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E/V Nautilus EM302 Multibeam Echosounder System Review

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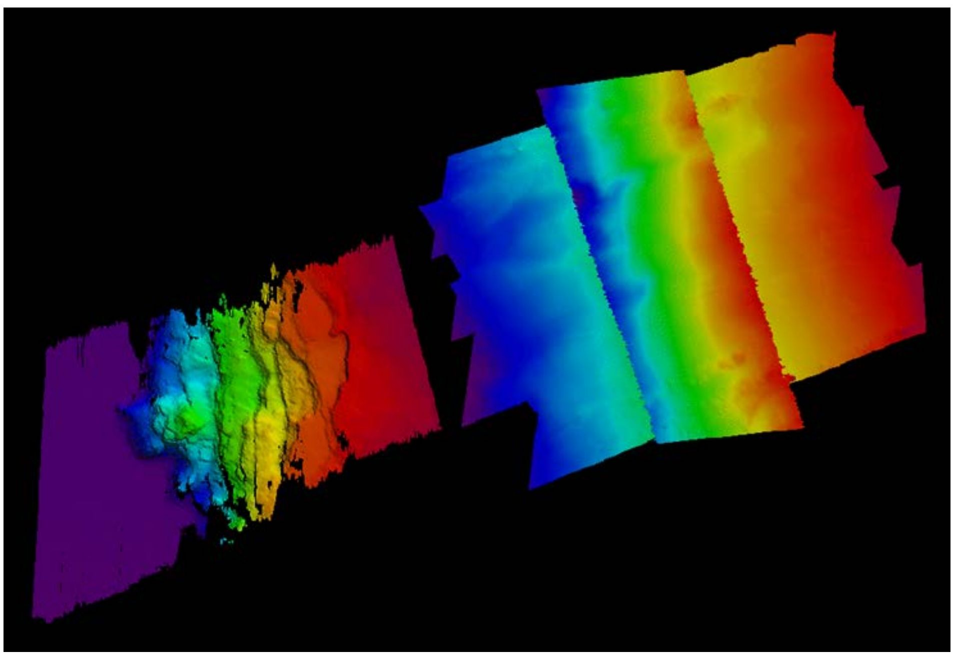
E/V Nautilus
EM302 Multibeam Echosounder System Review
NA040
May 14, 2014



Report prepared by:

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University of New Hampshire
Center for Coastal and Ocean Mapping/Joint Hydrographic Center
Durham, NH

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of UNH or the NSF.

Cover image: Bathymetry of the reference surface, one deepwater accuracy crossline survey pass, and one extinction survey pass at the continental shelf break off St. Petersburg, Florida. Data were processed with Caris HIPS 8.1 and are shown with individual color scales for contrast.

Introduction

The E/V *Nautilus* undertook leg NA040 to perform a review of the vessel's Kongsberg EM302 multibeam echosounder in the vicinity of the continental shelf break offshore of St. Petersburg, Florida, from May 4-9, 2014 (Fig. 1). Paul Johnson and Kevin Jerram provided logistical and technical support for data collection and analysis. This report:

- Describes the data collected.
- Provides an overview of the processing methods used on the data
- Presents the EM302 system performance for accuracy and coverage over the expected operational depth range.
- Documents changes made to the system configuration prior to the 2014 field season.
- Plots the EM302 transducer impedance data to document transducer health.

