UNITED STATES DEPARTMENT OF THE INTERIOR
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Digital Processing of Side-scan Sonar data with
the Woods Hole Image Processing System Software

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by

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Abstract

Since 1985, the Branch of Atlantic Marine Geology has been involved in collecting, processing and digitally mosaicking high and low-resolution side-scan sonar data. Recent development of a UNIX-based image-processing software system includes a series of task specific programs for processing side-scan sonar data. This report describes the steps required to process the collected data and to produce an image that has equal along- and across-track resolution.

INTRODUCTION

These notes comprise general procedures for processing high and low-resolution side-scan sonar data. Processing of sonar images to remove geometric distortions and radiometric errors is a critical prerequisite to digital mosaicking and image analysis. Programs utilized in this processing are a part of the Woods Hole Image Processing System (WHIPS) software that utilizes the Unidata NetCDF data access software (Paskevich, 1992). The side-scan sonar processing programs were developed to handle 8-bit side-scan sonar data. This report does not attempt to summarize and compare various systems, but instead summarizes the necessary steps required to process side-scan sonar images from any side-scan sonar system. Comparisons of different side-scan systems are available elsewhere, for example, Mazel, 1985, Tyce, 1986, and Johnson et al, 1990.

Further, this report does not provide detail of the programs utilized in the sonar processing. Documentation for each program that is referenced may be found in Appendix A of the WHIPS implementation documentation (Paskevich, 1992). The procedures summarized in Appendix A of this report are two examples that may be used as a cookbook for processing GLORIA or Klein side-scan sonar data. In addition, the flowchart diagram represented in Figure 1 may be used as a roadmap for the sonar processing. However, it should be stressed that it is very important for anyone processing side-scan sonar data to understand what is actually being done at each step of the procedure. The required programs and processing steps may require modifications for specific data types, but the general flow and steps required should not change drastically.

REQUIRED PROGRAMS

To process side-scan sonar data with WHIPS, several programs are required. These programs may be categorized as one of two types: 1- general image-processing programs; and 2- side-scan sonar specific programs. Unlike the more general-use programs, side-scan sonar specific programs utilize the *WHIPS side-scan sonar image* format. This format is an expanded version of the *WHIPS image* format and contains sonar header information for each of the individual sonar swaths. The programs execute in typical UNIX fashion with selected program options entered from the run-line. The required programs, divided into the two respective categories, are listed below.

general image processing programs:

filter - apply a low-pass, high-pass, zero replacement or divide filter to an image
lowpass2b2 - applies a 2 by 2 low-pass filter to an image
wtcombo - weighted combination of 2-4 input images

side-scan sonar processing programs:

mrgnav - merges navigation and altitude information into the header of a side-scan sonar WHIPS netCDF image file
restorehdr - modifies a WHIPS netCDF image by adding the header of a side-scan sonar image
shade - applies a simple shading correction to a side-scan sonar image
slant - correct a side-scan sonar image for water depth and slant-range geometry distortions

velocity - correct a side-scan sonar image for changes in ship's velocity that cause aspect ratio distortions

As described in the WHIPS implementation report, the general-image processing programs modify the *image* portion of the *WHIPS image* file. The side-scan sonar specific programs modify the image data but require that the *WHIPS image* file contain the additional side-scan sonar header information. The sonar header information contained in the image files are read and written by the side-scan sonar specific processing programs. General image processing programs may be applied to the *WHIPS side-scan sonar image*, but only the image portion of the file will be processed and output. The user should be aware that some steps required by the sonar processing utilize the general processing programs, and for further sonar processing to take place, the header needs to be restored to the *WHIPS image* file. The sonar header information may be added to a *WHIPS image* file by utilizing program **restorehdr**.

NAVIGATION FORMAT

If the side-scan sonar data to be processed contains correct fish position and altitude information, navigation preparation is not required. Otherwise, the user must create a navigation data set which represents the best estimate of the vehicle location and altitude. The information contained in this data file is to be merged into the side-scan sonar header before any processing can proceed. Since navigation processing can differ radically from site to site, this report does not cover navigation processing.

