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Abstract-The Naval Oceanographic Office collects subbottom acoustic data using the Remote Environmental Monitoring Units (REMUS) Autonomous Underwater Vehicle (AUV). The subbottom data are processed using customized playback software that creates a subbottom profile image that can be integrated into ArcGIS 9.2. A REMUS AUV test survey was recently completed that obtained quality subbottom profiler data that were used to demonstrate this image integration approach. Recent improvements in the processing software developed at the Naval Research Laboratory (NRL) have been used to decrease the time and effort required to efficiently utilize and integrate the subbottom profile imagery into the ArcGIS 9.2 product. This new software allows multiple subbottom images to be casily added to the ArcGIS 9.2 project while at sea, providing a more complete representation of the REMUS survey. The efficient integration of the subbottom imagery into an ArcGIS 9.2 project is a significant step in providing a more improved product.

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REMUS Subbottom Image Processing for Integration into ArcGIS

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Abstract-**The Naval Oceanographic Office collects subbottom acoustic data using the Remote Environmental Monitoring Units (REMUS) Autonomous Underwater Vehicle (AUV). The subbottom data are processed using customized playback software that creates a subbottom profile image that can be integrated into ArcGIS 9.2. A REMUS AUV test survey was recently completed that obtained quality subbottom profiler data that were used to demonstrate this image integration approach. Recent improvements in the processing software developed at the Naval Research Laboratory (NRL) have been used to decrease the time and effort required to efficiently utilize and integrate the subbottom profile imagery into the ArcGIS 9.2 product. This new software allows multiple subbottom images to be easily added to the ArcGIS 9.2 project while at sea, providing a more complete representation of the REMUS survey. The efficient integration of the subbottom imagery into an ArcGIS 9.2 project is a significant step in providing a more improved product.**

I. INTRODUCTION

Acoustic subbottom profile data have been collected by the Naval Oceanographic Office (NAVOCEANO) Remote Environmental Monitoring Units (REMUS) autonomous underwater vehicles (AUV) since the first introduction of a new parametric subbottom profiling system in 2001 [1]. Originally, the subbottom data obtained on the vehicle needed to be played back after completion of the data acquisition mission to generate short subbottom profile imagery segments. Creating this subbottom imagery was very time consuming because it essentially required one hour of processing time for each hour of recorded data. Thus, for a 20-hour data survey recorded on a REMUS vehicle, it required approximately 20 hours of processing time to create the subbottom imagery. Additionally, there was no efficient way to present a representation of a subbottom trackline or an image of that entire line in an ArcGIS project. After the imagery was created, only the short segments and single images were able to be added to the ArcGIS.

II. SURVEY OPERATIONS – SHIPBOARD AND REMUS AUV

A REMUS 6000B AUV test was completed in May 2009 aboard the USNS *Mary Sears* to validate environmental sensor operations (side scan and subbottom profiler), data recording, and overall AUV system performance. The survey duration was approximately 10 hours with a vehicle speed averaging 2.5 knots. The total distance surveyed was approximately 25 nautical miles with 100 survey lines. REMUS operated at altitudes between 1.0 to 50 meters above the seafloor. Fig. 1 shows the deployment of the REMUS vehicle off the stern of the ship.

Raw subbottom profile data are recorded in real-time aboard the REMUS AUV using the PFR-S 30 kHz system [1]. This subbottom system is a high frequency, parametric, normal incident system that ensonifies the bottom (nadir segment) immediately beneath the vehicle [2].

While REMUS collected subbottom data, high-resolution bathymetry data were obtained with a SIMRAD EM121a hull-mounted multi-beam system aboard the *Mary Sears*. Fig. 2 shows a color plot of bathymetry (feet) with REMUS survey tracklines. The processed bathymetry data were then integrated into ArcGIS 9.2 using 3-D Arc Scene to select optimal locations for installation of the bottom-moored navigation transponders. Fig. 3 is a 3-D image that shows the georeferenced location of the transponders, REMUS AUV ascent and descent pathways, and survey track lines.

