NOAA Technical Report OTES 10

Improved Depth Selection in the Bathymetric Swath Survey System (BS^3) Combined Offline Processing (COP) Program

Rockville, Md.
December 1982

U. S. DEPARTMENT OF COMMERCE
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John V. Byrne, Administrator

Ocean Technology and Engineering Services
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EXECUTIVE SUMMARY

BS^3 data from the August 1981 Operational Evaluation processed by the original Combined Offline Processing (COP) program failed to meet internal and external accuracy standards when compared with independent Hydroplot results.

A new version of the COP code has been developed which provides depth measurement accuracy to better than one percent of the depth for the inner 15 beams for all data sets from the April 1981 Field Experiment as well as for the Operational Evaluation. The outer six beams are believed to be better reserved for reconnaissance.

The new code has been transferred to NOS along with a totally reprocessed Operational Evaluation survey. It is recommended that this new version be henceforth used exclusively. The added computer time is minimal -- on the order of 25 percent.

Important diagnostic programs have also been developed which, if installed on the shipboard computer, could aid greatly in establishing the optimum input setup of COP and in analyzing the results.

Certain hardware problems have been identified which, if remedied, would permit the system to yield more reliable and more accurate results.

More sophisticated COP versions were developed which provided marginally improved performance at the cost of large and unacceptable increases in computer time. These have been archived for potential future interest.

CONTENTS

1.0 STATEMENT OF THE PROBLEM

The Bathymetric Swath Survey System (BS^3) utilizes the twenty-two fixed sonar beams of the Bosun sounder to scan a wide swath of up to ±50 degrees from the vertical under the survey vessel. It is believed that in this way the bathymetry/hydrography of the bottom can be better defined -- both in terms of reconnaissance and charting -- than with a single-beam, profiling system (McCaffrey 1981). The system includes heave, roll, and pitch corrections for refinement of the bottom estimates from the measured depths.

At-sea testing of the system was conducted in April 1981 and August 1981 aboard the NOAA Vessel DAVIDSON. The April "Field Experiment" in Puget Sound and off the coast of Oregon and the August "Operational Evaluation" in Alaska's Shelikof Strait provided data sets covering a wide variety of depths, topography, and sea surface conditions.

Results from the April tests validated the basic concepts and provided estimates of the depth measurement accuracy based on the totality of recorded soundings. These estimates indicated that the hardware accuracy was generally within the bounds of accepted standards for the inner beams, but that under many circumstances the noise statistics for several of the outer beams were excessively large (Pryor 1982).

The Shelikof Operational Evaluation data were processed by an operational BS^3 computer program called the Combined Offline Processor (COP). The numerous tasks of this complex code include the grouping of large numbers of soundings into geographic subsets called Sounding Arrays and Plottable Unit Areas (PUAs) and the selection of single representative depths from each PUA for output into the chart production chain.

These COP "selected soundings" were plotted as a "smooth sheet" and compared against an existing standard Hydroplot survey of the area by verifiers at the Pacific Marine Center. The accuracy of the COP selected soundings was found to be unacceptable, and the results were rejected.

Based on the earlier positive results, it was decided to attempt to upgrade the COP program in order to cause it to provide a more representative selection of soundings from those available. This report describes the techniques employed and the successful results of that upgrade.

2.0 APPROACH

2.1 General

The sounding selection criteria in original COP program were designed, in effect, for noise-free data. The very shoalest sounding in each PUA was selected and considered to be "verified" if it fell within 25 percent of the mean depth of the surrounding eight soundings. This is hardly a sufficient criterion when one considers that the accuracy standards require errors of less than roughly one percent of the depth. Selection of the shoalest sounding from a PUA guarantees a shoal depth measurement bias equal to or greater than the system noise level, because the most anomalous shoal soundings in the tail of the depth measurement noise distribution will be selected and verified. It is obvious that some kind of noise rejection procedure is required if the magnitude of the shoal bias is to be reduced.

The measurement noise arises from several independent sources. In the first place, it has been observed that some kind of interference can take place when the BS^3 is operated concurrently with other sonars. The most obvious embodiment of this problem occurs as anomalously high noise in beams ±5 and consequential large depth measurement errors which occur more or less regularly in time (at a beat frequency). This noise occurs most strongly in beams ±5 due to their unique lack of phasing circuitry (which incidentally acts to filter out much of the stray interference in other beams). Some unknown hardware problem has also had a more subtle and hence more potentially damaging effect on soundings from other beams such as ±3, in particular, which seem to act strangely at times.

Secondly, soundings with anomalously high or low return signal strengths have exhibited a propensity for severe depth biases -- both shoal and deep. Thirdly, the hardness of the bottom affects the acoustic penetration and can cause significant apparent depth variations (as was noted in the Bellingham data from the April Field Experiment).

Fourthly, the basic measurement uncertainty of the system varies significantly from beam to beam. It is increasingly large for the outer beams for which propagation and bottom reflection geometry cause severe temporal pulse stretching and associated pulse location uncertainty. It is the tail of this noise distribution which is most important and difficult to exclude from the set of COP-selected soundings. The computer code must also, however, be configured to be insensitive to all the other stray noise sources, or conversely, to be able to recognize and reject them.

2.2 Diagnostics

In order to solve problems, it is first necessary to recognize them. The COP program itself provided few clues as to data character or to how soundings became selected. A number of diagnostic programs and routines have been developed to permit detailed analyses of the relationships among data functionalities, intermediate results, and subsequent COP outputs, and to intercompare results against external and internal standards.

The most useful of these programs for continued useage are COPEDO, COPSTA, and COPMAT. COPEDO generates an output tape which, when read by

KOPOUT, produces a complete listing of the information associated with every beam return of every ping. This is very useful in identifying anomalous behavior and acts as a reference in which suspicious COP-selected soundings may be examined in detail. The drawback is that it consumes great amounts of computer time and paper, and hence may be run only over short, selected data segments.

COPSTA produces time series and histograms of data from single, specified beams. The time series can be used to determine whether or not the data from that beam is reasonable or excessively noisy due to some unrecognized noise process. This information can be used in a decision to summarily reject the data from certain offending beams. The program was modified to print the received signal strength as a plotter character. This permits a quick, visual correlation between depth outliers and their signal strengths; this, in turn, is an important piece of information which can be used to set the minimum acceptable signal strength threshold for COP processing.

COPMAT produces a matrix of information for every beam against every signal strength. The matrix contains the number of occurrences as well as the mean and standard deviation of depth differences between the given beam and beam 0. The occurrence rates can again be used to help set the minimum signal strength threshold on a purely statistical basis. If COPMAT is used to process data from a nearly flat, horizontal area, the depth difference statistics can be further used to set the signal strength threshold level on the basis of depth measurement biases incurred.

COP itself, in versions to be described, has been modified to permit the optional printing of the sounding array depths and a history of the selection and verification procedures. It also prints a modified set of information on the right-hand side of the vertical profile plot -- including complete time to hundredths of a second, beam number and signal strength of the selected sounding, and the number of rejects from the verification procedure for each PUA.

These programs and options could be quite useful on the ship for examining data character and recognizing problem areas. COPMAT is presently resident on the PDP 11/44 and would have to be adapted slightly to the shipboard 11/34.

2.3 Philosophy

The planned COP modification protocol is depicted in Figure 2-1. It was based upon the existence of Field Experiment data sets with a wide variety of characteristics -- depths from 100 to 2000 feet with varied topologies including flats, gentle slopes, steep slopes, and isolated peaks. The most straightforward case, Cape Disappointment, would be examined first. COP would be modified as necessary until satisfactory results were obtained. The same procedure would then be followed on successively more difficult data sets until the program could handle all data successfully. Feedback was included to insure that previous data sets were not adversely affected by subsequent changes. The resulting modified computer program would then be used to reprocess the Shelikof data for reverification at the Pacific Marine Center and be documented for use in upgrading the NOS standard operating version. This plan was successfully implemented and performed as envisioned.

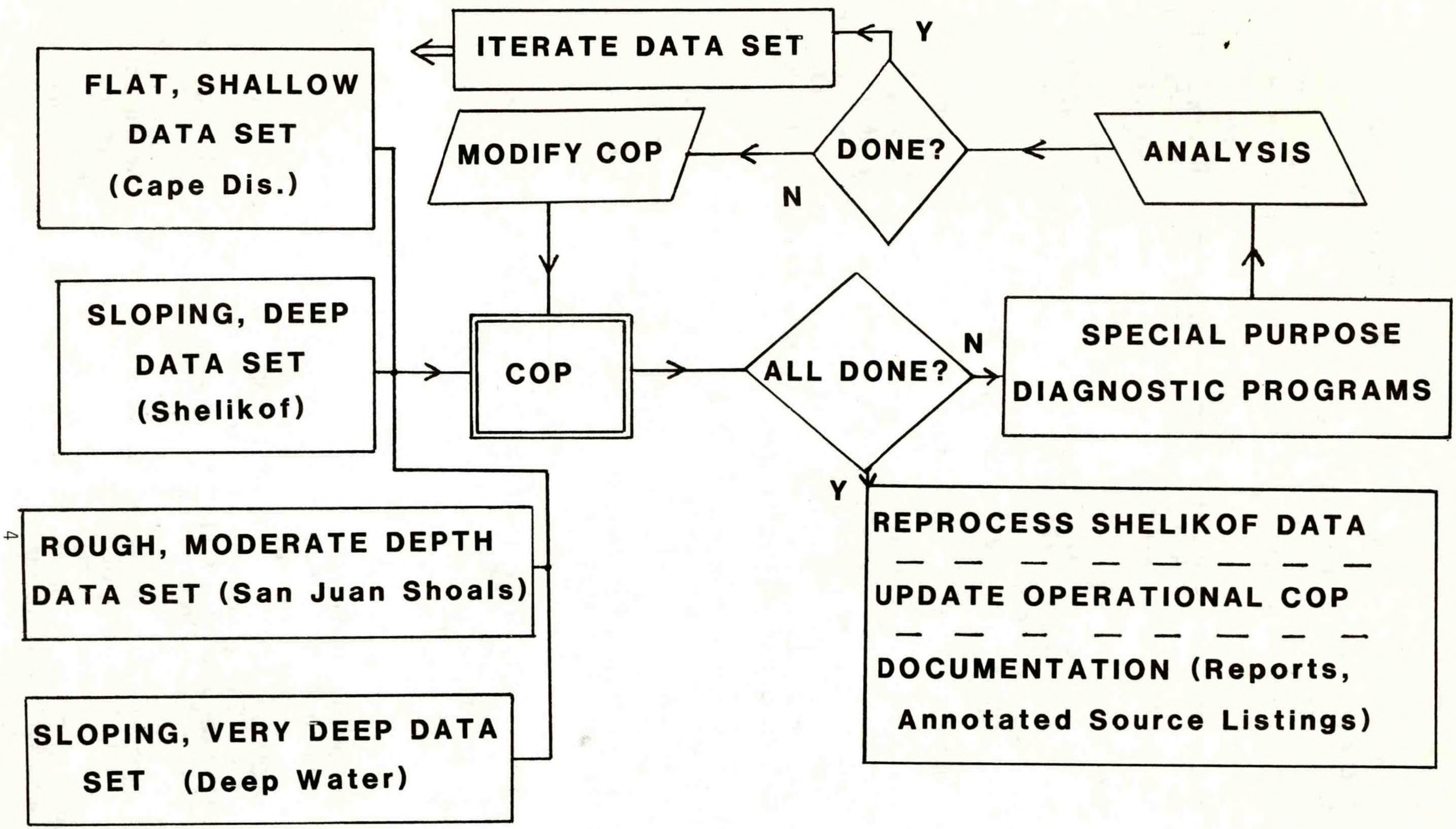


Figure 2-1. BSSS SOUNDING SELECTION ANALYSIS

2.4 Development of the "Baseline" Version

In simple terms, the COP code performs a series of operations which can be characterized as in Table 2-1. A goal of the effort was to retain this basic structure and to alter as few of the basic procedures as possible. This was, indeed, accomplished; the routines altered are marked with asterisks. The basic core of the program remains unchanged.