If the fish latitude and longitude information must be added to the *WHIPS side-scan sonar* header, a navigation data file must be created. The navigation data is recorded in a simple ASCII format. The navigation file must contain the following fields in the order listed below. The f*ish altitude* field is optional.

latitude
longitude
year
month
day
hour
minute
seconds
fish altitude

The navigation data file may be created in any manner the user desires. However, the user must consider the following items when creating the navigation data set:

1) Data fields must be separated by one or more spaces or tabs

2) The year must be a four digit value (e.g. 1991)

3) All fields, except the latitude, longitude and seconds, must be integer values

4) The latitude and longitude fields must be floating point values, and the position must be recorded in signed decimal degrees with south latitude and west longitude as negative values

5) The seconds portion of the time field may be recorded as an integer or floating point value

An example of a navigation data file (without the optional fish-altitude information) for processing of low-resolution side-scan sonar data is listed below. Note in the example, that the seconds portion of the time value is recorded as either a floating point value or integer value. For high-resolution side-scan sonar data, the user may want the higher accuracy in the seconds field.

```
42.34570 -70.79530 1989 4 3 5 20 3.2
42.34550 -70.79530 1989 4 3 5 20 6.7
42.34540 -70.79530 1989 4 3 5 20 18.4
42.34520 -70.79510 1989 4 3 5 20 30
42.34500 -70.79500 1989 4 3 5 20 36.2
42.34480 -70.79500 1989 4 3 5 20 48.7
42.34460 -70.79490 1989 4 3 5 21 0.4
42.34450 -70.79490 1989 4 3 5 21 6
42.34430 -70.79490 1989 4 3 5 21 18.2
42.34400 -70.79490 1989 4 3 5 21 30.6
```

If the fish altitude information stored in the side-scan sonar header must be updated, the fish altitude information may be recorded as the last field in the data records. An example of a navigation file with the fish altitude information for processing high-resolution side-scan sonar data is shown below.

```
35.34930 -74.80360 1987 2 25 23 0 0 1438
35.34838 -74.80377 1987 2 25 23 0 30 1449
35.34745 -74.80395 1987 2 25 23 1 0 1460
35.34653 -74.80412 1987 2 25 23 1 30 1471
35.34560 -74.80430 1987 2 25 23 2 0 1482
35.34460 -74.80443 1987 2 25 23 2 30 1493
35.34360 -74.80455 1987 2 25 23 3 0 1504
35.34260 -74.80467 1987 2 25 23 3 30 1515
35.34160 -74.80480 1987 2 25 23 4 0 1527
35.34070 -74.80498 1987 2 25 23 4 30 1538
```

PROCESSING SUMMARY

Two assumptions for processing side-scan sonar data are made in this report. The first assumption is that, if navigation data is necessary, the navigation data has been edited and transferred to the computer system for processing. The second assumption is that the user has stored the side-scan sonar data to be processed on the system in the required *WHIPS side-scan sonar* image format. The *WHIPS side-scan sonar* image format is defined using the UNIDATA NetCDF software (UNIDATA, 1991) and is described in detail in the WHIPS implementation report (Paskevich, 1992).

As mentioned earlier, if the side-scan sonar data contains the correct position and altitude information, navigation merging can be skipped. However, if the navigation or fish altitude was not recorded by the side-scan system or is in error, the user should correct the information contained in the header and begin the side-scan sonar processing by merging the navigation data set.

The side-scan sonar processing steps summarized here are similar to those implemented on other systems and are documented in various available reports: Chavez, 1986, Johnson et al, 1990, Miller et al, 1991. The flowchart in Figure 1 is a general processing procedure and shows the steps the user may take to process a side-scan sonar image. At the discretion of the user, additional image enhancement procedures may be applied at anytime during the processing flow. For example, if the image contains a large amount of noise it is recommended that the noise be removed before processing continues since processing may also enhance the noise.

