NOAA AHB Quality Assurance Inspections for Contract Hydrographic Surveys

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Introduction

The National Oceanic and Atmospheric Administration (NOAA) is supplementing in-house hydrographic survey efforts by awarding data acquisition contracts to private sector hydrographic firms. Since the first large-scale Gulf of Mexico (GOM) contracts were awarded in 1998, NOAA's Atlantic Hydrographic Branch (AHB) has received approximately $25 million of contract multibeam and side scan sonar surveys. In order to address government liability concerns of contract hydrographic data, AHB has implemented a Quality Assurance (QA) review process to ensure that the contract deliverables meet NOAA's quality standards and are readily usable when imported into NOAA chart production systems.

The QA process is comprised of three major phases with each one being performed by experienced NOAA hydrographic personnel. They are: (1) Observing data acquisition onboard contractor vessels, (2) Reviewing data processing at contractor offices, and (3) Inspecting officially received final deliverables received at the NOAA office.

This paper will focus on the quality assurance inspection of final deliverables at NOAA 's AHB office. For further details of Steps (1) and (2), please refer to Hydro 2001 Conference Abstract "NOAA –Contractor Working Relationships: A Case Study", by Mr. Gary Nelson, NOAA Pacific Hydrographic Branch and Mr. Jonathan Dasler, P.E., P.L.S., David Evans and Associates, Inc.

Primary focus – the Digital Smooth Sheet

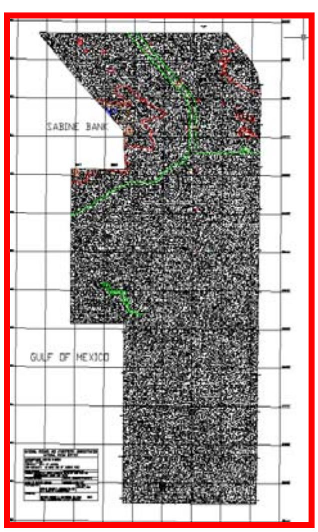


Fig. 1 Digital Smooth Sheet

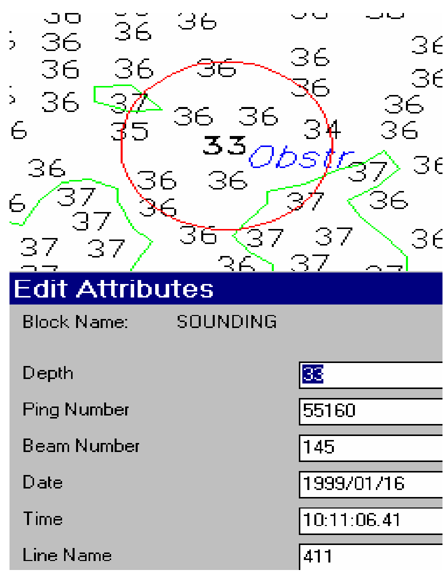


Fig. 2 Zoomed in view with attributes

The primary focus of the NOAA office review is assuring the quality of the digital Smooth Sheet. The digital Smooth Sheet is directly imported into NOAA's chart production systems and becomes the source information used to update corresponding nautical charts. A typical digital Smooth Sheet depicts only 20,000 –30,000 of the 1-3 billion soundings that may be collected in the raw multibeam data. Consequently, it is important that the digital Smooth Sheet accurately depict the most navigationally significant aspects from the wealth of multibeam data associated with the survey. In this sense, the other deliverables, including the Mylar Smooth Sheet plot, raw or corrected multibeam and side scan data tapes, and Descriptive Report, serve as source information used by NOAA reviewers to scrutinize the quality and completeness of the digital Smooth Sheet.

In order to confirm the quality of the digital Smooth Sheet, it is fundamentally important that the multibeam and side scan sonar datasets, from which the smooth sheet data is derived, meets National Ocean Service (NOS) hydrographic standards set forth in the Statement of Work (SOW) and NOS Specifications and Deliverables.

In general, the multibeam data is first reviewed by confirming system calibration and inherent vertical error. Contractor documentation for acquisition, processing, and quality control methods is also reviewed. Multibeam data is then verified by NOAA in CARIS by reviewing a combination of randomly and specifically selected multibeam lines. This review includes inspection of junctions of cross line vs mainscheme, generating Digital Terrain Model (DTM), and performing comparative checks of significant multibeam features against corresponding side scan sonar contacts. In addition, digital smooth sheet features are meticulously compared to the corresponding NOAA charts.

If major deficiencies or significant systematic errors are found, NOAA will require that the contractor resubmit corrected deliverables. Minor deficiencies, including subjective data interpretation issues, are usually corrected by NOAA editing the digital smooth sheet file to agree with the NOAA review findings.

NOTE: This list is not all-inclusive and many steps are performed in parallel.

Step 1. Inventory Deliverables

The NOAA office review generally occurs within 30-days of receipt and inventory of the final deliverables, which generally include:

- Digital file of Smooth Sheet with attributes (Microstation DGN or AutoCAD DWG file)
- Mylar plot of Smooth Sheet
- Raw or processed multibeam data tapes (Caris NT compatible)
- Corresponding tide, sound velocity, vessel configuration files. (Caris NT compatible)

- Side scan data tapes (Caris NT compatible)
- 5 meter bin ASCII XYZ data set
- Descriptive Report and supplemental reports
- Field logs
- Calibration documentation.
- Coverage plots, contact plots, mosaic plots, etc

Inventory of deliverables generally takes one day if the reviewer has prior knowledge of contractor-specific product formats. Otherwise a thorough review may take several days. As each survey typically includes numerous supporting documents and digital data files, it is helpful when contractors clearly label the deliverables in a manner that is both descriptive and intuitive to NOAA personnel who may not be intimately familiar with the contractor's unique filing structure and naming conventions.