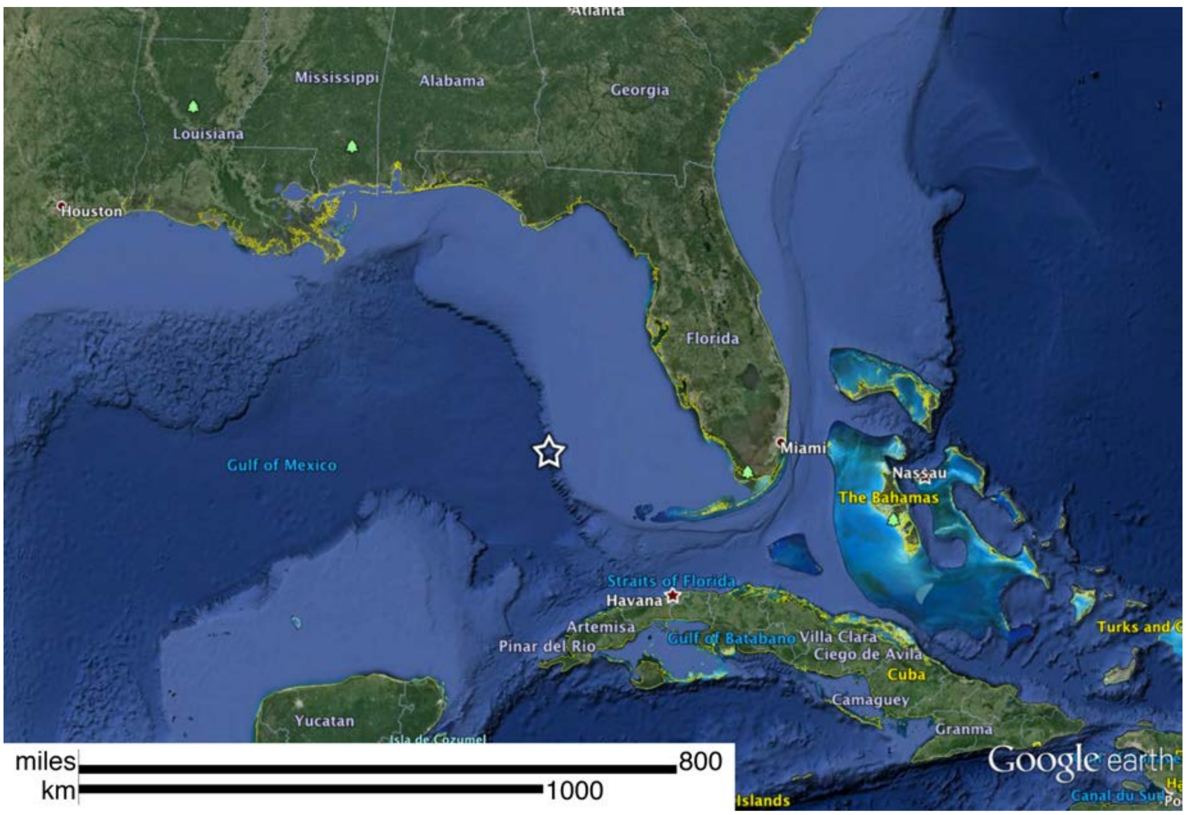

Figure 1. Star indicates location of the EM302 system testing site during NA040.

Cruise Participants

Nicole Raineault, OET
Ethan Gold, OET
Reuben Mills, OET
Michael Brennan, OET
Ian Vaughn, URI-GSO
Sarah Fuller, URI-GSO
Clara Smart, URI-GSO
Will Snyder, URI-GSO
Nolan Pretty, Knudsen
Donna Marie Burnell, Knudsen
Chuck Hohing, Kongsberg
Kevin Jerram, UNH-CCOM
Paul Johnson, UNH-CCOM
Tim Gates, Gates Acoustic Services
Marisa Yearta, Gates Acoustic Services
Gabriel Whitston, Maritime Management

Survey System Components

The mapping system consists of the following primary components:

1. Kongsberg Maritime EM302 multibeam echosounder (30 kHz), v1.3.1, s/n 110
2. Kongsberg Maritime Seafloor Information System (SIS), v4.1.3
3. Kongsberg Seatex Seapath 330+ vessel navigation system
    - Seapath 330+ GNSS antennae
    - MRU 5+, s/n C126NS2018
4. AML Oceanographic Micro-X surface sound speed sensor
5. Sippican expendable bathythermograph (XBT) profiling system

Activities

Cruise activities included calibration for residual angular offsets ('patch test'), creation of a reference surface, accuracy evaluation with respect to the reference surface, and coverage/extinction testing on and off the continental shelf break. Ancillary activities included support for watchstander training.

