

Evaluation of the Klein HydroChart 3500 Interferometric Bathymetry Sonar for NOAA Sea Floor Mapping

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Abstract—The National Oceanic and Atmospheric Administration (NOAA) follows a specific procedure in the operation of shallow water sea floor mapping. Recently, side scan sonar bathymetric technology (phase measuring interferometry) has been gaining acceptance and is being evaluated for NOAA's charting applications [1]. NOAA standard charting procedure includes the use and calibration of approved sensor technologies and procedures to generate or update published chart products [2]. This process is considered to be efficient and practical by NOAA. Currently, multibeam echo sounder systems (MBES) are used as the primary bathymetry sonar units due to the measurement accuracies that these systems have achieved. However, given the limited 4 to 6 times altitude ground coverage from a MBES and the increasing need for low cost, high quality data from both bathymetry and sidescan, NOAA has long been evaluating interferometric sonar for use in shallow water charting. The Klein HydroChart 3500 interferometric sonar provides 10 to 12 times altitude coverage without a gap in the nadir region of the bathymetry data. When combined with approved motion and navigation units, the HydroChart 3500 offers accurate bathymetry for survey and charting applications from 1.5m to 50m water depths. This paper presents common evaluation data to demonstrate the capability of the HydroChart 3500 in the critical mission of shallow water charting. In parallel, we address two questions raised by NOAA in assessing the use of this system. First, is the HydroChart 3500 compatible with the NOAA standard survey procedures? Second, does the quality of the bathymetric data meet the IHO standard throughout the full swath covering 10 to 12 times altitude without a nadir gap? To accomplish this evaluation, sea test data were collected from Portsmouth Harbor, Piscataqua River Estuary, New Hampshire with guidance from the Center for Coastal and Ocean Mapping (CCOM) at the University of New Hampshire. Patch tests were conducted based upon NOAA's procedure and the calibrated motion biases were checked by using the sonar-integrated Klein KMS-02 motion sensor. Surveys

were conducted over two reference areas. The data quality was quantified by calculating the one sigma grid surface over an area of 400 by 1000 meters, against depth and coverage. The results demonstrate that the Klein HydroChart 3500 is capable of meeting the IHO Special Order standards with 10 to 12 times altitude coverage, based on a signal to noise ratio over 8 dB.

I. HYDROCHART 3500 WITH NADIR GAP COVERAGE DEMONSTRATES PATCH TEST COMPATIBILITY

An accurate patch test, including motion and latency calibrations, is essential to the production of high quality swath bathymetry data. The existing patch test procedure from NOAA can be directly applied to HydroChart3500 for roll, yaw and latency calibrations. Due to the requirement for high quality nadir bathymetry data, pitch bias calibration has been a concern in the use of interferometric sonar systems [1]. Previous systems lacked usable data in this region and, thus, could not be applied in NOAA's procedure for patch test calibration to resolve pitch bias. It is therefore critical for an interferometric sonar to provide full swath bathymetry data without a nadir gap.

A recent development in the Klein HydroChart 3500 expands the capability to resolve accurate bathymetry data across the full swath, including the nadir region. Following this improvement, the system was evaluated to examine if pitch bias calibration could be accomplished with the HydroChart 3500 using NOAA's approved patch test procedure. For this purpose, survey data were collected from Portsmouth Harbor, Piscataqua River Estuary, New Hampshire. As shown in Fig. 1, two reciprocal lines (eastern lines) were surveyed at 5 to 6 knots with sonar range setting at 50m per side (100m full swath). The survey lines crossed an area with terrain

variability from 10m to 20m in depth covering a large rock outcropping and sloping gravel to pebble substrate. To execute the pitch bias calibration, the nadir region was fully covered with bathymetry data at a grid size of 0.5m. The nadir data crossing the steep slope and rocks were then extracted using the HYPACK MBMAX64 patch test utility. The pitch bias was obtained and evaluated based on several trials. Both the slope and the rock areas were compared with an increment of 0.2 degrees (default minimum increment is 0.5 degrees). The same procedure was repeated with a 1m grid size. The resultant pitch bias values ranged from 1.4 to 1.8 degrees. To select a pitch bias, the same procedure was applied to another pair of reciprocal lines (western lines) surveyed at the same speed and with the same sonar range setting. The results were matching at 1.8 degrees, therefore, we chose 1.8 degrees as the determined pitch bias between the sonar transducers and the inertial measurement unit.

