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FILTERING ERRONEOUS SOUNDINGS FROM MULTIBEAM SURVEY DATA

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Abstract

As part of its continuing efforts to improve data quality, the National Oceanic and Atmospheric Administration (NOAA) has recently implemented a "prefiltering" procedure designed to identify and remove erroneous or questionable soundings from multibeam sonar data collected in support of the United States Exclusive Economic Zone Bathymetric Mapping Programme. Since the start of the 1991 field season, a simple, yet effective, prefiltering algorithm has been incorporated into the standard post-processing software used aboard NOAA ships equipped with MicroVAX-based survey systems. In addition, the prefiltering routine is also being utilized as part of NOAA's current effort to convert its archive of older PDP-11 multibeam surveys to standard full-resolution "beam" format. The sounding verification criteria employed by the prefiltering algorithm is discussed in detail and statistical results from the first season of its implementation are presented.

INTRODUCTION

Since 1984, the National Oceanic and Atmospheric Administration has conducted an ongoing programme to systematically map the entire United States

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Exclusive Economic Zone using multibeam sonar systems. Due to the exceptionally large number of soundings acquired by these systems, NOAA has historically utilized a sounding selection algorithm to select representative subsets of soundings from which to generate its gridded datasets and bathymetric contour maps.

As part of the sounding selection process, each sounding under consideration is compared to its neighbour soundings, with those differing by more than preset limits being rejected and not considered for selection. Although this process has eliminated many erroneous soundings from being passed on to the gridding and contouring process, it does not remove suspect soundings from the full-resolution dataset. In addition, only those soundings under consideration for selection are subjected to the verification criteria, and as a result, erroneous soundings, those identified during the sounding selection process and others that were never reviewed, remain in the processed data.

Beginning with the start of the 1991 field season, the processing of multibeam data has been significantly enhanced with the inclusion of a "prefiltering" algorithm in the post-processing software designed to identify and eliminate erroneous or questionable soundings. Prefiltering was introduced to eliminate the need to manually edit or "window out" erroneous soundings that have historically been passed on to the processed datasets. Prefiltering applies a more stringent set of verification tests to all raw soundings, not just those chosen by the sounding selection process. Also, rather than merely passing over soundings that fail verification, soundings that do not pass through the prefilter are removed from the processed data and written to a separate "cull" file (Fig. 1).

The prefiltering routine has been implemented on NOAA's two new MicroVAX-based multibeam systems, Sea Beam on the MT. MITCHELL and Hydrochart II on the WHITING. In addition, prefiltering is also being utilized as part of NOAA's current effort to convert its archive of approximately 200 PDP-11 multibeam surveys to standard full-resolution "beam" format.

THE PREFILTERING CONCEPT

The prefiltering algorithm is incorporated into NOAA's standard MicroVAX multibeam post-processing program VAXCOP. Program VAXCOP performs two primary functions: first, it applies corrections to the raw merge files [1] generated during data acquisition, and second, it selects a representative subset of soundings from the corrected data. The sounding selection and verification routine within VAXCOP is well documented (HILLARD and LYNCH, 1989) and will not be reiterated here. VAXCOP produces two primary output files, a corrected full-resolution merge file and a selected soundings file.

[1] The term "merge file" refers to a specific data format, also called "beam" format, in which a single geographic position, the position of the center beam, is merged with each set of ping data (depths and crosstrack distances).