Upon further scrutiny throughout the review process, it is customary to find discrepancies in a small percentage of the deliverables, such as corrupt data files, or pages with typographical or numerical transcription errors. When notified of such discrepancies, it is the contractor's responsibility to expeditiously submit corrected deliverables. Final payment of the contract may be withheld until corrected deliverables are received.

Step 2. Patch Test and DTM Review

The patch test is usually reviewed during fieldwork and well before the final deliverables are received at AHB. However, visual inspections of final color-by-depth multibeam swath plots are immediately performed upon receipt and if they indicate potential systematic errors, the patch test data will be reviewed again. Patch test quality can be reviewed two ways, depending upon the reviewers discretion and the degree of his or her observations of actual patch test performance: (1) Import raw patch test data into CARIS calibration mode and independently determine biases and then compare NOAA results to contractor results. (2) Review fully corrected official multibeam data in CARIS and look for artifacts in flat areas and in areas where distinct features, such as wrecks, are covered by 2 or more overlapping multibeam lines. In general, any noticeable indication of motion, depth, position, or timing artifacts in the final data, even if minor in magnitude, may result in NOAA contacting the contractor for further explanation or corrective action.

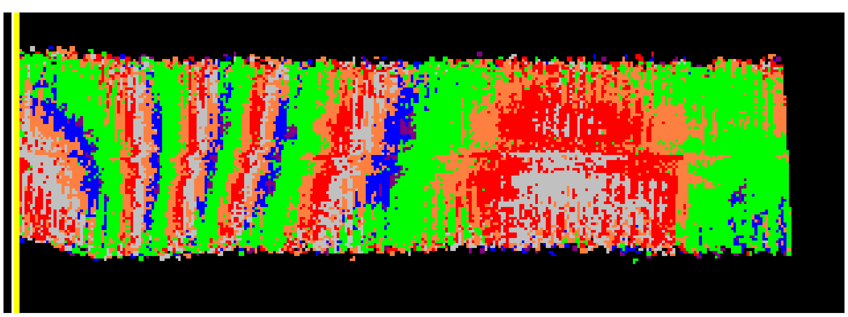


Fig. 3 Example of identified multibeam artifact as seen in CARIS subset mode (color change resolution set at 20 cm). The suspect line readily stood out against adjacent data in the final color-by-depth swath plot. The suspect line was then loaded into CARIS where NOAA reviewers confirmed that it contained unacceptable artifacts. Investigation subsequently determined that it was a snippet of uncorrected 'offline data' that was erroneously included in the final deliverables.

Another method of DTM and data review utilizes the XYZ 5-meter grid data file, performing a comparison by re-creating the survey. The file has all 5-meter grid soundings listed with necessary attributes needed to trace the sounding back to corresponding multibeam data. These attributes, colloquially referred to as the "bread crumb trail", include source information such as line number, day number, time, profile or ping number, beam number, and tidal corrector. AHB personnel imports the text file into other Geographic Information System (GIS) programs for confirmation of gross errors, tidal application, contour generation and comparison, and supplemental products such as MB DTM generated for public relations and possible use by others within the scientific community.

Another use of the XYZ data set aids the cartographer when smooth sheet contours require revision based upon data verification and editing. The smooth sheet sounding interval or spacing varies from contractor to contractor. In some cases, the smooth sheet does not display the quantity of data points required to determine where the specific contour is placed. The XYZ data will be imported into Microstation so the excessed soundings may be viewed and assist cartographer with proper contour placement. The cartographer is allowed "cartographic license" within limits, for these modifications supported by the excessed sounding data.

Step 3. Contractor -to- NOAA System Compatibility Check

A compatibility check is a crucial step that must be performed early in the review process. Experience has shown that when re-constructing and correcting raw multibeam data by NOAA in CARIS, slightly different values for beam, ping, position, and depth are likely to be obtained compared to the contractor's proprietary or Commercial Of The Shelf software (COTS) and AHB's CARIS processing system. This situation can occur when converting identical raw data and corrector files into the two systems directly copied from the same physical data storage tape. After a cooperative investigation by NOAA and affected contractors differences in values are believed to be due to inherent variations in proprietary software features, such as data field lengths, interpolation methods, and ray-bending algorithms.

However, differences can be greatly exacerbated if format, units, and coordinate conventions of contractor vessel configuration parameters are not clearly identified by the contractor or understood by NOAA reviewers. In addition, some contractor corrector files have formats that are not readily importable into CARIS and hence require trial-and-error format modification by NOAA reviewers, which can take days, or if particularly difficult, several weeks. Unfortunately, even after input files are properly modified for CARIS use, depth differences of up to 10 cm and position differences of up to 2-3 meters may be unavoidable.