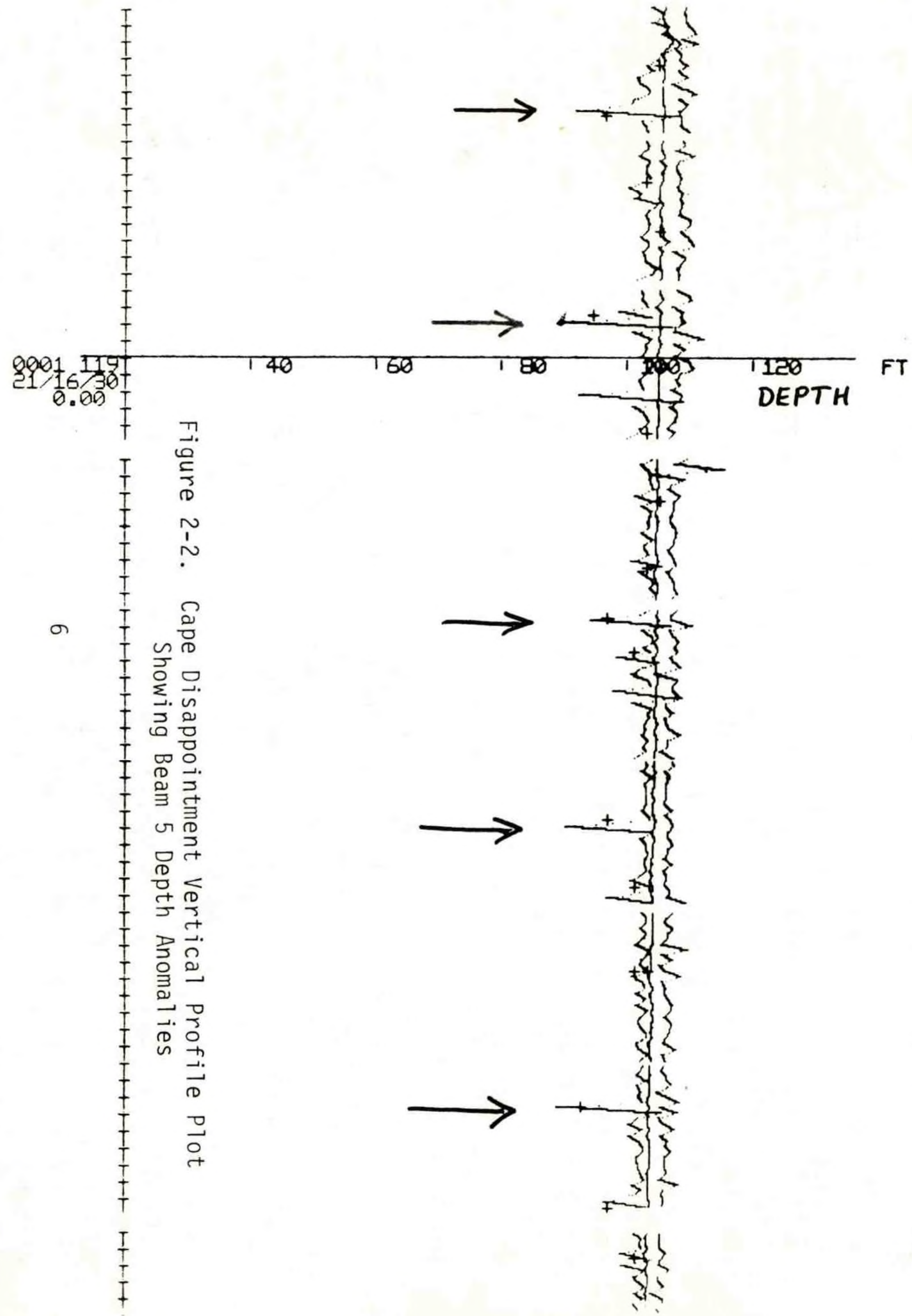
Table 2-1. Outline of COP Procedures

* Input
* Preprocessing
  Preliminary Correctors
  Build Sounding Array
  Define PUAs
* Sounding Selection
* Verification of Selected Sounding
  Final Correctors
* Output

An important requirement was that the increase in running time be kept to a minimum since typical data already required from 50 to 100 percent of the survey time for processing. This turned out to be a major stumbling block in the creation of "smarter" sounding selection and verification algorithms.

Preliminary runs on Cape Disappointment data with the "original" COP code produced noisy results as seen in Figure 2-2. It was determined by running KOPOUT on the COP output tape that the fairly regularly occurring anomalously shoal soundings all originated in beam +5 (where "+" denotes port and "-" denotes starboard). It is recognized that this beam is prone to interference from external signals due to a lack of beam directing electronics. The hypothesis is that stray signals were leaking in from the simultaneously running Ross sounder. Regardless of their origin, the anomalous soundings need to be suppressed in order for COP to perform satisfactorily. The first modification was thus the ability to arbitrarily "turn off" any beam from the input procedure. This is accomplished by converting all such data to zeros. The information printed on the right-hand side of the vertical depth profile plot was modified to include the beam number of the selected sounding as a diagnostic tool.

After turning off beam 5, the selected soundings were then seen to be dominated by outer beams -- as noted in Figure 2-3 -- because of their inherently higher noise level. (The numerals printed within the histogram are signal strengths.) Deletion of an outer beam generally leads to an increased population in the remaining outermost beams as seen for a similar case in Figure 2-4. The option to exclude beams will thus also be used to turn off as many of the noisy outermost beams as required in order to tune performance to a desired level. For cases such as this example where the noise exceeds the true athwartships bottom slope, the results will incorrectly imply that the vessel is running directly down a trough in the bottom topography. This may or may not be acceptable depending on the depth of this fictitious trough compared to the water depth. (This effect will be largely removed from the Cape Disappointment data by a later version of the code called COP6.)



TIME	REDUCED DEPTH	BEAM NUMBER	AMPLITUDE	PITCH AT ECHO	ROLL AT ECHO	POSITION DIST
21/16/12.48	104.5	-3	8	1.1	0.8	7.73
21/16/14.88	96.5	5	6	1.2	0.2	12.15
21/16/19.37	102.4	9	5	0.7	2.0	29.26
21/16/22.09	105.3	-2	8	-0.5	-2.3	6.63
21/16/27.04	93.8	5	6	0.1	1.5	12.70
21/16/33.60	103.4	-2	6	1.1	2.4	4.17
21/16/36.33	104.1	9	5	-0.1	-1.1	26.36
21/16/40.33	102.9	-3	9	-0.7	1.4	7.09
21/16/43.36	97.3	5	6	-0.4	0.1	12.19
21/16/45.77	100.0	-3	8	-0.7	-1.0	8.24
21/16/55.52	95.5	5	6	0.0	0.5	11.98
21/16/58.89	101.4	-9	6	-1.3	-0.5	28.07
21/17/03.52	103.8	6	5	-1.3	0.2	16.19
21/17/04.32	101.7	-9	5	-1.3	0.5	27.64
21/17/11.84	92.5	5	5	-0.8	0.5	11.59
21/17/17.44	97.3	-9	4	-1.0	-1.0	27.6[illegible]
21/17/19.37	100.2	-8	6	-0.9	-0.8	23.[illegible]

Figure 2-2. Cape Disappointment Vertical Profile Plot Showing Beam 5 Depth Anomalies

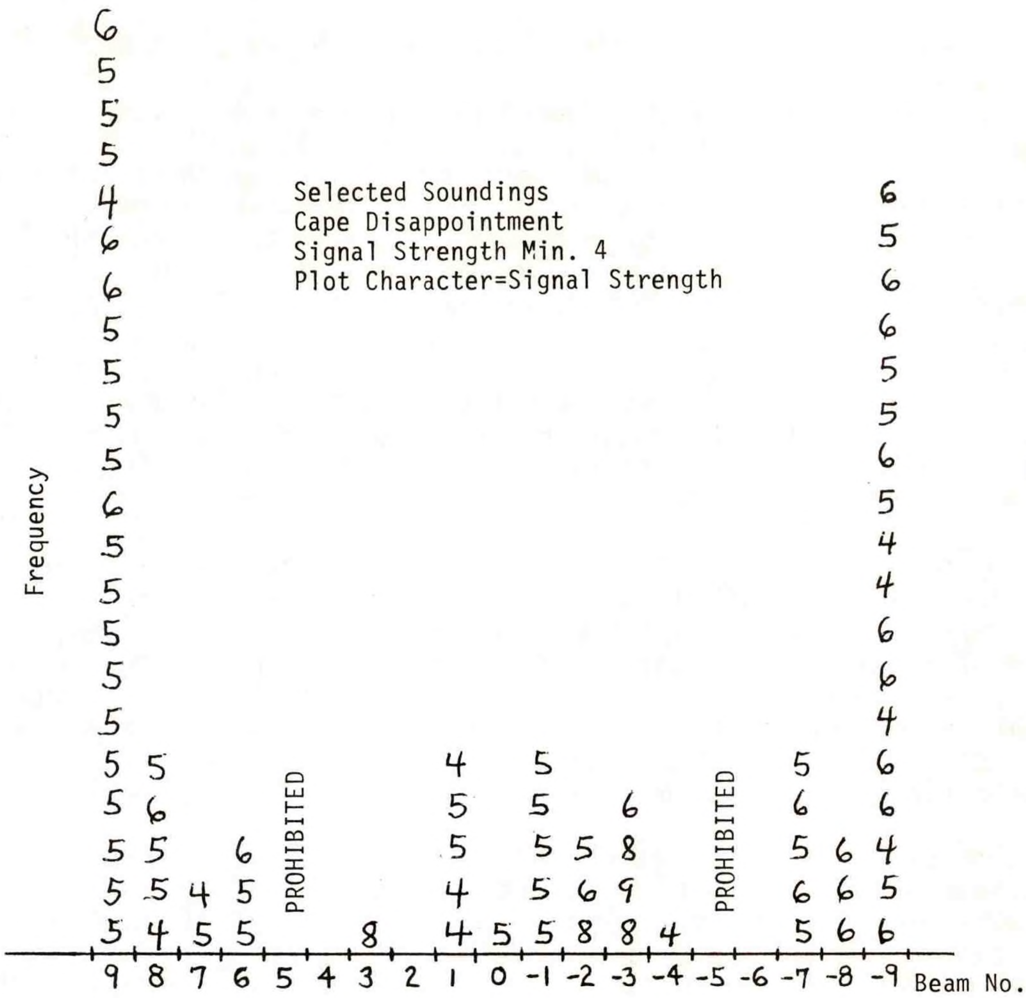


Figure 2-3. Histogram of Beam Selection Frequency for no ±5

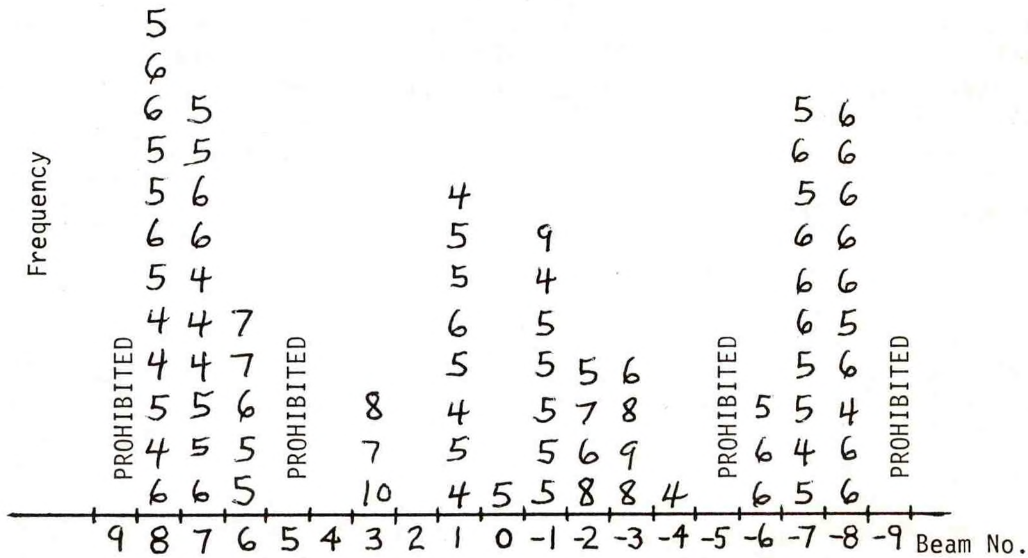


Figure 2-4. Histogram of Beam Selection Frequency for no ±5, and no ±9

An interesting effect was noted when all beams greater than ±4 were zeroed out, as seen in Figure 2-5. In this data set, the perferred beams were then ±1. The signal strengths from beams ±1 were noted to derive not from one population, but rather from two: one "strong" and one "weak". It was then noted in the vertical profile plot that many of the depths associated with the "weak" distribution were anomalous. This established the need to investigate the signal strength effect. The tool chosen to accomplish this was an existing program called COPSTA which was developed during the earlier Field Experiment data analysis. COPSTA has the ability to plot, among other things, time series from given beams. The plot was modified so that signal strength values were plotted (in hexadecimal) rather than asterisks. From the sample plot in Figure 2-6, it can be seen that depths associated with "weak" signal strengths tend to be very noisy and, when selected, would lead to large shoal biases. The signal strength value was also added to the right-hand side of the vertical profile plot.

