Multibeam Bathymetry from a Mine-Hunting Military Sonar

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ABSTRACT

Multibeam bathymetry is obtained from the AN/AQS-20 mine-hunting sonar system. The AN/AQS-20 Volume Search Sonar uses a swath of beams directed downward and perpendicular to the direction of motion to cover more than 180 degrees around the sensor. This coverage creates a coarse-sampling, multibeam sonar that can measure the bottom depth. Raw beamformed data are available from a dedicated experiment to demonstrate the feasibility for using this system to update existing bathymetric databases during mine hunting operations. Data processing uses a weighted-mean-time technique to determine the bottom reflection return from the downward directed beams within ±45 degrees of the nadir beam (producing ~ 90 degree swath). Data are compared with a recent multibeam survey covering the same location to determine the accuracy and optimize the data processing. The recent multibeam survey was obtained as a 'ground truth' using a conventional EM-1002 multibeam system. Comparison of the AN/AQS-20 data with the ground truth demonstrated good agreement for bathymetry and is within the requirements for mine warfare operations. Limitations on the bathymetry accuracy are related to the pressure sensor that measures tow-body depth.

I. INTRODUCTION

The new AN/AQS-20 mine hunting sonar system includes a Volume Search Sonar (VSS) that produces a swath of beams covering more than 180 degrees around the sensor directed downward and perpendicular to the direction of motion. This coverage is analogous to a coarsely-sampled, multibeam sonar like those used commercially to measure bathymetry. In this paper we examine bathymetry produced from a VSS system and compare this with a conventional Simrad EM-1002 multibeam system. The purpose for this development is to provide near real-time environmental data with fleet deployed systems.

Acquisition of real-time environmental data using tactical sensors designed for mine warfare and antisubmarine warfare is referred to as "Through The Sensors" (TTS) data acquisition. The concept is to use TTS data in near real-time to support tactical decision aids and sensor performance predictions thus enabling more efficient use of the tactical sensor. Accurate environmental data are critical to successful mine warfare operations. Due to the vast expanse of the littoral ocean regions and their temporal and spatial variability, real-time information assimilated with historical data is needed to adequately characterize the environmental battle space.

Ideally, collection of tactical oceanographic information precedes the mine warfare operations. When the situation is not ideal 'Rapid Environmental Assessment' can be performed which involves detailed and short-term oceanographic characterization of a limited objective area keyed to close support of imminent military operations [1]. With the move to forward deploy mine warfare capabilities, TTS data are needed to refresh the environmental picture.

Many types of environmental data are needed in the littoral. One of the most important is bathymetry which is required not only in mine warfare tactical decision aids but also for safety of navigation, acoustic propagation models, wave and surf forecast models, and tide models. The Navy uses Coastal Charts, High-resolution Bathymetry Charts, Combat Charts, Harbor and Approach Charts and Digital Bathymetric Databases to conduct its mission. Existing data and charts are inadequate to support the new emphasis on the Navy's littoral warfare mission that requires high data density in shallow water. Temporal stability of seafloor morphology in the near shore further contributes to environmental uncertainty. Given the principal littoral regions of interest to the U.S., and considering the existing holdings, there is a current requirement to survey 379 ship-year equivalents. Naval Oceanographic Office survey resources include eight ships that are a vital element providing hydrographic data; however, these ships were not intended for use in combat zones. The survey employment plan for these ships is good for addressing the long-range plan for a 379-yr. backlog in survey requirements. For rapid response scenarios in potentially hostile areas, TTS capabilities are needed.

II. BACKGROUND

The AN/AQS-20 is an airborne, variable depth, mine hunting sonar designed to detect, classify and identify moored and bottom mines using side-scan, forward-looking, and volume-search sonar systems from deep water to very shallow [2]. The sonar pod is towed in a reconnaissance mode by the Remote Minehunting System (RMS) miles ahead of the battle group, and in an area search mode by the CH-60 helicopters [3]. RMS is an unmanned diesel powered, semi-submersible vehicle designed for use from surface combatants [4]. A more complete description of these systems and their use within mine warfare is given in complementary papers for this issue [5] and [6].