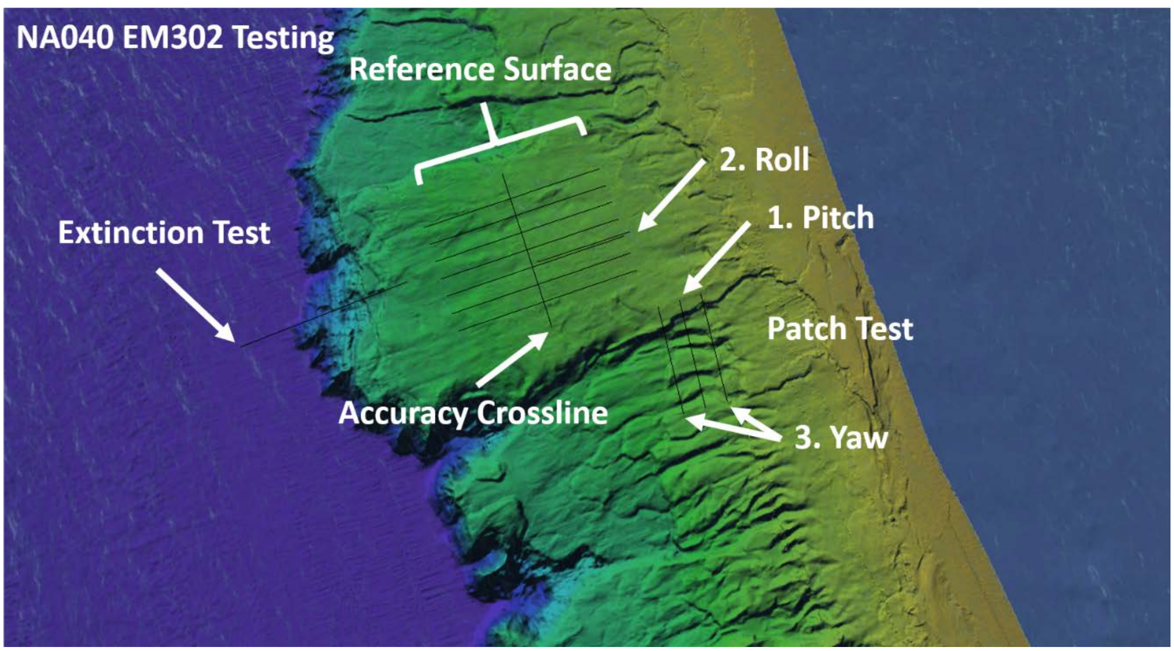

Figure 2. Layout of operational areas for EM302 trials (presented in Google Earth using historic multibeam echosounder data downloaded from the National Geophysical Data Center).

Overview of System Geometry

In this report, we use the term 'system geometry' to mean the linear and angular offsets of the primary components of the multibeam mapping system, including the transmit array (TX), receive array (RX), and ship navigation sensor (MRU). These parameters are critical for data collection in an unbiased and repeatable manner.

TX and RX Arrays

Linear and angular offsets of the TX and RX arrays were determined from a ship survey performed by Parker Maritime in Istanbul in March of 2013 (see Sea Acceptance Trial [SAT] report for details). Array offsets are not expected to have changed since the Parker survey. Accordingly, no array offset modifications are documented in this report.

MRU

Prior to the 2013 season, linear and angular offsets of the original MRU were determined from the Parker Maritime survey and SAT patch test, respectively. The original MRU was deemed faulty and replaced by Kongsberg engineers before the start of NA030 in July 2013. A patch test was performed at the start of NA030 to determine angular offsets between the replacement MRU and the ship reference system, holding all other offsets constant. The NA030 patch test results for angular offsets were applied for the remainder of the 2013 multibeam mapping season. No changes to linear offsets were recorded, as they were expected be on the order of millimeters and would not have had an appreciable effect on bathymetry (or, consequently, been resolvable through patch testing). The original MRU removed prior to NA030 was serviced by Kongsberg and reinstalled by Chuck Hohing in St. Petersburg prior to NA040.

