

Latest Developments in Bathymetric Data Processing and its Application to Sandwave Detection

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Abstract

Processing of high amounts of bathymetric data is a field of science and engineering, constantly subdued to improvements through research. Automation is increasing and many processing steps for data correction are provided; yet human interaction is still necessary as well. This article shall give a brief overview over the latest developments in post processing software for bathymetric and sonar imagery data, and new options these developments offer.

Benefits of merging data from various sources (e.g. multibeam, sidescan sonar) shall be shown, with an emphasis on displaying this data together in a combined product. Together with independent processing and subsequent products of the different datasets this offers good tools for further analysis of the surveyed geomorphology, as will be shown.

1. Introduction

1.1 General

Accurately covering the dynamics and interpreting the behavior of sandwaves and river dunes is not possible without a prior processing of the survey data. Proper correction and cleaning of the data is essential in order to get an unbiased picture of the bathymetry.

The most common of reason for such a bias is an outlier. Hence detecting them is one of the most important steps in the processing of high volume multibeam data. Erroneous soundings can be caused by several factors, including noise in the water column, the complexities of the seafloor, and physical limitations of the sonar system. These measurements need to be located and excluded from further processing to guarantee that correct products will be generated from the cleaned data. With the increasing volumes of bathymetric data being recorded by state of the art multibeam sonars, there is also an increasing need to reduce the cleaning and processing time required to generate products from the data. Of course a proper processing, i.e. application of corrections, of previously unprocessed or incorrectly processed data is mandatory.

To achieve both objectives - data quality and reduced processing time - modern multibeam post processing packages combine simple and advanced automatic data cleaning algorithms while at the same time allowing to tie in further available information to aid in data processing. Additionally to that offering a range of options on how to process the data from the various auxiliary sensors together with the depth information greatly enhances the possible quality of the final data.

This paper shall give a brief overview of the latest developments in the data cleaning sector, an idea on what possible processing steps can be done, and an outlook as to possible preliminary interpretation tools a standard processing software package can include.

1.2 Purpose of Data Processing

Why processing bathymetric data is necessary, especially when searching for specific features and trying to interpret them, can be easily seen in (Fig.1) below. Although the data is already well cleaned, it is quite obvious that something is odd between the picture on the left, and the (actually corrected) picture on the right. The difference between the data in the two pictures is, that for the left, the survey has not been set up properly, but the processing been performed, as for the right, the data has been processed with the proper set up.

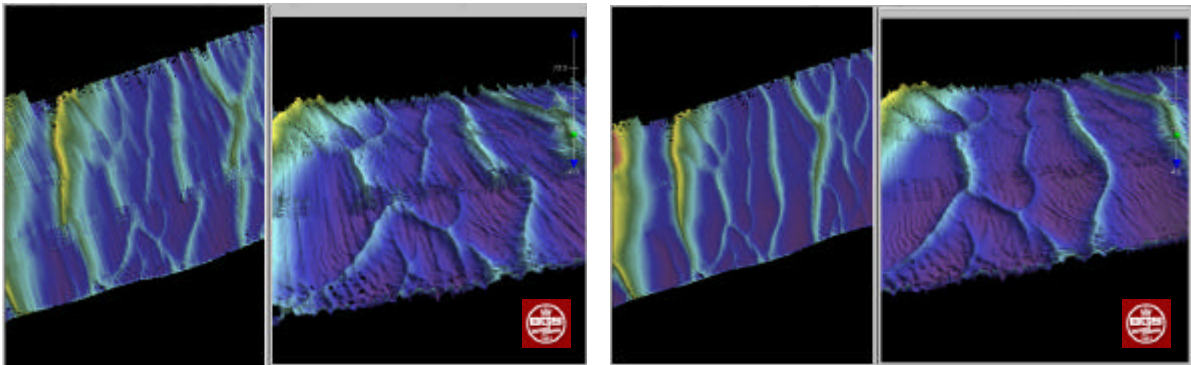


Fig. 1 - Effects of a badly setup data processing flow

Coming to think, that the only two issues here were a positional offset between the depth sensor and the navigation antenna, plus a time delay between the depth sensor and the motion sensor – which are both fairly common problems happening – the effects seem quite hazardous. The larger sandwaves obviously do not align very well anymore, as for the smaller ripples: they are not coming through in the left picture, but are overlaid by the motion artifacts.