III. DATA

Data to test these concepts were obtained from the Naval Surface Warfare Center, Coastal Systems Station Air Systems Development Branch (Code A21). Code A21 has conducted a number of initial tests on the ASQ-20 development system. A high-speed recording system, developed for AN/AQS-20 advanced testing, recorded these data during a dedicated mission for the VSS. The data used in this analysis came from a test conducted on June 14, 2001 in the Gulf of Mexico off the coast of Panama City, Florida in approximately 50 to 100 meters of water.

In addition, the Naval Oceanographic Office (NAVOCEANO) recorded a conventional EM-1002 multibeam bathymetry survey along the same ASQ-20 track in October of 2001. The NAVOCEANO data is used as the 'ground truth' bathymetry to compare with the AN/AQS-20 multibeam data in this analysis.

The AN/AQS-20 data included a position of the ASQ-20 tow body derived from GPS and a cable layback model, the depth of the tow body, acoustic velocity of the water, basebanded time series from the 54 beams of the VSS, and attitude (roll, pitch, yaw) of the tow body. For the analysis, the time series data for each beam are converted to slant-range from the bottom and combined with the corresponding position and tow body attitude data to compute the multibeam bathymetry along the test profile. Figure 1 is a map showing the location of the data. The profile consists of four line segments totaling approximately 85 km.

The transmitter produced a pulse at approximately one second intervals along the track. The returning pulse from the sea-bottom is received by a group of sensors and beamformed in hardware into two fans (one pitched slightly forward and a second pitched slightly aft) of 27 beams each. An illustration of the forward fan of beams (looking directly at the AN/AQS-20) is shown in Figure 2. Each beam has a width of approximately 9 degrees and is sampled sufficiently to obtain roughly 0.1 meter range resolution. The two sets of beams are recorded along with other attitude, position, and system data using a special high speed recorder for this test.

Preparation of the data for analysis consists of several steps to produce a range estimate from the sea-bottom return on each beam. The VSS multibeam data is decoded / demultiplexed from the original files and converted from the basebanded data back to the original time series. The data are deconvolved with the transmitter source pulse to produce a zero phase response, and the envelope magnitude is computed from the deconvolved data.

The initial bottom return of the incident nadir beam (directly downward looking beam) is determined from the envelope time series using a peak amplitude detection technique. This nadir bottom return time is used to construct a window over which to compute the bottom returns for the non-normally incident beams. The bottom return time for each beam is determined by computing the weighted-mean-time within a time window determined from the nadir bottom return. The weighted-mean-time (WMT) is computed using equation 1.

$$WMT = \frac{\sum_{i=1}^{N} A_i^2 t_i}{\sum_{i=1}^{N} A_i^2} \qquad \text{Eq. 1}$$

In Equation 1, *A* is the amplitude of the returned acoustic pulse, *t* is the time of the acoustic return, and *N* is the total number of samples in the window of the returning pulse. Limits of the window are defined by computing a beginning and ending travel-time curve from a horizontal bottom for each beam. The travel-time curves are defined by the angle of the beam, the range of the tow body from the bottom for the nadir beam, and by the velocity of the water. The WMT is adjusted for the start time of the transmitted pulse, and used to compute a bottom detection range for the beam.

The beam angles are adjusted for the roll, pitch, and heading of the tow body, and the position of the beams on the bottom are corrected for the ray bending due to the velocity structure of the water. Position of the tow body at the time of measurement is used to compute the location of the beam on the bottom. Tow body position is generated from the GPS position of the helicopter, tow body attitude and depth, and a cable layback model for the system. Depth of the tow body is determined from a pressure sensor and is used in the computations to determine the location and water depth of each sounding. Due to the large 9 degree beamwidth, only beams with an angle of less than 45 degrees from the nadir beam are used in the analysis. The results are written to a standardized bathymetry file format for analysis.