In the data processing, we used the Applanix POS MV inertial measurement unit, installed on the University of New Hampshire's R/V Coastal Surveyor, as the primary motion sensor. The calibrated pitch bias reflected the offset between the POS MV pitch reference plane and that of the sonar transducer. In the HydroChart 3500, Klein's KMS-02 motion sensor is embedded into the sonar head unit

and factory aligned with the forward direction of the transducers. In data collection, both the POS MV and the KMS-02 data were recorded, simultaneously, at the dock where the boat was most stable. Since the pitch reading from the KMS-02 reflects the actual pitch of the sonar head unit (including transducers), assuming a perfect alignment between the KMS-02 pitch reference and the forward direction of the transducers, the difference between the pitch readings from both sensors should reflect the bias tested above. As shown in Fig. 1, on the right part, the real-time display of both pitch readings indicates a difference of 1.5 degrees, about 0.3 degrees from the patch tested result (1.8 degrees) which may be caused by bias of the bench alignment. This comparison confirms the result from the NOAA pitch patch test. Following standard procedures, the other biases (roll, yaw and latency) were calibrated and applied to the survey data. The resultant bathymetric data from the four reciprocal lines, plus another latency test line, collected at a speed of 8 knots, were in agreement with each other. As shown in the transect profile line in Fig.1, where different colors represent different survey lines, the bumpy surface cut by the profile line is well represented by each of the different lines from different directions. This, again, confirms the result using the standard patch test method [1][2][3] used for pitch bias calibration.

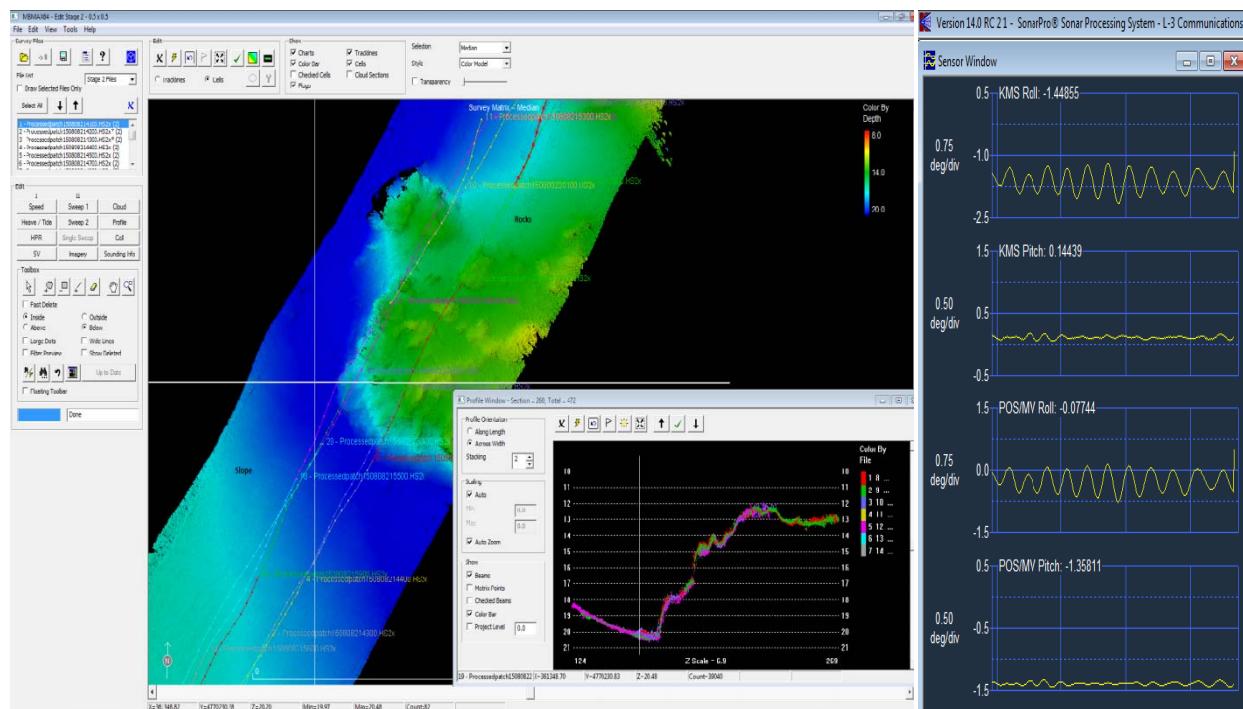


Fig. 1 Patch test lines and resultant multi-line agreement following pitch test.