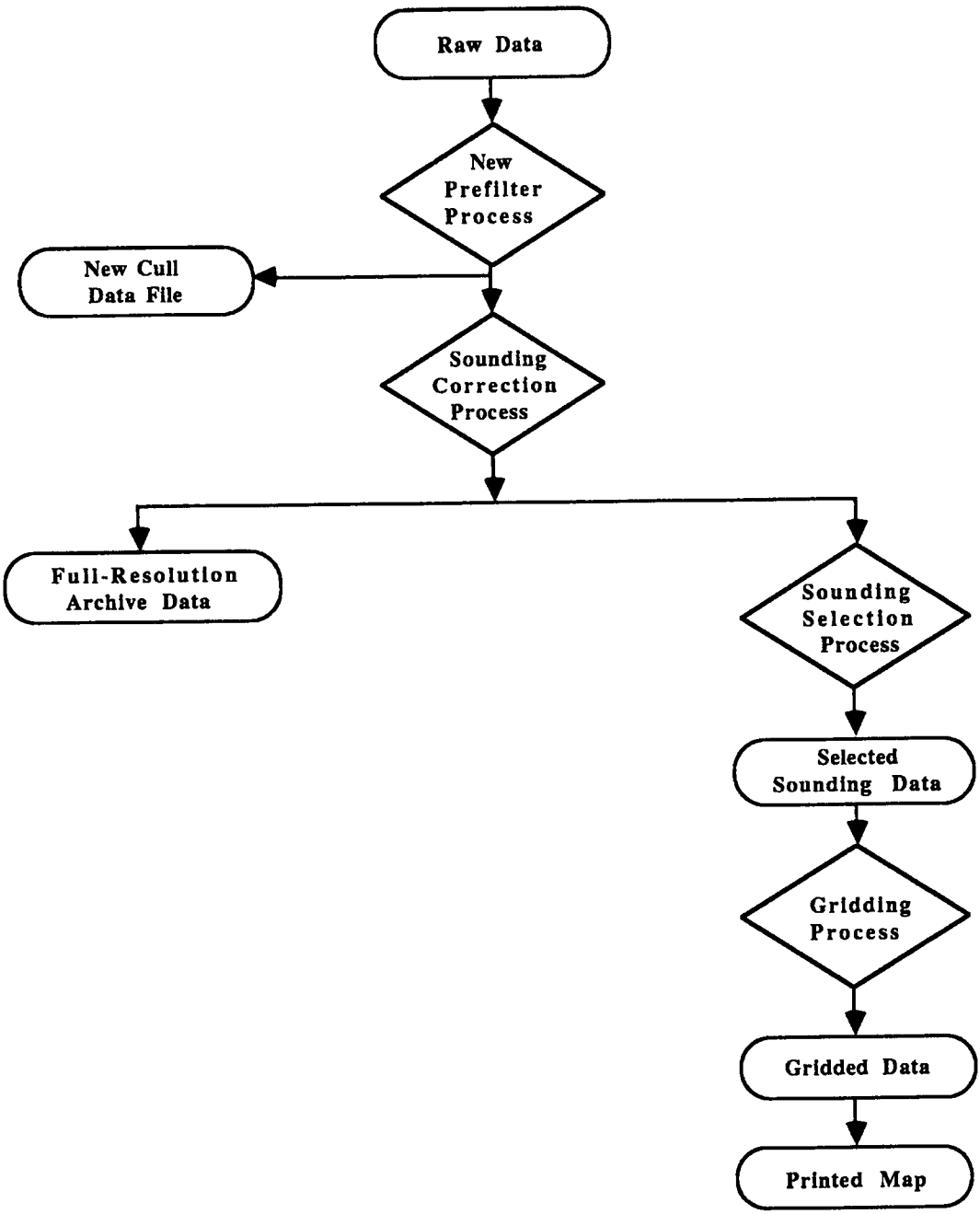

FIG. 1.- NOAA Multibeam Data Processing Overview.

Program VAXCOP executes the prefiltering option immediately upon reading in data from the raw merge file, before corrections are applied and before initiation of the sounding selection process (Fig. 1). Soundings that fail the prefilter verification tests are zeroed out in the corrected merge file, and are written to a separate cull file. The cull file exists to allow the user to undo the prefiltering process if so desired (Fig. 2).