IV. ANALYSIS

The corrected VSS data are compared with NAVOCEANO ground truth data to determine the accuracy of the VSS bathymetry. Figure 3 is a plot of the bathymetry for the nadir beam of the VSS (black) and the nadir beam of the NAVOCEANO bathymetry (blue) for the entire data set. The horizontal axis for the plot is the transmit pulse number from beginning of the data set (0) to the end (7329) which corresponds to time for the data, and the vertical axis for the plot is the water depth at that point. Vertical blue lines indicate the approximate division of lines 1-4 and in general divide the data set into major changes of heading. A plot of the difference between the VSS and NAVOCEANO nadir beams is shown below the bathymetry plot in Figure 3. The difference plot shows that the correlation between the NAVOCEANO ground truth and the VSS bathymetry is very good. The location of most VSS data points in the nadir beam comparison are offset horizontally less than 20 meters from the ground truth point.

Further inspection of Figure 3 reveals that the error is more consistent within a line than during the change between lines. These characteristics suggest that the difference between the two bathymetric data sets may have some dependence on heading or tow characteristics. It has been observed on other towed systems at NRL that the depth determined from a pressure sensor on a moving platform is very difficult to measure accurately due to the pressure associated with water moving past the sensor.

Additional investigation of the received time series from two groups of transmitted pulses revealed that a small distinguishable return from the water surface is observed. Correcting for the transmit pulse time, position of the receivers relative to the pressure sensor, and the water velocity, the depth below the water surface for the tow body is computed for two periods which each include eight sequential pulses. For the first time period, the tow body depth is determined to be 10.72 meters whereas the pressure sensor measured 9.15 meters. For the second time period, the tow body depth is determined to be 11.09 meters whereas the pressure sensor measured 9.14 meters. Based on this analysis, an average pressure depth correction of 1.76 meters is applied to all of the data processing including the data displayed in Figure 3.

A comparison of multibeam data for the NAVOCEANO and VSS bathymetry is shown in Figure 4. The files for both data sets are imported into the NAVOCEANO Bathymetric Hydrographic Processing Package (BHPP), gridded at 0.01 minute resolution (corresponding to approximately 18.5 meter grid spacing), and displayed to show the multibeam coverage. The VSS multibeam (yellowish-brown color) has smaller swath width coverage than the NAVOCEANO EM 1002 multibeam data (red color) due to the limited number of beams used in the VSS system. The multibeam residual difference between the VSS gridded data and the NAVOCEANO data is shown in Figure 5 with a contour interval of 0.5 meter. Blue contours in Figure 5 correspond to zero difference between the two data grids, green and yellow contours correspond to 0.5 meter lower and higher. The similarity of the two multibeam surveys is consistent with the observations of the nadir beam analysis.

V. RESULTS

The mean difference between the NAVOCEANO ground truth bathymetry and the VSS bathymetry for the nadir beams of the entire data set is 0.526 meters, which is well within the requirements for mine warfare applications. The mean difference is consistent with the reported 0.5 meters accuracy of the pressure sensor depth measurement. Comparison of the two multibeam data grids used in Figure 5 reveal an RMS residual of 0.61 meter for the region containing line 1, an RMS residual of 0.95 meter for the region containing line 2, an RMS residual of 0.63 meter for the region containing line 3, and an RMS residual of 0.60 meter for the region containing line 4. These results demonstrate the capability for the VSS to produce reliable multibeam surveys.

In addition, the tow body depth below the water surface is computed to be approximately 1.57 to 1.95 meters deeper than that measured by the pressure sensor. Based on these results, the multibeam bathymetry accuracy could be improved by using the VSS acoustic surface return to determine tow body depth instead of the pressure sensor. This technique can be incorporated into the data processing to replace the pressure sensor depth measurement and should improve the accuracy of the multibeam bathymetry from the VSS.