II. DATA QUALITY AND BATHYMETRY COVERAGE

As recommended by CCOM, two reference areas were surveyed. In this section, we will present the data from the larger reference area. It covers an area with dimensions of 430m (west to east) and 1000m (north to south). The water depth changes from 5m to 16m, from the western shore to the center of the river through a steep downward slope. As for the data collection, north to south and south to north lines were surveyed with a separation of 25m between adjacent lines. The sonar range was set to 75m per side (150m full swath) and a speed of 5 to 6 knots was maintained throughout the survey. This survey plan was established for two reasons. First, we needed to ensure that 10 to 12 times altitude coverage would be guaranteed. Second, we wanted each piece of ground to be overlapped by multiple survey lines, at different ranges, and with different directions of acoustic incidence, in order to create dense coverage of data points to best evaluate the resultant bathymetric data quality.

In data acquisition, motion and navigation data from the POS MV were sampled at 25Hz, while KMS-02 motion data were sampled at 100Hz. As shown in Fig.2, data were processed with corrections for lever arm offsets, as well as pitch, roll and yaw biases. Since the latency was calibrated to be less than 40ms, equivalent to the sample interval of the navigation data, we set the offset to zero, for GPS latency. Sound velocity profiles were measured using a Teledyne Odom Digibar, in the deepest location, both before and after the survey, and were applied relative to time in the data processing. On site, we experienced elevation changes of a couple of centimeters, observed from the GGA message, reported from the POS MV. These changes could be attributed to difference from locally measured tide (3m local semidiurnal range), or change in boat draft when traveling against the current versus with the tidal current, although the survey was made during low, nearly slack tide. However, in data processing, we did not see any significant bathymetric data step between lines, with the exception of one line. This line was then modified, to compensate for the difference. The data shown in fig.2 were not filtered, neither by range nor angle, to sustain the 10 to 12 times altitude ground coverage. However, these data were filtered by SNR at 8dB and quality factor [6] of 85%, only. The raw data were then binned to 0.5m grid cells for mapping and statistical analysis.

The data quality is of the most interest to the readers. To evaluate it, we applied the empirical method regularly used in the industry by calculating

the one sigma surface. We took the central part of the survey area, in order to avoid biases due to the complex natural terrain, which would introduce errors into the one sigma surface. Manual editing was conducted to remove obvious outliers in preparing the surface. In Fig.3, the left side shows the data from which the one sigma surface was generated. The data on the right side show the one sigma surface itself. The color bar sets red equal to a one sigma level of 0.13m, corresponding to a 0.25m depth uncertainty maximum, equivalent to the minimum value set for the Special Order bathymetry survey standard [4]. Therefore, from the one sigma surface, the red color sets the IHO Special Order threshold equivalent to 0.25m. It appears that the uncertainty is more elevated in the heavily overlapped areas. However, over all, the number of red cells is below 5% of the total area. The method is an empirical estimation of the final total propagated uncertainty, combining elements of the vertical and horizontal uncertainties. The result indicates that the soundings in each cell are within 0.25m uncertainty of the represented depths in each 0.5m cell, at the 95% confidence level. In this analysis, each cell contained approximately 60 to 100 independent data points used for statistical comparison. Therefore, one can conclude that the Klein HydroChart 3500 interferometric bathymetry survey system is capable of meeting IHO Special Order standards, with a ground coverage of 10 to 12 times altitude.

While the data from the larger survey area were edited to remove the obvious outliers, the data from the other shallower area (up to 3m) were not. As shown in Fig.4, in the shallower area, a cross line survey pattern was conducted. The data processing and filtering were automatically applied in HYPACK MBMAX64, using an SNR filter at 8dB, quality factor above 85%, and an angular filter to limit the swaths to 80 degrees per side (160 degree swath for 11.3 times altitude). The total data processing time was less than 1 hour for this whole area with a cross line pattern survey and requiring no manual editing. The agreement of data among different lines and from cross directions demonstrates the efficiency of the Klein HydroChart 3500 system to accurately survey bathymetry and meet the standards of responsible agencies such as NOAA. This capability was developed to benefit surveyors who need survey and processing efficiency.

III. CONCLUSIONS

A number of conclusions can be drawn from the data evaluation presented in this paper supporting the

use of the Klein HydroChart 3500 in NOAA sea floor mapping applications.