Contractor and NOAA personnel must also be mindful that even a few millimeters of depth difference between contractor and NOAA multibeam processing systems can result in apparent smooth sheet ambiguities of 1 foot due to meters-to-feet conversion and subsequent rounding to integer foot values. In addition, many contractors use a beam numbering convention that starts at 0 where CARIS starts at 1. Consequently, beam offsets of 1 are normal when reviewing some but not all contract surveys. Likewise, depending on the contractor's method of tabulating ping numbers at the start of successive survey lines, ping numbers may or may not have any correlation with those as seen by NOAA in CARIS, which resets the ping number to 1 at the beginning of every new line. In such cases, time (UTC) attributes are used to correlate smooth sheet features to corresponding mulitbeam data.

In any event, all differences between contractor and NOAA systems must be clearly understood in order to properly correlate digital Smooth Sheet features, which are attributed with values derived from contractor systems, back to the corresponding multibeam data as seen by NOAA office reviewers in CARIS software.

In addition, minor compatibility issues have also occurred with raw side scan sonar data viewed by NOAA in CARIS. If the format is Extended Triton Format (XTF), the side scan data may also be viewed in Triton Elac's ISIS software. Significant compatibility issues have also occurred with digital smooth sheet files, where it was discovered that AutoCAD (.dwg) smooth sheets experience position shifts of up to 200m when importing into NOAA's Microstation (.dgn) based chart production systems. Consequently, NOAA now requires that contract smooth sheets be delivered in Microstation (.dgn) only.

Contractors typically cooperate very closely with NOAA reviewers throughout the review process and specifically during compatibility checks. In order to address issues raised by NOAA reviewers, contractor personnel may often devote appreciable man-hours in telephone calls, email exchanges, or actual visits to the NOAA office.

Fig. 4 Digital Smooth Sheet with Contractor-system attributes

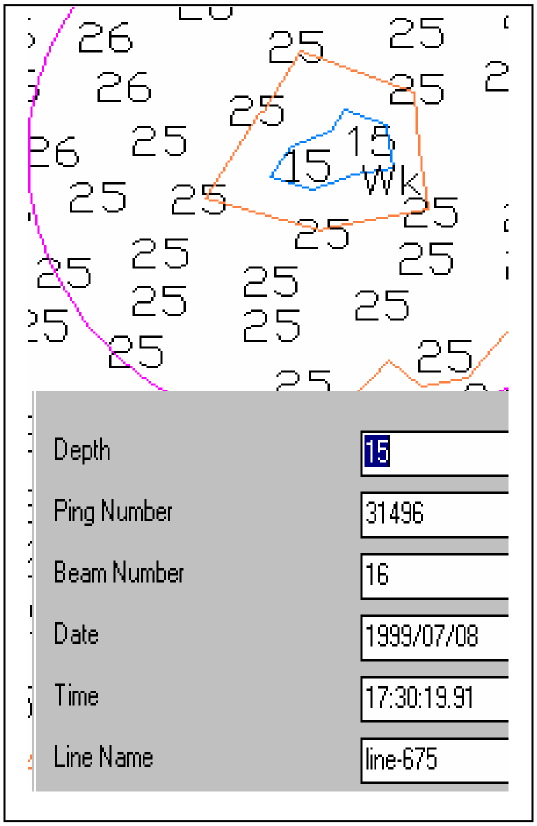
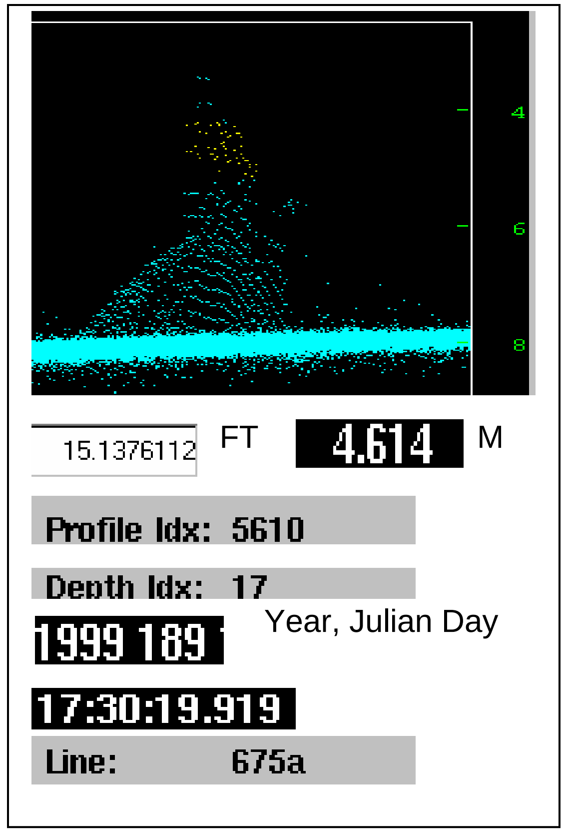


Fig. 5 Corresponding multibeam data as seen by NOAA in CARIS



Note: The Contractor's 15 ft smooth sheet value was based on a Contractor-system multibeam value of 4.60 m. In this case, the Contractor system and the NOAA system both showed values that rounded to 15 ft. **However, AHB determined that this point did not correspond to the true shoal point in the multibeam data and AHB eventually revised the feature to an 11 ft Wreck.**

