Processing EASTROPAC STD Data and the Construction of Vertical Temperature and Salinity Sections by Computer

FORREST R. MILLER and KENNETH A. BLISS

National Marine Fisheries Service, Circulars

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337. Program of Division of Economic Research, Bureau of Commerecial Fisheries, fiscal year 1969. By Division of Economic Research. April 1970, iii + 29 pp., 12 figs., 7 tables.

338. Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska. By Bureau of Commercial Fisheries. June 1970, 8 pp., 6 figs.

339. Salmon research at Ice Harbor Dam. By Wesley J. Ebel. April 1970, 6 pp., 4 figs.

340. Bureau of Commercial Fisheries Technological Laboratory, Gloucester, Massachusetts. By Bureau of Commercial Fisheries. June 1970, 8 pp., 8 figs.

341. Report of the Bureau of Commercial Fisheries Biological Laboratory, Beaufort, N.C., for the fiscal year ending June 30, 1968. By the Laboratory staff. August 1970, iii + 24 pp., 11 figs., 16 tables.

342. Report of the Bureau of Commercial Fisheries Biological Laboratory, St. Petersburg Beach, Florida, fiscal year 1969. By the Laboratory staff. August 1970, iii + 22 pp., 20 figs., 8 tables.

343. Report of the Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas, fiscal year 1969. By the Laboratory staff. August 1970, iii + 39 pp., 28 figs., 9 tables.

344. Bureau of Commercial Fisheries Tropical Atlantic Biological Laboratory progress in research 1965-69, Miami, Florida. By Ann Weeks. October 1970, iv + 65 pp., 53 figs.

346. Sportsman's guide to handling, smoking, and preserving Great Lakes coho salmon. By Shearon Dudley, J. T. Graikoski, H. L. Seagran, and Paul M. Earl. September 1970, iii + 28 pp., 15 figs.

347. Synopsis of biological data on Pacific ocean perch, *Sebastodes alutus*. By Richard L. Major and Herbert H. Shippen. December 1970, iii + 38 pp., 31 figs., 11 tables.

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David Starr Jordan lowering a STD probe.

(Drawing by Dale Mann)

CONTENTS

Figures

Appendix Figures

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ABSTRACT

During the EASTROPAC expeditions the STD (salinity-temperature-depth recorder) was established as the principal instrument for obtaining detailed profiles of temperature and salinity to depths exceeding 1,000 m. The STD system recorded data in digital form on magnetic tape and required computer processing to provide accurate temperatures and salinities at 1-m intervals for each hydrographic station.

Procedures for processing STD data from pre-processed digital logger tapes are described. Also included is a discussion of processing temperatures and salinities from the STD analog charts or from Nansen cast data when the digital data logger was not operative. Essential calibration of STD data from Nansen cast data is outlined. Finally, a computer program which prepares a final, annotated STD tape, with corrected temperatures and salinities, is described in great detail.

Another computer program was developed to provide for the EASTROPAC Atlas representative vertical sections of temperatures and salinities extracted from the final STD tapes. Details of computer methods employed to analyze and contour STD data are presented, and they are followed by an outline of computer requirements and program limitations.

The STD provided many detailed profiles along cruise tracks in the eastern tropical Pacific with an accuracy approaching those taken by Nansen casts; but it created new problems in processing oceanographic data. The problems, their solutions and recommendations are presented for those who may benefit from many months of processing STD data from EASTROPAC cruises.

INTRODUCTION

The EASTROPAC expeditions (1967-68) to the eastern tropical Pacific have provided the most extensive and continuous coverage of oceanographic and meteorological conditions ever obtained. Three multi-ship survey (summer and winter) cruises, linked by single-ship monitor cruises, probed the ocean depths with an electronic STD[1] (salinity-temperature-depth

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[1] The Appendix contains a brief description of the STD and its operation.

1

recorder) at unprecedented frequency. Six research vessels from the United States occupied stations which established the STD as the principal instrument for obtaining temperature and salinity data. The STD stations along the major cruise tracks, identified in EASTROPAC Information Papers 6, 8, 9, and 10 (Longhurst 1967, 1968, 1969a, and 1969b) and described briefly in the next section, have provided oceanographers with data of such a high degree of accuracy and vertical resolution that the microstructure of water masses in the eastern tropical Pacific could be examined in greater detail than was possible heretofore with conventional bathythermograph or Nansen cast data.

OBSERVATIONS

During the EASTROPAC cruises STD casts were completed from one side of a research vessel and followed by a Nansen cast from the opposite side for all primary stations on which complete hydrographic and biological observations were made. This procedure provided Nansen bottle temperatures and salinities, at 12 depths for 500-m casts and up to 20 depths for 1000-m casts, to compare with STD data. The STD analog profile of the water column (Fig. 1) was used at each station for determining the desired placement, relative to the thermocline, of Nansen bottles on the cable.

EASTROPAC stations were occupied at regular intervals along lines of longitude of various lengths between lat 20° N and 20° S. Stations were also occupied along diagonals and east-west lines connecting the major lines of longitude. The stations were designated A, B, and C, depending upon the types of observations made and the depths obtained. In most cases, stations were occupied every 20 nautical miles in the following order: A, C, B, C, A, C, B, C, etc. Between lat 5° N and 5° S, an additional "C" station was occupied between an "A" and "B" station. Characteristically, a 1000-m STD cast was made on all "A" stations, a 500-m cast on all "B" stations, and either a 300-m XBT (expendable bathythermograph) or 300-m STD cast on all "C" stations. In an area of special interest or between major lines of longitude, a 300-m or 500-m STD cast was made.

Lowering rates of the STD sensor were established to minimize irregular salinity val-
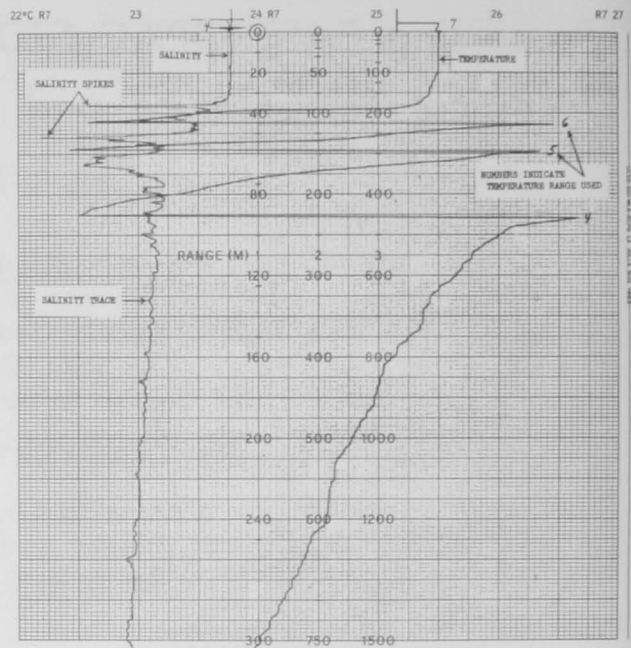
Figure 1.—Reproduction of original STD analog trace made on EASTROPAC Cruise 20, Station 208, on May 15, 1967 (lat 02°25′ S, long 104°56′ W). The salinity trace (on the left) shows "spikes" in the thermocline where temperature trace (on the right) shows rapid decrease with depth (frequent switchback of temperature trace).

ues. This was especially important through the thermocline where the STD sensor could not compensate quickly to the effect of rapid temperature changes on conductivity. Through experimentation, at various drop rates, satisfactory results were obtained at 35 m/min through the thermocline to approximately 200 m, and at 75 m/min at deeper levels.