- The standard patch test procedure can be directly applied to the system for both motion and latency offset calibrations. This supports the use of the Klein HydroChart 3500 as a hydrographic technology for NOAA survey operations in shallow water.
- The data quality resulting from a survey utilizing the HydroChart 3500 meets the IHO Special Order bathymetry criteria across 10 to 12 times altitude ground coverage. This demonstrates a significant improvement in the rate of coverage relative to the MBES systems in shallow waters.
- Metadata attributes, such as signal to noise ratio and quality factor allow for the efficient processing of data that supports the generation of high quality bathymetric map product.

The Klein HydroChart 3500 interferometric sonar is a cost effective tool that provides accurate and efficient shallow water survey capability.

[4] International Hydrographic Organization (IHO). "IHO Standards for Hydrographic Surveys, Special Publication No. 44, 5th Edition", 2008.

[5] Klein HydroChart 3500 manual, 2015.

[6] Lurton X. and Augustin J.M. "A measurement Quality Factor for Swath Bathymetry Sounders", IEEE Journal of Oceanic Engineering, 35(4), pp.852-862, 2010.

[7] Schmidt V., Weber T. and Lurton X. "A New Method for Generation of Soundings from Phase-Difference Measurements", Canadian Hydrographic Conference, April 14-17, 2014.

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REFERENCES

[1] Eisenberg J., Davidson M., Beaudoin J., Brodet S. "Rethinking the Patch Test for Phase Measuring Bathymetric Sonars", Proceedings: US Hydrographic Conference, Tampa, FL, April 25-28, 2011.

[2] National Oceanic and Atmospheric Administration, Office of Coast Survey, "Field Procedures Manual", April, 2010.

[3] HYPACK, Inc. "HYPACK 2014 Help Menu", 2014.