VI. CONCLUSION

The AN/AQS-20 can successfully provide multibeam bathymetry to within approximately 0.5 meter using the existing pressure sensor provided that offsets in the depth measurement can be calibrated. This meets accuracy required for mine warfare tactical decision aides like the Mine Warfare Environmental Decision Aid Library (MEDAL). These results were developed using data collected in a volume search mode with no modifications to the existing system. Future plans include changing the multibeam bathymetry processing to include detection of the water surface return plus optimizing the data processing software for autonomous operation.

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FIGURE CAPTIONS

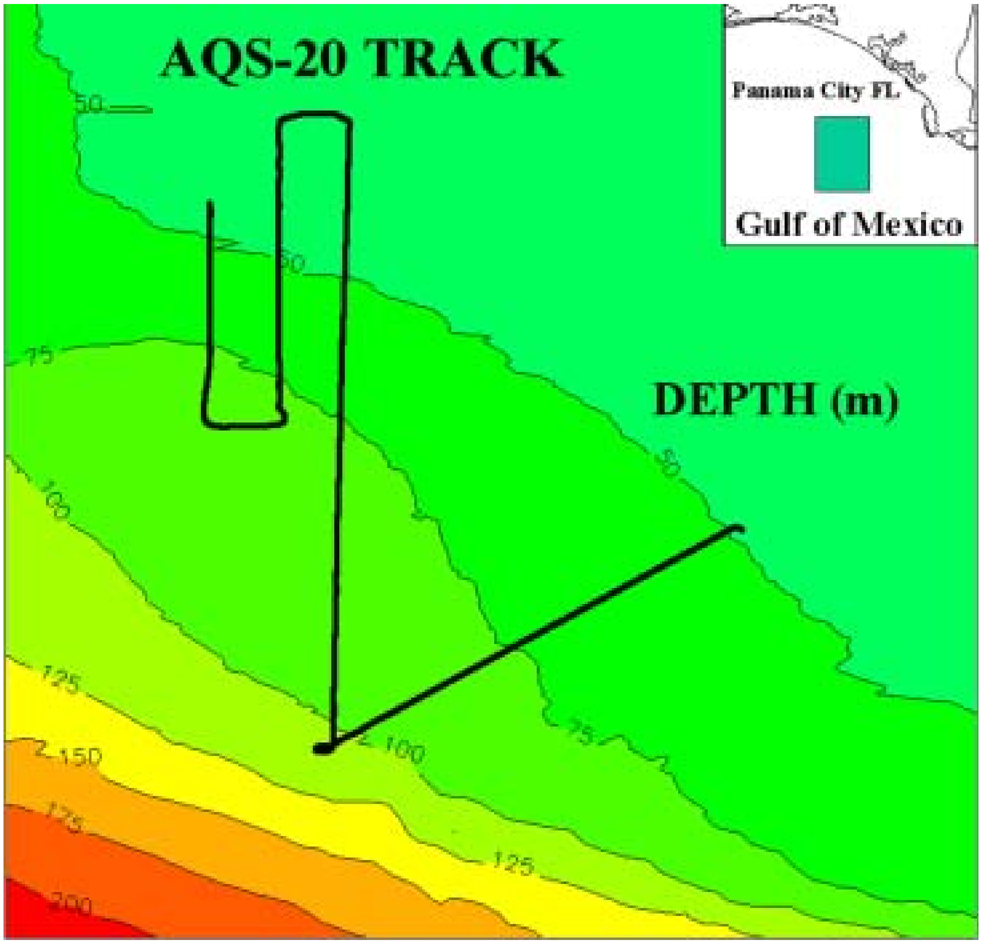
Figure 1. Map showing the location of the VSS multibeam test data off the coast of Panama City, FL. The profile consists of four line segments totaling approximately 85 km.

Figure 2. Illustration of the forward fan of beams is shown (looking directly at the AN/AQS-20). Two fans of 27 beams each are formed from the receiver units. One fan pitched slightly forward and a second pitched slightly aft.