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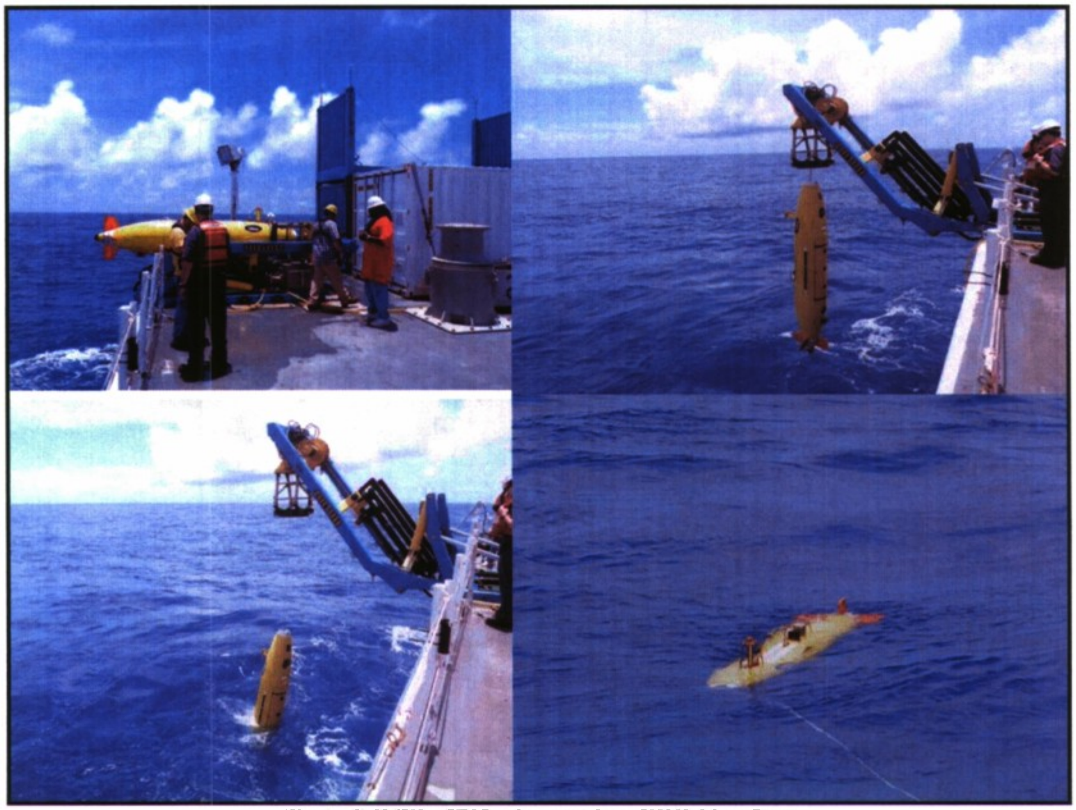

Fig. 1 – REMUS AUV Deployment from USNS *Mary Sears*

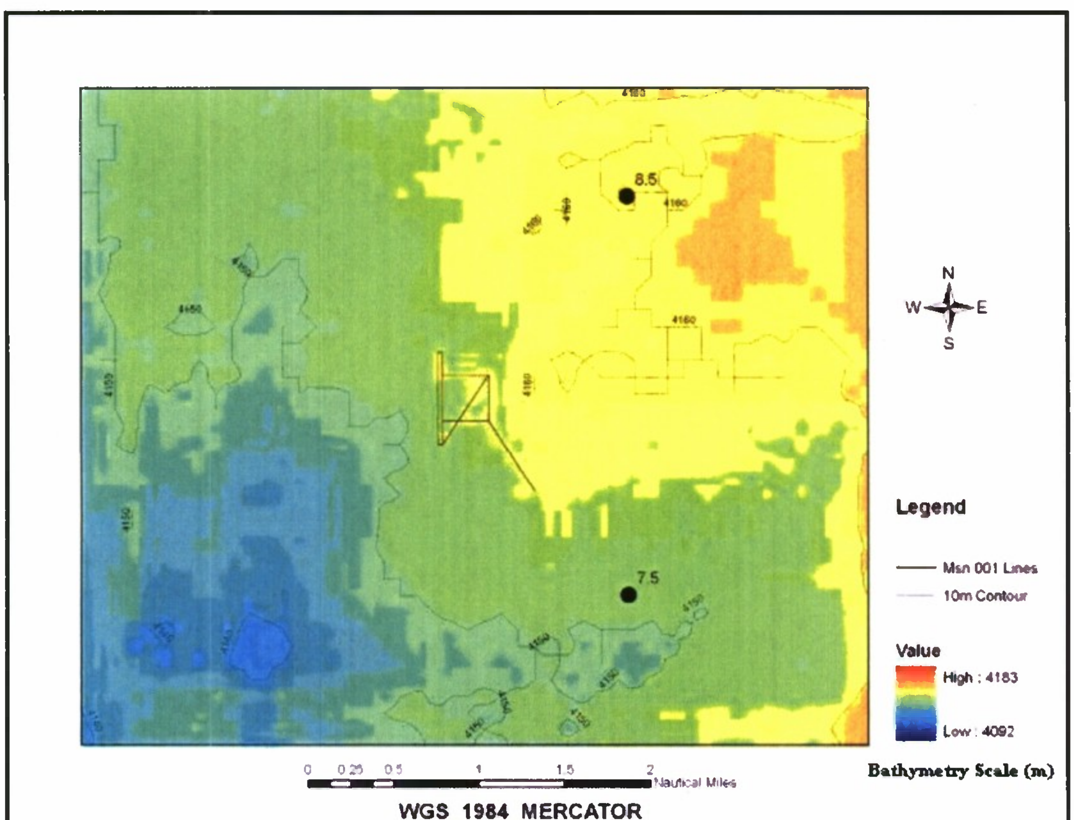

Fig. 2 – REMUS Survey Tracklines with Color Bathymetry Plot (meters)