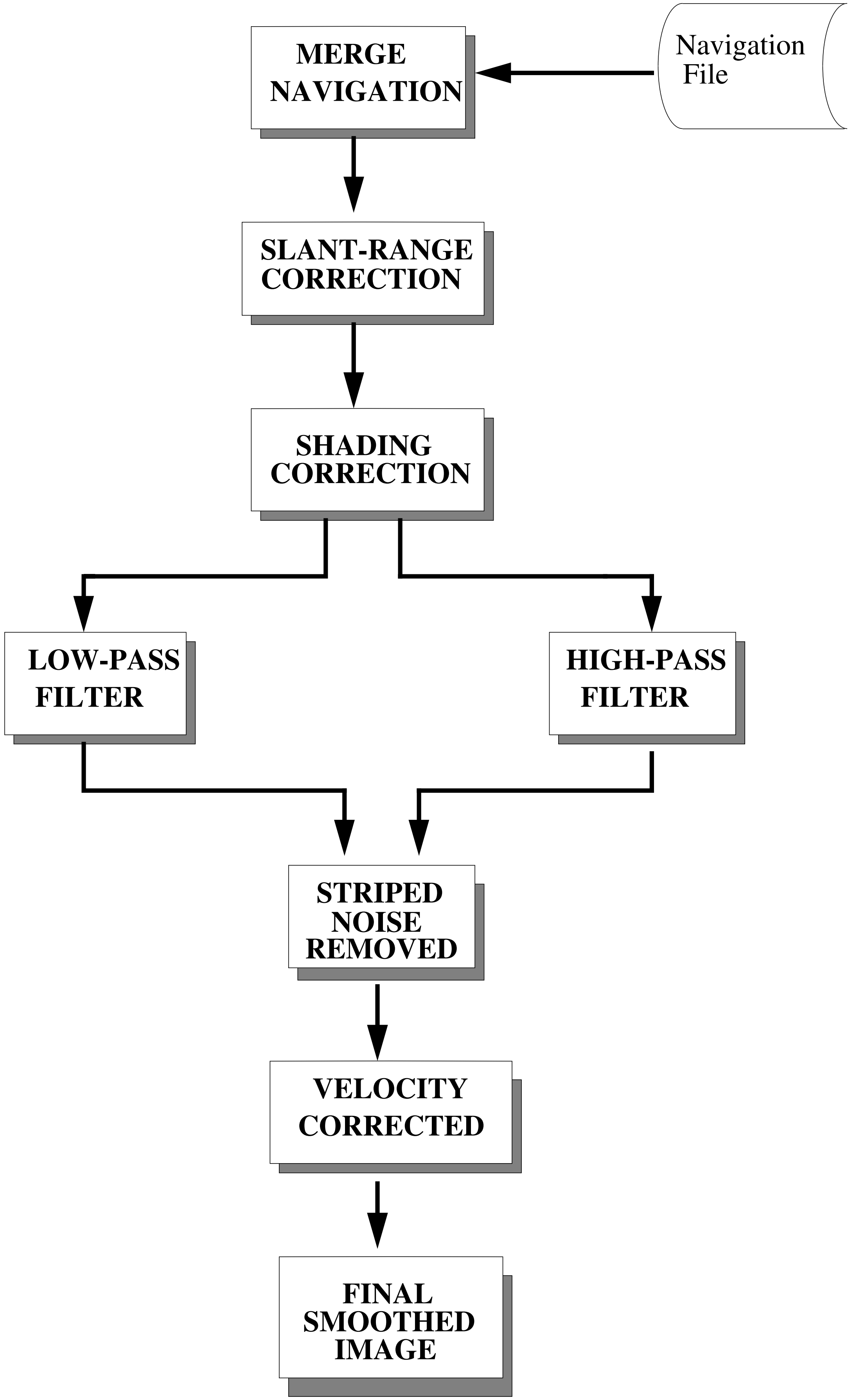

Figure 1 - general side-scan sonar processing steps

MERGING NAVIGATION

If it is necessary to update the fish position values contained in the sonar header, the user must begin by executing program **mrgnav**. If, in addition to the fish position, the *fish altitude* information does not exists or is in error, the user may select to modify the fish_altitude information into the *WHIPS sonar header* by specifying the **-f** option on the program run-line. When **mrgnav** executes, it will then modify the fish position, and optionally the fish altitude, contained in the header using the specified navigation file.

Program **mrgnav** will modify the sonar header information when one of two program tests are met. If the date and time of a header record matches a record from the navigation file, the header information is updated with the actual values contained in the navigation file. Second, if the date and time information for a header record falls between two given navigation records, **mrgnav** will compute the new header values using a simple linear interpolation.

SLANT TO GROUND RANGE CORRECTION

The first major step in processing of the side-scan sonar data is to remove the water column offset and to apply the slant-to-ground-range correction using program **slant**. The water column offset is the distance the sonar vehicle is above the sea floor. The slant-range distortion results from the geometry related to the data collection and the correction is computed assuming a flat seafloor. This program requires the fish altitude information from the sonar header. The user must specify the pixel size in meters in the across-track direction of the raw data and the pixel size desired in the output file. The image resolution values are specified by selecting **-r** and the selected resolutions (*resin, resout*) on the program run-line. For example, specifying *-r .2,.5* flags the program that the input data resolution is .2 meters with a desired .5 meters for the output file. By multiplying the *fish_altitude* value stored in the sonar header and the user supplied image pixel resolution, the water column offset is computed. This computed value represents the number of pixels, left and right, from nadir to the first return of valid image data.