In order to prohibit the selection of such anomalous soundings, an input procedure was established for selecting a desired minimum threshold level. Soundings not meeting the signal strength criterion are zeroed out. It was noted by running COPEDO that in the Cape Disappointment data (and others as well), the low-order beams (near vertical) tend to exhibit higher nominal signal strengths than high-order beams (large angles). Because of this, it was decided to permit each beam to have its own individual signal strength threshold which is selectable from the input procedure.

The use of beam rejection and beam selectable minimum signal strength thresholds caused a significant change in the COP selected soundings. Results for mean COP selected depths from various combinations of beams and thresholds are seen for three Cape Disappointment data subsets in Figure 2-7 along with corresponding standard deviations. For this particular data set, the program divided the Sounding Arrays into two PUAs: one on the port side (denoted "+") and one on the starboard side (denoted "-"). In this area the bottom is quite flat and gently sloping along the direction of vessel motion. The "standard" depths for this case may thus be assumed to be the center beam depths obtained with high signal strength thresholds as noted in examples "G" and "H". Example "A" is a run of COP in its initial configuration except for the suppression of the beam five noise. Note that these results are biased roughly three feet shallow in 100 feet of water. Excluding outer beams and raising thresholds above the old default of four (examples "B" through "F") is seen to have significantly reduced the biases and standard deviations to a more acceptable level.

This same approach was then applied to the Shelikof data as seen in Figure 2-8. Here, because the bottom was nearly horizontal along the direction of vessel motion and only slightly sloping athwartships, four data subsets, as indicated by the symbol numbers, are overplotted. Starboard and port PUA's are distinguished by being to the right or left of the corresponding abscissa, respectively. The same three percent shoal biases are again evident for the unmodified program.

Beam and threshold selection again proved somewhat useful in reducing the magnitudes of the biases, but this time not to an acceptable level. The residual shoal biases were highly variable in terms of both mean and standard deviation and varied from one percent to 2.5 percent even for tight

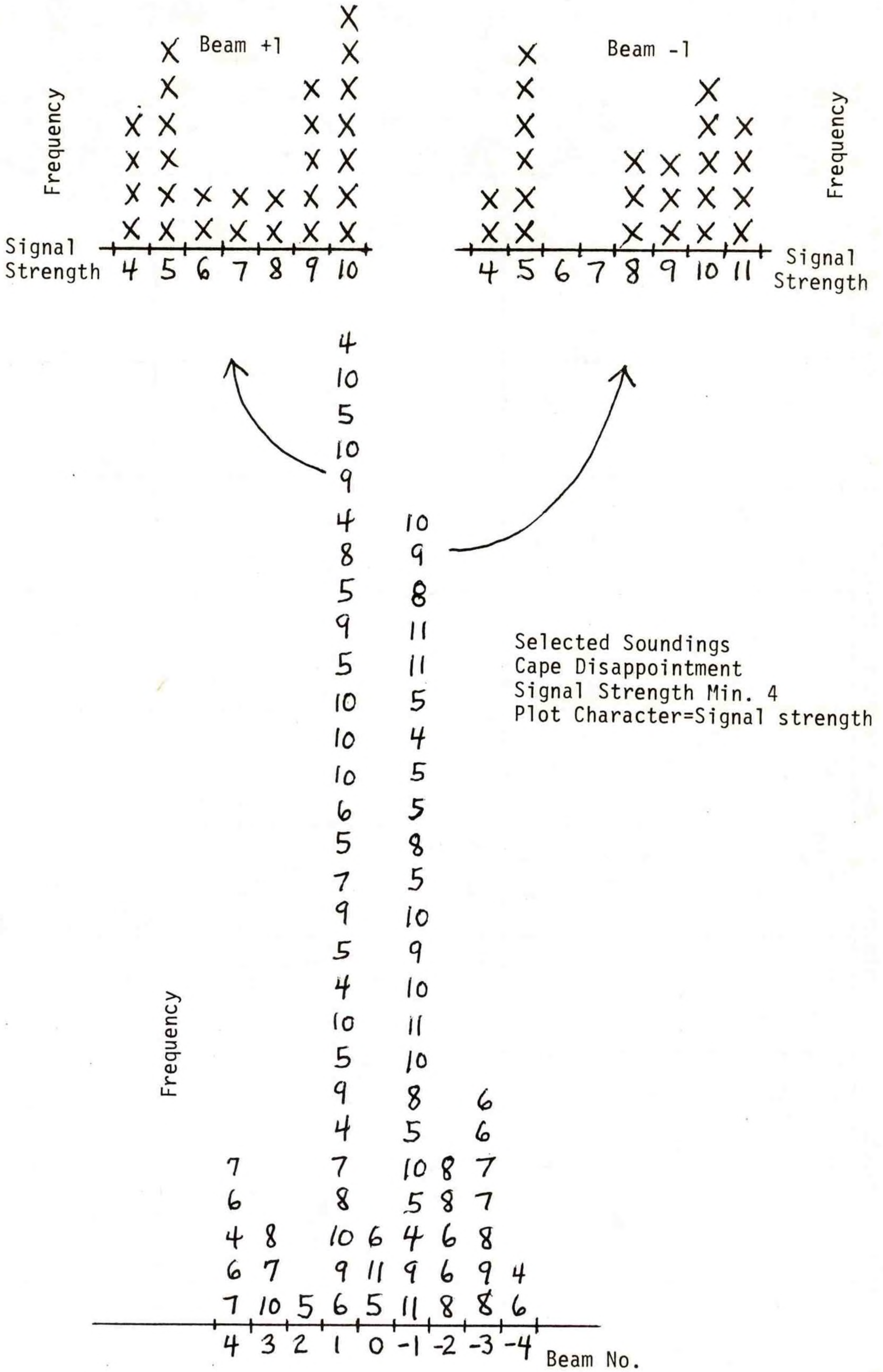
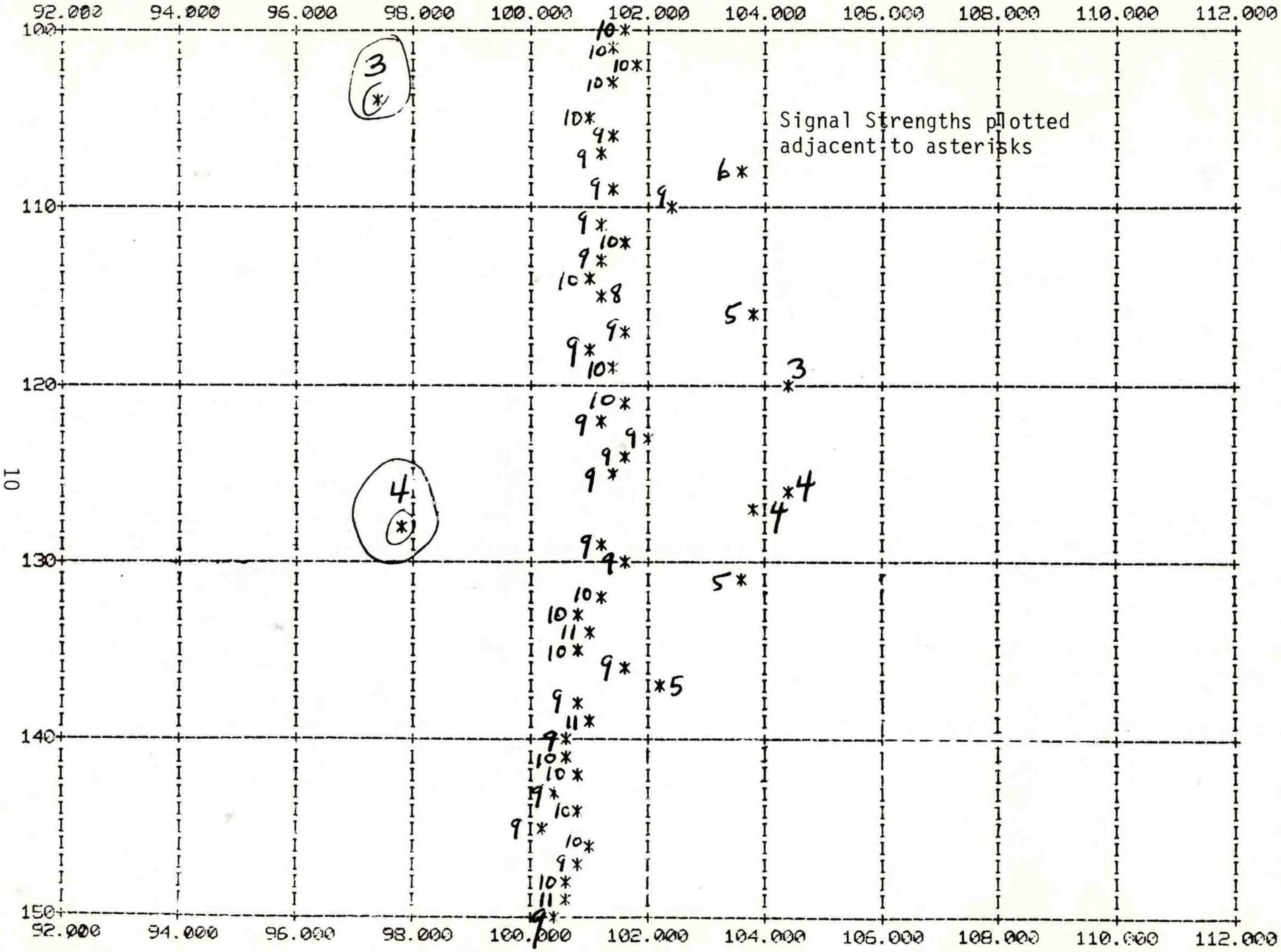


Figure 2-5. Histograms of Beam Selection and Signal Strength Frequencies



VALUES	SEQNUM
101.5597	-30257
101.3993	-30235
101.7966	-30213
101.5004	-30191
97.3538	-30169
101.1009	-30147
101.4344	-30125
101.1252	-30103
103.6459	-30081
101.4257	-30059
102.3253	-30037
101.2679	-30015
101.6141	-29993
101.2453	-29971
101.0716	-29949
101.2354	-29927
103.8358	-29905
101.6419	-29883
100.9335	-29861
101.4243	-29839
104.3726	-29817
101.6071	-29795
101.2106	-29773
102.0275	-29751
101.6265	-29729
101.4647	-29707
104.4682	-29685
103.8808	-29663
97.7699	-29641
101.2775	-29619
101.5920	-29597
103.6728	-29575
101.2606	-29531
100.7518	-29509
101.0012	-29487
100.7209	-29465
101.5251	-29443
102.1357	-29421
100.7160	-29399
101.0489	-29377
100.7030	-29355
100.5938	-29333
100.8348	-29311
100.4472	-29289
100.8424	-29267
100.3155	-29245
100.9174	-29223
100.8898	-29201
100.6759	-29179
100.6391	-29157
100.4235	-29135
VALUES	SEQNUM

Figure 2-6. COPSTA Time Series from Cape Disappointment Beam +1 Showing Weak Signal Strength Depth Anomalies