The fact, that there could be more, like time delays between the navigation, or the gyro sensors and the depth sensor, or like biased reading errors of either motion sensor (heave, pitch or roll), or the gyro, that there could be wrong sound velocity profiles used for the processing, or that there could be errors due to the tidal data applied to the survey (which even now in the lower right, there still remains), makes it evident, that a proper processing is essential.

2. Data Processing

2.2 An idealization

The whole idea of processing bathymetric and sidescan data can be easily displayed in a theoretical diagram like in (Fig 2). The initial information displayed in it is of course the source data. But that is not limited to only the depth sounder or side scan data, but as already indicated previously, includes navigation information, attitude sensors, tidal information, sound velocity profiles and others.

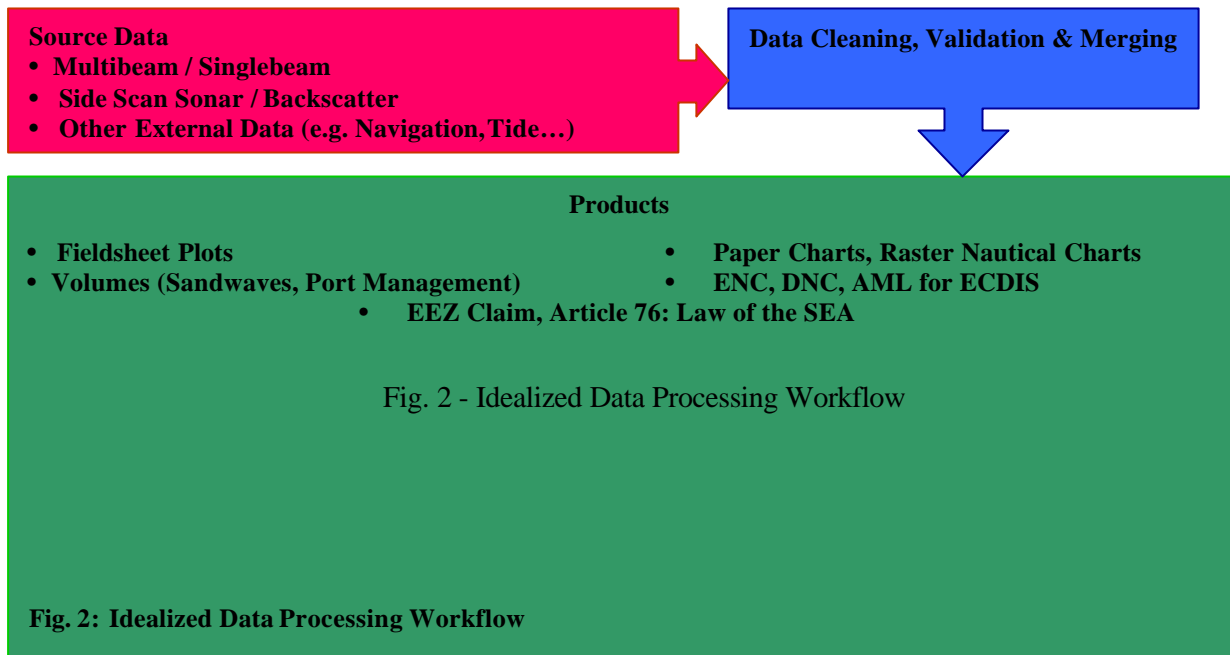


Fig. 2 - Idealized Data Processing Workflow

Fig. 2: Idealized Data Processing Workflow

Having acquired all the data the purpose of data processing then remains to perform the data cleaning and validation, and subsequently the merging of the source data into the final processed depth or acoustic image in order to generate the desired product. There is of course a range of such possibly desired products. The most common ones for data processing with an application in sandwave detection would be to create fieldsheet, documenting the current situation surveyed. Next might follow the calculations of volumes for a surveyed sandwave and difference volumes, to deduct information on the behavior or movement of the sandwave.

2.3 Multibeam Processing

For multibeam data, a workflow, which includes as much processing options as possible, could look like the one in (Fig.3).