It should be stressed that the slant to ground range correction is computed assuming a flat seafloor. Though this assumption is known to be less accurate than correcting to the actual sea floor bathymetry, we presently are only collecting bathymetry along the survey track lines and thus only know bathymetry at nadir. A more accurate correction requires determining the actual depth of each image pixel, as would be available with the collection and coregistration of acoustic swath bathymetry. The alternative processing, utilizing coregistered swath bathymetry, is a generally unavailable technique. As swath bathymetry collected with side-scan sonar data becomes available, this correction will benefit from further development.

SHADING CORRECTION

A simple shading correction is applied to the image next. The correction is currently applied using program **shade** which corrects for shading problems that occur in the across-track direction caused by power drop-off. The purpose of this program is to normalize the image in the across-track direction with respect to signal attenuation and the power drop-off characteristic of the system so that DN values in the near and far range can be more accurately compared.

Program **shade** executes in a two-pass processing phase. The first-pass computes the totals for each sample position of the image and then the average value for each sample. Those averages are then used to compute coefficients for the sample locations and are used for image shading corrections. The second pass applies the computed sample coefficient to the input DN values.

The program computes the sum of each sample position by totaling the samples of every other line from the input image. Values which fall between the tolerance limits specified by the user are totaled into the values for the sample locations. The user specifies the valid range by selecting the program key flag **-t** and the minimum and maximum values to be used (e.g. *-t 1,253*). Once the values are totalled, the average value for the sample locations are computed by dividing the sum by the number of points which fell within the specified tolerance limits (e.g. the number of valid pixels). The normalization value (**-n**) or, if not specified by the user, the average of the averages is divided by the sample average to compute the sample coefficients. A 1x11 recursive low-pass filter is then applied to the coefficients to smooth the data before the coefficients are applied to the image data. As each input record is read during the second-phase of processing, the input value is multiplied by the computed coefficient for that sample location producing an image with uniform brightness.

STRIPED NOISE REMOVAL

The next major step in the initial processing is to remove the striped noise which can be found in side-scan sonar images in the across-track direction. During data acquisition some lines of sonar data have lower values than adjacent lines because of vehicle instability or noise in the water column. Removal of the striped noise is accomplished by executing program **filter** and generating two separate images from the input data. One image will contain the high-frequency component of each individual line of data without the noise. The other image will contain the low-frequency background brightness of the image without the noise. The two resultant images are then combined, using program **wtcombo**, to recreate an image that is very similar to the original one, but without the noise.

The noise is removed using boxcar filters. The boxcar sizes for striped noise removal for GLORIA side-scan sonar data are 1 line by 71 samples for the high-pass component and 9 lines by 71 samples for the low-pass component. The filter sizes needs to be modified for other sonar systems. Selecting a proper filter boxcar size will require the user to experiment with his or her data set prior to beginning the actual processing.

Since the programs **filter** and **wtcombo** will only process the image portion of a *WHIPS image* file, the side-scan sonar header needs to be added to the resulting *WHIPS image* before further sonar processing can take place. This is done by executing program **restorehdr** and updating the *wtcombo file* with the header information from the *shade file*.

VELOCITY CORRECTION

The final geometric distortion which the sonar data must be corrected for are changes due to the ship's velocity that occur while the data is being collected. To correct for the aspect-ratio distortion and create an image with a 1:1 ratio, the user must execute program **velocity**. The default output image resolution is 50 meters. The user may override this by specifying the **-r** option on the program run-line along with the desired along-track *pixel_resolution* (e.g. *-r .5*).

The image is processed by stretching a group of lines referred to as segments. Stretching is actually accomplished by duplicating individual lines as determined by the aspect ratio for the segment. Since the aspect ratio is most commonly computed as a real number, some rollover in computing the number of times a line should actually be duplicated is applied. This means for a computed aspect ratio of 2.5, one line in the segment may be duplicated twice while the next line may be duplicated three times.