YR-JD	GMT	BEAM NBR	DEPTH	XTRACK DISTANCE	REASON	NEIGHBOURHOOD AVERAGE
91-151	13:41:50	5	1065	-658	LIMIT*	1034.7
91-151	13:41:50	7	1002	-349	LIMIT	1040.3
91-151	14:37:11	10	842	-154	LIMIT	889.4
91-151	14:52:46	16	-1	0	WILDPOINT**	0.0
91-151	16:11:14	3	-1	0	WILDPOINT	0.0
91-151	16:33:57	11	499	102	LIMIT	473.9
91-151	16:52:17	13	437	204	LIMIT	475.5
91-151	17:05:00	14	12	1	WILDPOINT	0.0
91-151	17:21:56	3	727	-657	LIMIT	751.7
91-151	17:43:14	1	791	-1149	NEIGHBOURS***	0.0
91-151	18:03:37	2	806	-1181	NEIGHBOURS	0.0
91-151	18:20:23	18	857	927	LIMIT	833.1
91-151	18:50:42	12	683	727	LIMIT	727.0
91-151	19:31:53	6	0	0	WILDPOINT	0.0
91-151	19:31:53	7	0	0	WILDPOINT	0.0
91-151	19:31:53	8	0	0	WILDPOINT	0.0

* Specified limit between sounding and neighbourhood average exceeded.
** Sounding exceeds wildpoint limit.
*** Insufficient non-zero neighbours to compute neighbourhood average.

FIG. 2.- VAXCOP Cull File Format

During prefiltering, each raw sounding takes a turn being the "comparison sounding", or the sounding currently under evaluation. The comparison sounding is examined relative to the weighted average of all non-zero neighbour depths taken from the "neighbourhood" of the comparison sounding. The prefiltering routine accepts or rejects the sounding based on this comparison.

There are currently three reasons for a sounding to be culled out during prefiltering:

- the depth or crosstrack distance is identified as a gross flier or "wildpoint";
- the difference between the depth and the neighbourhood average exceeds the specified limit;
- the sounding does not have enough non-zero neighbours to compute a meaningful neighbourhood average.

THE PREFILTER NEIGHBOURHOOD

Establishment of the comparison sounding neighbourhood depends on the type of data being processed. NOAA currently acquires two different types of MicroVAX-format multibeam data, Sea Beam in depths greater than 1,000 metres, and Hydrochart II in depths between 150 and 1,000 metres. With respect to Sea Beam data, the prefilter looks at the current ping, the one that contains the comparison sounding, and the three pings immediately before and after the current ping. The Hydrochart II system utilizes an alternating port and starboard sonar transmission procedure, with half of the depths for every return ping being zero. Therefore, to roughly cover the same geographic area as Sea Beam, the Hydrochart II prefilter neighbourhood is expanded by a factor of two, to six pings immediately prior to and after the current ping.

For both types of data, within the designated 7 or 13 ping block, only those depths from the current beam, the beam number of the comparison sounding, and the two adjacent beams are used to determine the weighted average (Fig. 3). The Sea Beam neighbourhood, therefore, consists of 7 pings by 3 beams, less the comparison sounding, or 20 depths. The Hydrochart II neighbourhood consists of 13 pings by 3 beams, less the comparison sounding, or 38 depths, of which about half will always be zero.

VERIFICATION CRITERIA

The prefiltering algorithm consists of three wildpoint limits and six sounding verification parameters, referred to as P1 through P6 for ease of discussion. The wildpoint limits, minimum depth, maximum depth, and maximum crosstrack distance are used to eliminate gross fliers from the raw data, prior to initiation of the more precise sounding verification process. Wildpoint limits are set in the field and should be updated regularly to reflect prevailing survey depth ranges. Although the wildpoint editing option previously existed in the sounding selection algorithm of program VAXCOP, it is now an integral part of the prefiltering process.