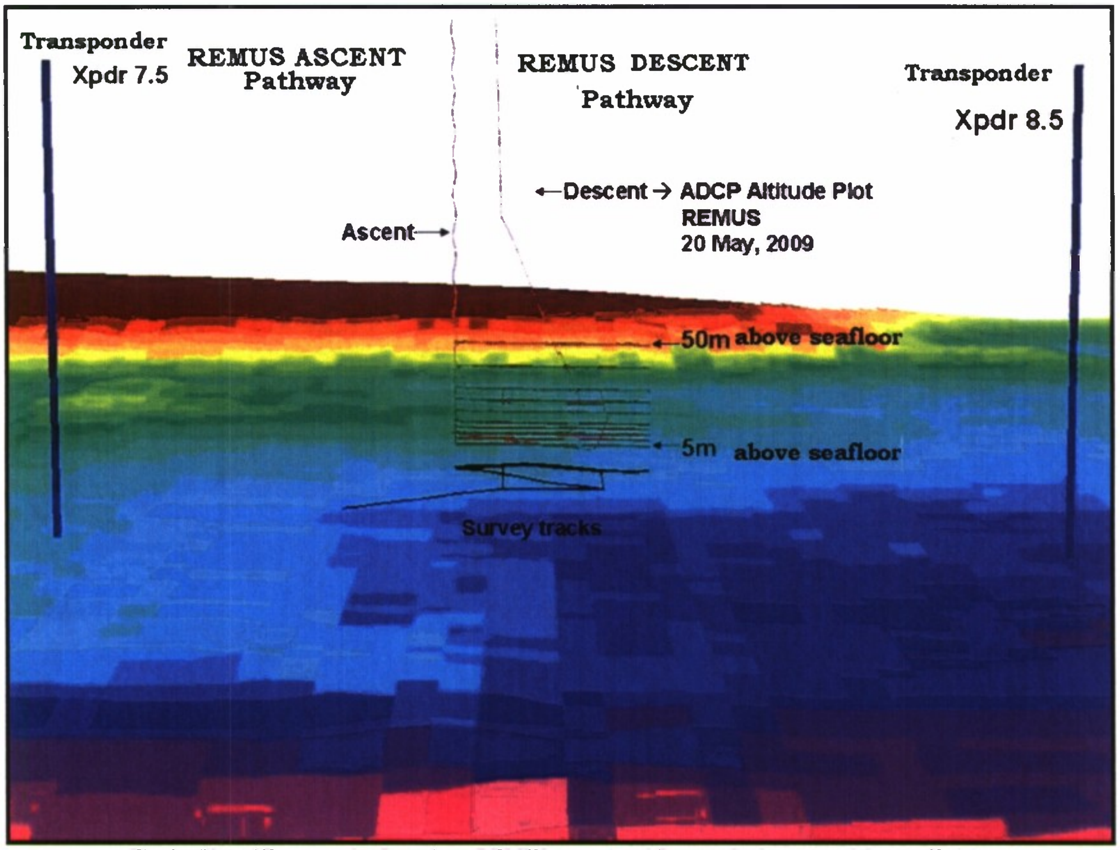

Fig. 3 – Plot of Transponder Locations, REMUS Ascent and Descent Pathways, and Survey Tracks

III. Transponder Calibration, REMUS Positioning, and Subbottom Profile Data Collection

Once the location of each transponder on the seafloor was selected, the transponders were surveyed in using the DS-7000 Transponder UV Navigation program on USNS *Mary Sears* ISS-60 ship navigation system. Once the transponders were calibrated, the REMUS AUV was launched and descended from the surface to a depth of 4150 meters. The vehicle then conducted a survey of the calibration box at an altitude of 30 meters above the seafloor to establish accurate positioning relative to the transponders. Sixty-eight additional survey lines were completed at varying altitudes between 1.0 and 50 meters above the sea bottom. These lines were completed at the different altitudes in conjunction with side scan sonar testing. Fig. 4 shows a 3-D plot of the 24 subbottom profile lines completed by REMUS AUV at altitudes between 5 and 30 meters.