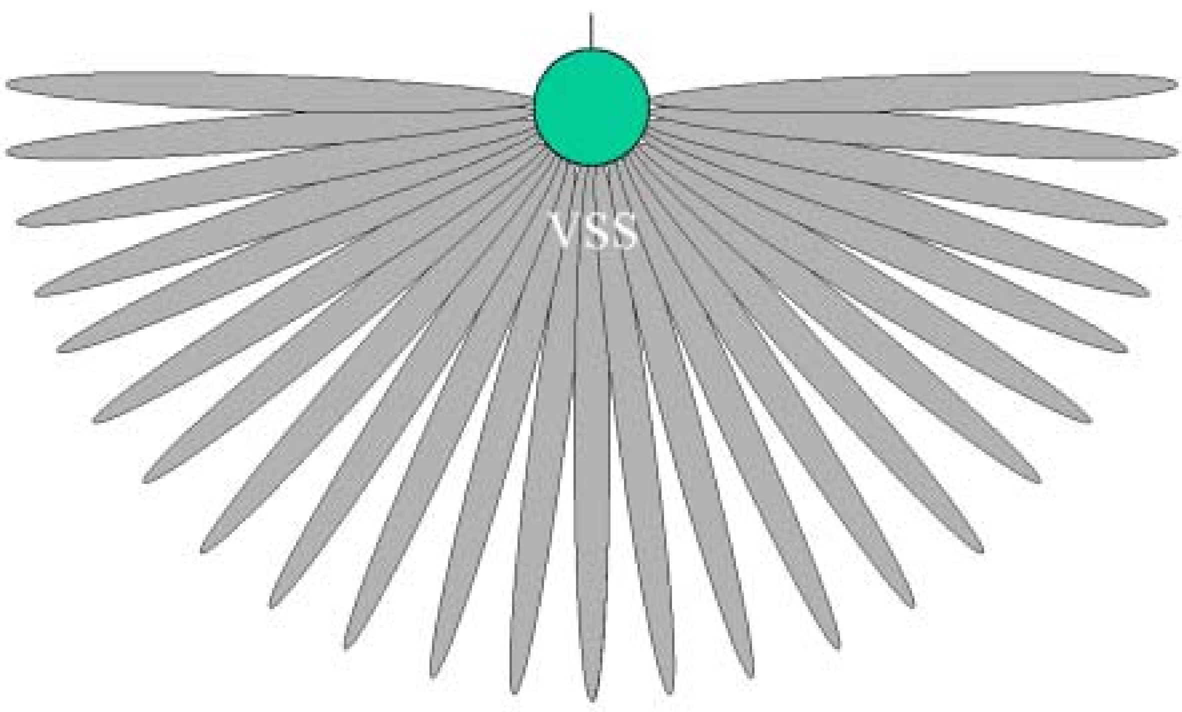
Figure 3. Plot of the bathymetry for the nadir beam of the VSS (black) and the nadir beam of the NAVOCEANO bathymetry (blue) for the entire data set. The X-axis for the plot is the transmit pulse number from beginning of the data set (0) to the end (7329) which corresponds to time for the data, and the Y-axis for the plot is the water depth at that point. Vertical blue lines indicate the approximate division of lines 1-4 and in general divide the data set into major changes of heading.