Unlike the variable wildpoint limits, the six sounding verification parameters are static, and were established through an iterative process of analyzing historical data and determining reasonable values that would eliminate erroneous soundings that were obvious, without adversely affecting the rest of the data. Based on this analysis, the following values were selected and used during the 1991 field season:

P1 = maximum time window = 30.0 seconds
P2 = minimum number of non-zero neighbours required = 6
P3 = current beam weight = 2.0
P4 = standard deviation limit = 2.0
P5 = fixed limit = 10.0 metres
P6 = variable limit = 1.5% of depth

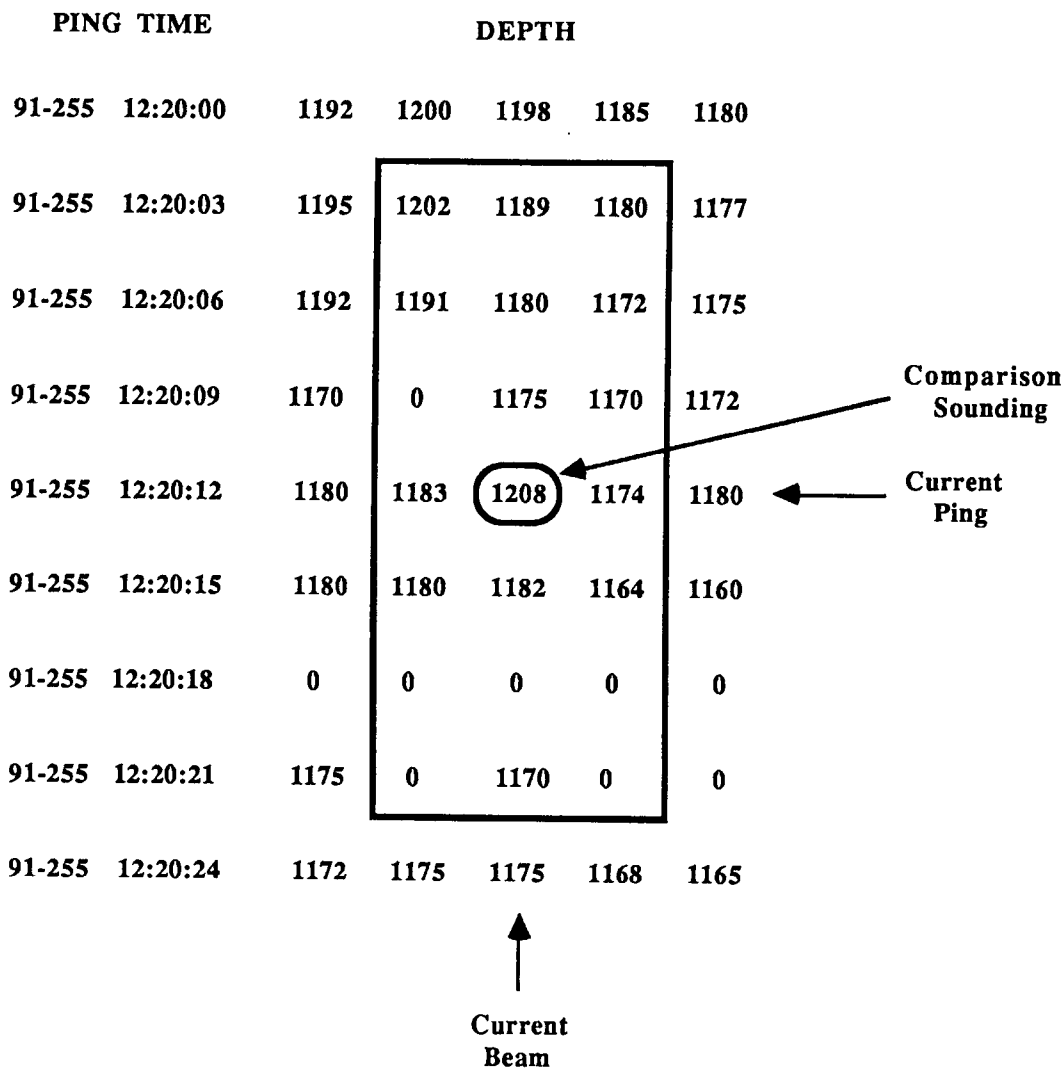

FIG. 3.- VAXCOP Prefilter Neighbourhood (Sea Beam).