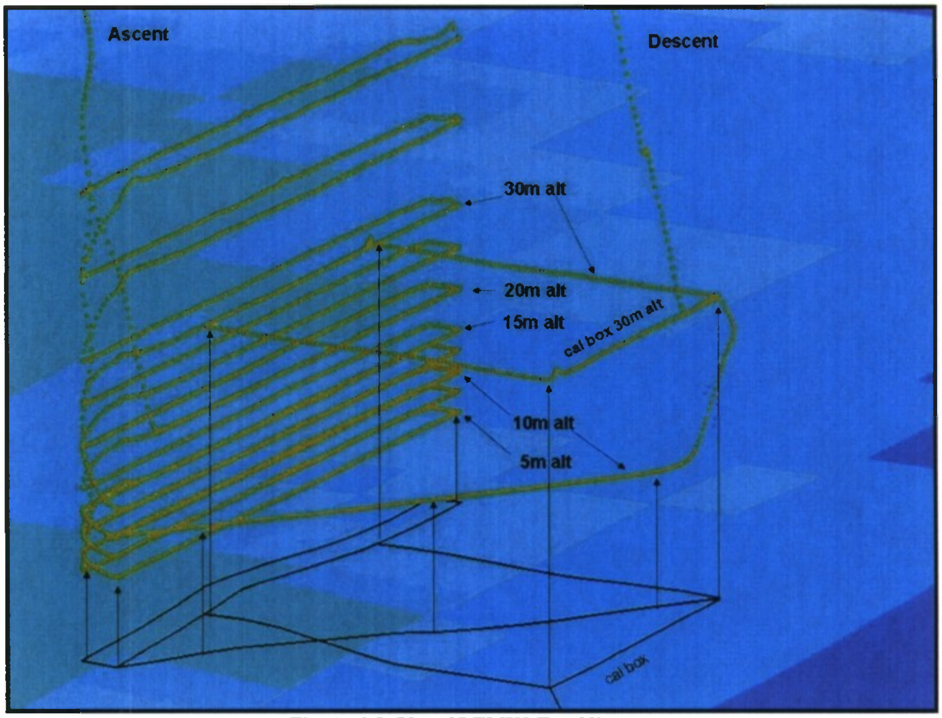

Fig. 4 – 3-D Plot of REMUS Tracklines

IV. Examples of Subbottom Data Collected at Different Altitudes

Figs. 5 through 9 show examples of subbottom data collected by REMUS at different altitudes (5m, 10m, 15m, 20m, and 30m) above the seafloor. Each figure contains a legend color bar of dB ranges of the measured subbottom signal return intensity. Black (-86) is indicative of softer sediments, mud-like, and white (0) indicates a harder seafloor.

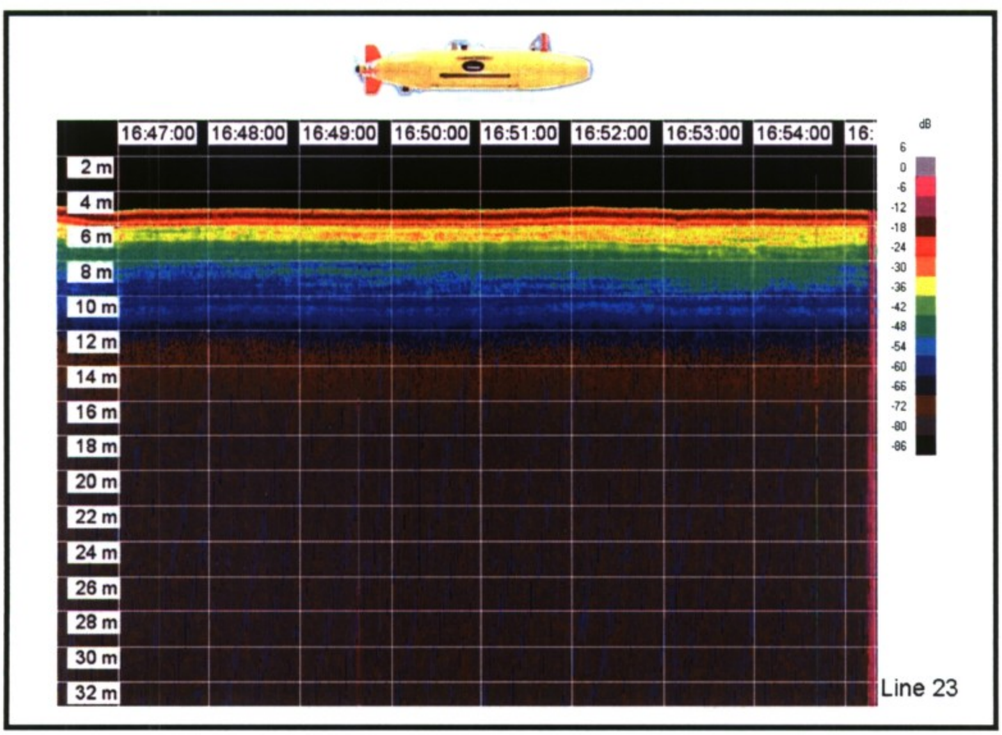

Fig. 5 – Plot of Subbottom Data (Line 23) collected at 5 m altitude above the seafloor

