true salinity and method 1.
Figure 8(c) illustrates the difference between the two methods.

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Figure 9. Program output for a particular station.

HS : historical salinity value (method 3)

HS': adjusted historical salinity curve (method 4)

V : sound speed computed from Z, T and S

V1-4: sound speed computed using methods 1-4

COR : correction applied at depth ID computed
from V

COR1-4: correction obtained using methods 1-4

DCOR1-4: error of methods 1-4 (difference between
COR1-4 and COR)

PC1-4: percentage of error of methods 1-4
(DCOR1-4 divided by ID)

III.   DISCUSSION OF THE RESULTS

Based on the foregoing analysis, four different possibilities have been considered for each of the six salinity averaging methods tested:

(1) No error exceeds the limits at any given depth.

(2) The error limit is exceeded only in the surface layer.

(3) The error limit is exceeded between the surface layer and the layer which contains the 30 m depth.

(4) Excessive errors have been found for layers deeper than 30 m.

A.   USE OF HISTORICAL SALINITY DATA DERIVED FROM ICAPS (FIRST FOUR METHODS)

The results obtained from using historical salinity data derived from the ICAPS water mass file are shown in Table IV. A discussion of these results, categorized by area, follows.

1.   Northern Area

The large variation of surface salinity in this region caused the depth correction for the first layer to exceed the acceptable limits for the first three salinity averaging methods considered. Excessive errors were found for 31.6%, 28.0% and 24.4% of the stations examined, respectively. A slight improvement is noted between methods 1 and 3, indicating that some benefit is derived from the use of an historical mean salinity profile. However, when the

TABLE IV

ERRORS RESULTANT FROM THE USE OF HISTORICAL SALINITY DERIVED FROM ICAPS (METHODS 1 TO 4).

Results are shown for the surface layer and for water depths shallower or deeper than 30 m. Numbers indicate the number of stations which exceeded the accuracy standards. Percentages are indicated in parenthesis.

Area		Total	S.L.	Method 1 ≤30	>30	S.L.	Method 2 ≤30	>30	S.L.	Method 3 ≤30	>30	S.L.	Method 4 ≤30	>30
North	Winter	248	95 (38.3)	38 (15.3)	3 (1.2)	78 (31.5)	21 (9.7)	2 (0.8)	73 (29.4)	21 (8.5)	2 (0.8)	0 (0.0)	0 (0.0)	0 (0.0)
	Spring	679	301 (44.3)	166 (24.4)	44 (6.5)	278 (40.9)	151 (22.2)	31 (4.6)	235 (34.6)	135 (19.9)	25 (3.7)	0 (0.0)	0 (0.0)	0 (0.0)
	Summer	643	151 (23.5)	56 (8.7)	1 (0.2)	130 (20.2)	27 (4.2)	0 (0.0)	115 (17.9)	21 (3.3)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Fall	195	10 (5.1)	5 (2.5)	0 (0.0)	8 (4.1)	3 (1.5)	0 (0.0)	7 (3.6)	3 (1.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Total	1765	557 (31.6)	263 (14.9)	48 (2.7)	494 (28.0)	205 (11.6)	33 (1.9)	430 (24.4)	180 (10.2)	27 (1.5)	0 (0.0)	0 (0.0)	0 (0.0)
South	Winter	450	1 (0.2)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Spring	350	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Summer	229	3 (1.3)	0 (0.0)	0 (0.0)	1 (0.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Fall	193	0 (0.0)	0 (0.0)	1 (0.5)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
		1222	4 (0.3)	0 (0.0)	1 (0.1)	1 (0.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Puget Sound/ Strait of Juan de Fuca	Winter	127	110 (86.6)	103 (81.1)	99 (78.0)	102 (80.3)	96 (75.6)	92 (72.4)	83 (65.4)	102.2	70 (50.9)	0 (0.0)	1 (0.8)	15 (11.8)
	Spring	149	131 (87.9)	129 (86.6)	125 (83.9)	126 (84.6)	125 (83.9)	121 (81.2)	125 (83.9)	123 (82.5)	119 (79.9)	0 (0.0)	1 (0.7)	3 (2.0)
	Summer	100	71 (71.0)	69 (69.0)	64 (64.0)	70 (70.0)	68 (68.0)	64 (64.0)	70 (70.0)	65 (65.0)	57 (57.0)	0 (0.0)	2 (2.0)	8 (8.0)
	Fall	96	65 (67.7)	64 (66.7)	58 (60.4)	58 (60.4)	56 (58.3)	54 (56.3)	47 (49.0)	36 (37.5)	34 (35.4)	0 (0.0)	4 (4.2)	4 (4.2)
	Total	472	377 (79.9)	365 (77.3)	346 (73.3)	356 (75.4)	345 (73.1)	331 (70.1)	325 (68.4)	301 (63.8)	280 (60.0)	0 (0.0)	8 (1.7)	30 (6.4)
		3459												

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historical salinity profile was adjusted to match the surface value (method 4), there were no stations which exceeded the acceptable limits.

The depth error of the first layer was often so large that sometimes the offset created induced an unacceptably large error in the second layer. This occurred for 14.9%, 11.6% and 10.2% of the stations examined, respectively. In very few cases (2.7%, 1.9% and 1.5%) the excessive difference in surface salinities created an excessive error which extended to the third layer.

There are two main reasons why this error is so large: 1) the observed salinity extends to very low values, and 2) most of the data only are defined at the surface and 30 m isopleths which creates a very wide first layer (15 m) over which that value is applied. The errors which occur due to low surface salinities generally do not cause the accuracy limits to be exceeded except close to the surface, for depths rarely exceeding 30 m. The salinity may be very low at the surface but it increases quite rapidly to nominal oceanic values in a few meters.

The error due to low surface salinities is of particular importance during the spring season (April-June) due to the large outflow of the rivers of Northern California and Oregon, especially the Columbia River. It is also noticeable in the winter season, but is considerably less important in summer. An example where this situation frequently occurred

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was in the area of influence of the Columbia River, where on one occasion a salinity as low as $8.02\%o$ was observed during the spring season.

2. Southern Area

Considering the least sophisticated of the salinity averaging schemes (method 1), only five stations out of 1222 (0.4%) showed any kind of deviation which exceeded the acceptable depth limits. Of these five, only one station, located adjacent to the Golden Gate Bridge in San Francisco, exceeded those limits in a layer other than the surface. For this station, unacceptable depth errors were found at depths between 70 and 80 m due to an inversion in the salinity profile. Of the other four stations, only one exceeded the error limit when the second method was used. All these stations were located in water more than 300 m deep, except one located about 8 miles south of Point Reyes, about half-way to the Farallon Islands. None of these observations exceeded the limits for the third and fourth methods. The general pattern resulted in a slight improvement in accuracy from the first to the third methods, and a significant improvement when the fourth method was applied. However, there were cases where, because of the large range in salinity, method 1 was more accurate than method 3. The pattern of the accuracy of the four methods was similar to that experienced in the Northern area.

3. Strait of Juan De Fuca and Puget Sound

Although method 4 demonstrated a significant increase
in accuracy, none of the four methods which used historical
salinity derived from the ICAPS file was deemed accurate
enough. This file does not define any water mass applicable
in the Strait of Juan De Fuca and Puget Sound, and the extrap-
olation of the ICAPS data to fit this region proved to be
insufficient in accuracy.

B. USE OF INFERRED SALINITY VALUE
(FIFTH AND SIXTH METHODS)

Salinity values of 31, 33 and 29 ‰ were selected as
representative of the Northern, Southern and Strait of Juan
De Fuca/Puget Sound areas, respectively. These values were
applied both throughout the entire water column (method 5)
or else were replaced by the observed surface salinity value
for the first layer only (method 6). The number of stations
that exceeded the acceptable limits for each of these methods
is shown in Tables V and VI. A further analysis of these
results follows.

1. Northern Area

Of the 1765 stations examined, 323 stations (18.3%)
had a surface layer error that exceeded the acceptable limits
when a value of 31 ‰ was used throughout the entire water
column (method 5). Only 117 (6.6%) exceeded the limits in
deeper layers, and only one in a layer deeper than 30 m.

TABLE V

ERRORS RESULTANT FROM THE USE OF A SINGLE VALUE OF SALINITY
THROUGHOUT THE ENTIRE WATER COLUMN (METHOD 5)*

Season:		Winter				Spring				Summer				Fall			
Area	Salinity	Total	S.L.	≤50	>50	Total	S.L.	≤50	>50	Total	S.L.	≤50	>50	Total	S.L.	≤50	>50
North	31‰	246				670							645				
South	33‰	450	0	0	0	350								+3		2	0
Puget Sound/ Strait of Juan de Fuca	29‰	127	22	16	8	149	15	16		100			5			42	22

*Table descriptions as in Table IV.

TABLE VI

ERRORS RESULTANT FROM THE USE OF A SINGLE VALUE OF SALINITY
THROUGHOUT THE ENTIRE WATER COLUMN (METHOD 6)*

Season:		Winter				Spring				Summer	Fall				
Area	Salinity	Total	S.L.	≤50	>50	Total	S.L.	≤50	>50	Total		Total	S.L.	≤50	>50
North	31‰	246	0 (0.0)	0 (0.0)	0 (0.0)	670	0 (0.0)	0 (0.0)		645		195			
South	33‰	450	0 (0.0)	0 (0.0)	0 (0.0)	350	0 (0.0)	0 (0.0)		220		+3	0	0	0
Puget Sound/ Strait of Juan de Fuca	29‰	127	0 (0.0)	0 (0.0)	0 (4.7)	149	0 (0.0)	0 (0.0)		0		96	0		11

*Table descriptions as in Table IV

When the observed surface salinity value was used in the first layer, no stations exhibited an unacceptable error.

2. Southern Area

No excessive errors were found when either method 5 or 6 was applied, for which a constant value of 33 ‰ was assumed for this area.

3. Strait of Juan De Fuca and Puget Sound

A salinity value of 29 ‰ was assumed for this area. Of the 472 stations examined, 113 stations (23.9%) exceeded the limits when this value was used by itself, but only 23 (4.9%) when it was substituted in the first layer by the observed surface salinity value.

It has been seen that for the three areas, and for any of the methods considered, most of the errors exceeding the accuracy limits occurred in the surface layer only. This does not affect the accuracy standards when the depth is deeper than about 30 m, which represents most of the area over which hydrographic surveys are conducted.

IV. CONCLUSIONS

The results shown in the previous chapter indicate that historical data can indeed be used in the computation of depth corrections due to variations in sound speed for the West Coast of the United States. Data derived from the ICAPS salinity file are completely acceptable only in the Southern area, although good approximations can be made in the Northern area. The situation in the Northern area, however, can be an artifact created by the observed data format. If the surface value as observed in the sea is applied to adjust the historical salinity curve from ICAPS, then the results are completely correct for all depths and seasons, both in the Northern and Southern areas. This by itself would indicate sufficient confidence to apply this method to actual hydrographic surveys in the areas considered. It would only require the use of a table, such as Table I, and the measurement of the surface salinity, the temperature being measured with an XBT. The advantages of this method over what is presently being done are significant, both in time and cost.