Calibration

A patch test was performed near the continental shelf break southwest of St. Petersburg (Fig. 2) at the start of NA040 to determine angular offsets of the newly installed (original) MRU. Descriptions of the rationale for calibration line planning are available in the *Cookbook for Caris HIPS 8.1 Patch Test with Kongsberg EM302*, which was developed with examples from NA040.

An XBT profile was acquired to 760 m depth prior to the calibration lines. All XBTs throughout NA040 were processed using WinMK and SVPEditor to remove spurious sound velocities, apply salinity data from the World Ocean Atlas, extend the cast to 12,000 m per SIS requirements, and load the resulting sound speed profile into SIS.

To increase alongtrack sounding density on the calibration lines, the vessel was operated at six knots over ground (slower than the typical survey speed of ten knots over ground), which provided minimum steerage while transiting with and across the locally strong currents. The EM302 was configured as follows to maximize ping rate:

Depth mode:	DEEP with FM disabled (CW transmit mode)
Dual-swath mode:	enabled
Yaw stabilization:	enabled
Pitch stabilization:	enabled
Beam spacing:	High density equidistant
Swath width:	Pitch: 15°/15° port/stbd
	Roll: 60°/60° port/stbd
	Yaw: 15°/55° port/stbd and 55°/15° stbd/port

Calibration survey data were collected using the NA030 patch test values as the initial starting point for real-time processing in SIS. Accordingly, the angular offsets determined from the NA040 calibration were 'residual' values to be added to the NA030 values. Angular offsets were determined in the order of pitch first, roll second, and yaw third to minimize. To minimize coupling of angular offsets in the calibration results, each angular offset was updated in SIS after completion of its respective calibration procedure and before the start of survey data collection for the next offset calibration. The SIS and Caris HIPS calibration tools were used independently by Johnson and Jerram, respectively, to estimate the residual angular offsets. Results from the independent estimates were in excellent agreement.

Calibration Results

Figures 3 - 5 depict single transects using the calibration tool in the Caris HIPS Subset Editor for the pitch, roll, and yaw calibration data sets. The final value for each offset is based on multiple transects in the Subset Editor calibration tool and represents, in agreement with results from the SIS calibration tool, the residual angular offset to be added to the SIS Installation Parameters for the MRU at the time of calibration (Table 1).

Angular Offset	NA030 Value	NA040 'Residual'	Post-NA040 Value
Pitch	-0.12°	+0.00°	-0.12°
Roll	+0.14°	+0.01°	+0.15°
Yaw	+0.09°	+0.02°	+0.11°

Table 1. Summary of MRU offset calibration results.

All MRU angular offsets entered in SIS after the NA040 calibration reflect the net totals resulting from the NA030 and NA040 patch tests. NA040 survey data for the reference surface, cross lines, and extinction tests utilized these values and appear to be free of offset-related artifacts.