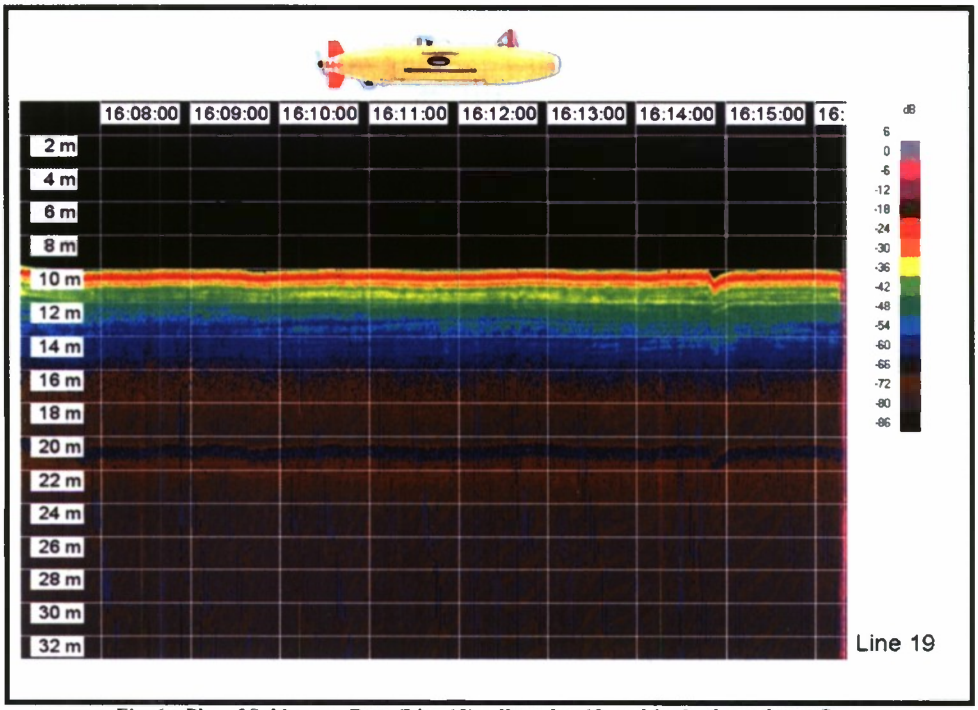

Fig. 6 – Plot of Subbottom Data (Line 19) collected at 10 m altitude above the seafloor

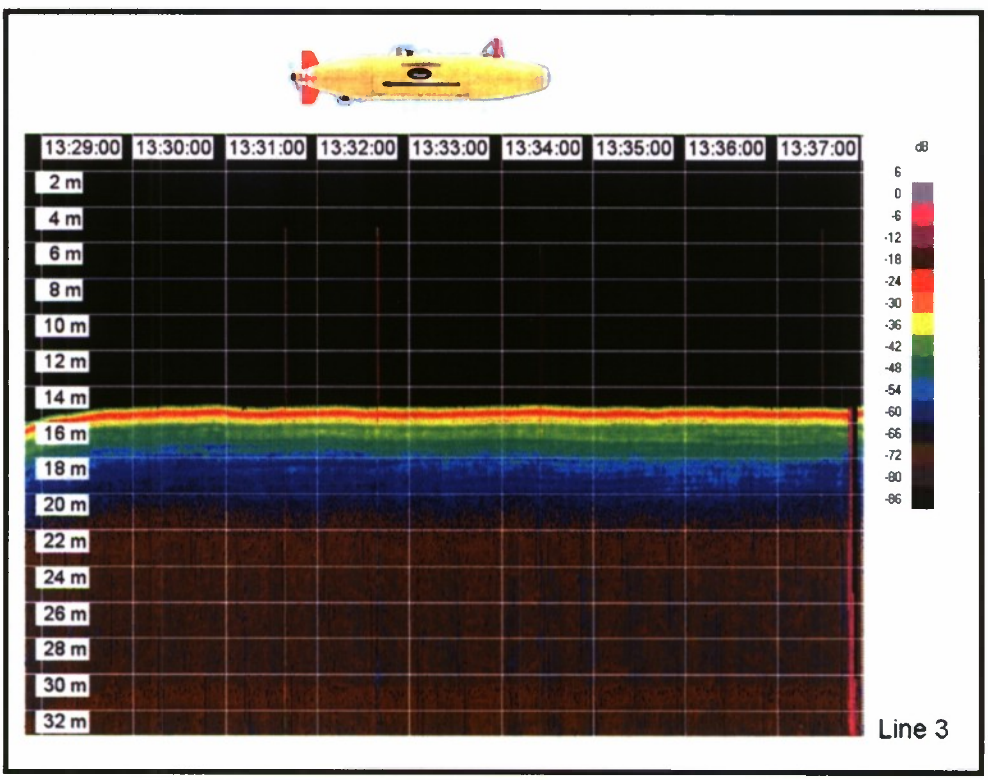

Fig. 7 – Plot of Subbottom Data (Line 3) collected at 15 m altitude above the seafloor