ICAPS water masses are representative of very large areas of deep water. For application to coastal hydrography it is better to create a file of the shelf area exclusively. A ten year period may be representative, but a longer period, including as many observations as possible should be better.

The use of a single salinity value derived from a large number of observations is the easiest method to be applied in the computation of depth corrections. One further step is to make a surface salinity observation and use that value for the computation of the first layer correction. The improvement of this method over the method currently in use, from a practical point of view, is remarkable.

This conclusion is applicable to the entire West Coast of the United States, excluding the Strait of Juan De Fuca and Puget Sound where the results were not favorable, and to San Francisco Bay area where there were insufficient data.

In summary, the applicability of the use of historical data in the computation of depth corrections is as follows:

1. Northern Area

A single value of salinity of 31 $\%_{00}$ is applicable throughout the entire water column except for the surface, where the salinity must be measured. In these situations, the more complex method 4, wherein the historical salinity profile derived from the ICAPS' data file is adjusted to the surface value, may also be used.

2. Southern Area

The use of a single salinity value of 33 $\%_{00}$, applicable throughout the entire water column, is sufficiently accurate for this region. Alternatively, the historical salinity curve derived from ICAPS can also be used with no adjustment for the surface layer.

3. Strait of Juan De Fuca and Puget Sound

The use of historical salinity data derived from any of the methods above is not recommended in this area.

APPENDIX A

WILSON'S EQUATION

Wilson first presented his empirical formula for the computation of the speed of sound in sea-water in the June 1960 issue of the Journal of the Acoustical Society of America [Wilson, 1960a]. In the October issue of the same year, a slightly modified version of this formula was introduced, with an extended range of applicability. This version is the formula commonly used and accepted as best representing the sound speed dependence on pressure, temperature and salinity. It fits data within the ranges of -4°C to 30°C in temperature, 1 kg/cm^2 to 1000 kg/cm^2 in pressure and 0 ‰ to 37 ‰ in salinity, with a standard deviation of about 0.30 m/s [Wilson, 1960b][4].

A value of 1449.14 is given for the sound speed at $T = 0°C$. $P = 0.0$ kg/cm^2 and $S = 35$ ‰. Corrections are added to this reference speed in order to compensate for the variations in pressure, temperature and salinity, either alone or in a combined effect. The revised formula is as follows:

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[4] An analysis of this formula for values of pressure, temperature and salinity outside the range for which the equation was derived showed that the error can go up to 2.13 m/s for extreme conditions of temperature and salinity expected to occur in the sea [Wilson, 1962].

$$V = 1449.14 + V_T + V_P + V_S + V_{STP}$$

where $V_T = 4.5721\,T - 4.4532 \times 10^{-2}\,T^2 - 2.6045 \times 10^{-4}\,T^3$

$$+ 7.9851 \times 10^{-6}\,T^4$$

$$V_P = 1.60272 \times 10^{-1}\,P + 1.0268 \times 10^{-5}\,P^2$$

$$+ 3.5216 \times 10^{-9}\,P^3 - 3.3603 \times 10^{-12}\,P^4$$

$$V_S = 1.39799(S - 35) + 1.69202 \times 10^{-3}(S - 35)^2$$

$$V_{STP} = (S - 35)(-1.1244 \times 10^{-2}\,T + 7.7711 \times 10^{-7}\,T^2$$

$$+ 7.7016 \times 10^{-5}\,P - 1.2943 \times 10^{-7}\,P^2$$

$$+ 3.1580 \times 10^{-8}\,PT + 1.5790 \times 10^{-9}\,PT^2)$$

$$+ P(-1.8607 \times 10^{-4}\,T + 7.4812 \times 10^{-6}\,T^2$$

$$+ 4.5283 \times 10^{-8}\,T^3) + P^2(-2.5294 \times 10^{-7}\,T$$

$$+ 1.8563 \times 10^{-9}\,T^2) + P^3(-1.9646 \times 10^{-10}\,T)$$

The units of temperature, pressure, salinity and sound speed are, respectively, degrees Celsius, kilograms per square centimeter, parts per thousand and meters per second. While temperature and salinity are usually directly measured, pressure is computed from depth. The dependence of pressure on depth is not linear and several expressions may be applied for this computation. An iterative process is used by NOS to determine pressure [Wallace, 1971]. This method was extracted from the User's Guide to NODC's Data Services [NOAA, Department of Commerce, 1974], where it is described as follows:

$$\sigma_o = -9.3445863 \times 10^{-2} + 8.14876577 \times 10^{-1} S$$

$$- 4.8249614 \times 10^{-4} S^2 + 6.7678614 \times 10^{-6} S^3$$

$$g_o = 0.980616 - 2.5928 \times 10^{-3}(\cos 2\emptyset) + 6.9 \times 10^{-6}(\cos 2\emptyset)^2$$

$$P(surface) = 10.1325 \text{ decibars}$$

$$g_i = g_o + 1.101 \times 10^{-7}(d_i + d_{i-1})$$

$$\rho_i = (1 + 10^{-3} \sigma_T)/R$$

$$R = 1 - [4.886 \times 10^{-6} P/(1 + 1.83 \times 10^{-5} P)]$$

$$+ P[-2.2072 \times 10^{-7} + 3.673 \times 10^{-8} T - 6.63 \times 10^{-10} T^2$$

$$+ 4.0 \times 10^{-12} T^3 + \sigma_o(1.725 \times 10^{-8} - 3.28 \times 10^{-10} T$$

$$+ 4.0 \times 10^{-12} T^2) + \sigma_o^2(-4.5 \times 10^{-11} + 10^{-12} T)]$$

$$+ P^2[-6.68 \times 10^{-14} - 1.24064 \times 10^{-12} T + 2.14 \times 10^{-14} T^2$$

$$+ \sigma_o(-4.248 \times 10^{-13} + 1.206 \times 10^{-14} T - 2.0 \times 10^{-16} T^2)$$

$$+ \sigma_o^2 (1.8 \times 10^{-15} - 6.0 \times 10^{-17} T)] + P^3(1.5 \times 10^{-17} T)$$

1. A first approximation gives P_i'' and ρ_i':

   $$P_i'' = P_{i-1} + \rho_{i-1} g_i(d_i - d_{i-1})$$

   with P_i'' computed this way, ρ_i' is calculated.

2. A second approximation using ρ_i' gives P_i' and ρ_i:

   $$P_i' = P_{i-1} + 1/2(\rho_{i-1} + \rho_i')g_i(d_i - d_{i-1})$$

   with P_i' ρ_i is calculated.

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3. Finally, with ρ_i

$$P_i = P_{i-1} + 1/2 \ (\rho_{i-1} + \rho_i) g_i (d_i - d_{i-1})$$

then, $P = 0.10197 \ P_i$

In the above expressions, the subscript indicates the depth that is being computed, and the number of primes is inversely proportional to the accuracy of the approximation. The meaning of the different parameters is the following:

d = depth in meters

T = temperature in degrees Celsius

S = salinity in parts per thousand

ρ = density

P = pressure in kilograms per square centimeter

Ø = latitude in degrees.
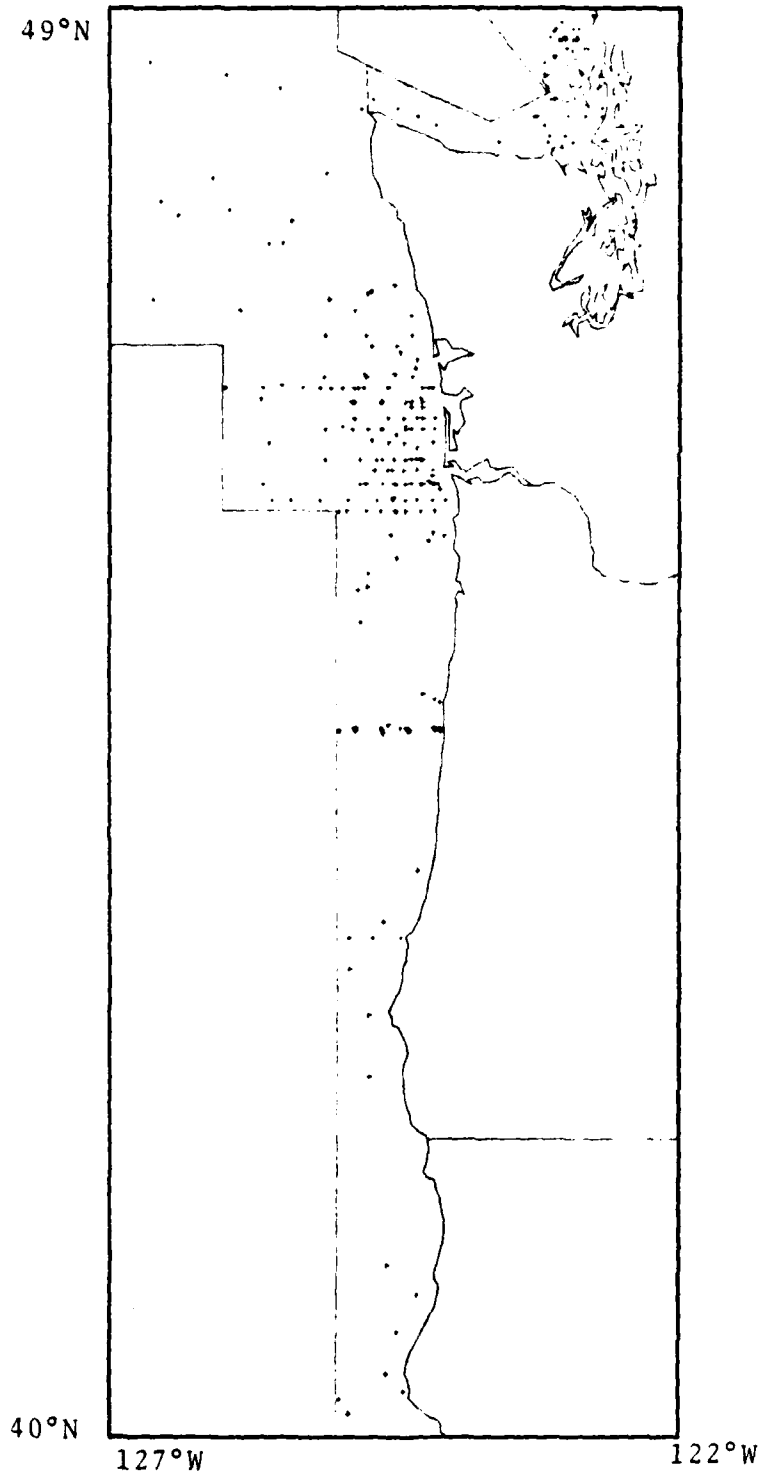
Figure B-1.   Location of stations for the northern area
and Strait of Juan De Fuca/Puget Sound, in winter.
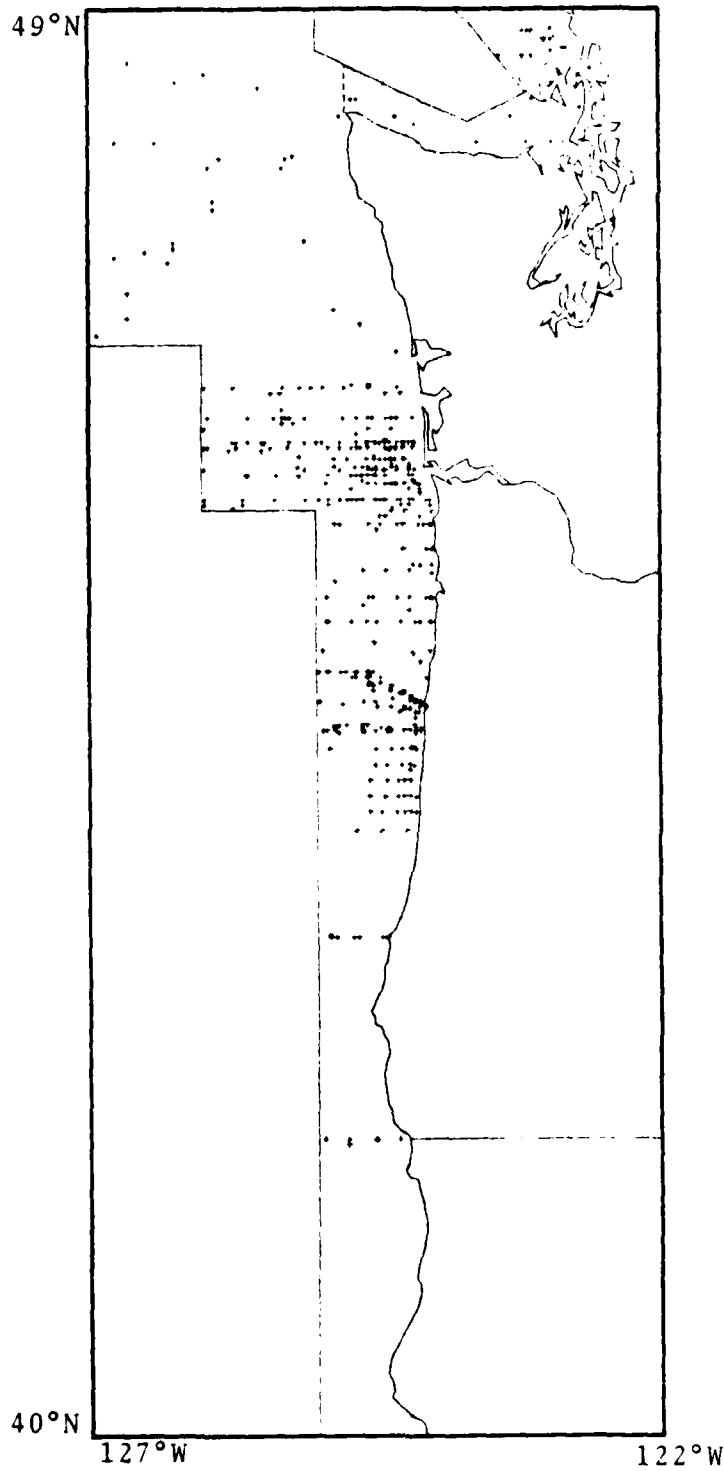
Figure B-2. Location of stations for the northern area
and Strait of Juan De Fuca/Puget Sound, in spring.
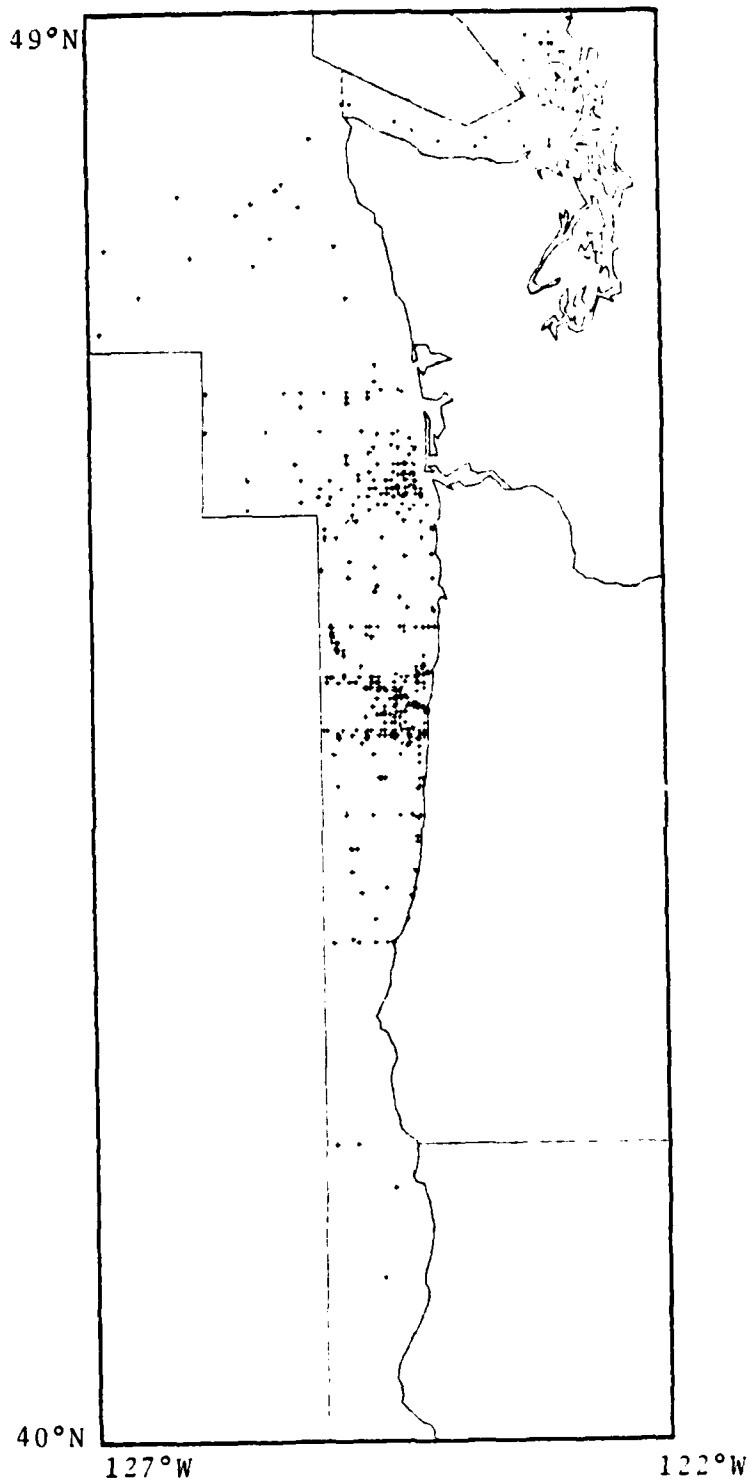
Figure B-3.   Location of stations for the northern area
  and Strait of Juan De Fuca/Puget Sound area, in summer.