DATA PROCESSING

Because the STD system was designed to record data at high rates in digital form on magnetic tape, processing of the digital data logger (DDL) tapes has been carried out by computer. The initial data processing of approximately 38 STD field tapes, collected during EASTROPAC, into 17 tapes (hereafter called intermediate tapes) of smoothed profiles of temperature and salinity at 1-m intervals was described by Jones (1969). The sections which follow discuss in detail the procedures, both manual and automated, which have evolved over many months of techniques developed for processing STD data from intermediate tapes into

corrected final data tapes, and thereafter, the construction of vertical sections of temperature and salinity.

Processing Data From a Digital Data Logger

The STD system is designed to be used with a digital data logger. The data logger records the data accurately and eliminates the tedious process of picking off inflection points of temperature and salinity from the analog trace and interpolating between points at 1-m intervals. If, for example, the STD probe is lowered to 500 m, the complete cast would consist of an STD tape record of depth, temperature, and salinity for each meter of depth extracted from the DDL tape, as well as a visual interpretation of the same data by means of an analog trace.

Computer printouts of the intermediate STD tapes have clearly shown that the ideal cast was rarely obtained. More commonly, the upper and/or lower few meters of data were missing on tape and occasionally half or nearly all of the data were missing. For this reason a computer program referred to as TAPEMOD was developed to fill in data at the missing levels. There were five types of corrections used in this program, depending on where and how much data were missing. They were designated by code as types 0 and 1 corrections for only a few surface and lower levels missing, types 2 and 3 for several lower and upper levels missing, and type 4 for the entire DDL record missing on tape. In a very few instances, anomalous data on tape had to be replaced. (This was done in a special section of the program.) Types 0 and 1 were internal corrections made by extrapolating temperature and salinity between two depths (specified on computer data control cards). Types 2, 3, and 4 were external corrections made by inserting data cards (containing temperatures and salinities) derived from an interpolation program. These corrections and the interpolation program will be discussed in greater detail in subsequent sections.

Processing Data From Analog Traces

On several EASTROPAC cruises a digital data logger was not used or it was inoperative

at least part of the time. In these situations the STD data were recorded only on the analog traces. Occasionally the entire STD system failed to operate so that Nansen casts provided the only data for determining temperatures and salinities. Fortunately, most of the STD data were recorded on tape in digital form and subsequently processed directly onto an intermediate data tape at 1-m intervals.

An analog trace of temperature and salinity vs depth was produced as the STD sensor was lowered (Fig. 1). Several points of inflection were manually picked off the temperature and salinity traces; these points were selected to describe adequately the temperature and salinity structure of that particular column of water. In the region of a sharp thermocline, particular care was needed in extracting data points. In this region, the temperature scale changes rapidly, which results in a nearly horizontal temperature trace compressed over a small change in depth. (Fig. 1 illustrates a typical sharp thermocline.) A data point was usually extracted at the top, midway through, and at the bottom of the thermocline. If the temperature gradient was not particularly severe, one or two additional data points were extracted in the thermocline.

The salinity trace in Figure 1 illustrates a feature called "spiking" which was frequently found in a sharp thermocline. This anomalous feature resulted when the STD sensor passed through a strong temperature gradient. This situation required reconstructing the trace by penciling in a revised profile line which either eliminated a single spike entirely or averaged adjacent spikes. Data at inflection points were then extracted from the penciled line. Depths, temperatures, and salinities extracted from each trace were subsequently punched onto IBM data cards. A computer program described in the following section used these data cards to interpolate between inflection points the depth, temperature, and salinity at 1-m interval.

The Interpolation Program

Prior to EASTROPAC the Inter-American Tropical Tuna Commission had developed a computer program to interpolate temperatures and salinities to standard depths. Because this program incorporated established mathematical

procedures for interpolating Nansen cast data to conform to typical profiles, it was adapted for use with STD data. A mathematical description of the interpolation scheme is presented by Forsbergh and Broenkow (1965). A general description of the interpolation program, as adapted for EASTROPAC, is as follows:

1. Depths, temperatures, and salinities extracted from STD analog traces or from Nansen cast data in the absence of STD traces are read into the computer from tape or card decks with one set of data and a header record for each station to be interpolated.

2. From information entered into the computer on control cards, the levels for which interpolation is to be performed are set up for each station.

3. Before the interpolation begins, thermosteric anomalies are computed for all of the levels for which the initial observations are entered. If there exists a subsurface maximum of temperature, the temperature profile (water column) is divided into three regions. Region 1 extends from the surface to the depth of maximum temperature or thermosteric anomaly. Region 2 lies between the depth of maximum temperature and the midpoint of the maximum temperature gradient in the thermocline. Region 3 includes all depths below the mid-thermocline depth. When no inversions exist in the mixed layer and the highest temperature is at the surface, the water column consists of Regions 2 and 3.

4. Temperature gradients are computed between successive pairs of temperatures from the surface to the lowest depth. The maximum temperature gradient is found and a depth, temperature, and thermosteric anomaly for the midpoint of maximum gradient is found by linear interpolation.

5. Interpolations at 1-m depth intervals of temperatures and thermosteric anomalies are computed for the upper and lower regions by a logarithmic equation. When a surface temperature and/or salinity is missing or a subsurface temperature maximum exists, the apparent surface values are determined by logarithmic extrapolation.

6. After all temperatures and thermosteric anomalies have been interpolated, the potential density anomalies are computed from the interpolated thermosteric anomalies. Finally, the interpolated salinities (at 1-m intervals) are determined by an iterative computational procedure using a transformed potential density anomaly equation (sixth degree polynomial) where the salinity is the only unknown. The initial value of salinity is set at 35‰ for the iteration.

The interpolated data are punched on cards or put onto tape by program option. The computer output also includes a printer listing of observed and interpolated values of temperature, salinity, potential density and stability (variation of potential density anomaly with depth). In addition, profiles of temperature vs. depth and temperature vs. salinity are printed. The printer output provides quality control information for determining the acceptability of the interpolations.

Each set (station) of observed data is interpolated from the uppermost to lowest required depths, and the data written on the output tape before the program loops back to work on another set. Copies of this program (FORTRAN source language) and a detailed write-up of its operation are available at the National Marine Fisheries Service (NMFS), La Jolla, Calif.

Calibrating STD Data

The STD data interpolated at 1-m intervals and stored on the intermediate tape were calibrated at selected levels against corresponding data of the Nansen cast. Two levels were chosen for calibration, one at the surface and the other at approximately 400 m. The latter seemed to be sufficiently below the thermocline to eliminate anomalous "spikes" (see Fig. 1) which sometimes appeared on the analog traces where there were strong temperature gradients. Temperature and salinity differences between STD data and Nansen data were calculated at each level and plotted against a sta-

tion number. At the 400-m level, a running average of the differences was plotted (Figs. 2 and 3). From these plots correction factors were determined by the least squares method and punched onto each station identification card (described in the next section). Every temperature and salinity value recorded on the intermediate tape was modified according to the signs and magnitudes of the corrections. The anomalous surface temperature and sa-

Figure 2.—Plot of temperature differences between digital data logger (DDL) and Nansen data at approximately 400 m. A correction factor, derived from a running average of nine values of temperature difference, is applied to the DDL temperatures. In this plot a correction of $+0.17°$ C is applied for stations 006 to 016 and a correction of $+0.07°$ C for stations 018 to 052.