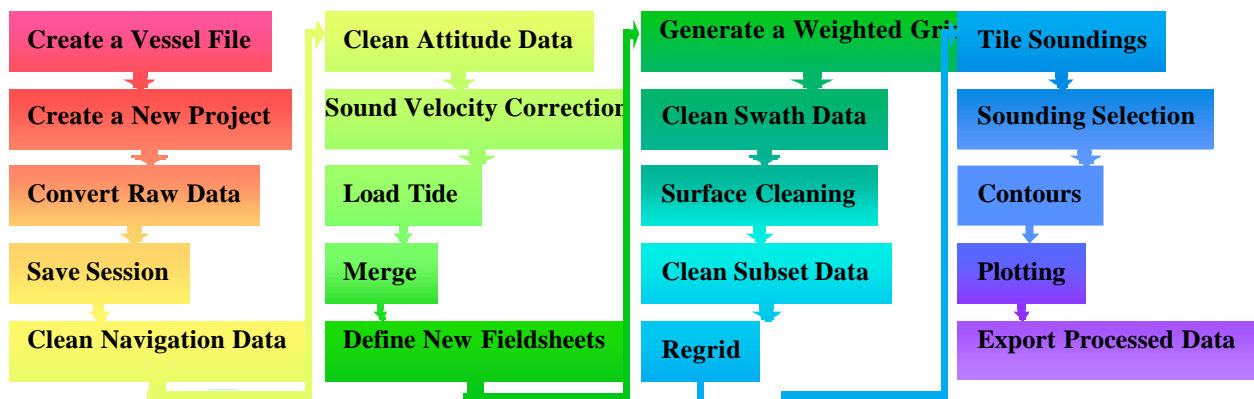


Fig. 3 - Possible Multibeam Processing Workflow

Some data might require all steps of processing, other might be obtained in an already preprocessed state, so that certain steps need not, or indeed sometimes must not be run again. It is however necessary to have all processing options available, in order to deal with the different kinds and stated of multibeam data, which might be used. That of course makes it necessary in the conversion step to have the ability to convert as many different formats as possible, since there is no common agreed on data format yet.

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Discussing all these steps here would go beyond the focus for this paper, although all these steps fall within the scope of the title. For the further discussion the focus shall be set to certain steps in the data cleaning and gridding step, where recently the most enhancements have happened.

The first step in the processing of bathymetric information being here discussed shall be the generation of a weighted grid. This assumes, that the cleaning of the auxiliary data has already been done, and necessary information, such as a sound velocity profile and tidal information has been loaded, and finally all that data has been merged together with the depth information.

Once the geo-referenced position for each sounding has been computed a weighted grid can be computed to provide a better understanding of the seabed topography. The grid is computed as a model of the mean seafloor, using the distance of each sounding from a grid node and the sonar characteristics, such as beam opening angle, footprint size and grazing angle, for calculating the weighting factor.

Such a grid can be useful during the processing itself, but also for further interpretation. Its use during processing is mainly the detection of outliers in the grid, as well as certain sensor artifacts, which traditionally show very well in grids. Once such areas have been identified, further inspection and corrected re-processing of the data can be performed in order to improve the quality of the final sounding.

For interpretation the use of a grid is obviously in terms of looking at the data, looking at the bathymetry / geomorphology. A grid is also necessary to run a 3D display of the data, which allows the interpreter of the data, to view the information from any angle and distance.

Tools, which might come in handy for such grid operations, include coloring and sun illuminating the grid. The color for the weighted grid can be switched between color-coded, shaded view or shaded grey scale view. A moveable light-source allows for best display of features and artifacts by casting the best shadow. A sample of such a grid view can be seen in (Fig.4).

Others might be such grid-processing tools as adding or removing a survey line from a grid, or interpolating a grid. The latter could be helpful, because the results of depth cleaning often create holes opening in surveys that were designed to have 100% coverage. While post-processing can never make up for the lost data, and in case of a requirement for a 100% survey a partial re-survey might become necessary, the effect of such holes on grids and products thereof can be minimized. Functionality offered might be for example an algorithm to first search for holes and then interpolates values for the grid at such locations, while leaving already populated grid cells untouched.

An already developed function scans rows of the Grid until it finds an empty cell, then it runs the following test: The function places the empty cell at the centre of either a 3x3 or 5x5 cell matrix. If the number of populated cells surrounding the empty one is greater than or equal to the 'Number of Neighbors', specified beforehand, the cell will receive the average value of these cells. Otherwise, the function will continue to the next empty pixel inside the grid. An example for this can also be seen in (Fig. 5).