Parameter P1 establishes a maximum time window for pings to be included in the prefilter neighbourhood. Of the 7 (Sea Beam) or 13 (Hydrochart II) pings, only those within 30 seconds of the current ping are used to compute the neighbourhood average. This parameter ensures that consecutive pings in the data stream are true neighbours and not separated by long distances. The 30 second value protects the filter against data gaps such as the Sea Beam hourly power amplifier checks which create holes of 30 seconds or longer.

Parameter P2 is the minimum number of non-zero neighbours required around the comparison sounding for the neighbourhood average to be meaningful. If the comparison sounding has fewer than 6 non-zero neighbours, it is automatically filtered.

Parameter P3 establishes the weight given to soundings along the "current beam" when computing the neighbourhood average. Soundings in the two adjacent beams are always given a weight of 1.0, whereas soundings along the current beam are given a weight of 2.0, because they are typically much closer to the comparison sounding than the other neighbours.

Parameter P4 is used to reject neighbours suspected of being fliers. The prefilter uses both "past" and "future" data relative to the comparison sounding to compute the neighbourhood average. The past data has already been filtered so it is known to be reliable, but the future data has not yet been filtered, so it may contain bad data. Bad data would distort the computed neighbourhood average and could cause an erroneous decision to be made about the comparison sounding. Therefore, the prefilter averaging is a two-step process. First the average and standard deviation of all neighbours are computed. Then each neighbour is compared to the average, and those neighbours farther from the mean than 2.0 times the standard deviation are removed from the average. The comparison sounding is then compared to the adjusted neighbourhood average. Soundings removed from the average are not otherwise removed from the data stream at this point, although they may be filtered when they take their turn being the comparison sounding.

Parameters P5 and P6 establish the limits on the comparison sounding relative to the weighted average of its neighbours. The comparison sounding must lie within + 10.0 metres + 1.5 percent of the neighbourhood weighted average to pass through the filter.

NUMERIC EXAMPLE

To illustrate how the sounding verification portion of the prefilter algorithm functions, the following example utilizes the standard parameter values listed above to determine the suitability of the comparison sounding highlighted in Figure 2.

The first step is to establish the time window for pings to be included in the neighbourhood. In this case, the three pings immediately before and after the comparison sounding are all within 30 seconds, therefore, all six pings will be used to compute the neighbourhood average.

The next step is to verify the number of non-zero neighbours in the neighbourhood. The number of non-zero neighbours in this example is 14, which is greater than the minimum number of 6 required.

The weighted average and standard deviation of all non-zero neighbourhood soundings (with soundings along the same beam receiving a weight of 2.0) are then computed to be 1179.37 and 9.08, respectively. Neighbour soundings farther than $2.0 \times 9.08 = 18.16$ metres from the weighted average are removed from the neighbourhood. There is one such sounding in this example, at 1202 metres. Removing this sounding reduces the number of non-zero neighbours to 13, which is still greater than the 6 required.

The adjusted weighted average is then computed to be 1178.11, which is used to determine the acceptable limit on the comparison sounding. In this example, the limit is equal to + 10.0 metres + 1.5% of 1178.11, or + 27.67 metres. Since the difference between the comparison sounding (1208) and the adjusted neighbourhood average (1178.11) is 29.89 metres, which exceeds the limit of 27.67 metres, this sounding would be rejected (set to 0).

1991 STATISTICAL RESULTS

During the 1991 field season, 30 MicroVAX-based multibeam surveys were conducted by NOAA, 18 Sea Beam surveys by the MT. MITCHELL (Table 1) and 12 Hydrochart surveys by the WHITING (Table 2). Of the approximately 39.4 million non-zero soundings acquired during these surveys, a total of 140,418 soundings were filtered for one of the three reasons previously outlined (Table 3).