Figure 3.—Plot of salinity differences between digital data logger (DDL) and Nansen data at approximately 400 m. One or more correction factors are derived from a running average of nine salinity difference values and applied to the DDL salinities. In the above plot, a correction of $-0.040‰$ is applied for stations 006 to 008 and a correction of $-0.015‰$ for stations 0170 to 052.

linity values on tape were corrected in the TAPEMOD program to correspond to those obtained from the surface calibration curves.

Preparation of the Final STD Tape

During the development of the computer programs to process STD data it became apparent that data on the intermediate tapes for each cruise had missing temperatures and salinities at the top and/or bottom of most of the casts. In addition, small temperature and salinity corrections were needed to correct nearly all STD data so that they would be consistent with Nansen data. Therefore, it was decided to prepare a final STD tape which incorporated the temperature and salinity corrections and the missing data. Furthermore, for proper identification of each set (station) of data, time, date, and location annotations were required at the beginning of each data set. Procedures for obtaining corrections and missing data have been described in the previous sections. The remainder of this section will describe the preparation and format of a final, annotated STD data tape. The format of the STD final tape was developed through a coordinated effort of the EASTROPAC staff from the NMFS, La Jolla, and Scripps Institution of Oceanography. Representatives of the National Oceanographic Data Center, Washington, D.C., were consulted as to their requirements for archiving of STD data on magnetic tapes and their distribution.

The STD data for each station of a cruise consisted of a separate file on the tape. Each tape contained as many files as there were usable STD casts taken during a cruise. The number of files (stations) of STD data was not recorded on the tape. However, EASTROPAC Information Papers No. 6, 8, and 9 indicate which stations have STD data on tape and the lowest depth reached on each cast.

Each file of STD data consists of three computer records written on tape in hyper-density (800 bits per inch) as described below. A partial computer printout of STD data for a station from the final tape is shown in Figure 4.

1. Record one contains, in binary-coded-decimal (BCD) form, the latitude, longitude, date, time (at beginning of STD cast) and
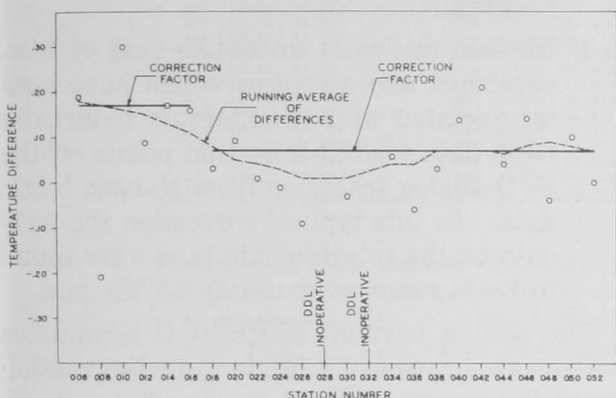
5

the depths between which modifications or additions were made.

2. Record two consists of two binary words giving, in order, the EASTROPAC station number followed by the lowest depth to which a usable cast was recorded.

3. Record three contains, in binary format, all depths, temperatures and salinities, in sequence, for each meter of depth from the surface to lowest depth recorded.

The computer program, TAPEMOD, which prepares a final tape, consists of three parts which run in sequence through each file of data from the first station to the last in a cruise. The first part of the program reads in program control data cards which designate the stations and inclusive depths that require modifications or additions. The first set of control cards contains, in ascending order, the station numbers and types of correction for each station. These are followed by a second set of control cards specifying the upper and lower levels to which the corrections are to be applied. Following these two sets of control cards is a set of station identification cards. There is a card for each STD station containing cruise number, station number, date, time, latitude, longitude, and the temperature and salinity correction factors. The first part of the program is concluded when the major program loop is entered and the STD data on the intermediate tape for a station is stored in the computer's memory.

The second part of TAPEMOD consists of determining from control data which type of modification, if any, is to be applied for a station to fill in missing data or replace existing data. Five types of corrections were described earlier; each is designed to perform one of the following functions:

1. Insert missing temperatures and salinities from input data at one or more 1-m levels from the surface downward for cases where the top of the mixed layer is not isothermal and/or isohaline. In all isothermal and isohaline cases, the program automatically fills in missing data upward from the first valid depth with data.

2. Interpolate internally missing temperatures and salinities between two predes-

ignated (by control cards) depths where the desired temperatures and salinities have been obtained from STD analog traces or Nansen cast data. This type of correction can be made between any two depths of the STD cast.

3. Insert missing temperatures and salinities which have been interpolated externally between given depths. These data are read into the program from tape or cards which were generated by the interpolation program.

4. Replace or insert an entire cast of temperatures and salinities which have been interpolated at 1-m intervals externally from data read at inflection points off the STD analog traces or from Nansen bottle data. In this type of correction the STD data on the intermediate tape were found to be in error over nearly all the cast.

The second part of TAPEMOD terminates with an application of a single valued correction for each temperature and another for each salinity—the values of which are predetermined and applied at all depths. If no corrections are to be applied for a station, the appropriate columns on the station location card are left blank.

In part three of this program, the salinity profiles are smoothed for a second time. The first smoothing of temperature and salinity profiles is accomplished when the intermediate tape is prepared (Jones, 1969). Additional smoothing of salinity profiles is accomplished in TAPEMOD using a step function filter developed by Taft and Jones at the Scripps Institution of Oceanography. The filter consists of a tapered running mean which smooths out the peaks (spikes) on the salinity profile and leaves the end points of each spike with very little alteration. Several filters were tested with EASTROPAC STD data.

Finally, the completed and corrected STD cast of data is written on the final tape in three records as described above. The top and bottom 50 m of data are listed by computer together with the station annotation record as shown in Figure 4. These listings serve as quality checks for the computer processing.

The program repeats the steps described above station by station until an entire cruise

STATION NO. 20 208   303 METERS IN DEPTH

FOR 15- 5-67 AT   800L ,LAT. -225n S LONG.104560 MAN-INTRP.   OTC   OM.; FINAL TAPE

VALUES INTERPOLATED AT 1 METER INTERVALS

DEPTH	TEMP	SALN	DEPTH	TEMP	SALN	DEPTH	TEMP	SALN	DEPTH	TEMP	SALN
(M)	(0C)	(0/00)	(M)	(0C)	(0/00)	(M)	(0C)	(0/00)	(M)	(0C)	(0/00)
0	25.34	35.213	1	25.34	35.213	2	25.34	35.213	3	25.34	35.213
4	25.34	35.213	5	25.30	35.211	6	25.29	35.211	7	25.28	35.211
8	25.27	35.211	9	25.30	35.211	10	25.37	35.211	11	25.39	35.211
12	25.40	35.212	13	25.39	35.212	14	25.39	35.212	15	25.40	35.213
16	25.40	35.214	17	25.39	35.214	18	25.38	35.215	19	25.34	35.214
20	25.36	35.214	21	25.37	35.214	22	25.35	35.213	23	25.33	35.212
24	25.31	35.211	25	25.30	35.211	26	25.29	35.211	27	25.28	35.207
28	25.27	35.201	29	25.26	35.194	30	25.23	35.182	31	25.19	35.170
32	25.13	35.165	33	25.06	35.165	34	24.86	35.170	35	24.65	35.163
36	24.45	35.151	37	24.04	35.179	38	23.63	35.132	39	23.17	35.127
40	22.70	35.123	41	22.56	35.123	42	22.42	35.124	43	22.28	35.119
44	22.14	35.113	45	22.00	35.099	46	21.89	35.106	47	21.77	35.114
48	21.66	35.114	49	21.55	35.102	50	21.44	35.089			
253	12.28	34.885	254	12.27	34.885	255	12.26	34.883	256	12.26	34.881
257	12.25	34.883	258	12.24	34.879	259	12.23	34.877	260	12.22	34.877
261	12.21	34.877	262	12.21	34.878	263	12.20	34.879	264	12.20	34.880
265	12.20	34.882	266	12.19	34.883	267	12.19	34.883	268	12.18	34.884
269	12.17	34.884	270	12.16	34.884	271	12.16	34.884	272	12.15	34.884
273	12.14	34.884	274	12.13	34.883	275	12.12	34.883	276	12.11	34.883
277	12.11	34.883	278	12.10	34.883	279	12.10	34.882	280	12.09	34.882
281	12.06	34.881	282	12.05	34.881	283	12.04	34.881	284	12.04	34.880
285	12.04	34.883	286	12.03	34.878	287	12.04	34.877	288	12.03	34.875
289	12.02	34.873	290	12.01	34.872	291	12.00	34.871	292	11.98	34.870
293	11.98	34.869	294	11.97	34.868	295	11.96	34.868	296	11.93	34.867
297	11.91	34.865	298	11.91	34.870	299	11.90	34.871	300	11.90	34.873
301	11.90	34.874	302	11.88	34.875						