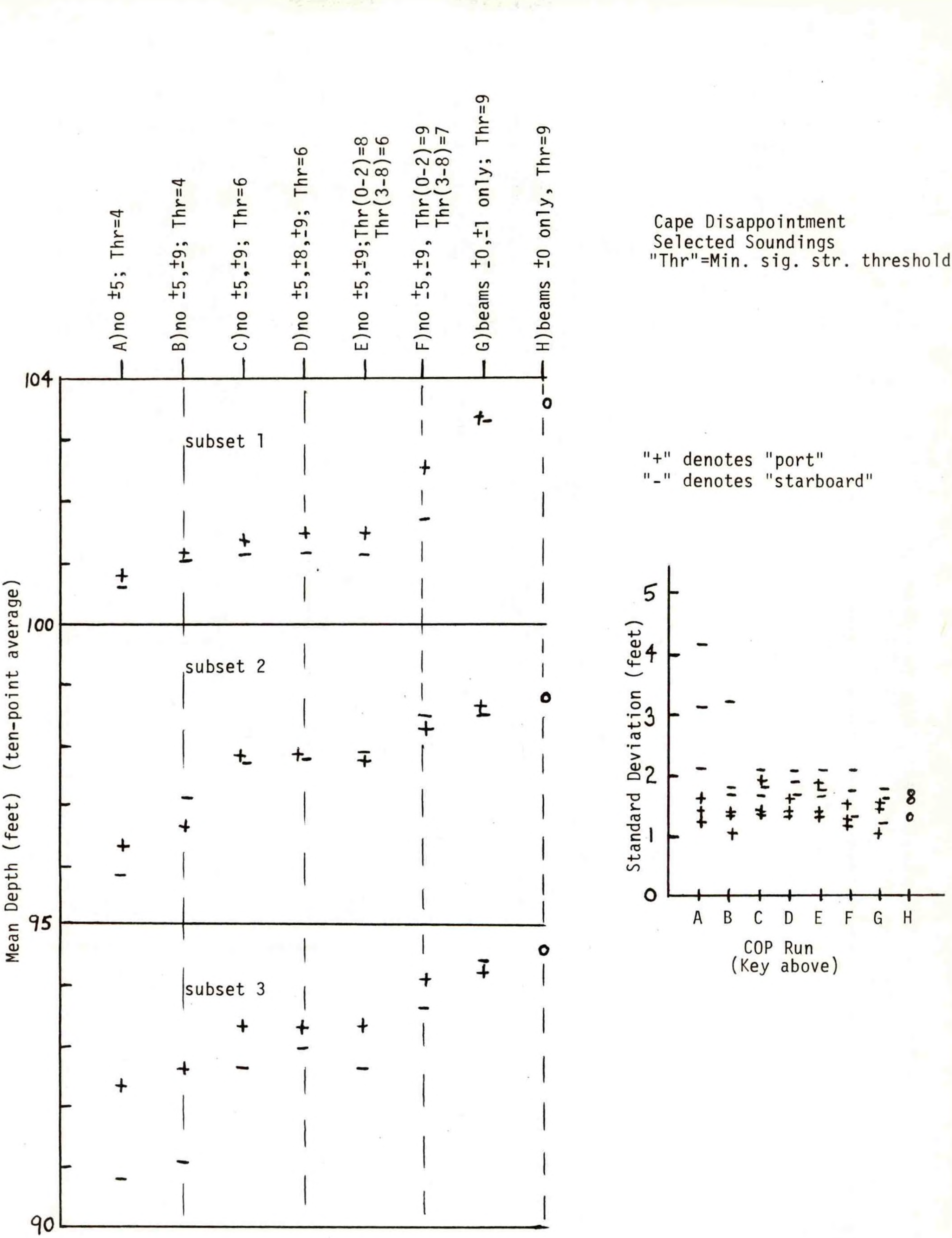


Figure 2-7. Mean COP-Selected Depths and Standard Deviations for Various Setups (Cape Disappointment)

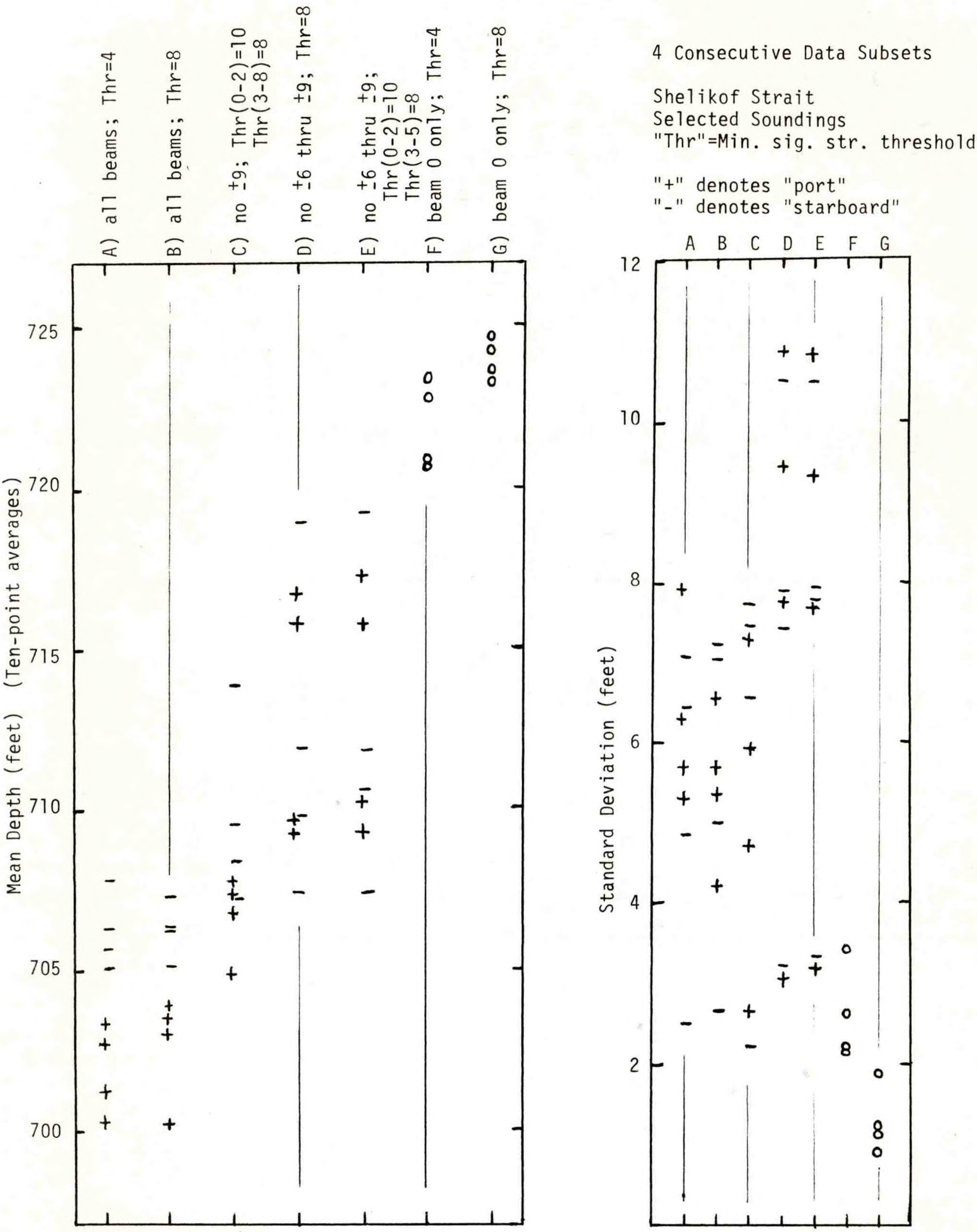


Figure 2-8. Mean COP-Selected Depths and Standard Deviations for Various Setups (Shelikof Strait)

restrictions on beam and threshold selection. A striking feature is that even though the biases were reduced, the standard deviations were increased. The cause for this, determined by looking at time series in COPSTA output, was that the gross outliers had been appearing in a moderately narrow range of depths. Once they were removed, the depth selection process moved to the outer fringe of the normal system noise band whose location was statistically more uncertain than the location of the outliers.

Also evident in the COPSTA output was the reason for the continuing difficulties: the gross outliers in the Shelikof data were frequently associated with very strong rather than weak returns. Many other strong returns, however, yielded highly satisfactory results. It was apparent at this time that beam and signal strength restrictions alone would therefore not suffice to adequately upgrade COP reported sounding accuracy.

Because improved sounding "selection" was not enough, it was decided to augment the existing verification procedure with a statistical measure which would work on the depth distribution itself. In the old criterion, verification is performed by considering the "neighborhood" of eight points surrounding the selected sounding in the Sounding Array. A selected sounding is rejected if its depth, d, differs from the mean depth of the surrounding neighborhood points, μ, by more than 25 percent of the mean depth, i.e., if $| d - \mu | > 0.25 \mu$. Rejected soundings are zeroed in the Sounding Array. The value 0.25 was defined in the program as a variable, and it could have been tightened somewhat, but not nearly enough to remove errors in the two to three percent range without becoming unduly restrictive compared to actual bottom depth variations.

What was needed was a new measure which would be sensitive to the noise level itself. That measure is σ, the standard deviation of the neighborhood depths about their mean, μ. The original verification criterion was retained in order to exclude gross outliers which could adversely affect neighborhood statistics. The new procedure was to follow the former in series with an additional conceptually similar criterion in which selected soundings are rejected for cases where $| d - \mu | > n \sigma$, where "n" is an adjustable parameter. Rejected soundings are zeroed in the Sounding Array. The basic philosophy underlying this expression is that single, isolated depth measurements differing significantly (in a statistical sense) from their neighbors do not, by definition, represent actual features of interest on the bottom. In addition, the order of selecting and verifying shoals before deeps were reversed to deeps before shoals. This permits anomalous deeps to be rejected before they can adversely influence neighborhood statistics.

This straightforward addition is extremely powerful because it provides a rejection criterion which depends upon the noise statistics of the data itself. For example, on a very flat, regular bottom a given depth difference may result in rejection, whereas for a more rugged bottom it might not, because the natural standard deviation of the neighborhood is larger. The parameter "n" can be tuned to control the noise sensitivity of the procedure. If the noise in the depth distribution is assumed to be roughly Gaussian in nature, then one can see that setting n = 3, for example, would cause roughly 1/4 percent of all soundings (not selected soundings) to be rejected, while n = 2 would cause roughly five percent rejection. In order to monitor the performance of the verification routine, a reject counter was added to the right-hand side of the vertical profile plot.

The results of this added verification procedure, as seen in Figure 2-9, are quite striking. Even for a very superficial edit at n = 3, the biases and standard deviations are reduced, and the data "character", which is significantly improved, clearly indicates the existence of a bottom slope athwartships whose magnitude shrinks, as expected, with suppression of the outer beams. For n = 2, the results are even more striking with extremely low standard deviations and a mean shoal bias of less than one percent of the depth. Table 2-2 contains a history of the standard deviations for three different verification algorithms over the four data subsets. The improvement in performance is quite clearly remarkable.

Algorithm:	$\lvert D - \bar{D} \rvert < 0.25\,\bar{D}$	former + $\lvert D - \bar{D} \rvert < 3\sigma$	former + $\lvert D - \bar{D} \rvert < 2\sigma$
port ("+")			
subset 1	9.55 ft.	8.48	1.89
2	10.85	2.03	1.57
3	7.77	1.83	1.92
4	3.07	3.05	1.46
starboard ("-")			
subset 1	7.87	9.81	7.17
2	7.43	7.38	1.37
3	10.48	7.55	1.14
4	3.20	0.94	0.89

Table 2-2. Standard Deviations for Shelikof Data Subsets: Four Consecutive Ten-Point Subsets Processed with Three Different Verification Algorithms. Standard Deviations in Feet; Depth = 720 Feet; Beams 0 thru ±5; Thr = 8

The single remaining large standard deviation noted in Figure 2-9 and Table 2-2 has been investigated and found to be the result of a three-point group of "anomalous" soundings. Although one could argue that this could be some actual feature, its characteristics are more closely akin to a random clumping of three of the not infrequent high signal strength shoal outliers. The important point to be made here, however, is that the new verification procedure did not reject the points. This is a clear indication that it is not carelessly chopping out data which might be representative of a physical feature or "item" of interest. In this case the "anomalous" sounding would be selected and verified by COP and appear on the output. The attention of the operator would be gained, and another pass over the area could be made if desired.