Used in a sensible way, this functionality allows for a quick production of a grid covering small data gaps, while not extending it over larger data gaps or extrapolating outside the surveyed area. It must not be forgot though, that the interpolated values are very likely to be based on soundings surrounding the area of the hole, yet not soundings covering that area.

The benefits of such a function can be seen in (Fig. 5) as well. The visual interpretation of the lower image containing small ripples is much easier, than the interpretation of the upper image.

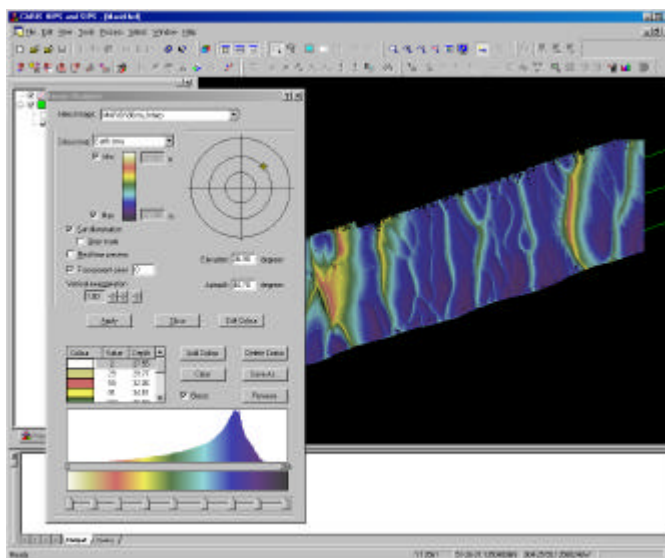
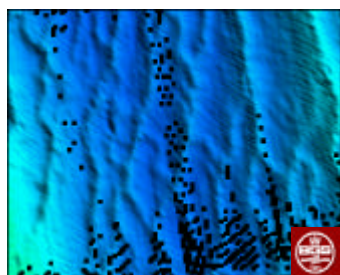
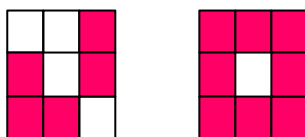


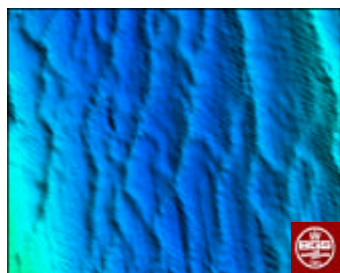
Fig. 4 - Gridded Sandwave Data and Grid Options



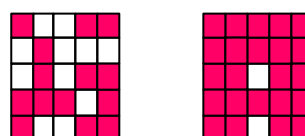
3 x 3 Matrix



5 Neighbours 8 Neighbours



5 x 5 Matrix



14 Neighbours 23 Neighbours

After having had a look at the grid it usually becomes obvious, which areas need more attention for the cleaning and which need less, although all the data needs to be cleaned. It has to be kept in mind, that a grid is a smoothed representation of the data, and that therefore not seeing an outlier in the grid does not mean that there are no outliers. For cleaning there are currently three methods common, some traditional, like the swath editing, some well established, like the subset cleaning, and some fairly new and still being enhanced, like the statistical surface cleaning. Those shall be introduced in the next paragraphs.

Fig. 5 - Raw & Interpolated Grid, and possible algorithm settings

To start with the manual cleaning tools, the first look will be at swath editing. Even though this is a traditional way of cleaning data, latest developments, especially in the 3D viewing graphics technology have improved the workspace. While still cleaning the data on a profile by profile base, and not in its true geographic reference frame, there are multiple views available, to inspect and if necessary edit the data. This can be seen in (Fig. 6) and might include a plan view, side and rear view, 3D view, a profile view, and possibly – yet not displayed here – include a backscatter view, or the data from side scan or motion sensors for best interpretation of the data visible. That allows making an as informed cleaning decision as possible, whether or not a sounding is an outlier, or carries a valid value.