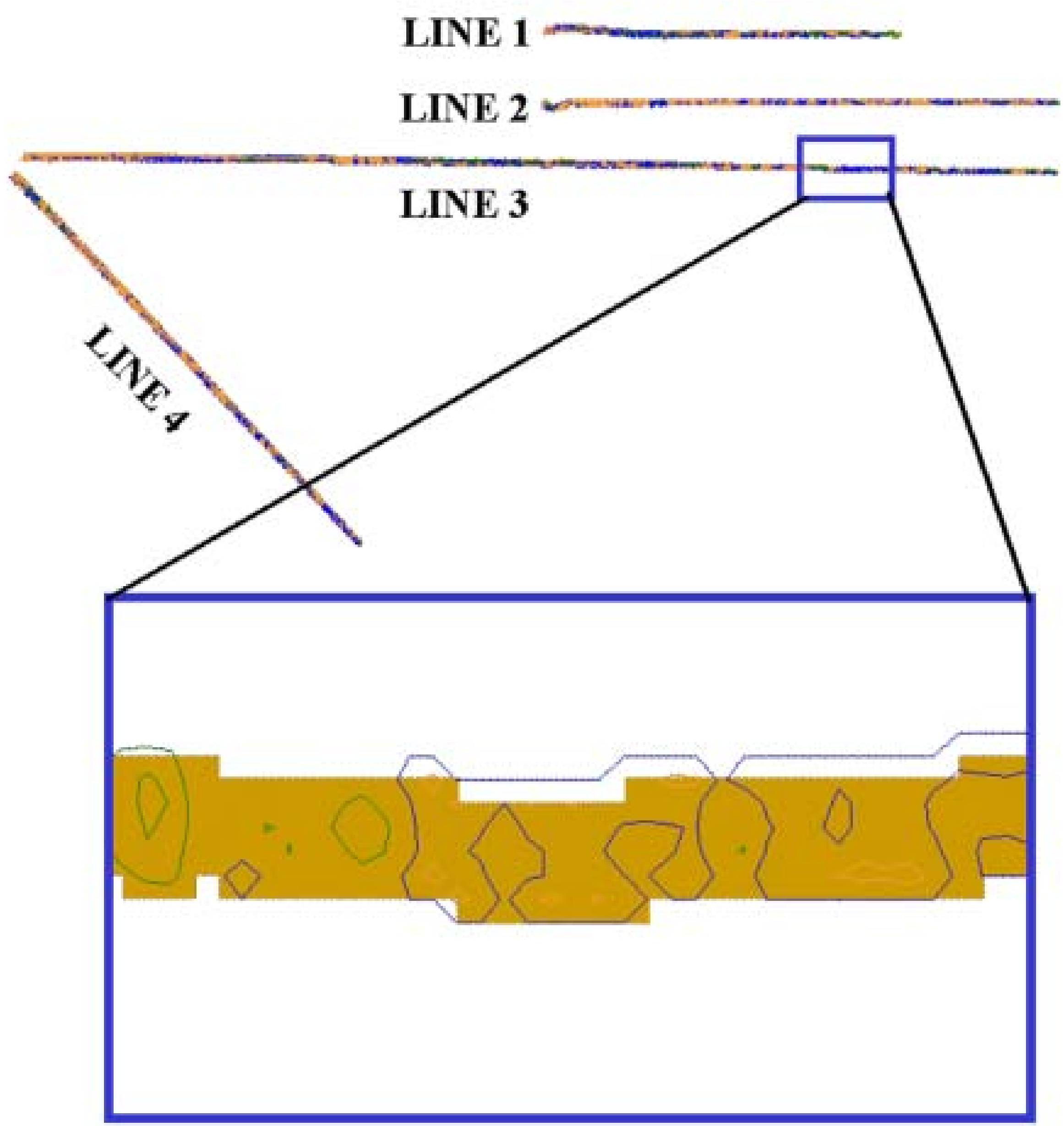
Figure 4. Comparison of multibeam data coverage for the NAVOCEANO and VSS bathymetry generated with the NAVOCEANO Bathymetric Hydrographic Processing Package. The VSS multibeam (yellowish-brown color) has a smaller swath width coverage than the NAVOCEANO EM 1002 multibeam data (red color).

Figure 5. Plot of the residual difference in bathymetry (approximately 18.5 meter grid spacing) produced from the VSS multibeam and the NAVOCEANO EM 1002 multibeam data. Blue contours correspond to zero difference between the two data grids, green and yellow contours correspond to 0.5 meter lower and higher.