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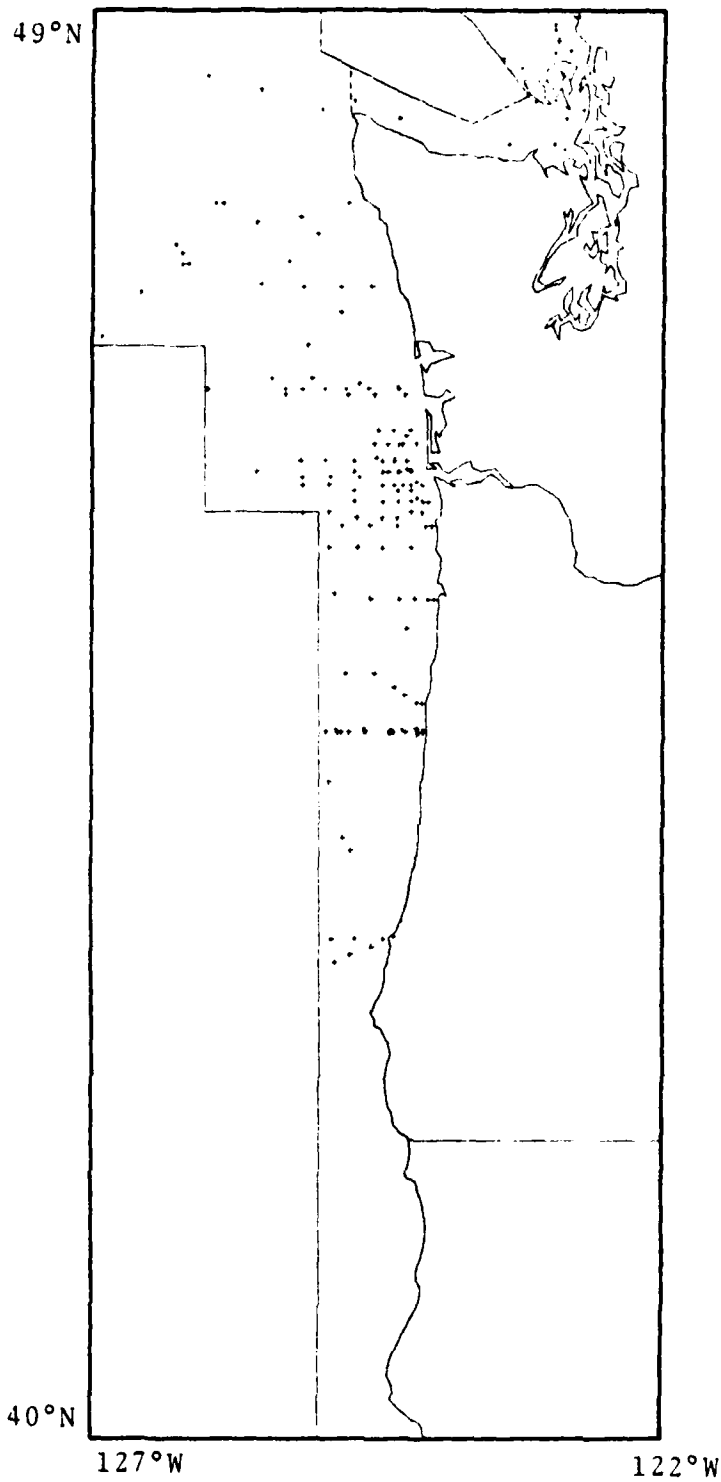
Figure B-4.   Location of stations for northern area and
     Strait of Juan De Fuca/Puget Sound area, in fall.
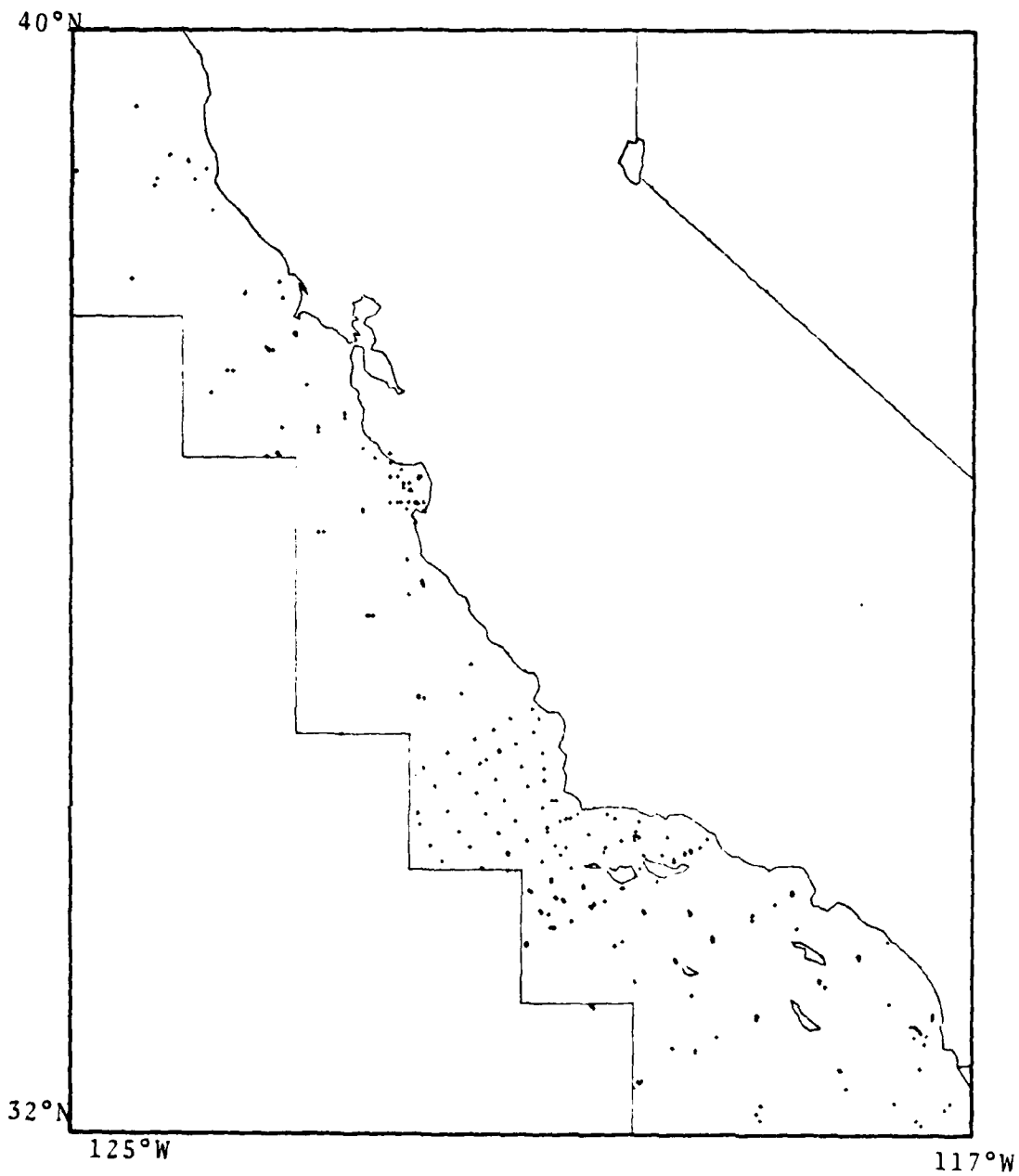
Figure B-5.   Location of stations for southern area, winter.
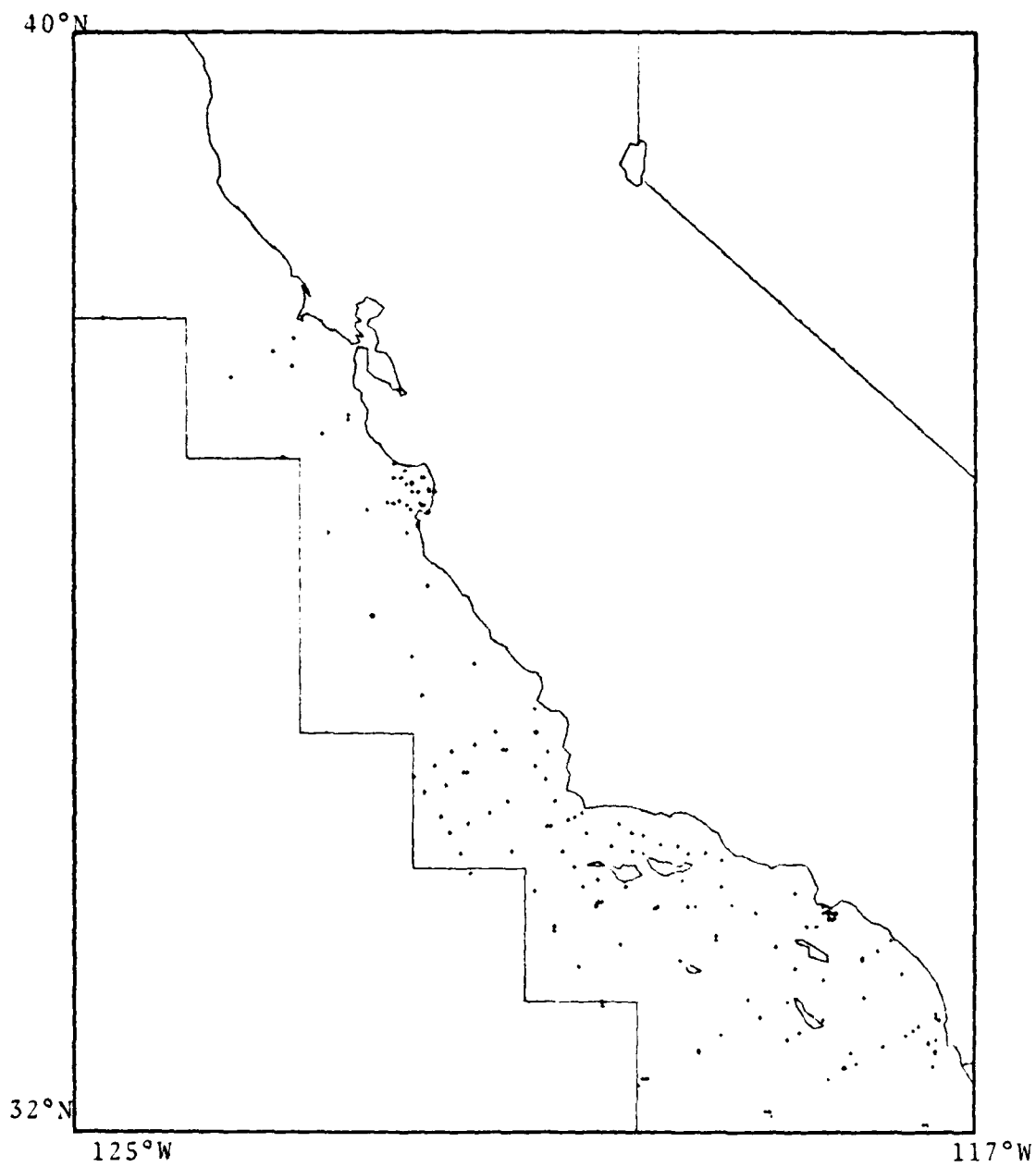
Figure B-6.   Location of stations for southern area, spring.
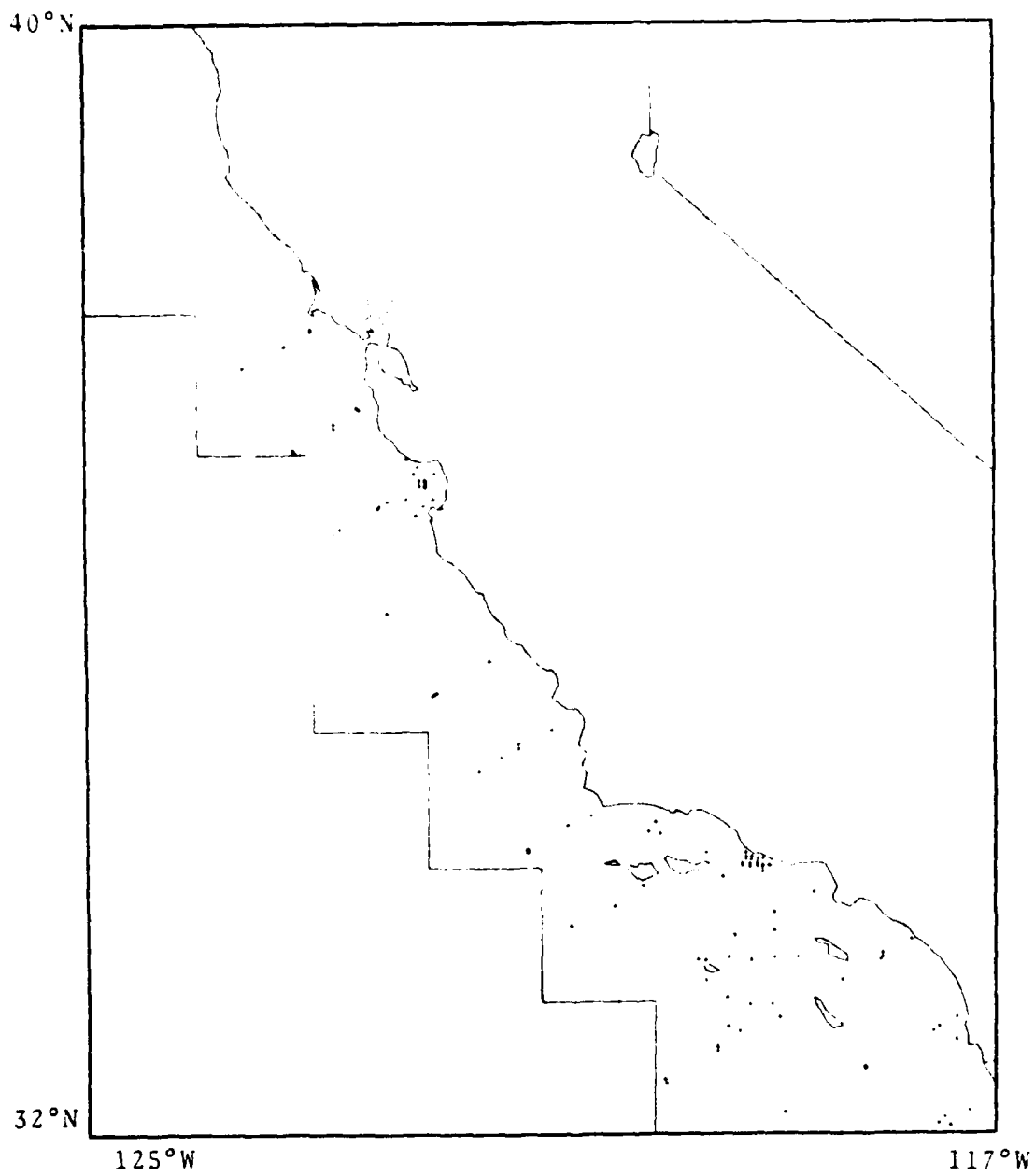
Figure B-7. Location of stations for southern area, summer.
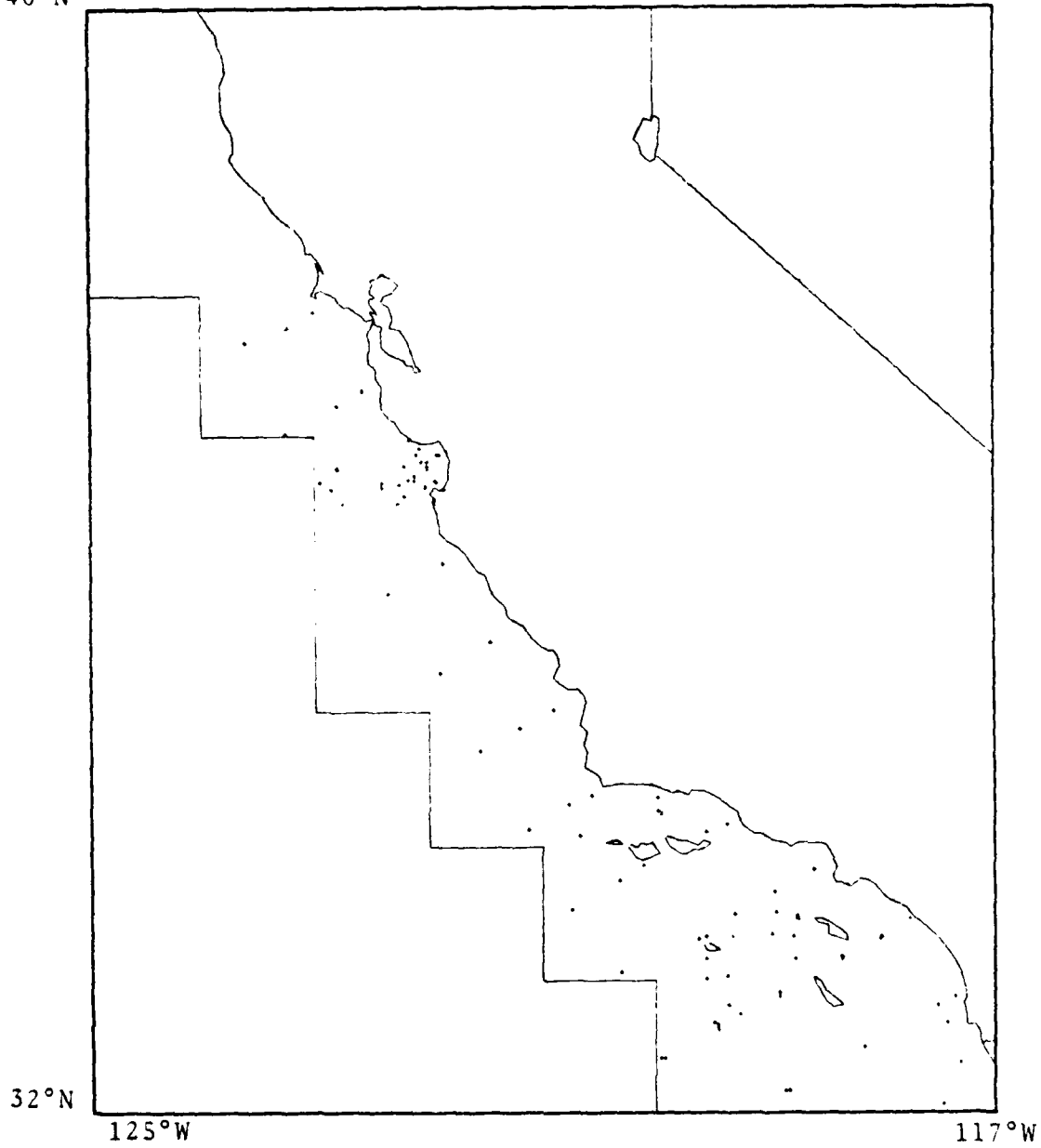
Figure B-8. Location of stations for southern area, fall.