To apply the velocity correction, the user may specify the number of lines to be contained in each processing segment by selecting the **-l** option and the number of lines (*delta_line*) on the program run-line (e.g. *-l 150*). By default, the segment is defined as 60 lines for 30-second GLORIA data and may be further considered as a 30 minute time block. When applying the velocity correction, the actual distance traveled from the beginning of the segment to the end of the segment is computed using Clarke 1866 spheroid values. Given the input and desired output resolution of the images, the program computes the distance travelled for the segment and how many lines should be contained in the segment to produce a proportionally correct image. For GLORIA data, this ratio averages 1:2.5, but aspect ratios as high as 1:4 have been seen for GLORIA side-scan sonar when the ship collecting the data has been caught in a strong current.

As each segment is processed, the heading for the current segment is computed and compared to the heading of the previously processed segment. When the heading between the two segments differ by more than the user specified *delta_heading* (**-h** option), the segment to be processed is reduced to one-third the *delta_line*s (**-l**). The heading comparison is done to reduce the effects of course changes in the data. The next segment processed returns to the *delta_-line* specification unless the *delta_heading* value is again exceeded. As the segments are processed, the new image is written to a temporary file and the number of lines output are totaled. When the end of the input file is encountered, the output file is defined utilizing the new number of lines in the temporary file.

SMOOTHING

The final enhancement process is to execute **lowpass2b2** and apply a 2 by 2 low pass filter for smoothing the image. This program processes only the image portion of the *WHIPS side-scan sonar image*. Because the delta velocity correction typically stretches the image 1:2.5 times, a 2 by 2 low-pass filter is applied to the image. This filter will smooth out the blockiness that can be seen in the velocity-corrected image without over smoothing and blurring the image.

After running **lowpass2b2**, the header information is again clobbered, and it must be restored to the *lowpass2b2* file from the *velocity* file by program **restorehdr**. This is the final step in the initial processing.

FUTURE DEVELOPMENTS

The side-scan sonar processing described here will benefit by further developments which could include improved slant-to-ground range correction procedures and improved shading techniques. It is hoped that improved shading techniques which will take into account the beam angle (Reed et al, 1989) can be implemented. Also, as digital mosaicking techniques are implemented, the need to stretch the image file in the along-track direction, as is currently done in the velocity program, may not be required. It is hoped that digital mosaicking can benefit by automated navigation of a swath of sonar data and placement of the swath in a cartographically defined area.

APPENDIX A

The following sequence of WHIPS programs and run-line options listed below represent the steps required to process one file of 30-second GLORIA side-scan sonar data. These run-line options may be used as a guide and modified to accommodate other sonar data.

```
% mrgnav -i gloria.pic -o gloria.mrg -n gloria.nav -f

% slant -i gloria.mrg -o gloria.slr

% shade -i gloria.slr -o gloria.shd -t 1,254

% filter -i gloria.shd -o gloria.hpf -b 1,71 -h -v 1,253

% filter -i gloria.shd -o gloria.lpf -b 9,71 -l -v 1,253

% wtcombo -i gloria.hpf,gloria.lpf -o gloria.wco -c 1,1 -a -128

% restorehdr -i gloria.wco -h gloria.shd

% velocity -i gloria.res1 -o gloria.vel

% lowpass2b2 -i gloria.vel -o gloria.2b2

% restorehdr -i gloria.2b2 -h gloria.vel
```

The following list is an example which can be used for processing Klein side-scan sonar data. The example below produces a sonar image with an input pixel resolution of 0.2 meters to a final processed image with a pixel resolution of 0.5 meters.

```
% mrgnav -i bosfile.pic -o bosfile.mrg -n navigation.dat

% slant -i bosfile.mrg -o bosfile.slr -r .2,.5

% shade -i bosfile.slr -o bosfile.shd -t 1,254

% filter -i bosfile.sh2 -o bosfile.lpf -l -b 9,71 -v 2,253

% filter -i bosfile.shd -o bosfile.hpf -h -b 1,71 -v 2,253

% wtcombo -i bosfile.hpf,bosfile.lpf -o bosfile.wco -c 1,1 -a -128

% restorehdr -i bosfile.wco -h bosfile.shd

% velocity -i bosfile.res1 -o bosfile.vel -r .5 -l 150

% lowpass2b2 -i bosfile.vel -o bosfile.2b2

% restorehdr -i bosfile.2b2 -h bosfile.vel
```

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