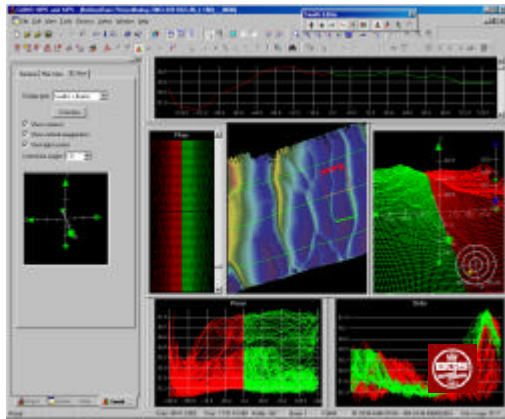


Fig. 6 - Swath Editing Data

While some functions make working easier, such as removing the general trend of the data during display, in order to see outliers better, the swath editor cannot cover the last detail of data cleaning in a region with very dynamic geomorphology. This is due to the fact, that data might be over-plotted over each other, and hence hiding an outlier behind. Though the 3D view partially helps, some apparent outliers in turn might prove to be valid soundings, but are displayed out of location, due to the profile-by-profile view. The clear benefit of the swath editor is that coarse outliers still are visible and easily editable in here, as well as the systematic errors in certain sections of the swath, which propagate throughout the survey line. Those are more easily visible and editable here, than in any other editor.

To partially automate a search for such effects, a basic set of filters is used in most post-processing software packages, such as depth gates, spike detection, the removal of depths coming from certain beams, having certain quality flags, and swath reduction based in beam-angles or across-track distance.

The subset editor as displayed in (Fig.7), allows viewing and analyzing all bathymetric data within a certain subset. This means the information of neighboring lines is pulled into one display for analysis in a 2D or 3D view and displayed in the proper geographic relationships. While the 2D view shows a predefined section of the subset from a certain selectable direction, the 3D view can be freely rotated, moved or zoomed into, in order to get the best view of the data. It proved that calibration artifacts could be detected easily in this display. Of course, as can be seen above, the sandwaves can be seen just as well.

The key to working effectively with a subset editor is to select the subset in such a way, and set all viewing properties to such parameters, that whatever the data where the interest lies in, can be seen best. If for example one would like to clean data in sandwave fields, it is good to select a display like in (Fig. 7), where the 2D view displays a cross-section that is perpendicular to the orientation of the sandwaves.

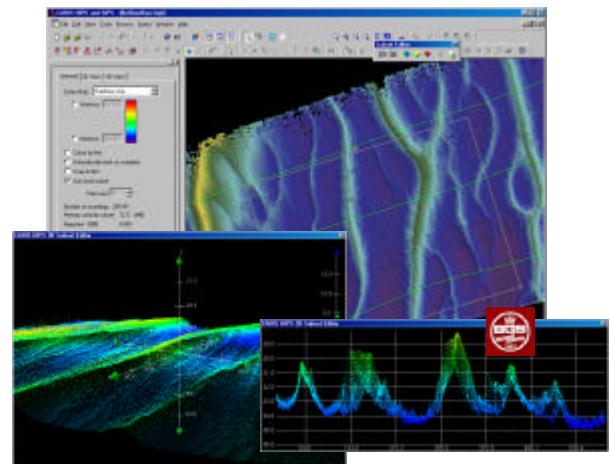


Fig. 7 - Subset Editor Interfaces

Compared to the two previously discussed depth-editing tools (swath editor and subset editor) the surface cleaning tool is the opposite, as it is an automatic tool. It first splits the data of a whole region into smaller tiles and then iteratively builds a polynomial surface for each tile, which best fits the data in the respective tile area. The user defines what kind of surface is to be built, by setting the order of complexity:

- Mean: $f(x, y) = b_0$ (1)
- Tilted Plane: $f(x, y) = b_0 + b_1x + b_2y$ (2)
- Curved Tilted Plane: $f(x, y) = b_0 + b_1x + b_2y + b_3xy$ (3)
- Quadratic: $f(x, y) = b_0 + b_1x + b_2y + b_3xy + b_4x^2 + b_5y^2$ (4)
- Cubic: $f(x, y) = b_0 + b_1x + b_2y + b_3xy + b_4x^2 + b_5y^2 + b_6xy^2 + b_7x^2y + b_8x^3 + b_9y^3$ (5)

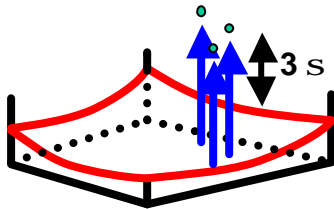


Fig. 8 - Theory behind Surface Cleaning

To decide on the grade of the polynomial function it is helpful to get an idea of the seafloor morphology from tools such as the shaded grid display. The computed surface is used to determine residuals for each individual sounding and a mean standard deviation of the residuals. Finally the user can define a threshold as a multiple of the computed standard deviation for the purpose of outlier detection and cleaning. The theory behind this and the decision of outlier detection and cleaning can be seen in (Fig. 8), where any point is rejected which has a residual (blue, dashed arrow) that exceeds the threshold (length of the black arrow, in this case selected to be 3σ).