APPENDIX C

COMPUTER PROGRAM

```
C     PROGRAM SVC
C
C     PROGRAM SVC USES HISTORICALY DERIVED SALINITY IN THE
C        COMPUTATION OF DEPTH CORRECTIONS DUE TO VARIATIONS
C        IN SOUND SPEED. IT USES FOUR DIFFERENT METHODS
C        FOR DERIVING THE HISTORICAL VALUES. THE DIFFERENT
C        DEPTH CORRECTIONS ARE COMPARED TO THE CORRECTION
C        OBTAINED USING THE OBSERVED SALINITY.
C
C
      INTEGER ON,DD,YY,TNO,TNSO
      REAL ID1,L1,L,ID,LC
      DIMENSION AVE(43,8),AVE1(43),COR(30),COR1(30),COR2(30)
     1  ,COR3(30),COR4(30),DCOR1(30),DCOR2(30),DCOR3(30),
     2   DCOR4(30),DCORR(30),DCR11(2000),DCR22(2000),
     3   DCR33(2000),DCR44(2000),ID(59),ID1(43),L(59),L1(43)
     4  ,PC(30),PC1(30),PC11(2000),PC2(30),PC22(2000),
     5   PC3(30),PC33(2000),PC4(30),PC44(2000),S(30),
     6   SH(22,8),SH11(30),SH22(30),SH3(30),SH4(30),SHH(22),
     7   SHHH(22),T(30),V(30),V1(30),V2(30),V3(30),V4(30),
     8   Z(22),Z1(30)
  100 FORMAT (F7.1,8F7.3)
  101 FORMAT (3I2,I5,A1,I6,A1,1X,A4,I3)
  102 FORMAT (10F7.3)
  200 FORMAT ('1',34X,'SOUTH (<40 N)',18X,'NORTH (>40 N)'//
     1   24X,'Z',2(6X,'W',2(6X,'S'),6X,'F',3X)/)
  201 FORMAT (20X,F6.0,1X,4F7.2,3X,4F7.2)
  202 FORMAT ('1',37X,'SOUTH (<40 N)',18X,'NORTH (>40 N)'//
     1   25X,'Z',2(7X,'W',2(6X,'S'),6X,'F',2X)/)
  203 FORMAT (20X,F7.1,2X,4F7.3,3X,4F7.3)
  204 FORMAT ('1','STATION NUMBER:',1X,A4//' DATE: ',I2,
     1   2('.',I2))
  205 FORMAT (/' LAT : ',I4,A1/' LONG: ',I5,A1)
  206 FORMAT (/' SH1:',F7.3/' SH2:',F7.3/)
  207 FORMAT (/5X,'Z',5X,'ID',7X,'T',7X,'S',6X,'HS',5X,
     1   'HS''',7X,'V',7X,'V1',7X,'V2',7X,'V3',7X,'V4'/)
  208 FORMAT (2F7.1,F9.3,2X,3F7.3,2X,5F9.3)
  209 FORMAT (//5X,'Z',5X,'ID',6X,'COR',3X,'COR1',3X,'COR2',
     1   3X,'COR3',3X,'COR4',5X,'DCOR1',2X,'DCOR2',2X,
     2   'DCOR3',2X,'DCOR4',5X,'PC1',4X,'PC2',4X,'PC3',4X,
     3   'PC4'/)
  210 FORMAT (2F7.1,2X,5F7.3,2X,4F7.3,2X,4F7.3)
  211 FORMAT (/' NUMBER OF DEPTHS:',I5)
  212 FORMAT (//' NUMBER OF OBSERVATIONS OFF:',53X,4I7/
     1   ' PERCENTAGE:',71X,4F7.2)
  213 FORMAT (/' LARGEST VALUE OBSERVED:',59X,4F7.3/
     1   ' MEAN:',77X,4F7.3/' STANDARD DEVIATION:',
     2   63X,4F7.4)
  214 FORMAT (//110X,'X   X'/111X,'X X'/112X,'X'/111X,
     1   'X X'/110X,'X   X')
  215 FORMAT ('1',45X,27('+')/46X,'+',25X,'+'/46X,
     1   '+     S T A T I S T I C S    +'/46X,'+',25X,'+',/
     2   46X,27('+')//)
  216 FORMAT (//49X,'PC1',4X,'PC2',4X,'PC3',4X,'PC4')
  217 FORMAT (/' TOTAL NUMBER OF OSERVATIONS:',I11/' TOTAL'
     1   ,' NUMBER OF OBSERVATIONS OFF:',11X,4I7/
     2   ' PERCENTAGE:',34X,4F7.2//' NUMBER OF STATIONS:',
     3   I20/' NUMBER OF STATIONS OFF:',21X,4I7/
     4   ' PERCENTAGE:',34X,4F7.2/)
  218 FORMAT (/' LARGEST SINGLE VALUE OBSERVED:',15X,4F7.3/
     1   ' LARGEST MEAN VALUE OBSERVED:',17X,4F7.3/
     2   ' LARGEST STANDARD DEVIATION OBSERVED:',9X,4F7.3)
  219 FORMAT (//' MEAN OF THE MEANS:',27X,4F7.3/' STANDARD'
     1   ,' DEVIATION OF THE MEANS:',13X,4F7.4)
```

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```
C
      FAC(VI)=(VI-VC)/VC
      PCTG(M,N)=FLOAT(M)/FLOAT(N)*100.
C
C     VC IS THE SOUND SPEED ASSUMED IN THE FATHOMETER.
      VC=1463.04
C
C-----------------------------------------------------------------
C
C     1. COMPUTE HISTORICAL SALINITY AVERAGES
C-----------------------------------------------------------------
C
      N=22
      DO 10 I=1,N
         READ (5,100) Z(I),(SH(I,K),K=1,8)
   10 CONTINUE
      WRITE (6,200)
      WRITE (6,201) (Z(I),(SH(I,K),K=1,8),I=1,N)
      J=0
      M=2*N-1
      DO 13 K=1,8
         DO 11 I=1,N
            SHH(I)=SH(I,K)
   11    CONTINUE
         CALL MEAN1(J,N,M,Z,SHH,AVE1,ID1,L1)
         DO 12 I=1,M
            AVE(I,K)=AVE1(I)
   12    CONTINUE
         J=1
   13 CONTINUE
      WRITE (6,202)
      WRITE (6,203) (ID1(I),(AVE(I,K),K=1,8),I=1,M)
C
C
      ON=0
      TNO=0
      NOFF1=0
      NOFF2=0
      NOFF3=0
      NOFF4=0
      DCOR1L=0.
      DCOR2L=0.
      DCOR3L=0.
      DCOR4L=0.
      PC1L=0.
      PC2L=0.
      PC3L=0.
      PC4L=0.
      DCR1ML=0.
      DCR2ML=0.
      DCR3ML=0.
      DCR4ML=0.
      PC1ML=0.
      PC2ML=0.
      PC3ML=0.
      PC4ML=0.
      DCR1SL=0.
      DCR2SL=0.
      DCR3SL=0.
      DCR4SL=0.
      PC1SL=0.
      PC2SL=0.
      PC3SL=0.
      PC4SL=0.
      NSOFF1=0
      NSOFF2=0
      NSOFF3=0
      NSOFF4=0
```