Figure 2-10 exhibits a typical Sounding Array of Shelikof data. Deeps (not generally reported) and shoals are selected and rejected, as noted in the associated "Debug" output, until selected soundings are verified. Rejected shoals have been circled for emphasis, and the verified shoal sounding is boxed. The tendency for higher noise in outer beams is obvious, as is the ability of the program to deal with it.

It is clear that the augmented verification procedure rejects only those soundings which are far out in the noise tails. This procedure, therefore,

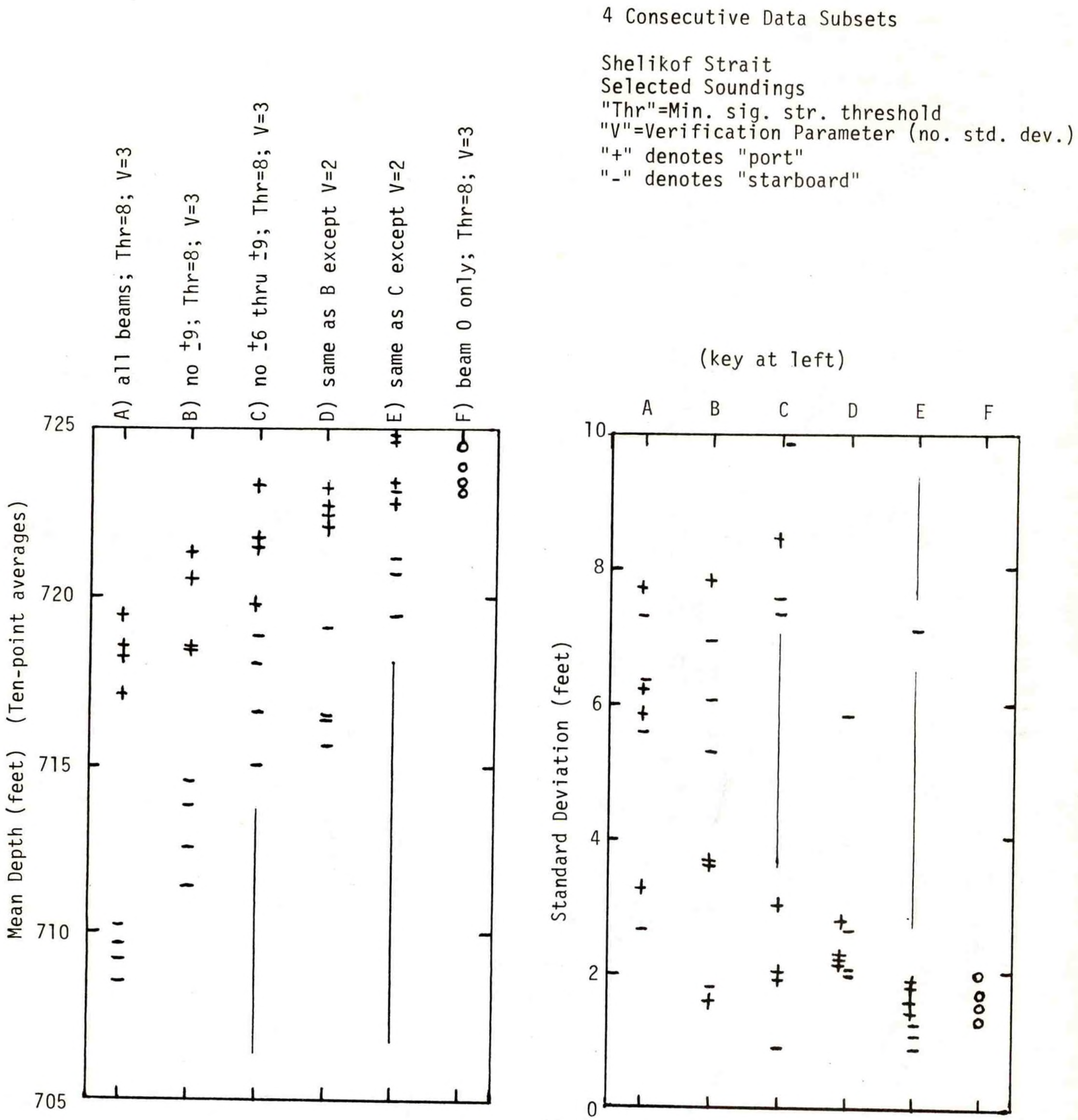


Figure 2-9. Mean Baseline COP-Selected Depths and Standard Deviations for Various Setups (Shelikof Strait)

```
SWAMRK =    19, NUMPUA =     1, SKOUNT =    16
SKOUNT:
19
 740.3 740.3 740.3 740.3 740.3 736.3 741.8 752.0 747.0 742.0 745.8 746.0 749.8 753.8 757.0 759.5 768.0 768.0 768.0 768.0 768.0
   0.0   0.0   0.0   0.0 730.8 739.8 737.3 748.8 740.3 743.0 745.0 751.5 747.8 754.5 763.3 755.8 765.8   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 740.8 736.0 747.0 738.0 757.8 742.5 746.8 749.5 727.8 748.3 758.8 757.5 757.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 739.8 733.3 740.0 745.5 741.5 745.8 747.0 753.8 753.3 732.8 765.0 751.5 771.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 735.8 752.0 740.5 743.0 742.3 740.8 746.5 746.5 753.8 760.0 752.3 765.3 767.8   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 719.3 739.0 736.5 742.0 748.8 742.5 746.5 747.0 744.8 756.8 748.0 764.5 760.3   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 739.8 736.3 746.5 744.5 740.0 743.5 745.0 744.0 753.8 754.3 757.3 762.3 760.3   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 736.5 741.8 739.0 744.8 740.5 744.0 739.3 744.5 721.0 748.5 754.0 758.3 754.5   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 731.0 734.8 737.3 746.5 752.0 740.3 743.8 743.5 747.8 751.5 748.0 756.8 764.8   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 733.0 734.3 741.5 743.0 741.0 743.8 743.0 749.0 762.3 754.0 751.0 751.8 762.8   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 740.3 731.0 745.3 739.3 741.5 742.3 743.8 743.0 747.0 744.3 754.5 754.3 758.8   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 736.8 736.3 744.3 745.3 740.3 742.5 743.0 747.8 743.5 754.5 758.3 754.0 754.8   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 722.0 737.8 736.5 743.3 735.8 742.5 741.0 745.3 744.3 741.5 751.5 755.5 740.8   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 732.3 746.5 738.8 745.0 736.3 740.0 742.8 742.3 751.0 744.5 752.3 752.0 745.5   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 729.5 733.0 740.5 743.0 744.5 739.0 742.0 741.5 747.8 748.3 752.3 746.8 760.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 731.8 736.3 734.3 739.8 741.5 740.8 743.8 738.3 747.5 744.3 752.5 746.8 754.0   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 743.5 728.8 737.5 717.8 736.8 740.3 744.0 745.5 743.0 753.0 742.3 752.3 751.3   0.0   0.0   0.0   0.0
   0.0   0.0   0.0   0.0 730.8 731.8 734.3 738.8 747.0   0.0 740.8 739.5 741.5 744.3 750.5 753.0 753.3   0.0   0.0   0.0   0.0
MAXDEP =   771.0, SWSAVE =     5, BMSAVE =   17
MAXDEP =   767.8, SWSAVE =     6, BMSAVE =   17
MAXDEP =   765.8, SWSAVE =     3, BMSAVE =   17
SWFRST =     3, SWLAST =    18, BMFRST =     2, BMLAST =    20
MINDEP =   717.8, SWSAVE =    18, BMSAVE =    8
MINDEP =   719.3, SWSAVE =     7, BMSAVE =    5
MINDEP =   721.0, SWSAVE =     9, BMSAVE =   13
MINDEP =   722.0, SWSAVE =    14, BMSAVE =    5
MINDEP =   727.8, SWSAVE =     4, BMSAVE =   13
MINDEP =   728.8, SWSAVE =    18, BMSAVE =    6
MINDEP =   729.5, SWSAVE =    16, BMSAVE =    5
```

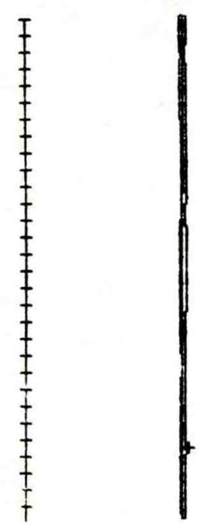


Figure 2-10. COP DEBUG Output of Shelikof Plottable Unit Area Showing Successive Rejection of Two Maxima and Six Minima Before Ultimate Verifications

22/36/05.27 123.1 6 8 -0.7 0.1 (

although it suppresses outliers and reduces gross biases, continues to yield depths which are biased shoal from the "true" mean depth by an amount roughly equal to the noise level associated with, say, the best 95 percent of the soundings (for n = 2). Because the inherent BS^3 depth measurement noise level is larger than that for single beam systems such as Hydroplot due to the high angle propagation geometry, this should and does (as will be seen in Section 3.0) result in a net shallow bias in the BS^3 soundings (compared to these earlier "standards") when the data are processed in this hydrographically "safe" manner. This bias can be reduced by using a smaller value of "n", but one runs the risk of beginning to reject true but extreme bottom features. The value of "n" is adjustable from the program input, and performance can thus be "tuned" as desired by the operator. This parameter has a very powerful effect on results, however, and it must not be varied carelessly without full knowledge of the potential consequences.

It was discovered that the new verification procedure performed so well that the beam dependent signal strength thresholds were no longer needed, and the program was converted back to the use of a single threshold value for all beams.

With the addition of the augmented verification criterion the program achieved its so-called "Baseline" configuration. All further efforts at improvement would be compared to this version for justification.

The Baseline code has one theoretical drawback which led to further attempted development efforts ("COPL" and "COPS" which will be described in Section 2.6). That drawback is the fact that, when operating over significantly sloping bottoms, the standard deviation of the neighborhood contributed by the slope alone may be large enough to permit undersirable, noisy soundings to pass through the verification procedure and thus increase the effective shoal bias and the noise on the selected soundings. No specific incidence of this problem has been identified to-date in test data and thus, although it is bound to occur, the problem seems to have minimal practical impact.

2.5 COP6 -- Final Version

It was observed that the Baseline code sometimes experienced quality control problems due to the inadequacy of statistics from the eight or fewer neighborhood soundings. In addition, the neighborhood is generally quite rectangular due to the large spacing in the beam-to-beam direction compared to that in the swath direction. In order to ameliorate both problems, it was decided to add an additional swath to each end of the neighborhood, thus making it three beams wide by five swaths long. The maximum number of neighborhood soundings is thus nearly doubled from 8 to 14. Furthermore, a neighborhood criterion requiring a minimum of six non-zero soundings was imposed. Selected soundings with fewer than six valid neighbors are rejected outright as being in an area of suspect validity.

Finally, the verification parameter (the number, "n", of standard deviations permitted from the mean) was lowered to a default value of 1.85. This value would result in the rejection of 6.4 percent of all soundings from a Gaussian distribution. The value was selected after examining the performance at 1.645 (ten-percent rejection) and 2.0 (five-percent rejection). The former performed very well and removed most of the shoal biases between BS^3 and "standard" data sets. It was felt, however, that the fairly large associated number of rejected soundings might prove worrisome in operational circles. The latter value excludes few points and is consequently more heavily biased. If the larger number of rejects is deemed acceptable from an operational point of view, a value on the order of n = 1.6 would provide superior depth measurement accuracy as will be seen in Section 3.1.

Sample data subsets from Cape Disappointment, Shelikof Strait, San Juan Shoals, Deep Water, and the Rosario Strait which had previously been run with the Baseline version were rerun with COP6. A decided improvement in performance (reduced bias and standard deviation) was noted in all areas. COP6 has thus proven itself and has become the best current "standard" version of COP.