Figure 4.—Partial computer printout of STD data for Cruise 20, Station 208, on May 15, 1967 (lat 02°25′ S, long 104°56′ W) as compiled on magnetic tape. The upper and lower 50 m are printed for an initial data quality check. The above calibrated data and analog data (Fig. 1) were taken simultaneously.

of STD data has been processed. As soon as a final tape has been written it is ready for use in constructing vertical sections of temperature and salinity. Vertical sections for selected stations (up to 54 stations per section) are constructed by a computer program described in the next section. There are available for reference at the NMFS Southwest Fisheries Center, La Jolla, complete 1-m listings of temperature and salinities for each station and all cruises. Listings of STD data for selected stations from the final magnetic tape can be obtained also for a small computer charge.

CONSTRUCTION OF VERTICAL SECTIONS BY COMPUTER

The Computer Program

A computer program was developed to provide a rapid and accurate means of constructing vertical cross sections of sea temperatures and salinities (Figs. 5 and 6) observed at stations along cruise lines. Although this program was designed to use STD data recorded on magnetic tape, other versions also are being used on the EASTROPAC Project, to contour other physical, biological, and chemical data obtained from Nansen bottle samples. The entire program is written in FORTRAN language used for compilation into computer language by the CDC 3600 computer. This FORTRAN language is compatible with the FORTRAN IV language used by other large scale scientific computers. The analyses are generated by computer, but the drawing of contours is done by a CalComp Plotter.

The program consists of a main part with the acronym VACOST (vertically analyzed contours of oceanographic salinities and temperatures) and two subprograms referred to as CONTRA and CONTRB. In VACOST temperatures and salinities for selected stations are read from magnetic tape into the computer's memory. The STD data are arranged into four two-dimensional arrays by station and depth. The four arrays consist of sets of temperatures and salinities which are subdivided into two arrays: one array contains temperatures or salinities for 0- to 300-m depths at 2-m intervals; the other array contains temperatures or salinities for depths from 300 to 500 m or to 1000 m at 5-m intervals. The temperature data are contoured from two arrays first while salinity data are temporarily stored on a computer disk file. After the temperature contour
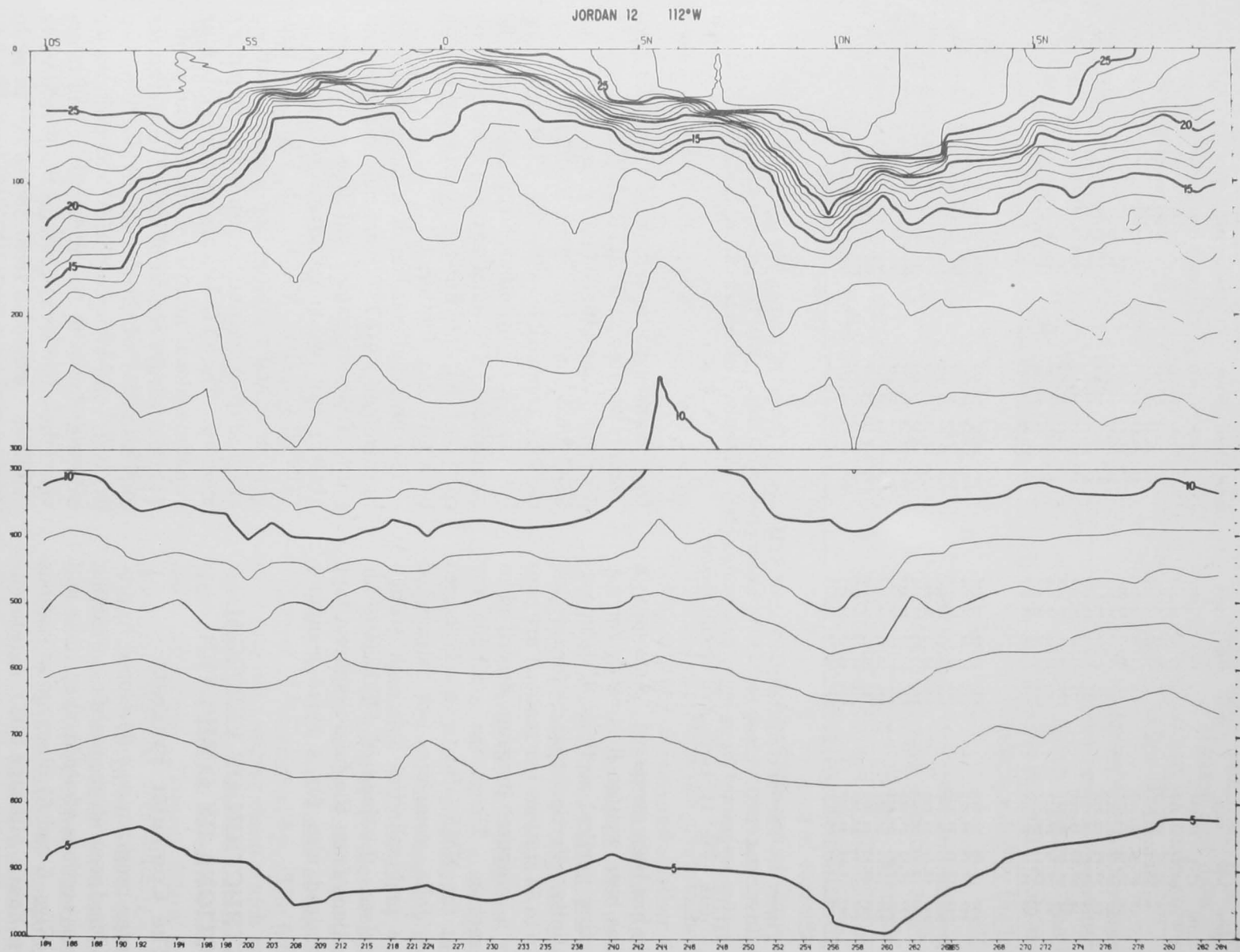
Figure 5.—Computer-drawn vertical section of temperature from STD data taken aboard the National Marine Fisheries Service RV *David Starr Jordan* on EASTROPAC Cruise 12 along long 112° W from lat 20° N to 10° S during February 1967. Isotherms, chart borders, and labels were constructed in the computer and drawn by CalComp Plotter. A draftsman relabeled and widened every fifth contour.