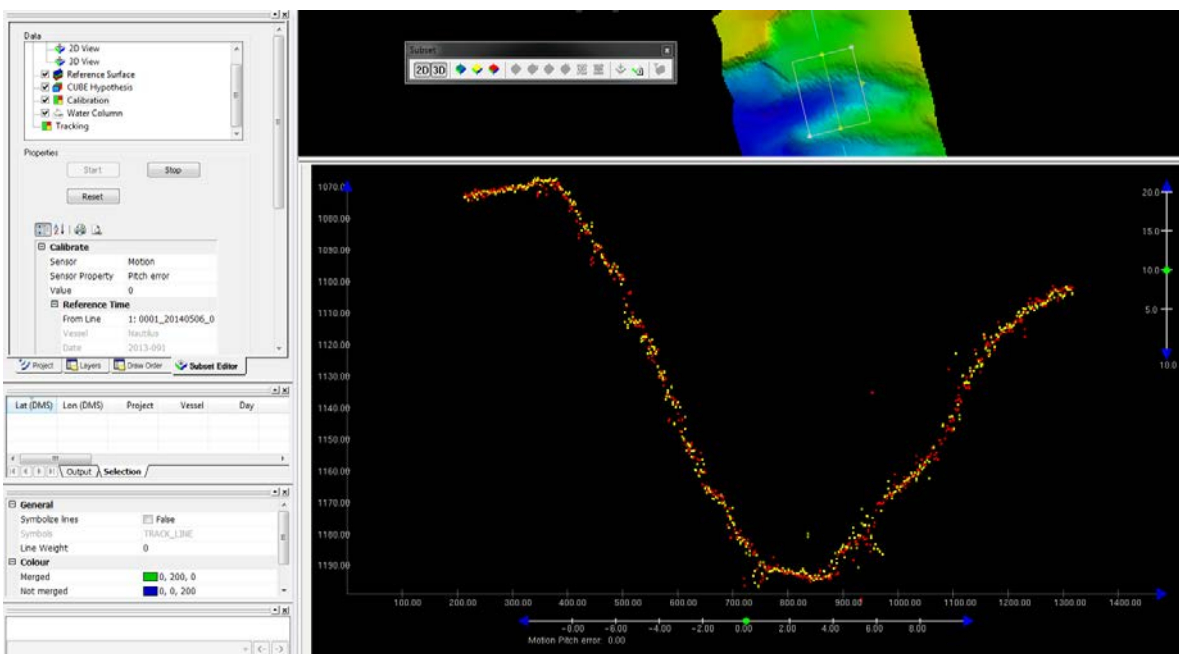

Figure 3. Pitch calibration in Caris yielding a residual MRU pitch offset of 0.00°.

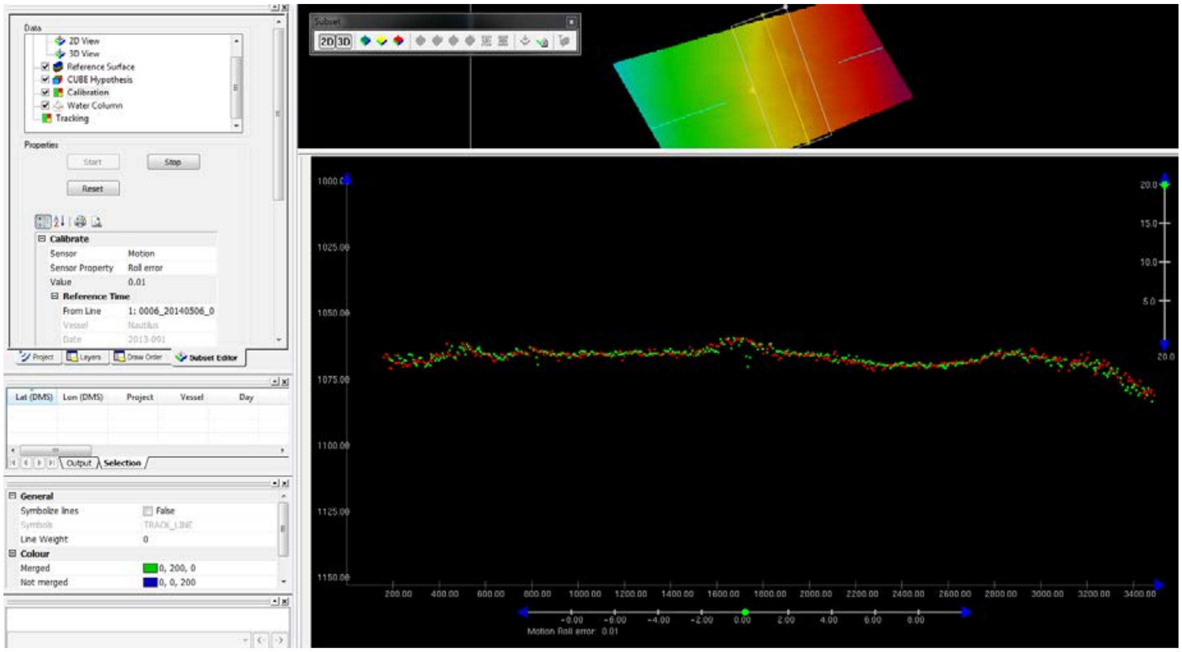

Figure 4. Roll calibration in Caris yielding a residual MRU roll offset of +0.01°.