The performance of the surface cleaning in a smaller region of the data seen before is displayed in (Fig. 9). It can be seen that the surface cleaning successfully rejected coarse outliers around the main feature. However, in a secondary attempt to reject more of the systematic effects in this data, coming from a small overlap in the outer beams between two lines, the surface cleaning was only partially successful. This is because the cleaning would need to be set too strict, cutting into the statistic noise of the data, and hence rejecting good data as well, creating some small artifacts on the left flank of the major sandwave. Therefore it could be concluded, that surface cleaning is a good tool to find coarse outliers, and it has proven itself very usable even beyond that in flat seafloor regions. Yet when it comes to geomorphologic active regions, it should merely be used for the automatic detection of coarse outliers.

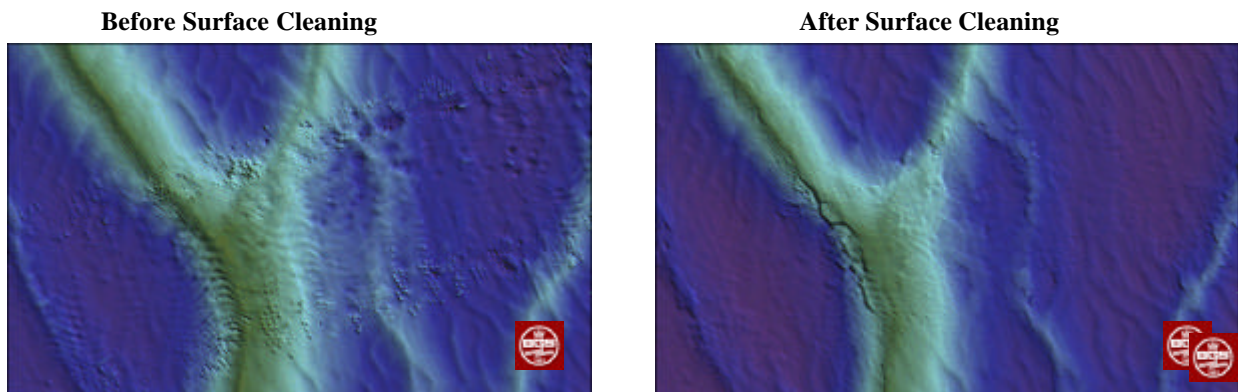
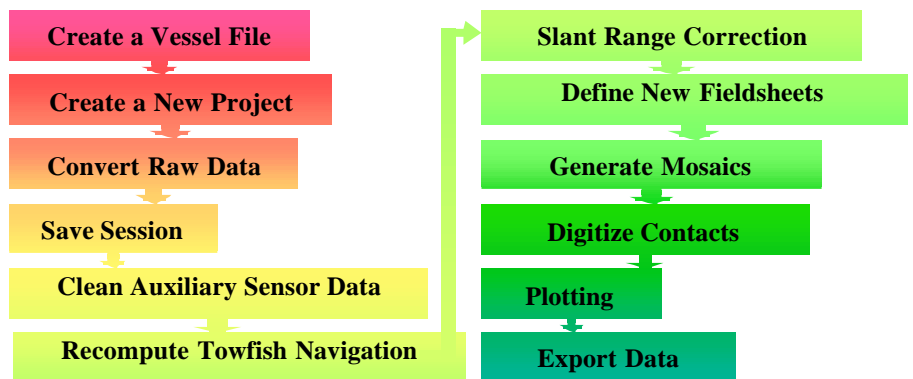


Fig. 9 - Bathymetric Data before and after repeated surface cleaning

2.4 Side Scan Processing

Similar to the multibeam processing, a possible workflow has been designed for the processing of sidescan information, and can be seen in (Fig.10). Some of the steps should be identical in a comprehensive post processing

Fig. 10 - Possible Side Scan Processing Workflow



software package. Special steps are the re-computation of towfish navigation, slant range correction, the generation of mosaics and the digitization of contacts.