VSS MULTI-BEAM

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LINE 2
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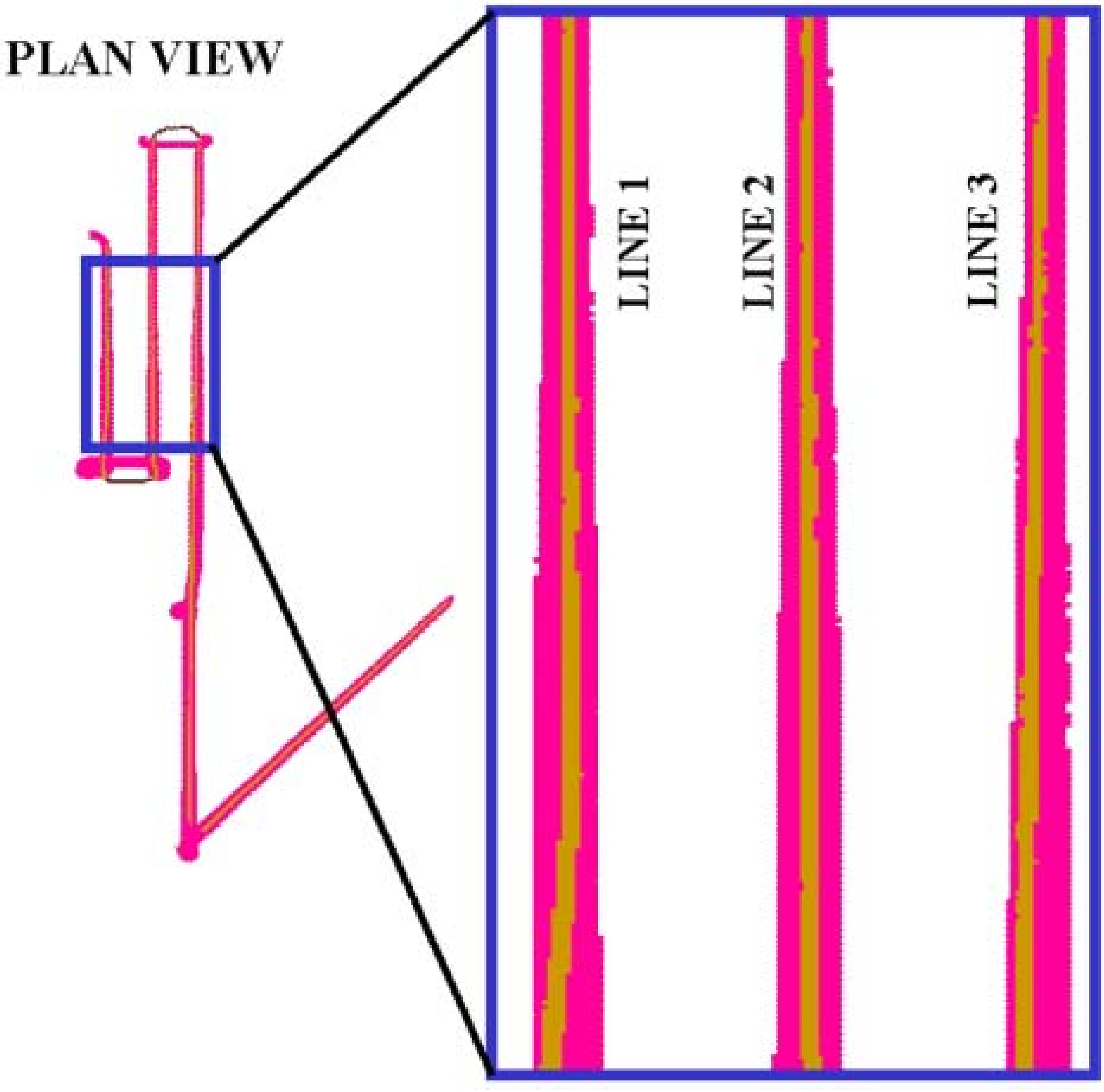