Figure 6.—Computer-drawn vertical section of salinities from STD data taken aboard the National Marine Fisheries Service RV *David Starr Jordan* on EASTROPAC Cruise 12 along long 112° W from lat 20° N to 10° S during February 1967. Isotherms, chart borders, and labels were constructed in the computer and drawn by CalComp Plotter. A draftsman relabeled and widened every fifth contour.

analysis is complete, salinities replace the temperatures in the same data array. The computer's memory size limits the program to using not more than 54 stations of data during one run.

Once an array of data is properly stored the program transfers control to the subprogram CONTRB, where the contour analysis is performed. First, the locations of isotherms (1° C interval) for the 0- to 300-m and 300- to 1000-m sections are determined, and CalComp Plotter commands are generated and written on a plotter (magnetic) tape. Then in a second pass through the program, locations of contours of salinities (isosals at 0.1‰ salinity) are determined, and appropriate CalComp commands are stored on the plotter tape following those for temperature.

The location of preselected contours in an array of data is performed in the CONTRB subprogram by means of a search routine. The boundaries or edges of each array are searched to find the beginning of a contour (if one begins at an edge). The search is continued inward from the edges using a four-point data subset, i.e., the data in the array for two consecutive stations and two depths, until an opposite boundary is reached or the contour closes on itself. When the end point of a contour is found, the search continues throughout the array to determine if there are other contours with the same value. This procedure is continued until the locations of all selected contours have been found in the array. The contour search routine is described in more detail in the next section.

The specific location of a contour within an array of data is given initially in terms of grid-point values which are referenced by depth and station number. When a contour falls between two grid points, a linear interpolation is made to find the exact grid location.

Plotting the Contours

The construction of the isotherms and isosals is done mechanically by means of the Cal-Comp Plotter whose commands for constructing the frame of the sections, and printing latitude and station numbers, are generated in subprogram CONTRA. The vertical sections are variable in length, depending on the number of stations used. For the EASTROPAC

Project the longest vertical sections have been drawn along specified meridians between lat 20° N and 20° S, and they are from 35 to 40 inches in length. Each vertical section is divided into two parts: the upper section consists of the contours from the surface to 300 m with a fixed vertical distance of 11.86 inches (scale: 10 m = 1 cm); and the lower section of contours extends from 300 m to 1000 m with a fixed vertical distance of 13.79 inches (scale: 20 m = 1 cm). There is a 0.6-inch break between the upper and lower parts of the section. The locations of stations are marked by ticks and numbers between the section break and along the base of the lower section.

The CalComp Plotter draws contours by receiving, in sequence from magnetic tape, the horizontal and vertical distances of points along a contour as measured from a predesignated origin which is located in the lower left corner of a vertical section. Since the plotter requires incremental distances between points in inches, transformations from grid distances to actual chart distances in inches are completed before the plotter tape is written. Because the stations are not uniformly spaced, the horizontal distances are also rescaled. All scaling and transforming of the contour locations are completed as soon as the grid locations of a single contour are found within an array of data points. The transformed locations of all contours having the same value are stored on the plotter tape along with plot commands before a contour with a different value is located.

In order to space the stations properly along the horizontal axis of each vertical section, the program requires information giving the distances between each station—for the EASTROPAC expeditions the horizontal distance is 60 nautical miles equal to 3 cm in distance. After reading STD data from tape, the computer reads in a set of data cards with the properly scaled distances between the stations used for a particular section. These distances are in inches; they are computed in another computer program which reads the latitude and longitude of each station from a station location card and computes the number of nautical miles and scaled distances in inches from one station to the next. (At a later date it may be possible to use the latitudes and longitudes as read from the first record of each station on the final STD

data tape to compute the distances between stations.) The input data giving distances between stations also contain the station numbers to be used to label the stations at the bottom of each vertical section. Also, the distances, in inches, between 5-degree-latitude marks are read into the program for scaling the 1-degree tick mark onto the section.

The Contour Search Routine

The description of the contour search routine which follows does not reveal every step in logic followed by the subprogram CONTRB in locating and following the path of a contour through an array of data. Rather, the general scheme, which is used repeatedly, is outlined in a descriptive form. It is not possible to determine from this description alone the program logic without reference to the computer program. However, the program logic is not unique, and it is possible to write another subprogram using a similar search routine as used in CONTRB—but with other variations in the search patterns through and around a cell.

It is important to note that this contour routine yields good results because: (1) a simple search and linear interpolation scheme is used in a manner which simulates that used by an analyst; (2) the search is very fast because no attempt is made to use high order polynomial curve or surface fitting, which does require considerable computer time; and (3) the array of data is completely contourable without any modification. When the data array is formed, the contour analysis consists only in finding the location of selected isotherms or isosals.

Each contour with a value (VC) is located within the array of M by N data points (Fig. 7) by the following computer program steps:

1. Set the value (VC) of a temperature or salinity contour and enter CONTRB subprogram with the location of the data array "V", the number of stations (M), and the number of depths (N) in the data array to be contoured.

2. Search the outer edges of the array for the crossing of the contour (VC). If no crossing can be found on the outer edges, continue to search around and inward toward the center until a crossing is found.
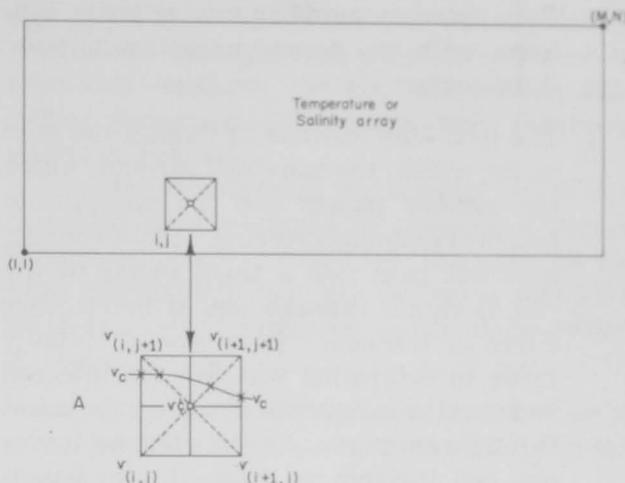

Figure 7.—A schematic diagram of a two-dimensional array of (M by N) data values of temperature or salinity formed in the computer prior to performing the contour analysis. A single cell (7A) within the array consists of data grid points for two adjacent stations and two consecutive depths. The location of a contour v_c within the cell is referenced from the lower left (i, j) coordinate. The (x) points represent crossing points at two edges and two diagonals passing through the center of the cell.

If no crossing is found, return to the main program. A check is made while moving through the array to assure that the boundaries are not being exceeded.

3. Once a contour crossing along an edge of a four point data subset (cell) between two adjacent stations is found, the search continues across the cell. The cell is divided into four equal sectors as shown in figure 7A; and the value at the center of the cell is found by

$$v_c' = \tfrac{1}{4} \ (v_{i,j} + v_{i+1,j} + v_{i+1,j+1} + v_{i,j+1})$$

where the subscripted (v) values represent data points of temperature or salinity at the four corners of a cell. By determining the edge of the cell through which a contour crosses, the sector of the cell into which the contour passes is marked. The proper indexing parameters for location are determined, and the next contour point is found by a linear interpolation along the diagonal from the nearest corner to the center of the cell (v_c'). The sector entered is marked by placing a (1) in a location of the array (KK) reserved for keeping track of cells already entered.