It has been determined, however, in Shelikof data that, even with the improved neighborhood statistics, three point adjacent outliers at about three percent shoal depths continue to be able to pass verification tests and become a selected sounding. (These particular errors are in beams ±3 and are associated with anomalously high return signal strengths as seen in Figure 2-11.) It is felt that such instances of hardware or environmentally induced errors cannot be reasonably removed by the code without fear of potentially rejecting small actual features or "items". Such problems are best dealt with by improving the hardware performance. Consequently, such errors in COP6 processed data must still be corrected by hand verification. This should pose no great problem since they are fairly rare and generally quite obvious.

2.6 COPL and COPS Versions

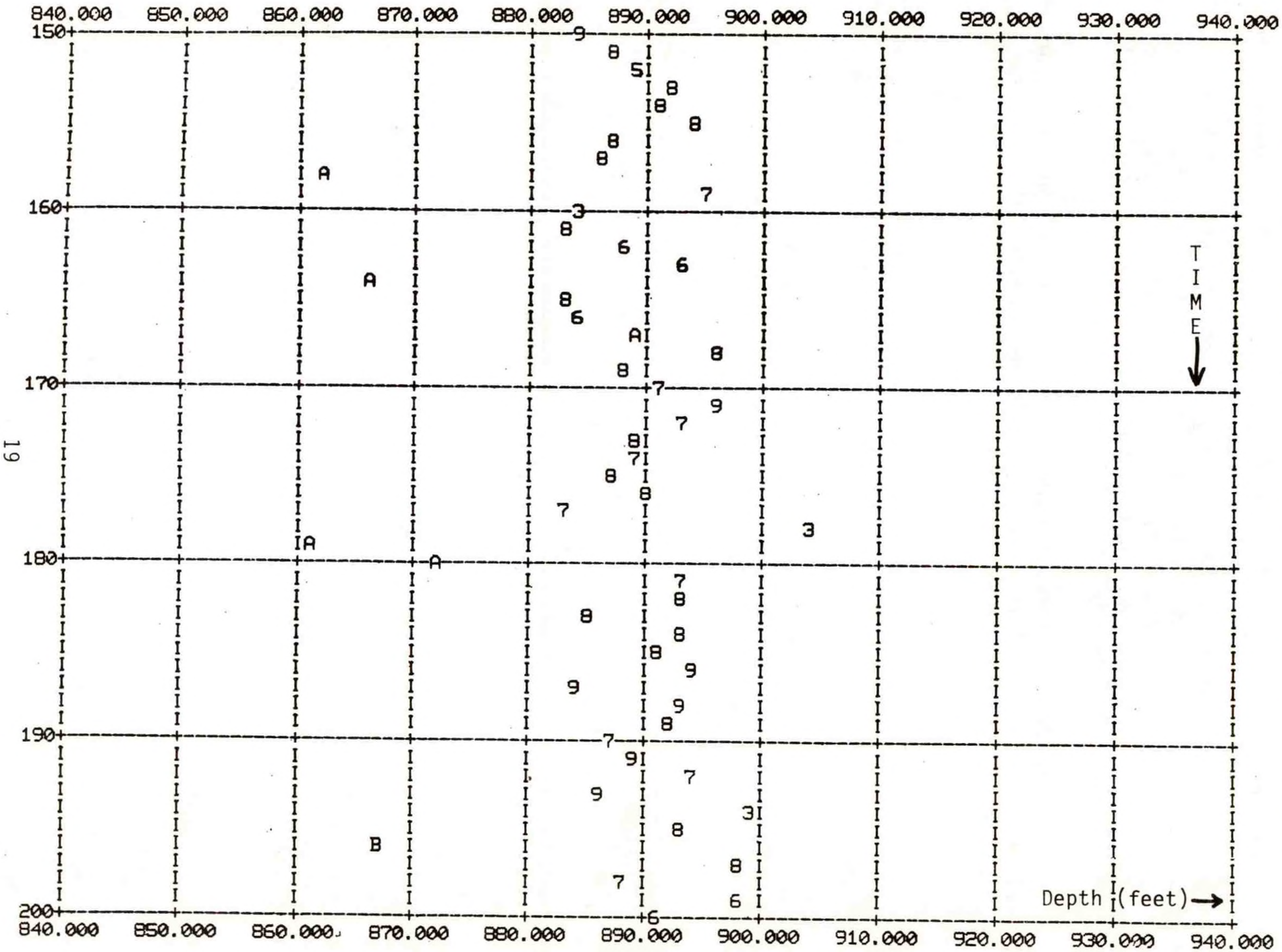
Verification procedures in COP6 are purely statistical in nature; i.e., they do not make use of any of the available geographic information regarding the relative locations of neighborhood soundings. It was believed that this information could be exploited in some manner in order to improve the ability of COP to reject outliers in steeply sloping regions. Two radically different versions of COP arose from this effort: COPL and COPS.

COPL is designed to exploit the local "slope" information in the neighborhood of a selected sounding. A new slope "space" is first created by calculating various normalized depth differences, and then the verification/rejection criteria are applied in that space until an acceptable verification occurs. This provides the theoretical ability to recognize outliers in sloping areas, but, because it is a crude form of a mathematical derivative, the process also increases the inherent noise level which reduces the potential gain of the technique.

COPS, in a major philosophical change, goes back in the program to the Sounding Array level (before PUAs are defined) and applies a two-dimensional (3x5) low-pass spatial filter to the entire Sounding Array to produce a new filtered array. Statistics are accumulated on the differences between the "raw" depths and the filtered depths, and an edit is performed at the 2.3 σ level to remove all points from the raw depth set with excessive differences. The filtered data set is then recalculated in the areas around the edited points in order to remove their effect. The Sounding Array of

********************** COPSTA V2.0-0 DATE: 25-OCT-82 TIME: 00:14:55 TAPE: STAR3 PAGE: 17 **********************

Plot character = Signal Strength in hexadecimal; i.e., "A"=10



VALUES	SEQNUM
884.0792	-29408
887.2195	-29386
889.2045	-29364
892.2781	-29342
890.9009	-29320
893.9991	-29298
887.1424	-29276
885.8196	-29254
861.8455	-29232
894.8303	-29210
883.5708	-29188
883.4960	-29166
888.3247	-29122
892.9215	-29078
866.3972	-29056
882.9912	-29034
884.4219	-29012
889.3698	-28990
896.3107	-28968
887.5276	-28946
891.4186	-28924
896.2669	-28902
892.7566	-28880
888.7585	-28858
889.0400	-28836
887.1001	-28814
890.1729	-28792
882.9572	-28770
903.4803	-28748
861.4639	-28726
871.8224	-28704
892.7468	-28682
892.8906	-28660
884.8015	-28638
893.2051	-28616
891.3558	-28594
894.4371	-28572
884.3751	-28550
892.6605	-28528
892.1264	-28506
887.0165	-28484
889.4850	-28462
893.5360	-28440
885.6027	-28418
898.8576	-28396
893.4213	-28374
866.7480	-28352
897.9139	-28330
888.4350	-28308
897.9955	-28286
890.8327	-28264
VALUES	SEQNUM

Figure 2-11. COPSTA Time Series of Beam -3 Showing High Signal Strength Shoal Depths

filtered data is then divided into PUAs and the selection/verification/rejection procedures are applied as usual. When a selected sounding is verified, one must look back to the "raw" depth matrix at that location for the selected depth. Because this single value is effectively drawn from a sample of the entire sounding population, its mean value, over a number of PUAs, will be the mean "true" depth. This is not, however, the hydrographically "safe" guaranteed shoal depth at that location, for it may indeed be drawn from the deep half of the distribution (since only its location was selected in the filtered data set). In order to obtain a hydrographically safe depth, a 3x3 neighborhood is again defined in the raw data space surrounding the site of the selected sounding in the filtered data. The shoalest of these nine depths is then reported as the selected sounding. The spatial "awareness" of this code is drawn from the spatial smoothing applied by the low-pass filter.

The design philosophies, statistical bases, and response characteristics of COPL and COPS are described in detail in Pearce and Kahn (1982).

3.0 RESULTS

3.1 Baseline and COP6 Codes

3.1.1 Background

Precision is a measure of short-term measurement uncertainty; it is customarily reported in terms of the standard deviation of a set of measurements from a given population about the mean value of those measurements. Bias is a measure of the long-term difference, or offset, between the measured mean and a "standard" or expected value. Repeatability is a more subjective measure which contains elements of both precision and bias, as well as long-term drift and susceptibility to uncontrolled external influences. It is typically defined in terms of the mean and standard deviation of the differences between two separate but supposedly equivalent measurement sets. These various descriptors of depth measurement accuracy will be described for the COP processed output of the BS^3 system for a number of independent data sets from survey areas with diverse characteristics.

Because the data density from the Bosun sounder is much greater than can be recorded on a smooth sheet or on a chart, some procedure must be invoked to extract a smaller set of representative or "selected" soundings. In the COP program this is accomplished by dividing the soundings into blocks called Plottable Unit Areas (PUAs) containing from tens to hundreds of soundings from which only one will be selected and reported. When dealing with BS^3 results, one must be careful to make the distinction between statistics drawn from the population of all soundings and those calculated for only the selected soundings. The former are characteristic of the hardware and the physics of propagation; the latter also depends very strongly on selection rules and parameters and can be quite different.

The measured noise characteristics of the Bosun depth sounder have been described by Pryor (1982). Figure 3-1, drawn from this report, provides a good example of the standard deviations of depth measurements in Deep Water as a function of the beam number. This functionally arises as follows. Larger beam numbers are associated with larger beam angles measured from the vertical. The beam geometry at larger angles causes the return pulses to be temporally stretched which in turn adds to the uncertainty of pulse location and hence increases depth measurement noise and reduces precision.

If the depth measurement error -- both in terms of bias and precision -- exceeds hydrographics standards for a certain subset of beams, then that portion of the data must be ignored in the sounding selection procedure. For the BS^3 system, this has been seen in Field Experiment data (such as Figure 3-1) to occur for beams greater than roughly ±7. Beams ±8, ±9, and ±10 have thus been frequently suppressed during processing in order to conform depth measurement errors to performance standards.

It was demonstrated by Pryor (1982) that if certain outer beams were excluded, the depth measurement accuracy of the hardware (bias and standard deviation for repeated passes over a given area) would meet accepted standards if wild points were first edited out by hand. Results for soundings selected by the original COP program from the Shelikof Operational Evaluation data, however, exhibited very large shoal biases and unacceptably high standard