```
C
C-----------------------------------------------------------------
C      2. READ DATA
C-----------------------------------------------------------------
C
   20 READ (5,101) YY,MM,DD,LAT,H1,LONG,H2,NS,KONT
      IF (DD.EQ.0) GO TO 80
      WRITE (6,204) NS,MM,DD,YY
      WRITE (6,205) LAT,H1,LONG,H2
      NOFF11=0
      NOFF22=0
      NOFF33=0
      NOFF44=0
      DCR1TL=0.
      DCR2TL=0.
      DCR3TL=0.
      DCR4TL=0.
      PC1TL=0.
      PC2TL=0.
      PC3TL=0.
      PC4TL=0.
      READ (5,102) (Z1(I),I=1,10)
      IF (KONT.EQ.0) GO TO 23
      DO 22 I=2,10
         IF (Z1(I).NE.0.) GO TO 21
         N=I-1
         GO TO 26
   21    IF (I.EQ.10) N=I
   22 CONTINUE
      GO TO 26
   23 READ (5,102) (Z1(I),I=11,20)
      DO 25 I=11,20
         IF (Z1(I).NE.0.) GO TO 24
         N=I-1
         GO TO 26
   24    IF (I.EQ.20) N=I
   25 CONTINUE
   26 READ (5,102) (T(I),I=1,N)
      READ (5,102) (S(I),I=1,N)
      ON=ON+1
      IF (LAT.GT.4000) GO TO 27
         K=1
         IF (MM.GE.4) K=2
         IF (MM.GE.7) K=3
         IF (MM.GE.10) K=4
         GO TO 28
   27 CONTINUE
         K=5
         IF (MM.GE.4) K=6
         IF (MM.GE.7) K=7
         IF (MM.GE.10) K=8
   28 CONTINUE
C
C-----------------------------------------------------------------
C      3. MAKE COMPUTATIONS WITH TRUE VALUES
C-----------------------------------------------------------------
C
      CALL LAYER (N,Z1,L,ID)
      CALL CORREC(LAT,VC,N,Z1,T,S,L,V,COR)
C
C-----------------------------------------------------------------
C      4. MAKE COMPUTATIONS WITH 200, 1000,3000 M AVERAGES
C-----------------------------------------------------------------
C
      SH1=AVE(19,K)
      IF (Z1(N).GT.200.) SH1=AVE(33,K)
      IF (Z1(N).GT.1000.) SH1=AVE(43,K)
```

```
            DO 40 I=1,N
               SH11(I)=SH1
         40 CONTINUE
            CALL CORREC(LAT,VC,N,Z1,T,SH11,L,V1,COR1)
            CALL DCRR(N,COR1,COR,ID,DCOR1,PC1)
            DO 41 I=1,N
               AP1=ABS(PC1(I))
               IF (AP1.GT.PC1TL) PC1TL=AP1
               IF (AP1.GT..25) NOFF11=NOFF11+1
         41 CONTINUE
            IF (PC1TL.GT.PC1L) PC1L=PC1TL
            CALL STAT (N,PC1,PC1M,PC1S)
            IF (ABS(PC1M).GT.PC1ML) PC1ML=ABS(PC1M)
            IF (ABS(PC1S).GT.PC1SL) PC1SL=ABS(PC1S)
            PC11(ON)=PC1M
            PRC11=PCTG(NOFF11,N)
            IF (NOFF11.GT.0) NSOFF1=NSOFF1+1
C
C-------------------------------------------------------------------
C     5. MAKE COMPUTATIONS WITH 50, 100, 150, 200, 300, 500,
C        750, 1000, 1500, 3000 M AVERAGES
C-------------------------------------------------------------------
C
            SH2=AVE(9,K)
            IF (Z1(N).GT.50.)  SH2=AVE(13,K)
            IF (Z1(N).GT.100.) SH2=AVE(17,K)
            IF (Z1(N).GT.150.) SH2=AVE(19,K)
            IF (Z1(N).GT.200.) SH2=AVE(23,K)
            IF (Z1(N).GT.300.) SH2=AVE(27,K)
            IF (Z1(N).GT.500.) SH2=AVE(32,K)
            IF (Z1(N).GT.750.) SH2=AVE(33,K)
            IF (Z1(N).GT.1000.) SH2=AVE(37,K)
            IF (Z1(N).GT.1500.) SH2=AVE(43,K)
            DO 50 I=1,N
               SH22(I)=SH2
         50 CONTINUE
            CALL CORREC(LAT,VC,N,Z1,T,SH22,L,V2,COR2)
            WRITE (6,206) SH1,SH2
            CALL DCRR(N,COR2,COR,ID,DCOR2,PC2)
            DO 51 I=1,N
               AP2=ABS(PC2(I))
               IF (AP2.GT.PC2TL) PC2TL=AP2
               IF (AP2.GT..25) NOFF22=NOFF22+1
         51 CONTINUE
            IF (PC2TL.GT.PC2L) PC2L=PC2TL
C
            CALL STAT (N,PC2,PC2M,PC2S)
            IF (ABS(PC2M).GT.PC2ML) PC2ML=ABS(PC2M)
            IF (ABS(PC2S).GT.PC2SL) PC2SL=ABS(PC2S)
            PC22(ON)=PC2M
            PRC22=PCTG(NOFF22,N)
            IF (NOFF22.GT.0) NSOFF2=NSOFF2+1
C
C-------------------------------------------------------------------
C     6. MAKE COMPUTATIONS FOR EACH CORRESPONDING HISTORICAL
C        SALINITY VALUE
C-------------------------------------------------------------------
C
            DO 60 I=1,22
               SHHH(I)=SH(I,K)
         60 CONTINUE
            CALL INTRPL (22,Z,SHHH,N,Z1,SH3)
            CALL CORREC(LAT,VC,N,Z1,T,SH3,L,V3,COR3)
            CALL DCRR(N,COR3,COR,ID,DCOR3,PC3)
            DO 61 I=1,N
               AP3=ABS(PC3(I))
               IF (AP3.GT.PC3TL) PC3TL=AP3
```

```
         IF (AP3.GT..25) NOFF33=NOFF33+1
   61 CONTINUE
      IF (PC3TL.GT.PC3L)  PC3L=PC3TL
      CALL STAT (N,PC3,PC3M,PC3S)
      IF (ABS(PC3M).GT.PC3ML) PC3ML=ABS(PC3M)
      IF (ABS(PC3S).GT.PC3SL) PC3SL=ABS(PC3S)
      PC33(ON)=PC3M
      PRC33=PCTG(NOFF33,N)
      IF (NOFF33.GT.0) NSOFF3=NSOFF3+1
C
C-------------------------------------------------------------
C      7. MAKE COMPUTATIONS WITH ADJUSTED HISTORICAL
C         SALINITY CURVE
C-------------------------------------------------------------
C
      ADJ=S(1)-SH3(1)
      DF=30.0-Z1(1)
      DO 71 I=1,N
         IF (Z1(I).GE.30.0) GO TO 70
         SH4(I)=SH3(I)+ADJ*(30.0-Z1(I))/DF
         GO TO 71
   70    SH4(I)=SH3(I)
   71 CONTINUE
      CALL CORREC(LAT,VC,N,Z1,T,SH4,L,V4,COR4)
      CALL DCRR(N,COR4,COR,ID,DCOR4,PC4)
      DO 72 I=1,N
         AP4=ABS(PC4(I))
         IF (AP4.GT.PC4TL) PC4TL=AP4
         IF (AP4.GT..25) NOFF44=NOFF44+1
   72 CONTINUE
      IF (PC4TL.GT.PC4L)  PC4L=PC4TL
      CALL STAT (N,PC4,PC4M,PC4S)
      IF (ABS(PC4M).GT.PC4ML) PC4ML=ABS(PC4M)
      IF (ABS(PC4S).GT.PC4SL) PC4SL=ABS(PC4S)
      PC44(ON)=PC4M
      PRC44=PCTG(NOFF44,N)
      IF (NOFF44.GT.0) NSOFF4=NSOFF4+1
      WRITE (6,207)
      WRITE (6,208) (Z1(I),ID(I),T(I),S(I),SH3(I),SH4(I),
     1     V(I),V1(I),V2(I),V3(I),V4(I),I=1,N)
      WRITE (6,209)
      WRITE (6,210)  (Z1(I),ID(I),COR(I),COR1(I),COR2(I),
     1    COR3(I),COR4(I),DCOR1(I),DCOR2(I),DCOR3(I),DCOR4(I)
     2    ,PC1(I),PC2(I),PC3(I),PC4(I),I=1,N)
      WRITE (6,211) N
      WRITE (6,212) NOFF11,NOFF22,NOFF33,NOFF44,PRC11,
     1    PRC22,PRC33,PRC44
      WRITE (6,213) PC1TL,PC2TL,PC3TL,PC4TL,PC1M,PC2M,
     1    PC3M,PC4M,PC1S,PC2S,PC3S,PC4S
      NOFF=NOFF11+NOFF22+NOFF33+NOFF44
      IF (NOFF.NE.0)  WRITE (6,214)
      TNO=TNO+N
      NOFF1=NOFF1+NOFF11
      NOFF2=NOFF2+NOFF22
      NOFF3=NOFF3+NOFF33
      NOFF4=NOFF4+NOFF44
      GO TO 20
C
C-------------------------------------------------------------
C      8. COMPUTE STATISTICS
C-------------------------------------------------------------
C
   80 CONTINUE
      PRC1=PCTG(NOFF1,TNO)
      PRC2=PCTG(NOFF2,TNO)
      PRC3=PCTG(NOFF3,TNO)
      PRC4=PCTG(NOFF4,TNO)
```

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```
PRCT1=PCTG(NSOFF1,ON)
PRCT2=PCTG(NSOFF2,ON)
PRCT3=PCTG(NSOFF3,ON)
PRCT4=PCTG(NSOFF4,ON)
CALL STAT (ON,PC11,PC11M,PC11S)
CALL STAT (ON,PC22,PC22M,PC22S)
CALL STAT (ON,PC33,PC33M,PC33S)
CALL STAT (ON,PC44,PC44M,PC44S)
WRITE (6,215)
WRITE (6,216)
WRITE (6,217) TNO,NOFF1,NOFF2,NOFF3,NOFF4,PRC1,PRC2,
1    PRC3,PRC4,ON,NSOFF1,NSOFF2,NSOFF3,NSOFF4,PRCT1,
2    PRCT2,PRCT3,PRCT4
WRITE (6,218) PC1L,PC2L,PC3L,PC4L,PC1ML,PC2ML,
1    PC3ML,PC4ML,PC1SL,PC2SL,PC3SL,PC4SL
WRITE (6,219) PC11M,PC22M,PC33M,PC44M,PC11S,PC22S,
1    PC33S,PC44S
STOP
END
```

```
C
C  ----------------------------------------------------------------
C
C      SUBROUTINE MEAN1
C
C  ----------------------------------------------------------------
C
       SUBROUTINE MEAN1 (J,N,K,Z,P,AVE,ID,L)
C
C      SUBROUTINE MEAN1 MAKES A WEIGHTED AVERAGE OF PARAMETER
C          P, USING SUBROUTINE LAYER1 FOR  COMPUTATION OF
C          THE WEIGHTS.
C
C
C      MEANING OF THE PARAMETERS:
C      INPUT:
C          "J"   - FLAG; AVOID RECOMPUTATION OF THE WEIGHTS IF
C                       THEY HAVE BEEN COMPUTED BEFORE.
C                  =0 IF SUBROUTINE HAS NOT YET BEEN USED
C                       WITH THE SAME WEIGHTS.
C                  =1 (OR DIFFERENT THAN ZERO) IF SAME
C                       WEIGHTS ARE TO APPLY.
C          "N"   - NUMBER OF OBSERVATIONS.
C          "K"   - =2N-1 - DIMENSION OF ARRAYS AVE, ID, L
C          "Z"   - ARRAY FOR THE DEPTH. DIMENSION N.
C                     Z(1) MUST BE ZERO.
C          "P"   - ARRAY FOR THE QUANTITY TO BE AVERAGED.
C                     DIMENSION N.
C
C      OUTPUT:
C          "AVE"- AVERAGE ARRAY. WILL CONTAIN THE WEIGHTED
C                     AVERAGE FOR EACH DEPTH GIVEN AND ALSO
C                     FOR EACH INTERMEDIATE DEPTH. DIMENSION K.
C          "ID"  - INTERMEDIATE DEPTH. DIMENSION K (SEE
C                     SUBROUTINE LAYER1).
C          "L"   - LAYERS. DIMENSION K (SEE SUBROUTINE
C                     LAYER1).
C
       REAL ID,L
       DIMENSION Z(N),P(K),AVE(K),ID(K),L(K),R(43)
       IF (J.NE.0) GO TO 300
          CALL LAYER1(N,K,Z,L,ID)
   300 CONTINUE
       SUM=0.D0
       AVE(1)=P(1)
       DO 301 I=2,K
          J=IFIX(FLOAT(I+1)/2.)
          R(I)=P(J)
          SUM=SUM+L(I-1)*R(I)
          AVE(I)=SUM/ID(I)
   301 CONTINUE
       RETURN
       END
```