Step 4. Identifying Selected Multibeam Lines for CARIS review

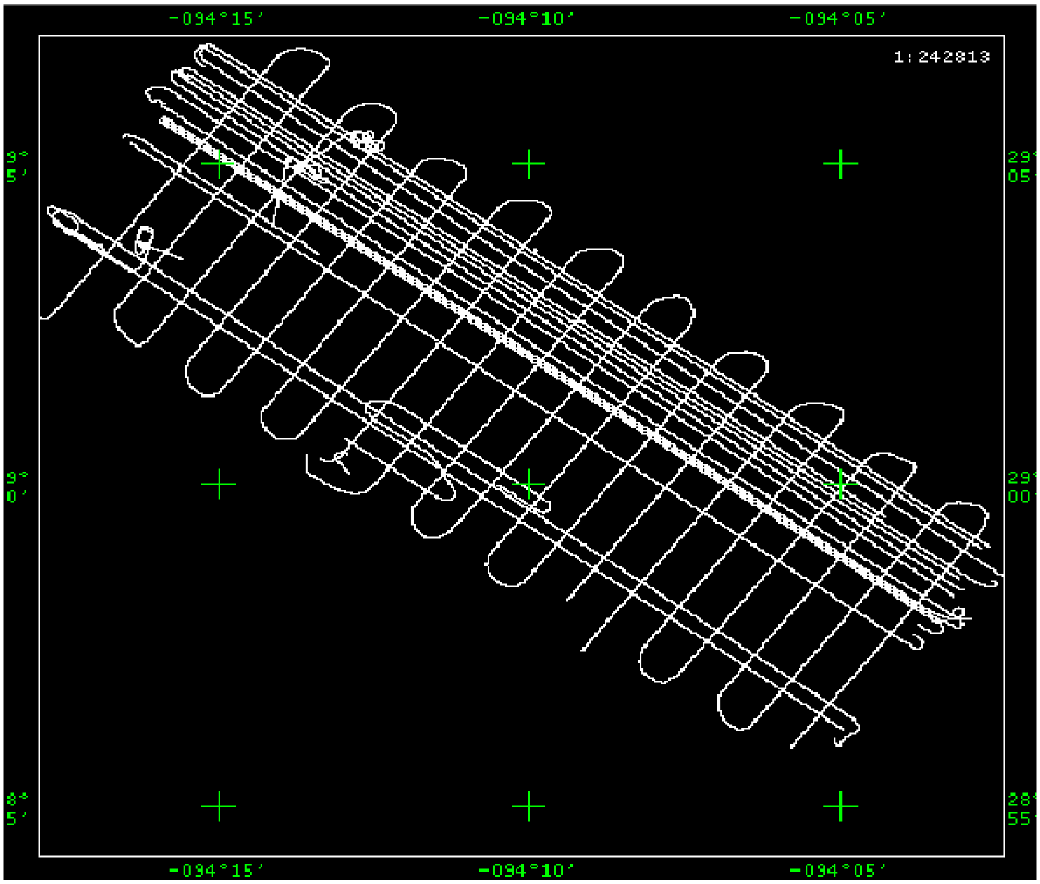
It should be noted that the primary function of the NOAA review is one of data verification. It is not the function of the NOAA review to reprocess contractor data. Consequently, NOAA may choose to load only a small percentage of the raw multibeam data in CARIS for review. However, at a minimum, multibeam lines associated with the following criteria are loaded in CARIS for review:

- All cross lines.
- All wrecks, rocks, and obstructions depicted on the Smooth Sheet.
- All item investigation lines –including when the contractor determined that investigated side scan items were not detected in the subsequent investigative multibeam lines.
- Shoal soundings critical to navigation –including the shoalest soundings in navigation safety fairways, channels, and anchorages. Knowledge of draft of vessels using the area is heavily considered when selecting shoals to be reviewed.

- Suspicious shoal or deep soundings, as indicated by 2 ft or more difference compared to surrounding soundings.
- 5-10% of mainscheme lines –randomly distributed spatially, temporally, across tide zones, and across all vessel configurations used.

The deliverables are searched for all data files associated with these lines. The efficiency of the search is greatly aided by Line Name, Beam, and Ping attributes contained in the Digital Smooth Sheet. However, due to compatibility issues, the attribute information alone may be insufficient or even misleading. Consequently, NOAA reviewers rely on thorough Descriptive Reports, as well as "user-friendly" methods of labeling and packaging of the deliverables by contractors.

Fig. 6 Example of selected multibeam lines loaded in CARIS for NOAA review.