As the data in Table 3 illustrates, most (97.9%) of the 132,996 soundings filtered from Sea Beam surveys were due to an insufficient number of non-zero neighbours required to calculate meaningful neighbourhood averages. In contrast, the majority (78.6%) of the 7,422 soundings filtered from Hydrochart II surveys were because the difference between the soundings and the neighbourhood averages exceeded the specified tolerance.

Table 1. Individual Sea Beam Survey Prefiltering Statistics

Survey	Type	Non-Zero Soundings	Soundings Prefiltered	Wild-points	Insufficient Non-Zero Neighbours	Out of Agreement with Neighbours
B00250	SB	708,852	16,576	48	16,524	42
B00251	SB	1,051,072	3,330	92	3,323	7
B00252	SB	987,143	1,161	60	1,157	4
B00261	SB	1,109,213	2,390	121	2,370	20
B00263	SB	642,459	32,177	27	32,153	24
B00264	SB	510,340	4,811	41	4,804	7
B00266	SB	296,435	2,163	13	2,159	4
B00268	SB	1,220,295	6,432	109	6,411	21
B00271	SB	1,135,327	7,490	281	7,471	19
B00272	SB	1,295,582	9,763	107	9,711	52
B00275	SB	2,081,948	3,824	239	3,771	53
B00277	SB	1,963,155	2,608	275	2,552	56
B00282	SB	1,970,230	16,916	290	16,800	116
B00286	SB	4,081,077	17,950	356	17,909	41
B00290	SB	2,072,516	980	200	978	2
B00291	SB	614,826	37	37	36	1
B00294	SB	1,433,728	3,587	169	3,525	62
B00295	SB	560,811	801	90	781	20
Totals		23,735,009	135,541	2,555	132,435	551

Table 2. Individual Hydrochart Survey Prefiltering Statistics

Survey	Type	Non-Zero Soundings	Soundings Prefiltered	Wild-points	Insuffisient Non-Zero Neighbours	Out of Agreement with Neighbours
B00262	HC	1,543,135	639	227	174	238
B00265	HC	1,570,308	118	47	0	71
B00267	HC	1,452,657	1,832	328	13	1,491
B00269	HC	110,111	344	17	19	308
B00270	HC	2,509,983	1,549	557	24	968
B00273	HC	639,168	328	1	0	327
B00274	HC	285,852	577	42	0	535
B00276	HC	209,290	1,305	38	2	1,265
B00278	HC	634,598	417	19	1	397
B00279	HC	2173,421	89	33	2	54
B00284	HC	2,059,827	216	29	17	170
B00285	HC	2,434,332	8	0	0	8
Totals		15,622,682	7,422	1,338	252	5,832

Table 3. Composite 1991 Field Season Prefiltering Statistics

	Sea Beam	Hydrochart	Overall
Total Non-Zero Soundings	23,735,009	15,622,682	39,357,691
Total Soundings Prefiltered	135,551	7,422	142,973
% of Total Soundings	0.57	0.05	0.36
Wildpoints	2,555	1,338	3,893
% of Total Soundings	.01	0.009	0.01
% of Prefiltered	1.9	18.0	2.7
Insufficient Non-Zero Neighbours	132,435	252	132,687
% of Total Soundings	0.56	0.002	0.34
% of Prefiltered	97.9	3.4	92.8
Out of Agreement with Neighbours	551	5,832	6,383
% of Total Soundings	0.002	0.04	0.02
% of Prefiltered	0.41	78.6	4.7

CONCLUSION

The process of prefiltering multibeam data has proven to be an effective method of removing erroneous or questionable soundings prior to the creation of full-resolution processed datasets and/or printed bathymetric map products. In many instances, prefiltering allows individual bad soundings to be removed from

the processed data, whereas in the past, such soundings could only be extracted by manually editing blocks of data by time. Not only are the final processed data cleaner as a result of prefiltering, the time savings associated with reducing the amount of manual data editing can be significant depending on the overall "cleanliness" of the raw data.

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