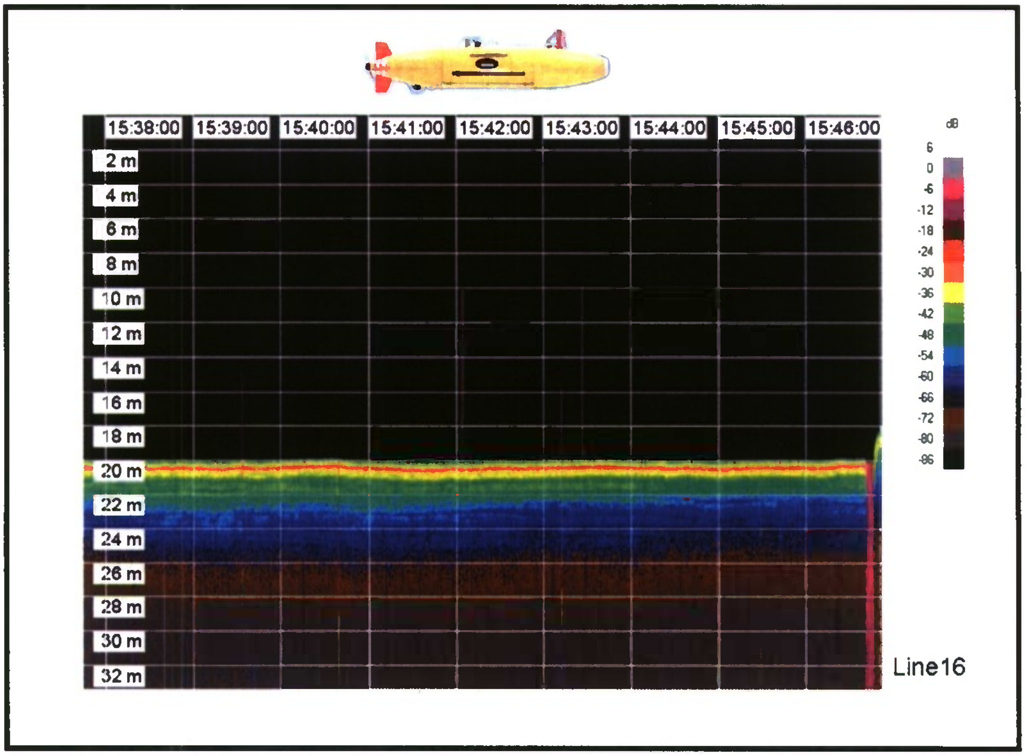

Fig. 8 – Plot of Subbottom Data (Line 16) collected at 20 m altitude above the seafloor

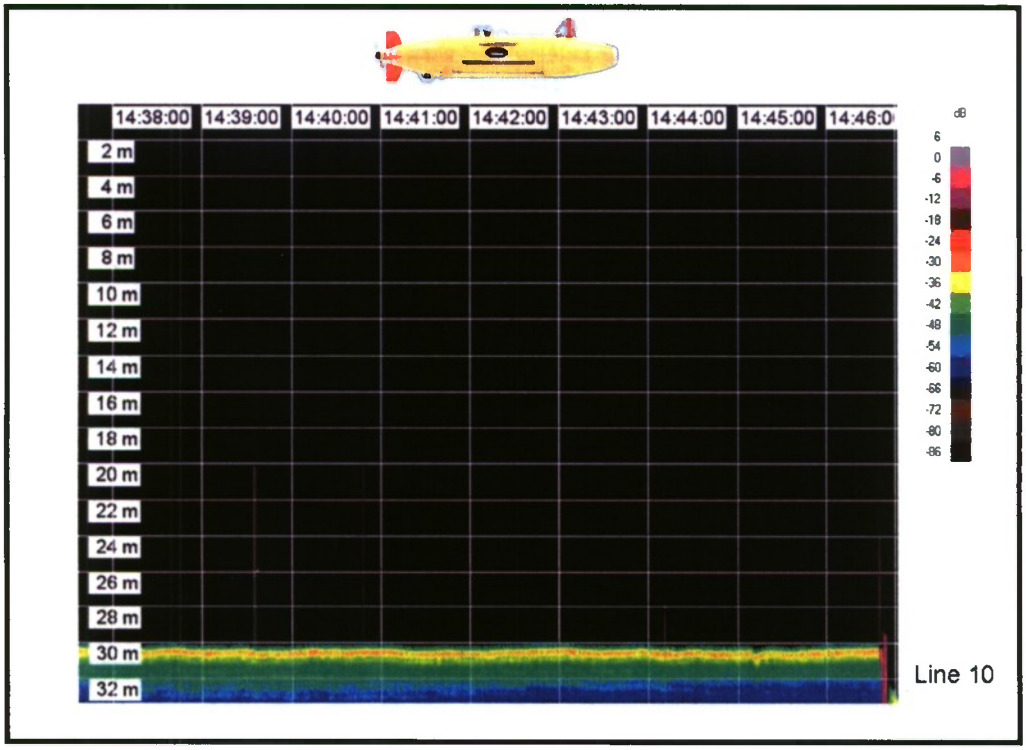

Fig. 9 – Plot of Subbottom Data (Line 10) collected at 30 m altitude above the seafloor

V. REMUS AUV Recovery and PMP Batch Processor Software

Upon the recovery of the REMUS vehicle (Fig. 10), all sensor/systems data are downloaded onto LACIE external hard drives for data storage. Once the raw subbottom data is downloaded, the PMAP Copy Program is used to create a hierarchical directory structure.