The latest developments with respect to processing acoustic imaging data are within the slant range correction and the mosaicing. These shall be introduced in more detail in the following paragraphs.

The first development discussed is concerned with the slant range correction. Up to now the usual way to slant-range-correct side scan data is to use the altitude of the sonar sensor above the seafloor as the depth of all samples within a side scan profile. While this is an accepted method, it bears the possibility for misplacing the side scan echoes in areas with a dynamic topography.

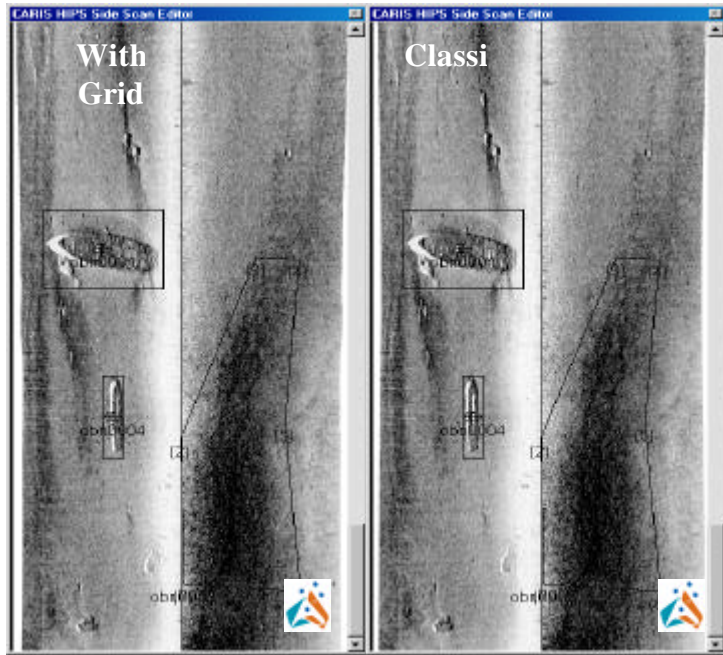


Fig. 11 - Slant Range Correction by different means

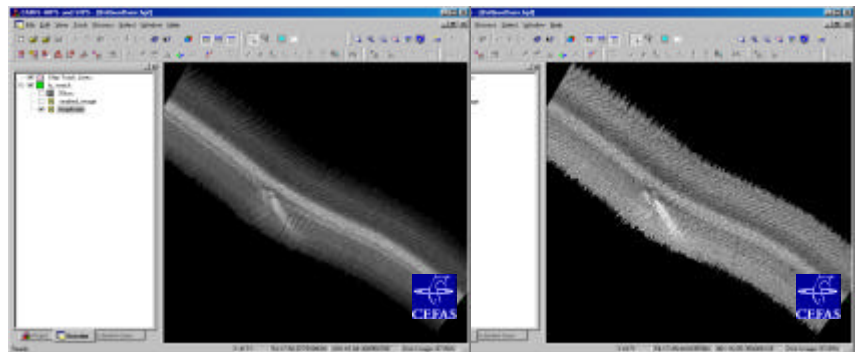
To better take care against such misplacements, post-processing software should now include an option to rather use a grid for the slant range correction and thus to take changing topography into account.

In the images in (Fig 11) this can be best seen when comparing the outer edges of the data in either image. Looking at the left edge of the data that was slant range corrected with a grid, the edge is changing more, than in the data corrected with the classic method.

The next logical step after slant range correcting side scan data would be to mosaic it. Latest developments in the mosaicing process do not so much refer to true side scan data, but pseudo side scan information and backscatter data coming from multibeam sensors. Previously the multibeam imagery information was only visible in the swath editor as auxiliary

information. This has started to change now, in terms of being able to mosaic backscatter and pseudo-sidescan data. As this data is coming from multibeam sensors, a slant range correction is not necessary.

Of course the quality of such data compared to true side scan still legs behind, yet quite often, there is only one or the other, and in such cases, the backscatter information is welcomed additional information. And as shown in (Fig. 12) the results from such a mosaic still offer a good impression of the seafloor



3. Data Combination and Analysis

Latest developments in the 3D visualization technology allow to display mosaiced imagery data, like side scan, pseudo side scan and backscatter data draped onto a 3D bathymetric model. This can be seen in (Fig. 13) to the left and in the middle. Together with a color coding the side scan data by intensity, this allows for a great step forward in analyzing the data in terms of what kind of bottom is located where, not only in position, but in true 3D.