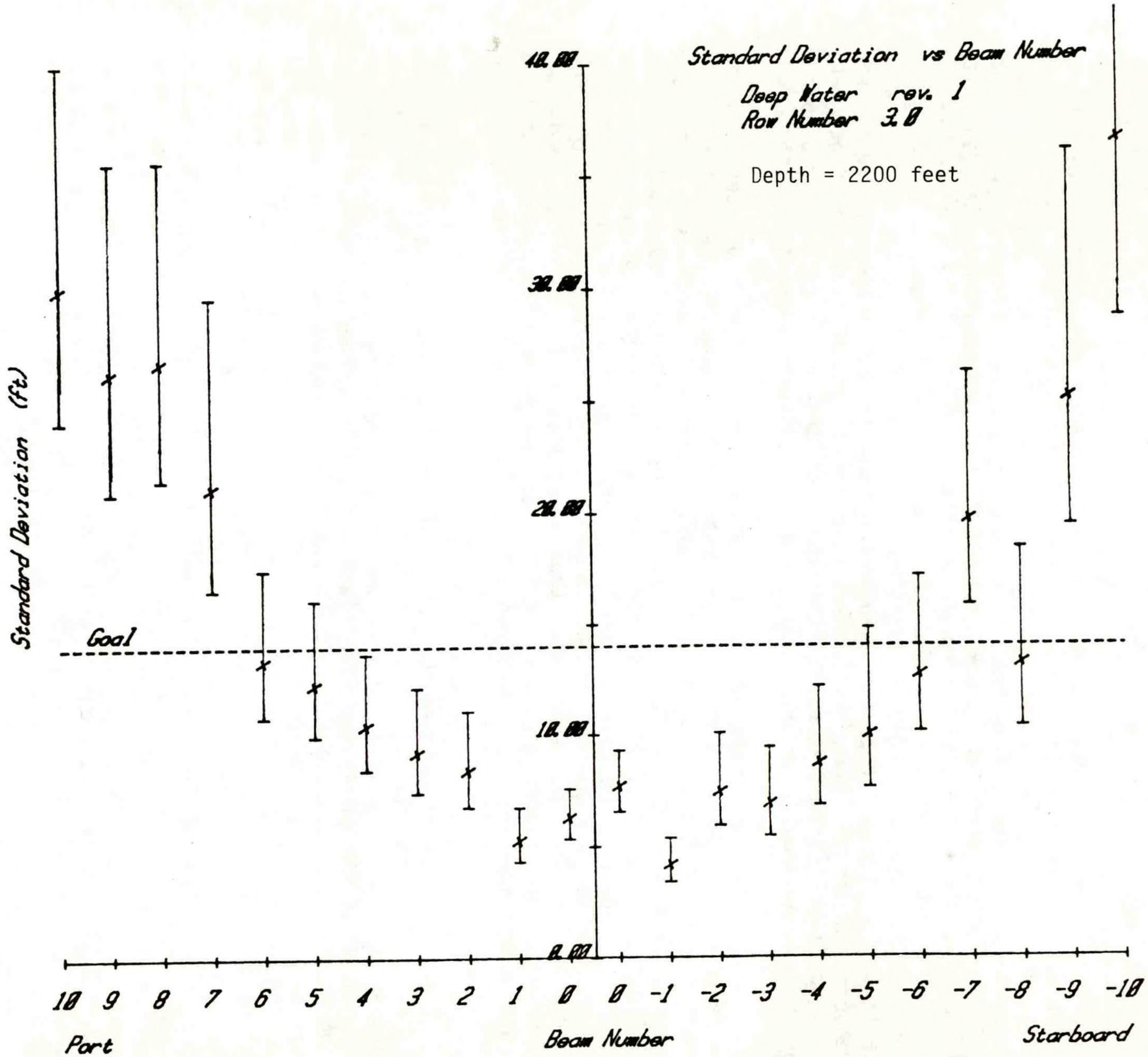


Figure 3-1. Standard Deviation of Measured Depths vs Beam Number for DEEP WATER (Pryor 1982)

deviations. The problem was thus to modify the COP code to cause it to be less sensitive to noise and to select soundings more representative of the actual depth. This was accomplished, as described in Section 2.0, with the development of the "Baseline" and COP6 versions of the COP code.

3.1.2 Roll Bias

Before conducting depth comparisons with external standards, it was necessary to perform internal consistency checks. An apparent roll bias had been noted in the April 1981 Field Experiment data. This bias, which could be conceived to be a slight misalignment of the Bosun transducers on the vessel, appeared to have a magnitude of roughly +0.4 degrees based on the interpretation of all soundings (rather than selected) from a number of test sites.

Overlapping passes on the same heading in the San Juan Islands "Shoals" area provided the opportunity to investigate this hypothesis with selected soundings from the Baseline code. With a positive roll bias, soundings on port side of the vessel would appear to be slightly deep, and on the starboard side slightly shallow. Thus, if a starboard beam from one pass overlaps a port beam from another pass, then the mean depth difference can be used to calculate the magnitude of a roll bias.

The comparison was run with beam +8 from line 2E against beam -9 from line 5E. Without any attempt to compensate for the suspected roll bias, the mean depth difference in selected soundings along the lines was determined to be 9.9 ± 6.0 feet in 450 feet of water with an estimated uncertainty of ±1.0 feet due to positional misregistrations over the prevailing bottom slope. With an assumed roll bias of +0.4 degrees added to the Survey Summary Files, this difference was reduced by about 60 percent to 3.9 ± 5.5 feet.

The roll bias hypothesis was thus confirmed, and the implication is that the Bosun transducers are indeed mounted with a certain roll offset whose magnitude may exceed +0.4 degrees. A decision was made to use the conservative +0.4 degrees value for all subsequent processing, however, because it was based on more extensive statistics. A future mission could easily be mounted to investigate the roll bias magnitude more carefully.

3.1.3 Repeatability

The term repeatability carries with it the meaning of long-term self consistency (as opposed to "precision" which tends to have short-term implications). Consecutive passes over the Deep Water site were so closely spaced compared to the swath width that great overlap resulted. Depths from two such overlapping passes (day 117, 08/41/12 - 08/48/38 and 08/47/49 - 08/57/52) with the "faired" transducers were processed by COP6 for beams 0 through ±7 (but excluding ±5 due to interference) at a minimum signal strength threshold of six and for a verification parameter of 1.85σ. Selected soundings were overplotted using SPLOT, and depth differences between adjacent soundings were determined by hand. The resulting mean difference, calculated over 48 depth pairs, regardless of beam number, was 3.2 ± 12.3 feet in 2,150 feet of water, with no wild differences. This excellent performance for both the mean and standard deviation could not be achieved prior to the development of the COP6 code. Even the Baseline code produced a few wild points which required hand editing.

Another aspect of repeatability might be termed "consistency". One can speak of consistency as the ability to produce a large number of equal or nearly equal soundings from data acquired over a flat bottom (with differences of less than, say, one percent). Consistency is embodied in survey data in two ways: continuity along a survey line over a flat bottom, and agreement of cross-line comparisons. These measures of consistency have been examined in Shelikof data processed by COP6 and both have been found to be present with rare exception.

Those exceptions were several instances where isolated selected soundings of, say, 141 fathoms appeared in an area consisting otherwise of 144 to 145 fathom values. Investigation showed that these apparently anomalous soundings were able to pass through the verification process because the raw data, as seen before, contained three such soundings in a row in beam -3. Beam ±3 anomalies, often associated with unusually high signal amplitudes, are also evident in other data sets and are believed to be related to a hardware problem. They do not occur frequently enough to justify excluding all data from those beams, but when three or more clump together, they can "support" each other to a great enough extent to permit the middle one to pass the verification criterion. The program has not been coded to exclude such groups because of the possibility that a small real feature or "item" could possibly have similar characteristics. The only way to suppress these infrequent anomalies is to determine the problem in the hardware and correct it. Meanwhile, these stray points can be recognized and removed during post-processing hand verification.

3.1.4 Accuracy

The original COP program produced selected soundings with large shallow biases and excessive standard deviations because it neither suppressed wild outliers nor attempted to ignore the far-reaching tails of the system noise distribution. This came about because of the philosophy that the shoalest soundings should be selected to provide a margin of navigational "safety".

This approach proved unsatisfactory because much of the Bosun data is significantly noisier than Ross data due to the different propagation geometry and pulse location algorithm. The modifications to the COP code which resulted in versions termed "Baseline" and its successor, "COP6", were designed specifically to attempt to suppress wild outliers and reject soundings in the extreme tails of the noise distribution. This does not totally eliminate the shallow bias inherent in the philosophy, but rather reduces its magnitude to a hopefully acceptable level. The operating point is selected by fixing the value of the verification parameter -- the number of standard deviations permitted from the mean of the surrounding neighborhood depths. As this parameter is made smaller and more of the noise tail is rejected, the number of rejections increases, and the magnitude of the shoal bias decreases.

Because the depth measurement noise of a beam increases with its off-nadir angle, there is a strong propensity for selected shoal soundings to come from the outermost active beams in the PUA, as long as the bottom topology is relatively flat compared to the noise level (recall Figure 2-4, for example). With beam dependent biases of this type, it appears that the survey vessel is constantly moving along a trough in the bottom topology. This potentially undesirable aspect of system performance is mitigated as long as the magnitude of this artificial trough is well within the acceptable error budget. The maximum bias and standard deviation magnitudes for COP outputs are legislated by excluding as many outer beams as necessary from the COP processing. The most unfortunate aspect of the overall processing philosophy is that the highest precision data is discarded and reported results lie near the top of the noise band.

The accuracy standards utilized for evaluation of Bosun/BS^3 results were Ross or Raytheon data acquired either simultaneously on the BS^3 or on the same day with Hydroplot (as in the case of the Field Experiment), or from an independent survey (as for the Operational Evaluation). Comparing results from such diverse systems is, however, both difficult and dangerous. Because the Bosun data is more widely spread over the bottom, there are not always Ross or Raytheon soundings nearby for comparison. Worse, the Ross/Raytheon soundings were not corrected for heave, roll, or pitch as were the Bosun results. For tests in rough conditions this means that the "standard" Hydroplot results are, in effect, inaccurate depths plotted at inaccurate locations.

Because of these problems, several different techniques were utilized in order to make optimum use of the available data. In relatively flat, shallow areas such as Cape Disappointment and Rosario Strait, Bosun depths were compared directly with the Ross data most closely associated with the ping time of the selected soundings, regardless of the beam number, by means of a special-purpose program named STNSTA. This produced a conservative or "worst case" result because actual bottom slope contributes to observed differences. For San Juan Shoals, plotted depths from program SPLOT were overlaid on a light table and compared by hand with simultaneous or same day Hydroplot results. This lead to satisfactory results because the sea was calm during the mission. This procedure was less than satisfactory, however, for Deep Water because of large roll and pitch effects. To alleviate these, a special version of COP was developed to make appropriate corrections. This output was then plotted via SPLOT and again compared by hand on a light table with overlaid Bosun results. This procedure proved successful. Differences derived from overlay comparisons may also be considered to be conservative estimates of error because the comparisons are always made over a certain separation distance, and bottom slopes will again inflate the resulting statistics.

Table 3-1 contains a summary of BS^3 accuracy results. The reported accuracy results on the left side of the table were derived from runs of the Baseline code. Shoal biases are indicated as negative. In several instances, gross outliers were hand edited before calculation of the statistics. In later tests of COP6, few such anomalies arose. COP6 is slightly more selective than Baseline, and hence reports slightly deeper results. Examples of this important bias reduction are reported in the table. It can be seen that depth measurement biases and standard deviations with the new COP codes have been reduced to less than one percent of the depth. The residual mean biases for COP6 processed BS^3 data can be adjusted slightly via the verification parameter, but for a value of "n" around 1.85 they appear to be quite acceptable. It is important to note, however, that these are mean values and that wild points may still occassionally slip through the COP6 code -- particularly in the case of repetitive hardware problems.

LOCATION	ACCURACY (FT) (BASELINE) $\mu \pm \sigma$	D (FT)	BEAMS	MIN. SIG. THR.	BIAS REDUCTION COP6-BASEL. (FT)	"n" VER. PRM.	NET COP6 MEAN BIAS (FT)	% D
Cape Disappointment	-1.3 ± 0.6	100	0 → ±7 no ±5	6	0.6	1.85	-0.7	-0.7
Rosario Strait	-1.6 (±0.8) ± 1.4 (±0.3)	240	0 → ±7	7	-- --	--	--	
Shelikof Strait	-2.6 ± 2.9 -3.8 ± 4.1 -3.8 ± 4.1	930 930 930	0 → ±5 0 → ±7 0 → ±7	6 6 6	-- -- 3.6 ± 3.6 2.4 ± 4.0	-- 1.645 1.85	-- -0.2 -1.4	 -0.02 -0.15
San Juan Shoals	+2.6 ± 2.6 -1.5 ± 2.3	470 400	0 → ±7 0 → ±1	8 8	0.7 ± 3.1 -- --	1.85 --	+3.3 --	+0.7
Deep Water	-2.7 (±5.3) ± 14.4 (±7.2)	2150	0 → ±7 no ±5	6	6.0 ± 15.3	1.645	+3.3	+0.15

Table 3-1. BS^3 Accuracy Comparisons

Due to the limited nature of these intercomparisons, the reported accuracy results should be construed as "indicative" rather than "definitive".

The Deep Water data reported in Table 3-1 originated from several early lines run with the standard "faired" Bosun transducers. Because of heavy seas and rolls of up to ten degrees, it was apparently believed that the "dome" transducers would provide superior results. The transducers were switched, and the bulk of the Deep Water tests were conducted with the dome. It was noteworthy that, contrarily, the dome data was decidedly noisier, and the data from the fairings was thus used for performance analysis.