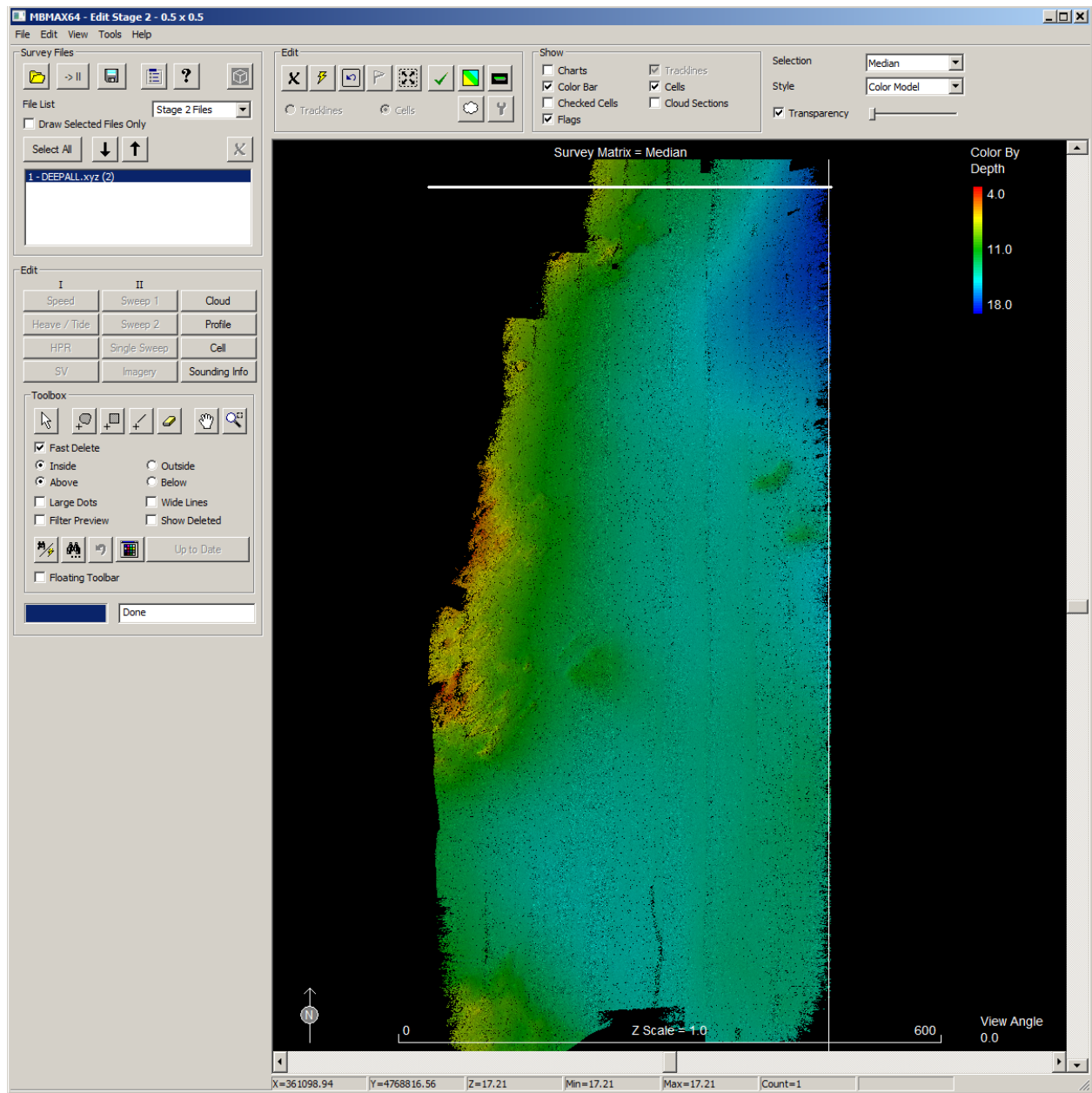


Fig.2 Bathymetry data from the bigger survey area. Depth changes from 5 m to 16m west to east. Data processing applies motion and navigation data from POS MV.