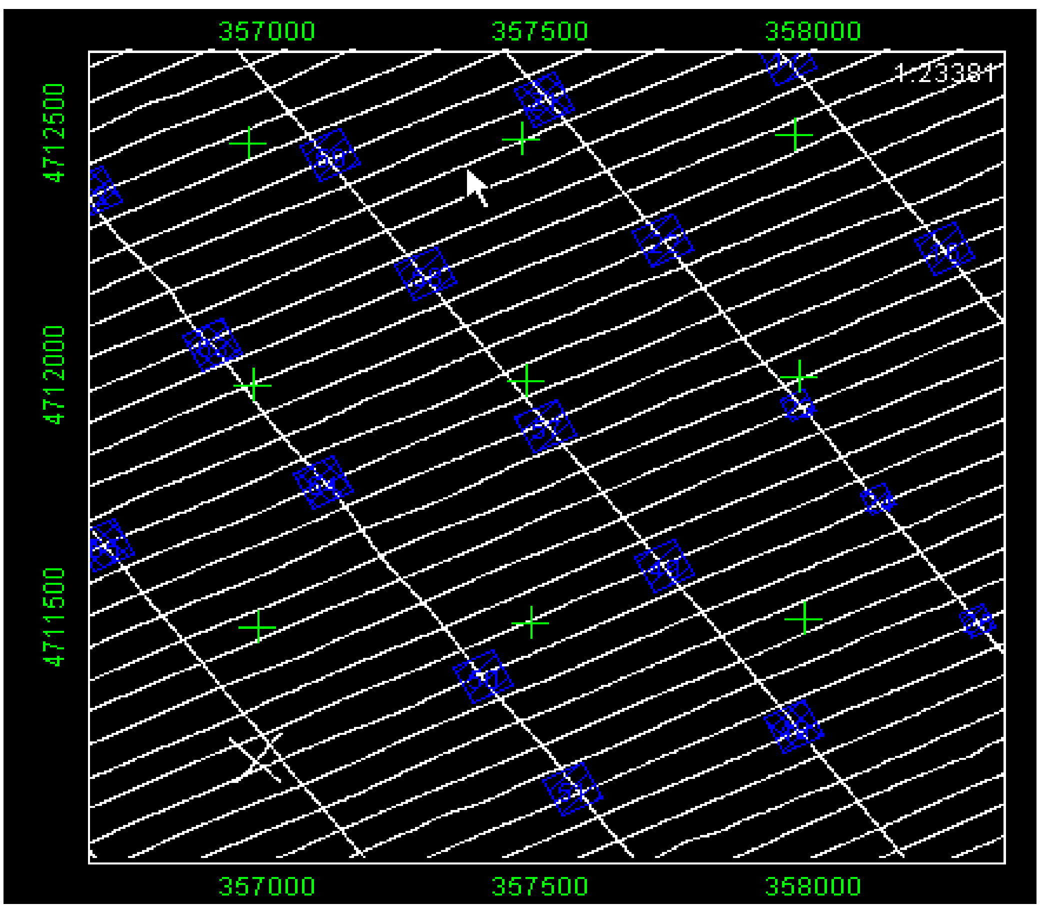


Step 5. Cross line comparison

Once system compatibility is confirmed and all multibeam selected for review has been loaded, the selected multibeam is reviewed in CARIS to better understand the magnitude and source of remaining systematic vertical errors and to confirm that they are within limits specified in the NOS Specifications and Deliverables. As a proper vessel configuration parameters are confirmed in Step 3, System Compatibility Checks, remaining vertical error concerns are generally evaluated by reviewing cross line comparisons, sound velocity correction, and tide correction.

Cross line comparison entails reviewing the submitted documentation covered within the Descriptive Report and supporting beam comparison provided with survey documentation. AHB verifiers look at many cross comparison regions within the survey limits inspecting on a random basis or selecting geographic regions within the survey limits that do not have high relief or rapid changes in bathymetry. Areas of this nature are preferred so that a valid comparison can be made between the main scheme data and that of the cross line data. Comparison is made between the inner and outer beams of the cross comparison swath data to that of the main scheme sounding data. If there are artifacts with sound velocity refraction or roll artifacts, this is the area where the artifacts will be visible indicating problems. A good comparison will yield agreement of one foot or less. Below is a screen grab indicating the cross comparisons performed on contract data.

Fig. 7   Identified Cross Line junctions for review



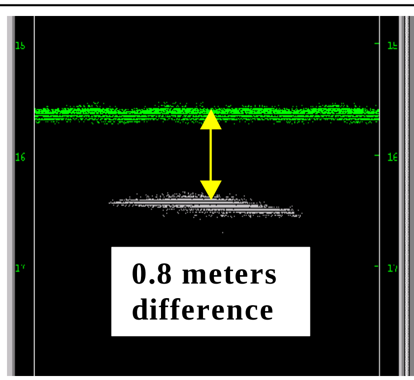
Cross line comparisons include reviewing statistical analysis reports, visually inspecting color by depth multibeam swath plots (on which even minor differences of 0.1 meters can be readily detectable, and differences of more than 0.3 meters can be outright glaring). The following is an example of a statistical analysis indicating generally good agreement between mainscheme and cross line data. Cumulative percents of more than 90% for 30cm depth difference generally indicate acceptable junctions.

Fig. 8 Statistical Analysis (performed by Contractor) of Mainscheme vs Cross Lines

Depth Difference Range			All Difference		Positive Difference		Negative Difference		Zero Difference
From		To	Count	Cumulative Percent	Count	Cumulative Percent	Count	Cumulative Percent	Count
00.0cm	->	10.0cm	1,412,312	47.20	796,228	38.72	549,880	67.51	73,146
10.0cm	->	20.0cm	1,117,659	84.55	905,052	80.45	213,392	93.95	
20.0cm	->	30.0cm	428,371	98.87	360,186	98.56	47,417	99.84	
30.0cm	->	40.0cm	33,041	99.97	29,585	99.96	1,209	100	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

However, when the survey as a whole has apparently acceptable statistical analysis, isolated unacceptable errors may still exist. Generally, isolated differences exceeding 0.3 meters will be investigated, and the submission of corrected deliverables by the contractor may be warranted. For example, the following graphic shows an isolated unacceptable 0.8 m difference between cross line (upper) and mainscheme line (lower).