LINE 4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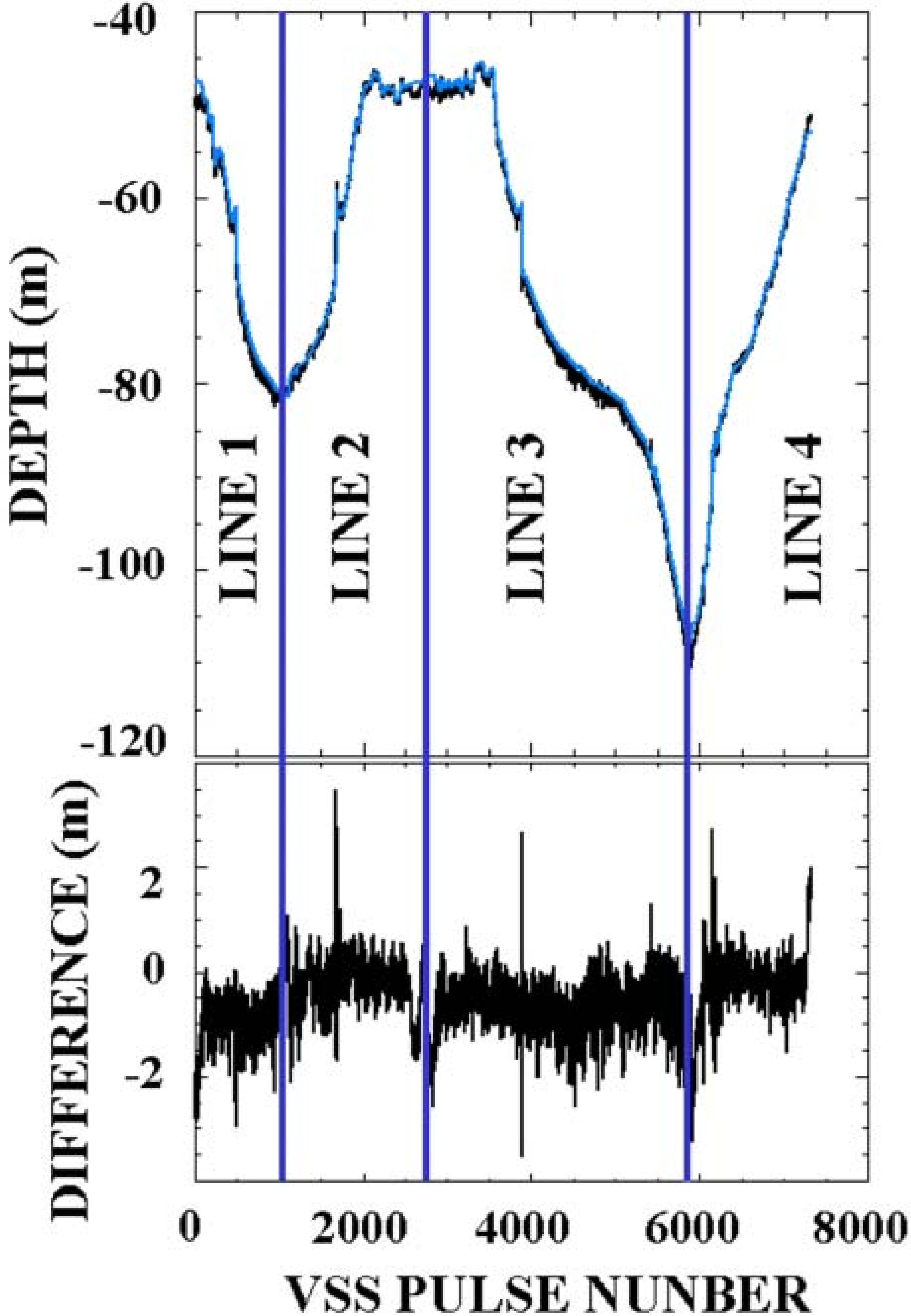
LINE 2
LINE 3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VSS PULSE NUNBER