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```
C
C-------------------------------------------------------------
C   SUBROUTINE LAYER1
C-------------------------------------------------------------
C
      SUBROUTINE LAYER1 (N,K,Z,L,ID)

C     SUBROUTINE LAYER1 COMPUTES THE INTERMEDIATE DEPTHS
C         OF A GIVEN WATER COLUMN AND THE LAYERS BETWEEN
C         THEM.  IT DIFFERS FROM SUBROUTINE LAYER BY
C         CONSIDERING EACH GIVEN DEPTH AS AN INTERMEDIATE
C         DEPTH.
C
C     MEANING OF THE PARAMETERS:
C     INPUT:
C         "N"   - NUMBER OF DEPTHS GIVEN.
C         "K"   - =2N-1 - NUMBER OF INTERMEDIATE DEPTHS.
C                 DIMENSION OF ARRAYS L, ID.
C         "Z"   - ARRAY FOR THE DEPTH. DIMENSION N.
C                 Z(1) MUST BE ZERO.
C
C     OUTPUT:
C         "L"   - LAYERS IN BETWEEN EACH INTERMEDIATE DEPTH.
C                 K-1 LAYERS ARE CONSIDERED.
C         "ID"  - INTERMEDIATE DEPTHS.  BOTH EACH GIVEN
C                 DEPTH AND HALF-WAY IN BETWEEN TWO
C                 SUCCESSIVE GIVEN DEPTHS ARE CONSIDERED.
C                 ID(1) IS THE SURFACE AND ID(K)THE LAST
C                 GIVEN DEPTH. DIMENSION K.
      REAL ID,L
      DIMENSION Z(N),ID(K),L(K)
      M=N-1
      DO 401 I=1,M
      J=2*I
      ID(J)=(Z(I)+Z(I+1))/2.
      IF (ID(J).EQ.700.) ID(J)=750.
  401 CONTINUE
      DO 402 I=1,N
      J=2*I-1
      ID(J)=Z(I)
  402 CONTINUE
C     LAYERS
      L(1)=ID(2)
      J=J-1
      DO 403 I=2,J
      L(I)=ID(I+1)-ID(I)
  403 CONTINUE
      RETURN
      END
```

```
C -----------------------------------------------------------------
C        SUBROUTINE LAYER
C -----------------------------------------------------------------
C
C
       SUBROUTINE LAYER (N,Z,L,ID)
C
       SUBROUTINE LAYER COMPUTES THE INTERMEDIATE DEPTHS
C          OF A GIVEN WATER COLUMN AND THE LAYERS BETWEEN
C          THEM. IT DIFFERS FROM LAYER1 BY NOT CONSIDERING
C          THE GIVEN DEPTHS AS INTERMEDIATE DEPTHS.
C
C       MEANING OF THE PARAMETERS:
C       INPUT:
C          "N"  - NUMBER OF DEPTHS GIVEN.
C          "Z"  - ARRAY FOR THE DEPTH. DIMENSION N.
C                    Z(1) MUST BE ZERO.
C
C       OUTPUT:
C          "L"  - ARRAY FOR THE LAYERS. DIMENSION N.
C          "ID" - ARRAY FOR THE INTERMEDIATE DEPTHS.
C                    DIMENSION N.
       REAL ID,L
       DIMENSION Z(N), L(N), ID(N)
C
C       FIND INTERMEDIATE DEPTHS ID
C
       M=N-1
       DO 501 I=1,M
          ID(I)=(Z(I+1)+Z(I))/2.
  501 CONTINUE
       ID(N)=Z(N)
C
C       FIND LAYERS
C
       L(1)=ID(1)
       DO 502 I=2,N
          L(I)=ID(I)-ID(I-1)
  502 CONTINUE
       RETURN
       END
```

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```
C------------------------------------------------------------
C      SUBROUTINE CORREC
C------------------------------------------------------------
C
      SUBROUTINE CORREC (LAT,VC,N,Z,T,S,L,V,COR)
C
C     SUBROUTINE CORREC COMPUTES THE DEPTH CORRECTIONS
C        DUE TO VARIATIONS IN SOUND SPEED.IT USES
C        SUBROUTINE WILSON TO COMPUTE SOUND VELOCITY
C        AT DEPTH Z, AND APPLIES THE CORRECTIONS TO THE
C        ASSUMED SOUND SPEED VC. CORRECTIONS ARE DETERMINED
C        BY LAYERS L AND SUMMED ALGEBRAICALLY TO GIVE THE
C        CORRECTION AT THE BOTTOM OF EACH LAYER.
C
C     MEANING OF THE PARAMETERS:
C     INPUT:
C        "LAT"- LATITUDE IN DEGREES.
C        "VC" - SOUND SPEED ASSUMED IN THE FATHOMETER.
C        "N"  - NUMBER OF DEPTHS GIVEN.
C        "Z"  - ARRAY FOR THE DEPTH. DIMENSION N.
C               Z(1) MUST BE ZERO.
C        "T"  - ARRAY FOR THE TEMPERATURE. DIMENSION N.
C        "S"  - ARRAY FOR THE SALINITY. DIMENSION N.
C
C     OUTPUT:
C        "V"  - ARRAY FOR THE SOUND SPEED. DIMENSION N.
C        "COR"- ARRAY FOR THE CORRECTIONS. DIMENSION N.
C
      REAL L,LC
      DIMENSION Z(N),T(N),S(N),L(N),COR(N),V(N)
      FAC(VI)=(VI-VC)/VC
      CALL WILSON (LAT,Z(1),T(1),S(1),V(1))
      LC=L(1)*FAC(V(1))
      COR(1)=LC
      DO 600 I=2,N
         CALL WILSON (LAT,Z(I),T(I),S(I),V(I))
         LC=L(I)*FAC(V(I))
         COR(I)=COR(I-1)+LC
  600 CONTINUE
      RETURN
      END
```

```
C
C -------------------------------------------------------------------
C      SUBROUTINE DCRR
C -------------------------------------------------------------------
C
       SUBROUTINE DCRR (N,COR1,COR,ID,DCOR,PC)

       SUBROUTINE DCRR GIVES THE DIFFERENCES BETWEEN
C          THE DEPTH CORRECTIONS OBTAINED BY A PARTICULAR
C          METHOD AND A REFERENCE METHOD.
C
C      MEANING OF THE PARAMETERS:
C      INPUT:
C          "N"   - NUMBER OF DEPTHS GIVEN.
C          "COR1"- ARRAY FOR THE CORRECTIONS FROM THE
C                   METHOD USED. DIMENSION N.
C          "COR" - ARRAY FOR THE CORRECTIONS FOR THE
C                   REFERENCE METHOD. DIMENSION N.
C          "ID"  - INTERMEDIATE DETHS TO WHICH THE CORRECTIONS
C                   APPLY. DIMENSION N.
C
C      OUTPUT:
C          "DCOR"- ARRAY FOR THE DIFFERENCE IN THE
C                   CORRECTIONS. DIMENSION N.
C          "PC"  - PERCENTEGE OF THE DIFFERENCE TO
C                   THE DEPTH.
C          "PC"  - ARRAY FOR THE PERCENTAGE OF THE
C                   DIFFERENCE TO THE DEPTH.DIMENSION N.
C
       REAL ID
       DIMENSION COR1(N),COR(N),ID(N),DCOR(N),PC(N)
       DO 700 I=1,N
           DCOR(I)=COR1(I)-COR(I)
           PC(I)=DCOR(I)/ID(I)*100.
   700 CONTINUE
       RETURN
       END
```

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```
C
C----------------------------------------------------
C      SUBROUTINE STAT
C----------------------------------------------------
C
       SUBROUTINE STAT (M,A,MEAN,STDEV)
C
C      SUBROUTINE STAT COMPUTES THE MEAN AND STANDARD
C          DEVIATION OF THE ARRAY A, WHICH HAS M ELEMENTS
C
C      DIMENSION MUST BE ASSIGNED IN MAIN PROGRAM FOR ARRAY A
C
       DIMENSION A(M)
       REAL MEAN
C
C      COMPUTE MEAN
C
       IF (M.GT.1) GO TO 800
           MEAN=A(1)
           STDEV=0.
           RETURN
  800  SUM=0.
       DO 801 I=1,M
           SUM=SUM+A(I)
  801  CONTINUE
       MEAN=SUM/FLOAT(M)
C
C      COMPUTE STANDARD DEVIATION
C
       SUM=0.
       DO 802 J=1,M
           TERM=(A(J)-MEAN)**2
           SUM=SUM+TERM
  802  CONTINUE
       STDEV=SQRT(SUM/FLOAT(M-1))
       RETURN
       END
```