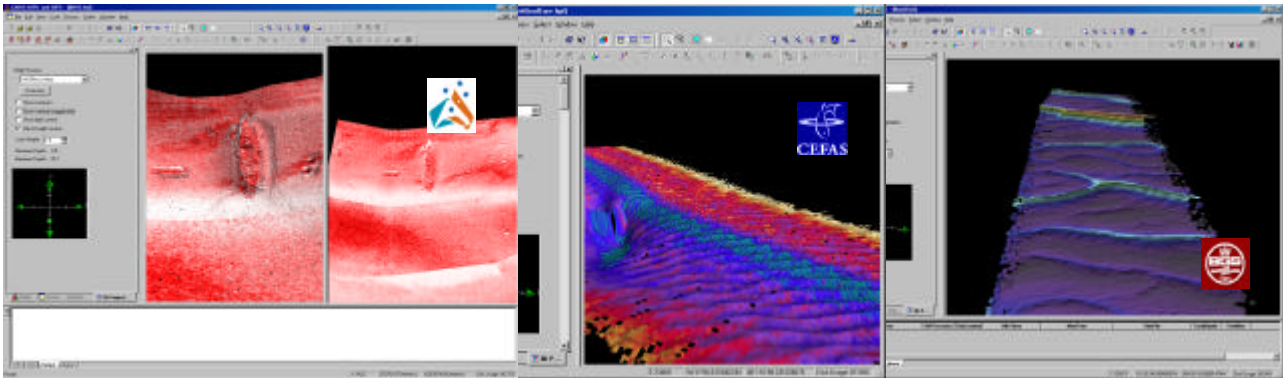


Fig. 13 - Side Scan and Backscatter Data draped over grid in 3D

Additionally the mere 3D viewing of grids, as displayed in (Fig.13) on the far right, is a good tool for visual inspection and interpretation of the surveyed and processed data. Also using a mosaic during swath editing or subset editing as an additional source of information, what data to reject and what data not to, is an advantage. Such a scenario for the swath editing is displayed in (Fig. 14).

4. The next steps

Additional interpretation tools might be included in post-processing software, which can be very useful for sandwave detection, interpretation and visualization. Such tools may include, but not be limited to, processing options for calculating volumes and difference volumes (which might give indication for mass transport), to display such difference terrain models, and tools to generate slope and aspect map. This might be either direct part of a post processing software package, or be included in a GIS software, that is part of the package.

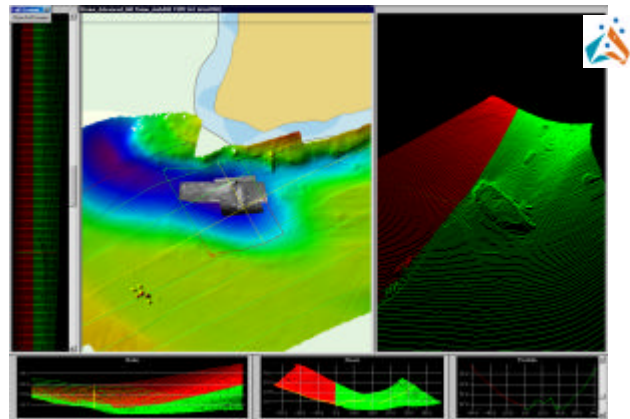


Fig. 14 - Using a Mosaic in the Swath Editor

5. Future developments

Future enhancements, which are already partially developed, and will soon be released, include a statistical error propagation tool, allowing to calculate depth and positional errors for each sounding, the BASE surface, which makes use of these bathymetric error models as well as provides a base model for derived products such as grids, charts, and contours at certain scales, more batch processing and 3D editing option, as well as more 3D visualization options in terms of the ability to fly through the grid.

Acknowledgment

All data shown in the figures used in this paper has been given to us by either clients or as a part of public data for conferences. The copyright to the data remains with these institutions and shall be acknowledged. All data is labeled in this paper according to the source it is coming from, and we wish to express thanks to those institutions, namely the British Geological Survey (BGS), the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) in the United Kingdom's Department for Environment, Food and Rural Affairs, and finally the Australian Defence Science and Technology Organisation (DSTO).

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 Data Labels: BGS  CEFAS  DSTO 