This prevents running two or more contours with the same value through the same sector.

4. The next step consists of finding the next sector within the same cell through which the contour passes and the appropriate points of diagonal crossing. If the contour does not pass into a third sector of the cell, it passes through one of three other edges of the cell. Tests are continually made to determine whether the intercell movement continues or the contour passes through an edge. As the contour leaves one cell through an edge, it also passes into an adjacent cell; and the steps described above are repeated. Three or four location points are found for each contour within a cell.

5. The search routine continues from cell to cell until a boundary of the array is reached or the beginning of the contour is again reached, i.e. the contour closes on itself. The program control returns again to the main program where the value of the next contour to be found is assigned and control returns again to CONTRB.

6. Before the location points of each contour are written on the plotter tape with appropriate plotter commands, the x (horizontal) and y (vertical) points along each contour are rescaled from grid values to inches from the plot origin. Finally, a running three-point smoother (with central point weighting) is applied to remove small irregularities which may be imposed on contours by not having a continuous field of data.

The program also prints out in an array the values of temperatures and salinities used during the contour analyses (optional).

Computer Requirements and Restrictions

1. Size and type: A medium or large-scale scientific computer similar to the CDC 3600 with a 32,000 word or greater memory core is required.

2. Source language: FORTRAN-63 for the CDC 3600 or a compatible FORTRAN IV language is used. (It may be necessary to modify some FORTRAN statements if FORTRAN IV is required as a source language.)

3. Tape drives: To compile the FORTRAN source program into machine language, two or more tape drives are used. At the time of execution, one magnetic tape drive is required to store CalComp commands and contour data points, and one scratch tape or disk file is used to store salinities.

4. Output equipment: A CalComp (30-inch drum) incremental (resolution: 100 increments/inch) Plotter, model 723, a tape drive, and a converter unit are required. Computer printer is needed to list out the temperatures and salinities which are being contoured. (An array format is optional.)

Computer Program Data Limitations

1. Core memory size must be 32,000 words or greater.

2. The product of the two dimensions of a data array times four must not exceed 32,000 because of a logic routine used in CONTRB for contour search.

3. The width of a vertical section cannot exceed 29.5 inches, but it may be any desired length.

4. A single analysis cannot use more than 54 stations of data because of memory size. However, two analyses can be run and spliced together by using the same station data for the last of one section and the first of the following section.

Library Subroutines Required

1. CalComp subprograms as described by California Computer Products, Inc. These subroutines are usually on the library tape at installations using the CalComp Plotter.

2. Standard Share type mathematic subroutines as: negative zero test, tape rewind and file skipping, tape read/write routines, print routines, arc tan function, minimum function of a number, and square root function.

Computer and Plotter Timing

1. To analyze contours at intervals of (1° C) for temperature and (0.1‰) for salinity from the surface to 1000 m for 50 stations requires approximately 4.5 min of computer time on the CDC 3600.

2. To plot the contour analyses in two separate plots for the dimensions described in 1 above requires 25 min of CalComp 30-inch plotter time.

CONCLUSIONS

The STD afforded oceanographers on EASTROPAC an opportunity of observing accurately and rapidly temperatures and salinities to great depths. Many oceanographic features only partially observed or understood from Nansen bottle or BT data have been documented and analyzed in great detail. The environmental conditions for the study of fishery ecology have become more definitive partly because of the STD.

While the STD has provided detailed profiles of water columns with an accuracy approaching that of Nansen cast data, it has created some new problems in processing, displaying and archiving oceanographic data. Most of the STD data processing and computer programming was begun in the last quarter of 1967, except for the initial computer work done by Jones (1969). The National Marine Fisheries Service, which was the principal funding agency during the EASTROPAC cruises, also provided most of the funds for data processing. Since processing large amounts of STD data on magnetic tape had never been carried out before, considerable expenditures in money and man hours have been devoted to the development of a procedure, involving both manual and computer techniques, which would insure accurate results with minimum personnel involvement.

Due to the enormous quantity of STD data collected from the ETP area and to unforeseen programming difficulties that eventually occurred, a great deal of manual effort as well as computer time was necessary to generate the data quality that was finally achieved. In the early stages, processing centered around program development followed by a quality inspection of the field tape printouts. As processing progressed through each step, as outlined in preceding sections, various unforeseen difficulties were continually encountered requiring program revisions.

In order to minimize the manual effort and computer time required in processing future STD data, it is recommended that users of the STD adhere strictly to the following standard STD shipboard procedures and those described in Appendix A:

1. Lower sensor through the thermocline to about 200 m at a rate not exceeding 35 m/min.

2. To insure the STD has reached the desired depth, determine the actual depth obtained with the sensor by reading the frequency control panel. Inaccurate pen setting on the analog trace will produce inaccurate depth readings.

3. Allow a sufficient warm-up period, at least 15 min, for the sensor and recorder. This precaution will generally eliminate the recording of anomalous data in the surface levels.

4. Check the pen positions on the analog charts with bucket temperature and salinograph to insure proper initial positioning.

The procedures described in this paper are not unique and there may be other simpler or more complicated approaches; but wherever magnetic tape is used it is recommended that: (1) the tapes be of high quality; (2) large numbers of corrections should be programmed onto tape; and (3) the final STD data tapes should be well annotated and written with fairly uniform record lengths in a density mode of 556 bits per inch. Higher data density modes on magnetic tape may increase the cost of processing tapes when computer tape units are slightly out of adjustment.

Most of these recommendations were incorporated into the STD operating procedures before the EASTROPAC cruises were completed. However, it should be emphasized that if a digital data logger is not used and if operating procedures are not closely followed, the processing of STD data into useful information which can be profiled or contoured into sections will be very tedious and expensive. The STD

system is designed to be used with a digital data logger, and the correct use of the entire system will provide data tapes which are easy to process.

The initial set of vertical sections of temperature and salinity produced by computer are preliminary contour analyses from which the analyst can determine the accuracy of STD data for each station as related to adjacent stations. Large irregularities in the data are revealed graphically in the contour patterns of the vertical sections. The smaller irregularities and subtle changes in salinity can be examined in detail by reconstructing the vertical sections by computer using different contour intervals. Final computer-drawn vertical sections, which incorporate all desired changes in the STD data records, have been prepared for the EASTROPAC Atlas with only minor alterations being applied to the sections by a draftsman.

ACKNOWLEDGMENTS

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APPENDIX

OPERATION OF THE STD SYSTEM

By

RAYMOND E. SHUEY[2]

The Bissett-Berman, *in situ* Salinity/Temperature/Depth (STD) data system[3] is an ensemble of underwater sensors lowered by an armored single-conductor cable. The sensor's operating voltage is sent down the cable from the power supply section of the deck unit.

Salinity measurement utilizes an inductive probe to measure conductivity of which the final readout is in parts per thousand. Temperature is measured with a sensing element which is a fast-response, platinum resistance thermometer. Depth is measured with a platinum strain gauge.

Sensor output signals from these three measurements (frequency modulated) are multiplexed and sent up the single-conductor cable. A set of discriminators in the deck unit separate and convert the three FM signals into d-c analog voltages. The signals continue to a digital data logger (DDL) unit which scans all sensors and then records in computer-compatible format onto magnetic tape. The analog signals are plotted on an x_1, x_2, -y recorder with salinity and temperature presented as functions of depth. The chart is its own function as it advances thus recording depth. Prior to making an STD cast, the following procedure is followed:

1. The recorder and sensor power-supply switches (Appendix Fig. 3) are turned on approximately 15 min in advance for warm-up.