The next step relies on PMAP Batch Processor Program, a software program created by the Naval Research Laboratory (NRL). Then, using an EXCEL© comma-separated file containing start and end survey line times as input, the PMAP Batch Processor Program, is used to create a post-survey database file, command files, line images, ping data, and seismic images.

Next, the Ping Viewer program is used to read the command ping data files created by the PMAP Batch program. The ping data files are cross referenced to the PMA Mission database to provide time and position information for each seismic trace or ping. A seismic waterfall image is generated that displays the acoustic representation of the bottom and subbottom along a REMUS track line [2] [3]. The Ping Viewer Program is used to create these graphic files of the displayed subbottom image. The Ping Viewer Program additionally creates ESRI© polyline shapefiles of the survey lines correlating to the subbottom images. For this work, the subbottom imagery created during the batch processing phase has been incorporated into an ArcGIS project. This produces a three-dimensional view of the bottom and shallow subbottom geologic structure beneath the REMUS AUV. The subbottom images are hyperlinked to REMUS track line shape files. Each line file can subsequently be selected individually on screen to open and visualize the corresponding subbottom line image. This enables a quick analysis of the subbottom data set along each survey track line while at sea [4] [5].

The PMAP Ping Viewer Program has two modes of operation: batch processing mode and interactive mode. In the batch processing mode, a command file created by the PMAP Batch Processor Program is read and controls the creation of the subbottom images and ESRI© shapefiles. The PMA database can also be imported into an ESRI© ArcMap program to display the survey lines. The maps created in ArcMap have hyperlinks from the survey lines to the graphic images of the subbottom profiles. Fig. 11 illustrates the PMAP processing workflow diagram that occurs at sea.