Fig. 9 Unacceptable Cross Line comparison



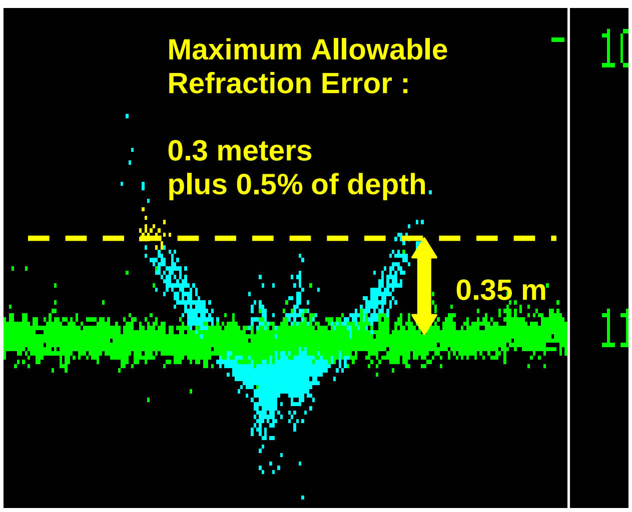
Subsequent investigation of this junction concluded that the mainscheme (lower) line was a supplemental line that was not corrected for tides because it was not needed for coverage, however, the contractor erroneously included it on the officially delivered multibeam data tapes.

Step 6. Review of Sound Velocity Correction

Sound velocity corrections can have a substantial impact on the quality of a survey, especially in flat and shallow areas such as the Gulf of Mexico. The June 2000 NOS Specifications and Deliverables state that the allowable maximum sound velocity error is 0.30 meters plus 0.5% of the depth. Consequently, in a typical Gulf of Mexico survey of 45 ft depth, a 1.2 ft error in sound velocity is allowable. If a substantial of number of lines have allowable sound velocity refraction of this magnitude in the form of cupping of outer beams, portions of the survey, and corresponding areas of affected charts, will be effectively shoal-biased by one foot, due to imprecise sound velocity correction alone. This can be both navigationally and economically significant in regions where deep draft vessels operate with under-keel clearances of only a few feet.

Considering these factors, sound velocity correction is closely evaluated. Records of velocity casts are closely scrutinized to ensure that frequent and proper casts were taken. Nevertheless, instances of maximum allowable sound velocity error have been found when investigating suspicious shoal soundings on the digital smooth sheet.

Fig. 10 Velocity Error



Example of a raw multibeam line (showing all beams) with excessive sound velocity refraction. Shown is a profile of the suspect mainscheme (blue) line intersecting a valid cross line (green). When processing, the contractor removed outer beams from the suspect (blue) line that exceeded the maximum allowable velocity error. However, approximately 0.3 meters of velocity error remained in the outer portion of the accepted swath.

In response to NOAA's concerns, many contractors have begun using real-time or undulating velocitimeters in order to obtain more precise velocity correction. Subsequent reviews of surveys using real-time velocity correction confirms that instances of Smooth Sheet soundings with maximum allowable velocity error has markedly declined.

Step 7. Review of Tide Correction

To date, all contracts received by NOAA's AHB office have used NOAA-provided tide data and tide zoning. Contractors simply download verified tide data from nearby approved NOAA tide gauges directly from the NOAA website. Tide format may have to be altered for input into their own acquisition and processing systems. Consequently, tidal correction has required minimal review. However, isolated instances of applying tide data tagged with UTC time to multibeam data erroneously tagged with local time have resulted in isolated tide correction errors. In addition, there have been instances where contractors have generated

Smooth Sheets using an errant multibeam line that was inadvertently left uncorrected for tides due to an oversight during processing. In such instances, the errors are often readily detected by visual inspection of the contractor's color by depth multibeam swath plots.

NOAA reviewers may also choose to download the applicable tide data from the NOAA website and compare it directly to the contractor's data file by generating a difference file.

Future east coast contracts will very likely require that contractors generate their own tide correctors. This is already the case for many west coast contract surveys received at NOAA's Pacific Hydrographic Branch (PHB). When generating tide correctors, contractor responsibilities includes establishing and operating secondary or tertiary tide gauges, datum determination, and final tide zoning. In such instances, final tidal data is reviewed by NOAA personnel from the Center for Operational Oceanographic Products and Services (CO-OPS), who work closely with AHB or PHB reviewers.

Step 8. Review of multibeam data for critical depths portrayed on smooth sheet

Once the vertical error of the multibeam data is evaluated, corresponding multibeam data of the following specific smooth sheet features are reviewed with special attention given to all charted features, wrecks, rocks, obstructions, shoals, and suspicious soundings. The procedure entails acquiring data attributes for that particular sounding or feature. The submitted smooth sheet, whether a Microstation (.dgn) or AutoCAD (.dwg) drawing has all soundings, side scan contacts, navigational aids, and baring features attributed with pertinent information related to the "bread crumb trail". AHB verifiers will inquire as to the attributes and then locate the exact beam and ping from within the data file. If agreement is not confirmed, then screen grabs are generated and added to the AHB Survey Review document that supports the changes pertaining to the smooth sheet based upon the data and hydrographic verifier interpretation.

When reviewing a sounding on the digital smooth sheet. The NOAA reviewers seek to find answers to the following questions.

- Is it a real feature or is it an erroneous sounding due to multibeam noise or pings on fish?
- Has the feature been confirmed by side scan sonar records?
- Does the Multibeam least depth value agree with corresponding side scan sonar estimated contact heights?
- Does the Smooth Sheet depth value represent the actual true shoal point seen in the multibeam data? Or was the true multibeam shoal point inadvertently removed by automated filtering?
- Is the data inconclusive? If so additional fieldwork may be warranted.