```
C----------------------------------------------------------------
C
C      SUBROUTINE WILSON
C----------------------------------------------------------------
C
C      SUBROUTINE WILSON (LAT,Z,T,S,C)
C
C      SUBROUTINE WILSON COMPUTES THE SOUND VELOCITY IN WATER
C         USING WILSON'S EQUATION (1960). THE EQUATIONS USED
C         IN THIS SUBROUTINE WERE EXTRACTED FROM "USER'S
C         GUIDE TO NODC'S DATA SERVICES (NOAA,DEPARTMENT
C         CF COMMERCE,1974).
C
C      THE PRESSURE USED IN THIS EQUATION IS COMPUTED IN
C         AN ITERATIVE PROCESS ALONG DEPTH. THE SUBROUTINE
C         SHOULD BE CALLED SEQUENTIALLY FOR THE DIFFERENT
C         DEPTHS, STARTING FROM THE SURFACE (Z=0).
C
C      MEANING OF THE PARAMETERS:
C      INPUT:
C         "LAT"- LATITJDE IN DEGREES.
C         "Z"  - DEPTH.
C         "T"  - TEMPERATURE.
C         "S"  - SALINITY.
C
C      OUTPUT:
C         "C"   - SOUND SPEED.
C
       T2=T**2
       T3=T**3
       T4=T**4
       S2=S**2
       S3=S**3
       IF (Z.NE.0.) GO TO 900
          P1=10.1325
          P=P1
          OLAT=FLOAT(LAT)/100.
          X=COS(2.*OLAT*3.1415927/180.)
          Z1=0.
   900 CONTINUE
C
C      COMPUTATION OF JENSITY
C
       F1=-(T-3.98)**2*(T+283.)/(503.57*(T+67.26))
       F2=1.0843E-6*T3-9.8185E-5*T2+4.7867E-3*T
       F3=1.667E-8*T3-8.164E-7*T2+1.803E-5*T
       F=6.76786136E-6*S3-4.82496140E-4*S2+8.14876577E-1*S
       DC1=3.895414E-2
       DC2=-0.22584586
C
       SGMT=F1+(F+DC1)*(1.-F2+F3*(F+DC2))
C
C      COMPUTATION OF PRESSURE
C
       SGM0=-9.3445863E-2+8.14876577E-1*S-4.8249614E-4*S2+
      1   6.7678614E-6*S3
       SGM02=SGM0**2
       G0=0.980616-2.5928E-3*X+6.9E-6*X**2
       GI=G0+1.101E-7*(Z+Z1)
       I=0
       TP=P1
   901 TP2=TP**2
       TP3=TP**3
       R=1.-(4.886E-6*TP/(1.+1.83E-5*TP))+TP*(-2.2072E-7+
      1   3.673E-8*T-6.53E-10*T2+4.E-12*T3+SGM0*(1.725E-8-
      2   3.28E-10*T+4.0E-12*T2)+SGM02*(-4.5E-11+1.E-12*T))+
      3   TP2*(-6.68E-14-1.24064E-12*T+2.14E-14*T2+
```

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```
      4    SGMO*(-4.248E-13+1.206E-14*T-2.E-16*T2)+
      5    SGMO2*(1.8E-15-6.0E-17*T))+TP3*1.5E-17*T
           RO=(1.+1.E-3*SGMT)/R
           IF (Z.EQ.0.) GO TO 903
           I=I+1
           IF (I.NE.1) GO TO 902
           TP=P1+RO1*GI*(Z-Z1)
           GO TO 901
  902 TP=P1+.5*(RO1+RO)*GI*(Z-Z1)
      106 IF (I.EQ.2) GO TO 901
C
  903 P=.10197*TP
C
C          SOUND SPEED EQUATION
C
           P2=P**2
           P3=P**3
           P4=P**4
           VP=1.60272E-1*P+1.0268E-5*P2+3.5216E-9*P3
      1    -3.3603E-12*P4
           VS=1.39799*(S-35.)+1.69202E-3*(S-35.)**2
           VT=4.5721*T-4.4532E-2*T2-2.6045E-4*T3+7.9851E-6*T4
           VSTP=(S-35.)*(-1.1244E-2*T+7.7711E-7*T2+7.7016E-5*P
      1    -1.2943E-7*P2+3.158E-8*P*T+1.579E-9*P*T2)
      2    +P*(-1.8607E-4*T+7.4812E-6*T2+4.5283E-8*T3)
      3    +P2*(-2.5294E-7*T+1.8563E-9*T2)+P3*(-1.9646E-10*T)
C
           C=1449.14+VP+VS+VT+VSTP
C
           P1=TP
           Z1=Z
           RO1=RO
           RETURN
           END
```

```
C
C---------------------------------------------------------------
C      SUBROUTINE INTRPL
C---------------------------------------------------------------
C
       SUBROUTINE   INTRPL(L,X,Y,N,U,V)
C
C      SUBROUTINE INTRPL IS PART OF THE IBM SCIENTIFIC
C         SUBROUTINE PACKAGE EXISTING AT THE NAVAL
C         POSTGRADUATE SCHOOL COMPUTER CENTER.
C
C INTERPOLATION OF A SINGLE-VALUED FUNCTION
C THIS SUBROUTINE INTERPOLATES, FROM VALUES OF THE FUNCTION
C GIVEN AS ORDINATES OF INPUT DATA POINTS IN AN X-Y PLANE
C AND FOR A GIVEN SET OF X VALUES (ABSCISSAS), THE VALUES OF
C A SINGLE-VALUED FUNCTION Y = Y(X).
C THE INPUT PARAMETERS ARE
C      L   = NUMBER OF INPUT DATA POINTS
C              (MUST BE 2 OR GREATER)
C      X   = ARRAY OF DIMENSION L STORING THE X VALUES
C              (ABSCISSAS) OF INPUT DATA POINTS
C              (IN ASCENDING ORDER)
C      Y   = ARRAY OF DIMENSION L STORING THE Y VALUES
C              (ORDINATES) OF INPUT DATA POINTS
C      N   = NUMBER OF POINTS AT WHICH INTERPOLATION OF THE
C              Y VALUE (ORDINATE) IS DESIRED
C              (MUST BE 1 OR GREATER)
C      U   = ARRAY OF DIMENSION N STORING THE X VALUES
C              (ABSCISSAS) OF DESIRED POINTS
C THE OUTPUT PARAMETER IS
C      V   = ARRAY OF DIMENSION N WHERE THE INTERPOLATED Y
C              VALUES (ORDINATES) ARE TO BE DISPLAYED
C DECLARATION STATEMENTS
       DIMENSION      X(L),Y(L),U(N),V(N)
       EQUIVALENCE    (P0,X3),(Q0,Y3),(Q1,T3)
       REAL           M1,M2,M3,M4,M5
       EQUIVALENCE    (UK,DX),(IMN,X2,A1,M1),(IMX,X5,A5,M5),
      1               (J,SW,SA),(Y2,W2,W4,Q2),(Y5,W3,Q3)
C PRELIMINARY PROCESSING
   10  L0=L
       LM1=L0-1
       LM2=LM1-1
       LP1=L0+1
       N0=N
       IF(LM2.LT.0)          GO TO 90
       IF(N0.LE.0)           GO TO 91
       DO 11   I=2,L0
          IF(X(I-1)-X(I))     11,95,96
   11     CONTINUE
       IPV=0
C MAIN DO-LOOP
       DO 80   K=1,N0
          UK=U(K)
C ROUTINE TO LOCATE THE DESIRED POINT
   20     IF(LM2.EQ.0)        GO TO 27
          IF(UK.GE.X(L0))     GO TO 26
          IF(UK.LT.X(1))      GO TO 25
          IMN=2
          IMX=L0
   21     I=(IMN+IMX)/2
          IF(UK.GE.X(I))      GO TO 23
   22     IMX=I
          GO TO 24
   23     IMN=I+1
   24     IF(IMX.GT.IMN)      GO TO 21
          I=IMX
          GO TO 30
```

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```
       25    I=1
             GO TO 30
       26    I=LP1
             GO TO 30
       27    I=2
C CHECK IF I = IPV
       30    IF(I.EQ.IPV)           GO TO 70
             IPV=I
C ROUTINES TO PICK UP NECESSARY X AND Y VALUES AND
C            TO ESTIMATE THEM IF NECESSARY
       40    J=I
             IF(J.EQ.1)             J=2
             IF(J.EQ.LP1)           J=LO
             X3=X(J-1)
             Y3=Y(J-1)
             X4=X(J)
             Y4=Y(J)
             A3=X4-X3
             M3=(Y4-Y3)/A3
             IF(LM2.EQ.0)           GO TO 43
             IF(J.EQ.2)             GO TO 41
             X2=X(J-2)
             Y2=Y(J-2)
             A2=X3-X2
             M2=(Y3-Y2)/A2
             IF(J.EQ.LO)            GO TO 42
       41    X5=X(J+1)
             Y5=Y(J+1)
             A4=X5-X4
             M4=(Y5-Y4)/A4
             IF(J.EQ.2)             M2=M3+M3-M4
             GO TO 45
       42    M4=M3+M3-M2
             GO TO 45
       43    M2=M3
             M4=M3
       45    IF(J.LE.3)             GO TO 46
             A1=X2-X(J-3)
             M1=(Y2-Y(J-3))/A1
             GO TO 47
       46    M1=M2+M2-M3
       47    IF(J.GE.LM1)           GO TO 48
             A5=X(J+2)-X5
             M5=(Y(J+2)-Y5)/A5
             GO TO 50
       48    M5=M4+M4-M3
C NUMERICAL DIFFERENTIATION
       50    IF(I.EQ.LP1)           GO TO 52
             W2=ABS(M4-M3)
             W3=ABS(M2-M1)
             SW=W2+W3
             IF(SW.NE.0.0)          GO TO 51
             W2=0.5
             W3=0.5
             SW=1.0
       51    T3=(W2*M2+W3*M3)/SW
             IF(I.EQ.1)             GO TO 54
       52    W3=ABS(M5-M4)
             W4=ABS(M3-M2)
             SW=W3+W4
             IF(SW.NE.0.0)          GO TO 53
             W3=0.5
             W4=0.5
             SW=1.0
       53    T4=(W3*M3+W4*M4)/SW
             IF(I.NE.LP1)           GO TO 60
             T3=T4
```

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```
          SA=A2+A3
          T4=0.5*(M4+M5-A2*(A2-A3)*(M2-M3)/(SA*SA))
          X3=X4
          Y3=Y4
          A3=A2
          M3=M4
          GO TO 60
   54     T4=T3
          SA=A3+A4
          T3=0.5*(M1+M2-A4*(A3-A4)*(M3-M4)/(SA*SA))
          X3=X3-A4
          Y3=Y3-Y2*A4
          A3=A4
          M3=M2
C DETERMINATION OF THE COEFFICIENTS
   60     Q2=(2.0*(M3-T3)+M3-T4)/A3
          Q3=(-M3-M3+T3+T4)/(A3*A3)
C COMPUTATION OF THE POLYNOMIAL
   70     DX=UK-P0
   80     V(K)=Q0+DX*(Q1+DX*(Q2+DX*Q3))
          RETURN
C ERROR EXIT
   90     WRITE (6,2090)
          GO TO 99
   91     WRITE (6,2091)
          GO TO 99
   95     WRITE (6,2095)
          GO TO 97
   96     WRITE (6,2096)
   97     WRITE (6,2097)    I,X(I)
   99     WRITE (6,2099)    L0,N0
          RETURN
C FORMAT STATEMENTS
 2090 FORMAT(1X/22H   ***    L = 1 OR LESS./)
 2091 FORMAT(1X/22H   ***    N = 0 OR LESS./)
 2095 FORMAT(1X/27H   ***    IDENTICAL X VALUES./)
 2096 FORMAT(1X/33H   ***    X VALUES OUT OF SEQUENCE./)
 2097 FORMAT(6H    I =,I7,10X,6HX(I) =,E12.3)
 2099 FORMAT(6H    L =,I7,10X,3HN =,I7/
    1          36H ERROR DETECTED IN ROUTINE    INTRPL)
          END
```

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