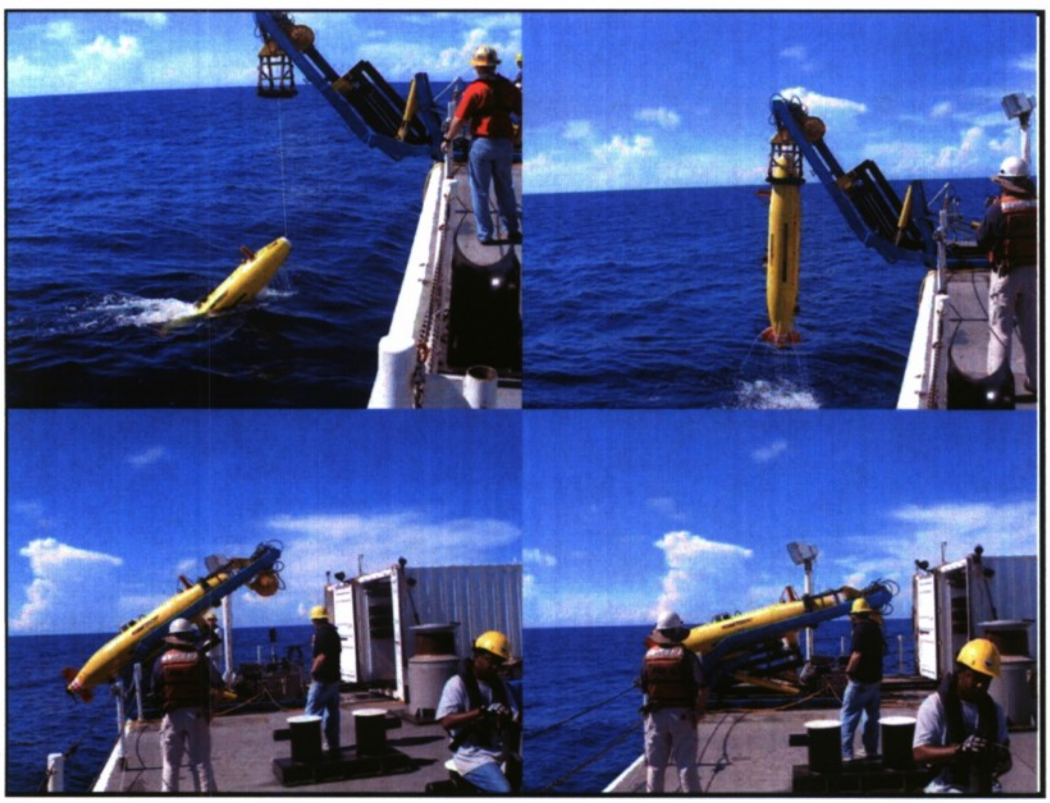

Fig. 10 – REMUS AUV Recovery

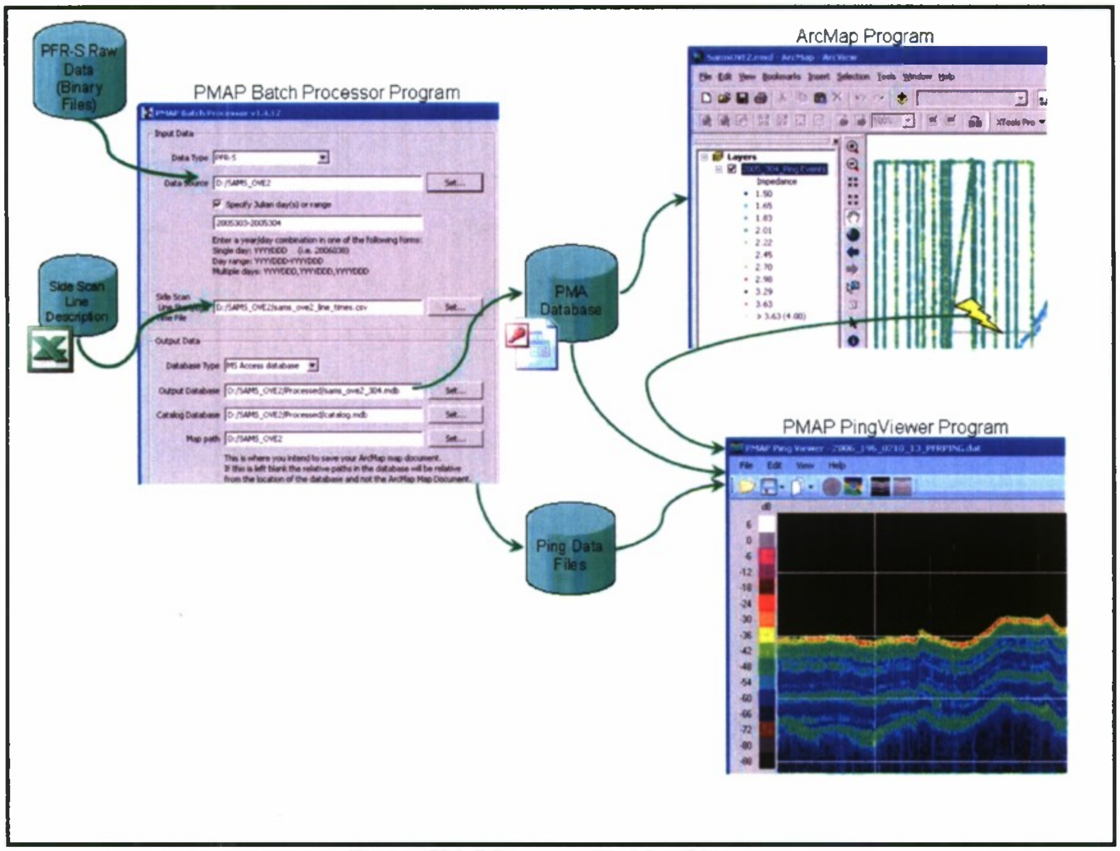

Fig. 11 – PMAP Processing Workflow Diagram

Presently, the subbottom profiles represented in the imagery are artificially flattened. That is, undulations in the return signal that result from programmed vehicle altitude adjustments are removed, thus presenting the bottom as perfectly flat. The vehicle is programmed to remain at a constant altitude above the bottom to obtain optimal side scan sonar imagery. These vehicle altitude variations cause undulations in signal return of the bottom profile, which are not currently accounted for in the signal processing. Although subbottom geologic features are represented correctly in the artificially bottom-flattened images, the real seafloor profile is not. Thus, some bottom geologic features may be more difficult to distinguish from surrounding features in the flattened images. However, comparison of the flattened images to non-flattened seismic imagery created by the batch processor is possible to assist in further analysis if needed.

VI. Summary

Automation of subbottom data copying and processing was accomplished at sea in post-acquisition/near-real time using the NRL-developed PMAP Software Suite. This batch processing software creates subbottom imagery that was easily integrated into an ArcGIS project to visualize seafloor and subbottom geologic structures along the REMUS AUV survey path. Using the PMAP software suite, the REMUS subbottom imagery was easily created and copied into the appropriate directories, which provide an efficient mechanism to integrate the subbottom imagery into an ArcGIS project. This was a significant step in providing an improved product that allows thorough visualization of seafloor facies and subbottom geologic structures along the survey paths. Future PMAP versions will allow the user to view both the flattened bottom/subbottom images and the real seafloor profile on the processed images.

Disclaimer

The inclusion of names of any specific commercial product, commodity, or service in this paper is for information purposes only and does not imply endorsement by the Navy or NAVOCEANO.

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