Example: Review of a suspicious sounding.

The 36 ft sounding was considered suspicious because it was 2 ft shoaler than surrounding depths in region believed to be very flat. A review of the corresponding multibeam data by NOAA in CARIS indicated that the sounding came from a random 2-meter tall noise spike. A review of side scan data confirmed that there were no side scan contacts in the area. Further investigation by the contractor concluded that the noise spike was only partially filtered out from the official data set and that a 2-ft tall stub erroneously remained. The 36 ft sounding was subsequently removed from the digital smooth sheet file by NOAA.

Fig. 11
Digital Smooth Sheet with
Contractor-system values

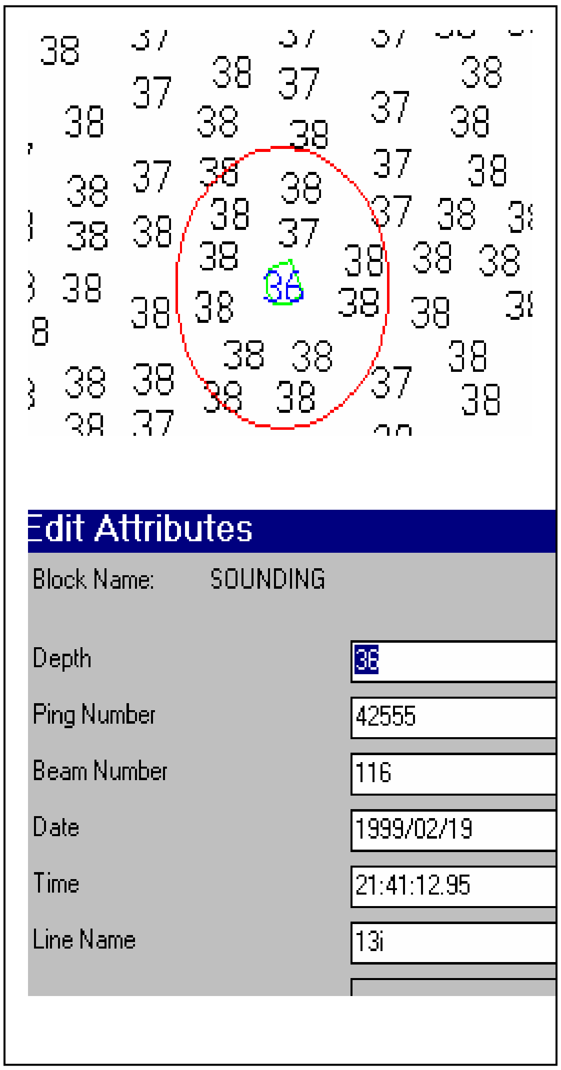
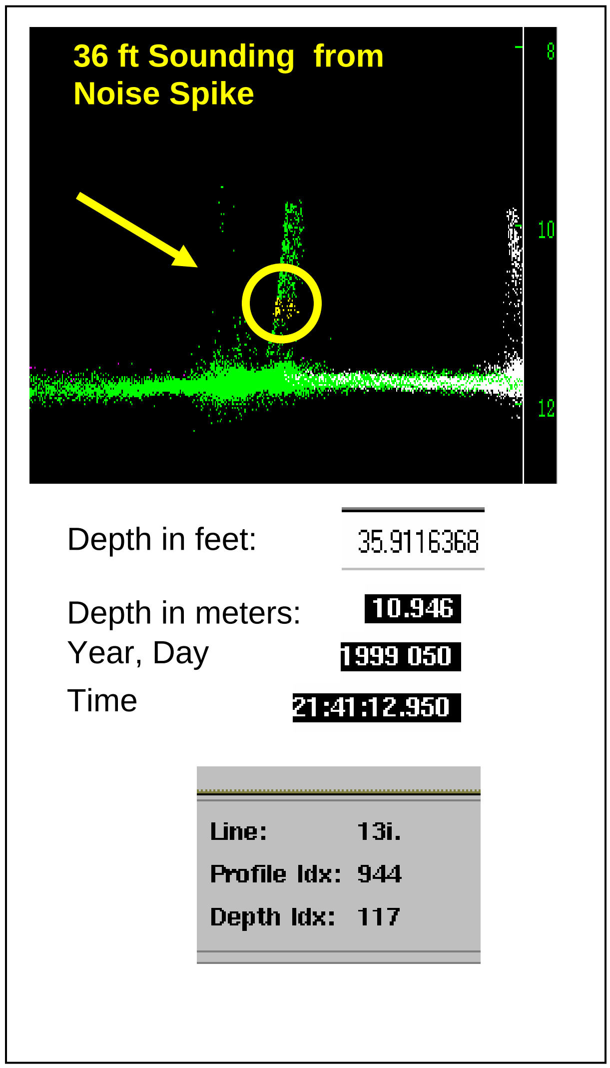