2. The depth discriminator range is set to 0-300 m, 0-750 m, or 0-1500 m, depending on final depth desired.

3. Salinity-temperature-range switches are set to read surface values.

4. The station number is punched (inserted) on the DDL tape, and the sample interval is decided and set by a switch (sampling rate minimum of 100 m to a maximum of 16 sec).

5. The STD "fish" (Appendix Fig. 1) is lowered into the water just below the surface (Appendix Fig. 2) for a short soaking period.

6. The chart recorder (Appendix Fig. 3) is actuated with balance-motor switch.

7. The temperature pen is set on the surface line of the analog strip chart.

8. The salinity pen is set slightly above surface line to allow for pen crossing.

9. The data logger (Appendix Fig. 3) is switched on, and the cast is begun with the lowering of the fish at approximately 35 m/min.

Until the fish is below the thermocline, the temperature-range switch, and in some instances the salinity-range switch, on the discriminators will need adjusting to avoid having the pens run off the scale. When the fish is below the thermocline the lowering rate may be increased to approximately 75 m/min since water is more stable. The deck unit usually includes an electronic frequency counter which can be used to monitor any of the three sensors. When the desired depth is reached, the DDL, balance motor, and recorder are switched off. The fish is retrieved at approximately 75 m/min while depth is monitored on the frequency counter.

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[3] The system is also referred to as the salinity-temperature-depth data acquisition system, Hytech Model 9006.
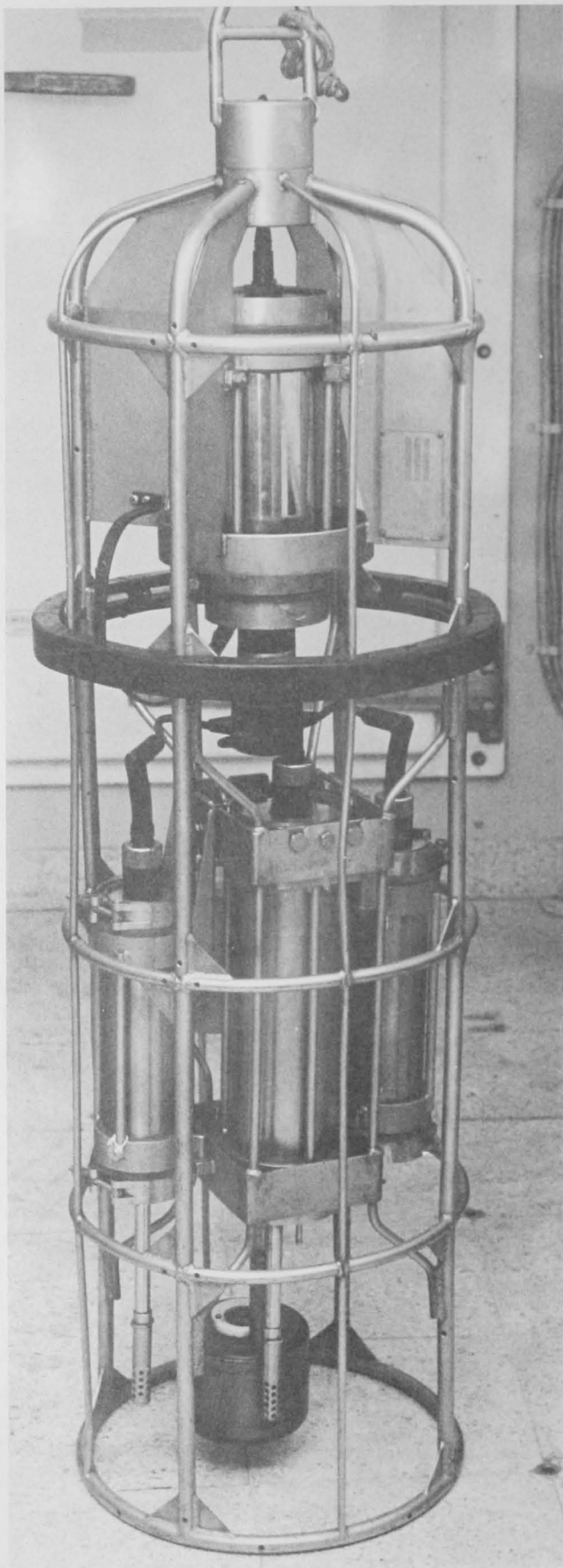
Appendix figure 1.—The STD probe unit or "fish" showing the protective cage for the temperature, depth, and salinity probes near the bottom. The probes lead into pressure cases which house the electronics. The pressure case near the top contains the multiplexing units which combine the signals and send them up the single-conductor cable.
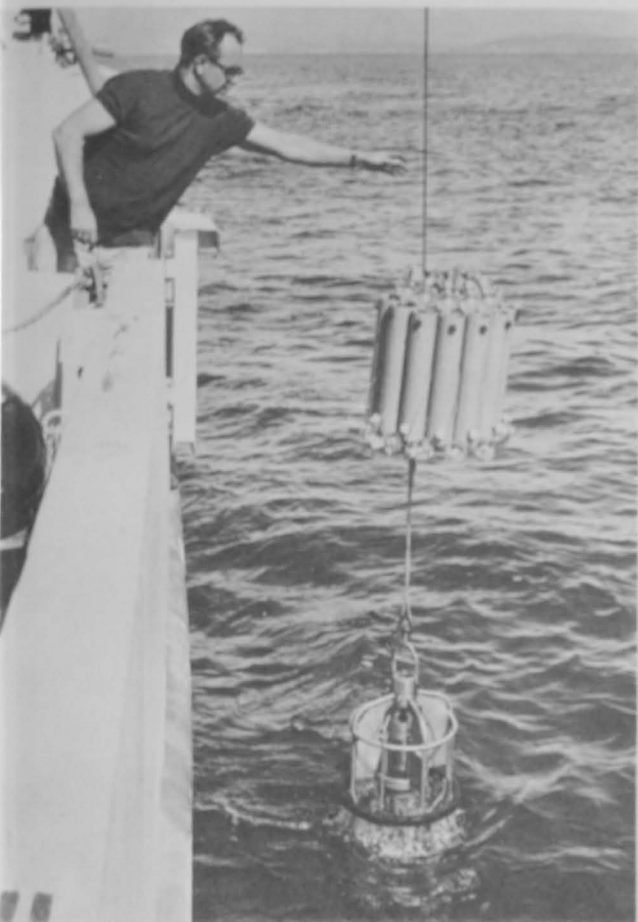
Appendix figure 2.—Lowering the fish from RV *David Starr Jordan* to a soaking position prior to starting the cast. Robert Counts of the Southwest Fisheries Center steadies the cable just above a Nisken water sampler which is attached to the STD cable for a common lowering.
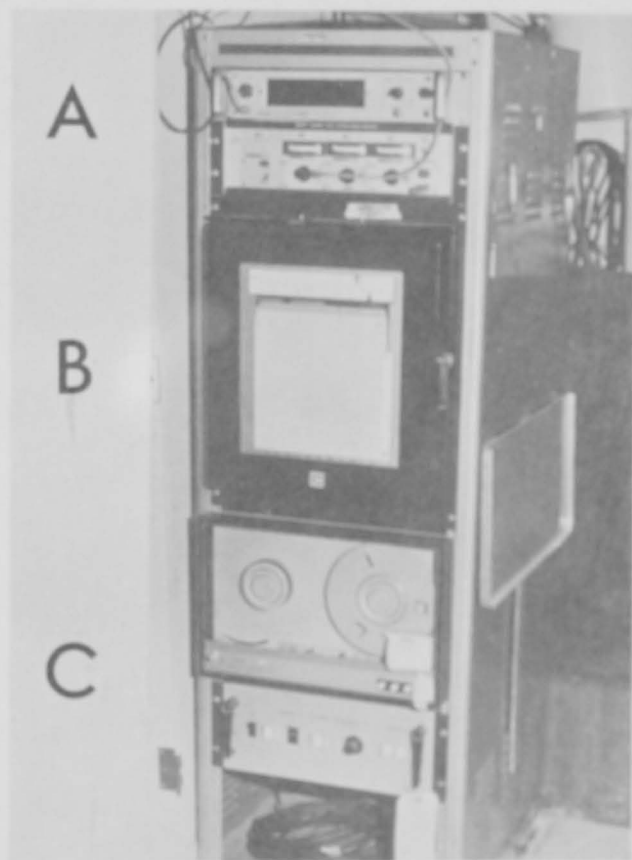
Appendix figure 3.—The STD electronic receiver unit (A), analog recorder (B), and digital data logger (C). The STD cast is monitored by frequency counters in (A) and the temperature-salinity tracer on the analog recorder. Magnetic tape mounted on the digital data logger unit records digitized signals.