The improvement in performance of COP6 over Baseline is demonstrated in the vertical profile plots from Cape Disappointment as seen in Figures 3-2b and a, respectively. The Baseline results, in addition to being biased 0.6 feet shallower, are visibly noisier and exhibit the typical trough effect with many selected soundings coming from beams 6 and ±7. For the COP6 results, however, the selected soundings come from beams 6, 7, and -1. This indicates that the more powerful COP6 edit procedure has suppressed the noise enough to display the almost imperceptible natural slope of the bottom perpendicular to the vessel track.

The processing time for COP6 varies with the data characater and the value of the verification parameter, but for typical circumstances with n = 1.85, COP6 runs only about 25 percent slower than the original COP code.

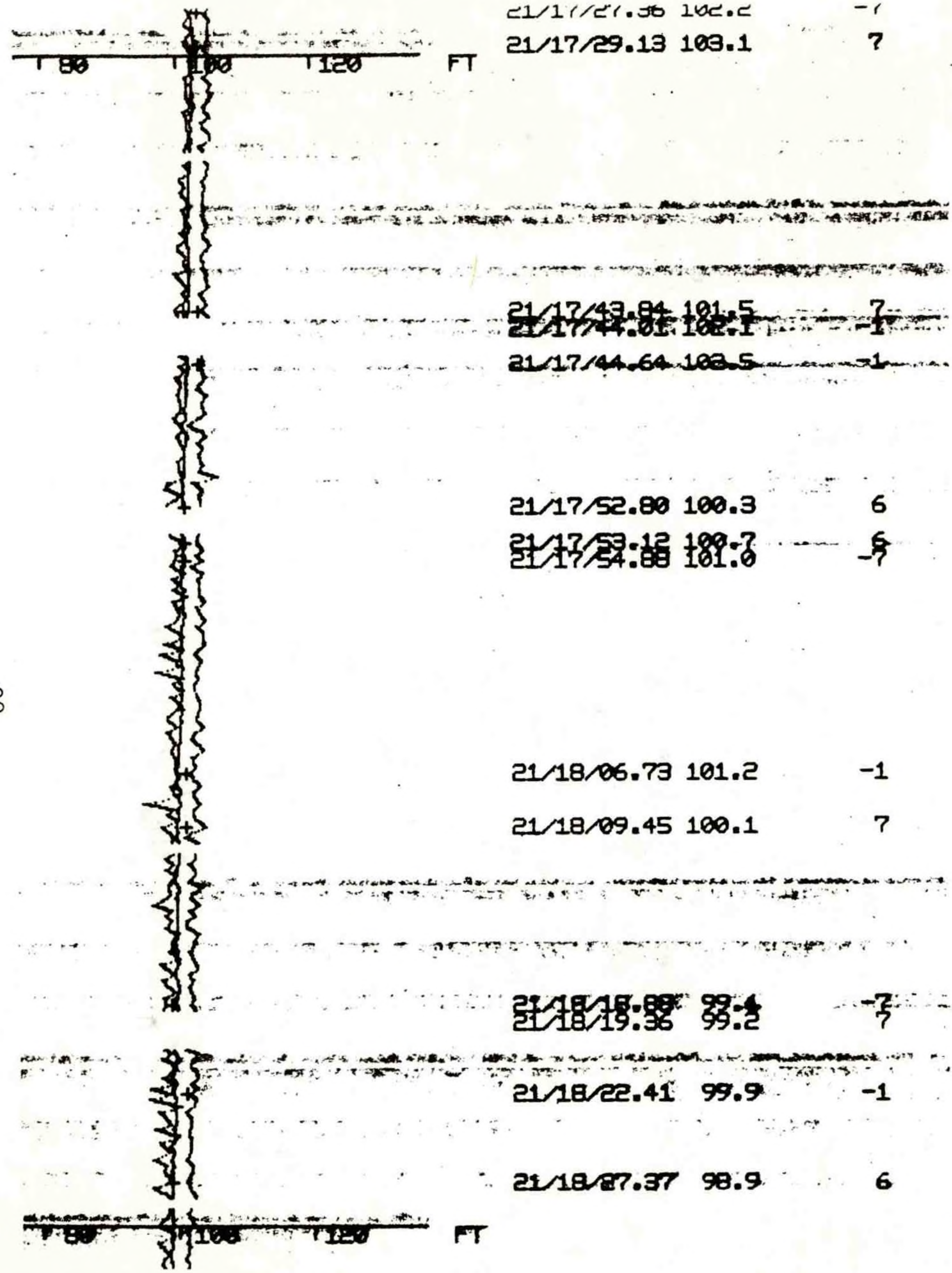
3.2 COPL and COPS Versions

The details and performance characteristics of these diverse codes are described in detail in Pearce ad Kahn (1982). Various versions of COPL proved to be only marginally "smarter" than COP6 at a cost of from 10 to 50 percent increase in running time. COPS was also marginally smarter and theoretically superior, but at a 100-percent increase in running time. Because such large increases in running time are unacceptable in the shipboard environment, both COPL and COPS have been documented and shelved for the present. When floating-point hardware becomes available, run time will be reduced, and these slower but more sophisticated versions may perhaps be worth another try.

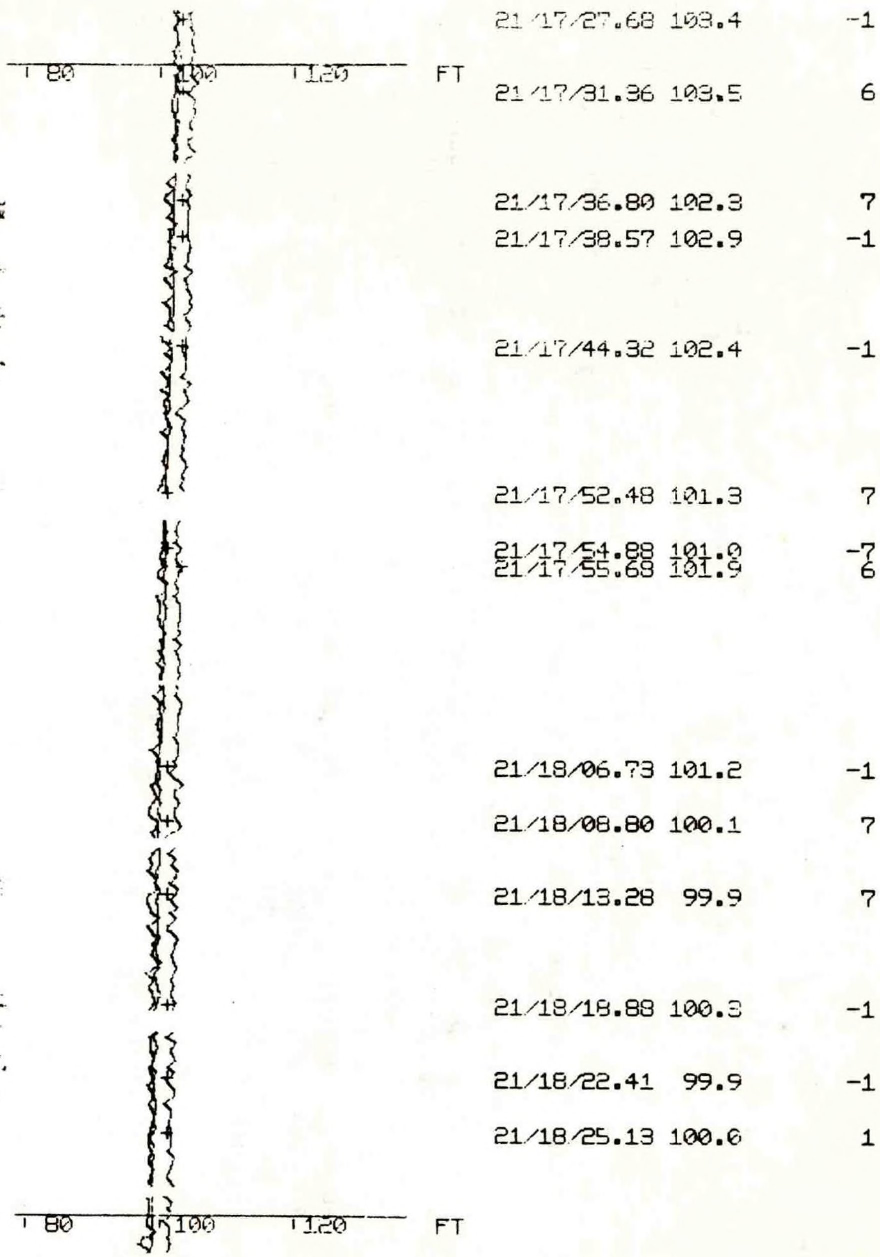
3.3 Output Products

The BS^3 "Accuracy Enhancement" task has resulted in the generation of several new versions of the COP data processing code. The best of these in terms of performance gained for minimum increase in run time is called COP6. The new code has been annotated and transferred to NOS for use in upcoming surveys. Its performance is documented in this report. Several more sophisticated versions with longer running times have been described in a separate report and archived on magnetic tape.

The August 1981 Shelikof Operational Evalution data set has been completely reprocessed with COP6 and submitted to NOS for validation. It is expected that the results, in terms of depth measurement accuracy, will now be quite satisfactory. Several supplementary programs, COPEDO, COPSTA, and COPMAT, have been modified or developed. These could prove useful in examining data character and quality in conjunction with COP runs if available onboard the survey vessel.



a) COP Baseline



b) COP6

Figure 3-2. Vertical Profile Plots from Cape Disappointment Showing Improved Noise Reduction by COP6

4.0 CONCLUSIONS

It has been demonstrated that a modified version of the original COP data processing program can produce sets of representative selected soundings from Bosun/BS^3 data which agree with Hydroplot results to within one percent of the depth, across a wide range of depths and bottom topography, for an assumed roll bias of +0.4°. The precision of these selected soundings at the one standard deviation level (68 percent of the time) is within one percent of the depth. The repeatability of the system for overlapping passes is well within one percent of the depth. Crossline checks have been seen to be within one percent of the depth. The exact magnitude of the roll bias needs to be determined from a simple, carefully designed field test.

In order to achieve these results, the program must reject noisy soundings in the tails of the measured depth population. The number of rejections, which can be varied by means of a "verification parameter", should be expected to be substantial -- as much as ten percent of all raw soundings. The verification parameter should be left at 1.85 in order to maintain the reported depth measurement accuracies. It should be changed only with full knowledge of all possible ramifications.

The new code, termed "COP6", produces these results at a modest (25 percent) increase in processing time. Further minimal improvements in performance have been achieved only at a cost of greatly increased run time.

Hardware problems exist in BS^3 which can cause data from certain beams to be spurious. If the incidence of anomalous soundings is sufficiently damaging to performance, the offending beams or signal levels can be totally excluded from processing. Otherwise, one must expect clumps of such bad data to be capable of passing through the verification steps in COP6 and generating occasional spurious results. The solution is to improve the hardware performance. The software cannot be expected to detect the difference between hardware errors and the potential bottom features which they mimic.

5.0 RECOMMENDATIONS

- 0 It is recommended that the original NOS COP code be replaced with the newly developed version called COP6 for all BS^3 processing.

- 0 It is also recommended that COPSTA, COPEDO/KOPOUT, and COPMAT be made available for shipboard use. The latter will need to be converted from a PDP 11/44 to the /34. These diagnostic programs can add valuable insights into the data which will permit optimization of the COP6 setup in terms of signal strength and beam edits.

- 0 In general, it appears that accuracy standards can be met for the inner 15 beams (0 through ±7). The outer six beams are better relegated to reconnaissance duty.

- 0 The original minimum signal strength threshold level of four appears to be too low. A minimum default value of six is preferred. This can be raised even higher as appropriate and desired.

- 0 It would be wise to further investigate the exact magnitude of the roll bias attributed to the transducer mounting angles. Until such time, a value of +0.4 degrees is recommended for all data sets.

- 0 The usage of dome or faired transducers in rough seas needs further examination. It appears from the Deep Water data set that the fairings are to be preferred.

- 0 Beams ±5 appear prone to interference which causes significant periodic anomalies. Procedures for eliminating this problem would be very valuable because the loss of beam five affects verification on beams four and six.

- 0 Beams ±3 are also excessively noisy in several data sets. The electronics should be examined to determine the cause.

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