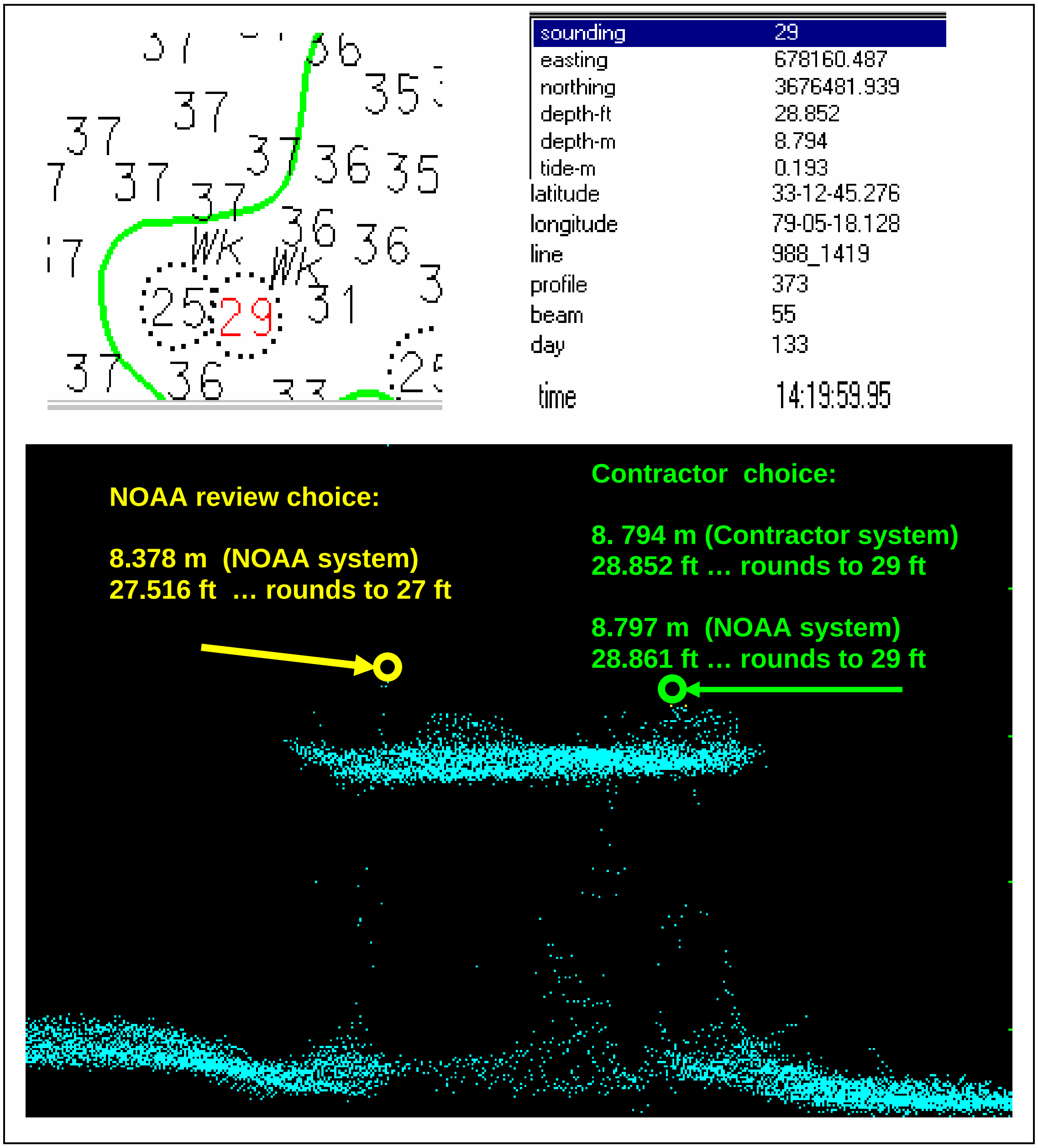
Fig. 12
Corresponding multibeam data
as seen by NOAA in CARIS



Example: Review of a least depth on a wreck.

The 29 ft wreck depicted on the digital Smooth Sheet was selected for review along with all other wrecks, rocks, and obstructions depicted on the Smooth Sheet. The Descriptive Report described the item to be a sunken barge. A review of side scan sonar records confirmed this. However, a review of the corresponding multibeam data revealed that the contractor did not choose the shoalest point for the least depth value. The digital Smooth Sheet feature was eventually edited to a 27 ft wreck by NOAA personnel.

Fig. 13 Review of 29 ft Wreck on Digital Smooth Sheet



Inspection Results

Upon completion of the NOAA quality assurance inspection, an official letter of recommendation to either accept or reject the survey is made and forwarded to NOAA's Silver Spring Office. In addition, an internal QA review report is generated which documents survey strengths and weaknesses, recommended NOAA edits to the digital Smooth Sheet, any recommendations for additional fieldwork, and suggested improvements in the NOAA contract administration process.

Conclusions

The NOAA AHB quality assurance inspection process for contract surveys continues to evolve and improve. Of particular note, NOAA is working to reduce system compatibility issues, which have made effective review difficult at times.

To date, NOAA AHB's quality assurance review process has uncovered no major deficiencies in any contract survey that would warrant non-acceptance, and consequently, AHB has officially accepted all contract surveys that have thus far been delivered. However, the QA review process routinely reveals a substantial number of minor (fixable) deficiencies, including data interpretation issues that if left undiscovered and uncorrected, would result in charting inaccuracies that are potentially navigationally significant to mariners.

In addition to identifying and correcting errors in the final deliverables, the QA process has had the added benefit of providing valuable feedback to the contractors, which they have generally used to improve their performance on subsequent contracts. Likewise, the QA process has provided feedback within NOAA for clarified contract language and improved technical requirements.