at the bench scale, pilot plant, and demonstration plant levels can be easily incorporated to keep the program current with the available knowledge about each process.

Typical process flow sheets were developed with suitable options for each of the processes. These were used along with the available information on the process to prepare the material and energy balance portions of the program. Changes in flow sheets, types of equipment, processing sequences, and operating conditions, may be made following the internal program changes procedures.

From the material and energy calculations, the major items of equipment are sized and their cost estimated through built-in design and cost information. The program then determines the operating and manufacturing costs subject to the input data and internal assumptions of the model.

Two important features of the program are the built-in consistency of estimates for different processes and the continuity of estimates during the several stages of development of a given process. The uniformity of estimates results primarily from the use of a common set of equipment cost subroutines and a common set of assumptions regarding such cost items as indirect costs, land, engineering, etc. Since input data include the cost of labor, plant size, and cost indices, the program is useful in many broad-based studies of FPC production in different parts of the world at the present and in the future.

The model provides for each FPC process to be studied both internally and externally in comparison with alternate processes. Internal costs identify areas needing further research and development. The ability to estimate costs for a number of processes for a wide range of input conditions provides the broad comparison type information needed to guide a variety of research and development projects. The engineering economic model contains five process plant programs: fish meal; biological; isopropyl alcohol extraction; press cake-biological; and press cake-isopropyl alcohol extraction. Process descriptions and flow sheets are presented in the next chapter.

Fish meal processing is a common operation and there are many such plants throughout the world. Fish meal is used for animal feed while the other processes make products for human consumption. It was included to provide a basis for comparison and because frequently intermediate meal products are a starting point for the FPC processes. The other processes are viable candidates for commercial manufacture of FPC.

B. Cost Estimation

In the development and use of the model it is important to have accurate cost information. Equipment and capital cost data were obtained from a number of recent publications. These figures were compared and reviewed for consistency and accuracy. In several instances costs were adjusted to meet the actual experience of individuals knowledgeable in the field of marine protein manufacturing. Finally all costs were adjusted to the base of early 1970.

The adjustment of cost data from the past several years to an early 1970 value was made using the Marshall and Stevens Equipment Cost Index which is published in the periodical *Chemical Engineering*. The M & S Equipment Cost Index is based on a value of 100 in the year of 1926. The early 1970 base value of 297.5 is used for equipment costs in this report.

Adjustment in costs from one year to another is accomplished by multiplying the known cost by the ratio of the index values at the two years involved to obtain the desired cost. The choice of the M & S Index over several other indices that are available was based on the fact that the components used in the M & S Index are more nearly those present in FPC plants, and the general observation that all the indices have been moving at about the same rate in recent years.

Use of these indices over more than a few years leads to considerable uncertainty and is not recommended. It is hoped that users of the model will continually update the data from the best sources available and not resort to changing the cost index alone. Equipment is continually being developed and many specific items do not follow the average trends.

There is a wide variation in costs at any given time. This is due in part to the inventory and backlog situation of the individual manufacturers and suppliers. The best cost information is a written quotation for a specific item

to be purchased during a given period. In a number of instances, particularly for the IPA-Extraction process (17), quotes on equipment were available and were used in adjusting the literature data. Essentially the same thing was done, through discussions with experienced persons, for the typical fish meal process.

The capital cost estimating procedure of Guthrie (6) was used in developing the process engineering economic model. A module technique is employed in which cost elements having similar characteristics and relationships are grouped together. This grouping is discussed in the program output section. Published equipment cost information was obtained from a number of sources (6, 7, 8, 9, 10, 12, 13, 14, and 15). The cost data were fit to appropriate equations and are contained in the cost subroutine. This portion of the computer program and procedures for changing the data are discussed later in the report.

Costs of chemicals and raw materials were taken from recent issues of the *Oil, Drug and Paint Reporter* and from actual purchasing experience. Some of these are program input items and can be changed whenever the program is used. The cost of fish is quite varied and depends greatly on local conditions. Fish meal manufacturers often make contractual arrangements with the boat owners whereby the final price paid is dependent upon the income ultimately received from selling the fish meal. This input item will require close attention of the program user. The tradition of the industry of speaking in terms of fish rather than weight can also be a point of confusion. For menhaden, one million fish is taken to be 755,000 pounds of fish.

C. Process Economics

The model develops the construction, operating, and production aspects of each process subject to specific input and internal information. It does not deal with the economics of selling the products and the resulting profits and return on investment.

Each of the processes makes several products and consequently requires the managerial decisions of cost allocation to establish selling prices of products. Marketing, inventory management, product distribution, and sales con-tracting are important factors in the final decision on commercial operation. The model is intended to provide processing information upon which preliminary deliberations and decisions of the venture risk type can be made.

It is most important in using the model to recognize its limitations. Of the processes in the model only fish meal processing is a commercial operation at present. Even in this case the model attempts only to give representative information for a somewhat typical kind of plant under average conditions in the United States. Several IPA extraction plants for FPC production are under construction. The model IPA process is based on a modified analysis of the National Marine Fisheries Service Experiment and Demonstration Plant at Aberdeen, Washington. In all other instances the processes are in the early pilot plant level of development.

The model is also generally limited to use for plants handling 50 or more tons per day of fish. Modern domestic fish meal plants handle 1,000 or more tons per day and it is expected that FPC plants will be in the range of 100 or more tons per day. There is significant interest in processing FPC on board ships and developing small village industry operations. Use of the model in the 10 to 50 tons per day range will require some modification or at least close attention and judgment about the details of the output.

The model is presently applicable to coastal plants. To place one of these processes on board a ship will require significant changes. Generally space is a limiting factor on board ship and the processes would need to be redesigned for compactness. Special modifications to the ship could be costly, while certain land operation requirements, such as pollution control, might be eliminated, resulting in savings.

Village industry operation, and operation in foreign countries in general, will require a number of changes. The model provides for modern, instrumented, continuously operating plants. Equipment costs are for the United States and, in general, the plants are custom-made large facilities. Smaller plants, in the 10 ton per day sizes, might be mass-produced and thereby benefit from unit cost reduction much like appliances. If the appliance approach is not used on-site fabrication of village level