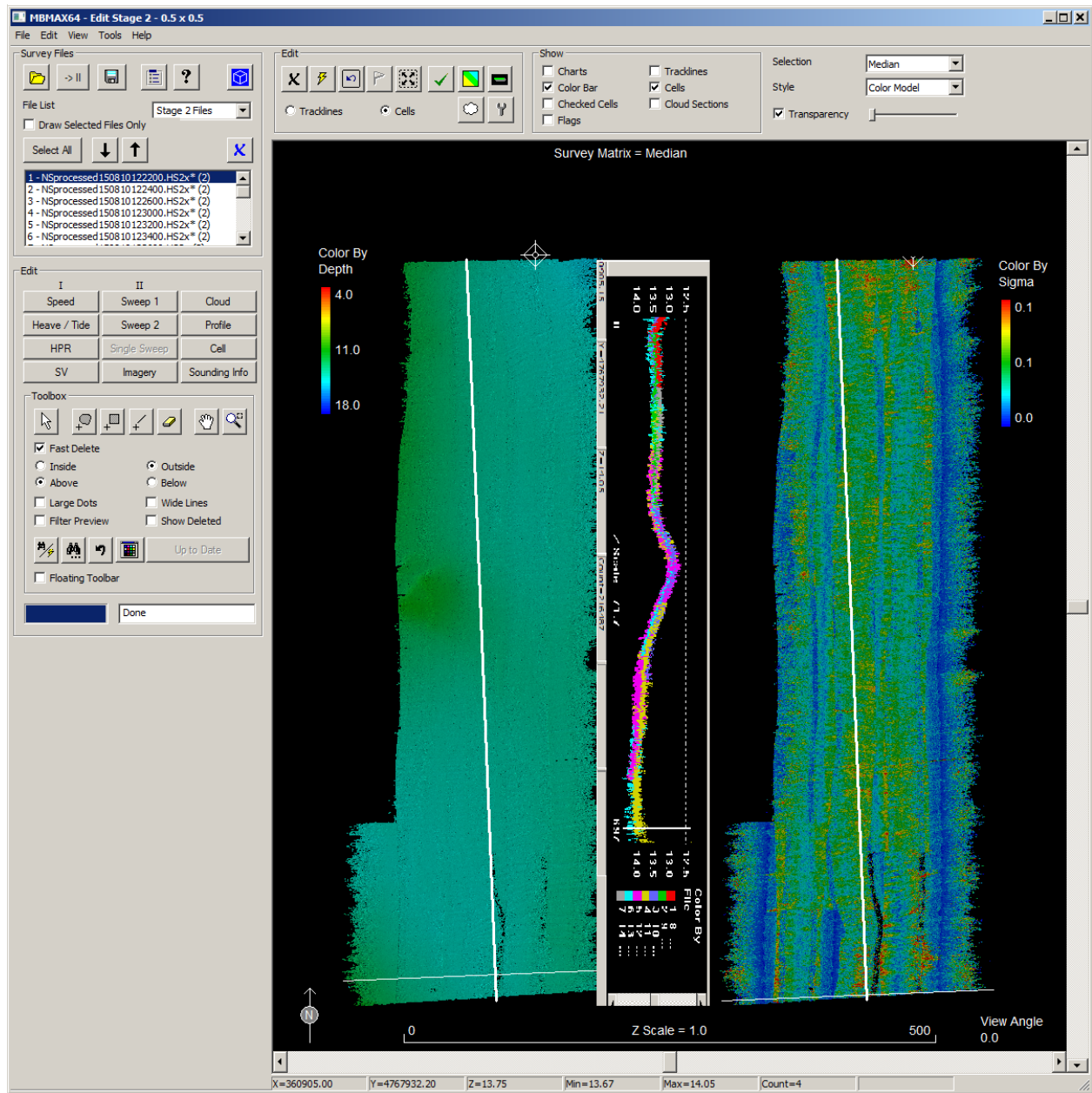


Fig.3 One sigma surface over the test area

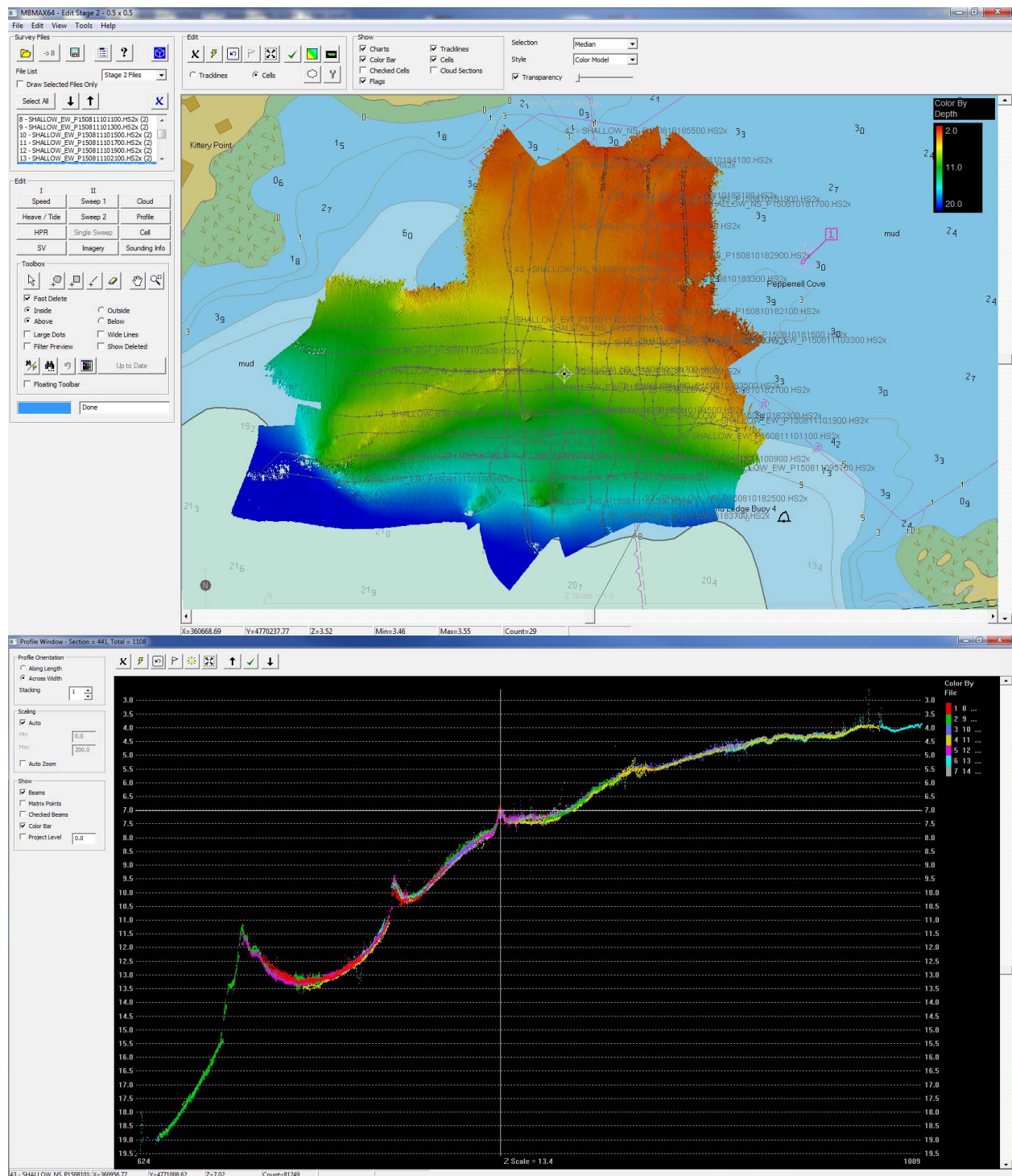


Fig.4 Data over the smaller area, without any manual editing