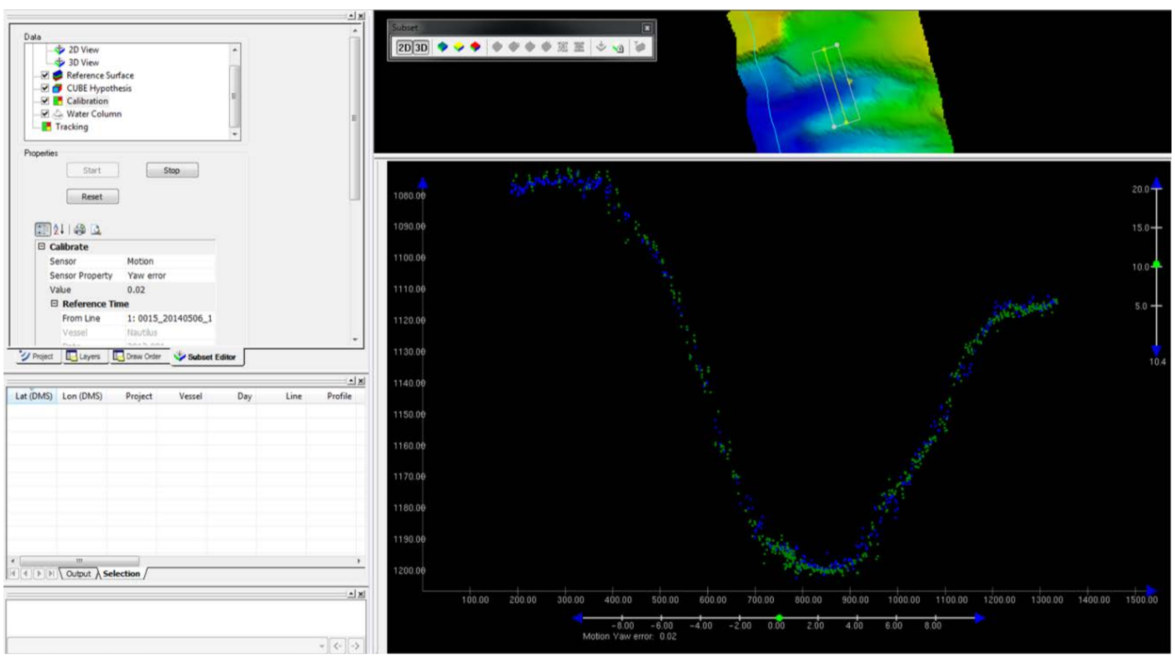

Figure 5. Yaw calibration in Caris yielding a residual MRU yaw offset of +0.02.

System Geometry and SIS Parameters (09 May 2014)

Table 2 includes the SIS configuration for the linear and angular offsets of the TX and RX arrays and the MRU as of the end of the NA040 leg on May 9, 2014. Aside from MRU angular offsets determined from the NA040 patch test, no modifications were expected or made to the SIS Installation Parameters. These offsets represent the survey configuration which will be used at the start of the 2014 Nautilus operational season based on existing documentation and patch test results. All values are with respect to the Kongsberg (SIS) reference frame. These parameters are to be used until sensor locations or orientations are modified or it is determined that a new patch test should be undertaken.

	X (m)	Y (m)	Z (m)	Roll (°)	Pitch (°)	Yaw (°)
Vessel Reference Origin	0.000	0.000	0.000	-	-	-
Navigation Reference Point	0.000	0.000	0.000	-	-	-
EM302 TX	+3.496	-0.137	+2.731	+0.61	+0.01	+0.22
EM302 RX	+1.516	+0.033	+2.732	+0.72	+0.32	+0.08
Seapath MRU	-	-	-	+0.15	-0.12	+0.11

Table 2. SIS PU parameters for linear and angular offsets as of the end of NA040. Note that MRU linear offsets are not specified because navigation data from the Seapath 330+ is referenced to the center of the TX array, per Kongsberg convention for navigation input.

Accuracy assessment

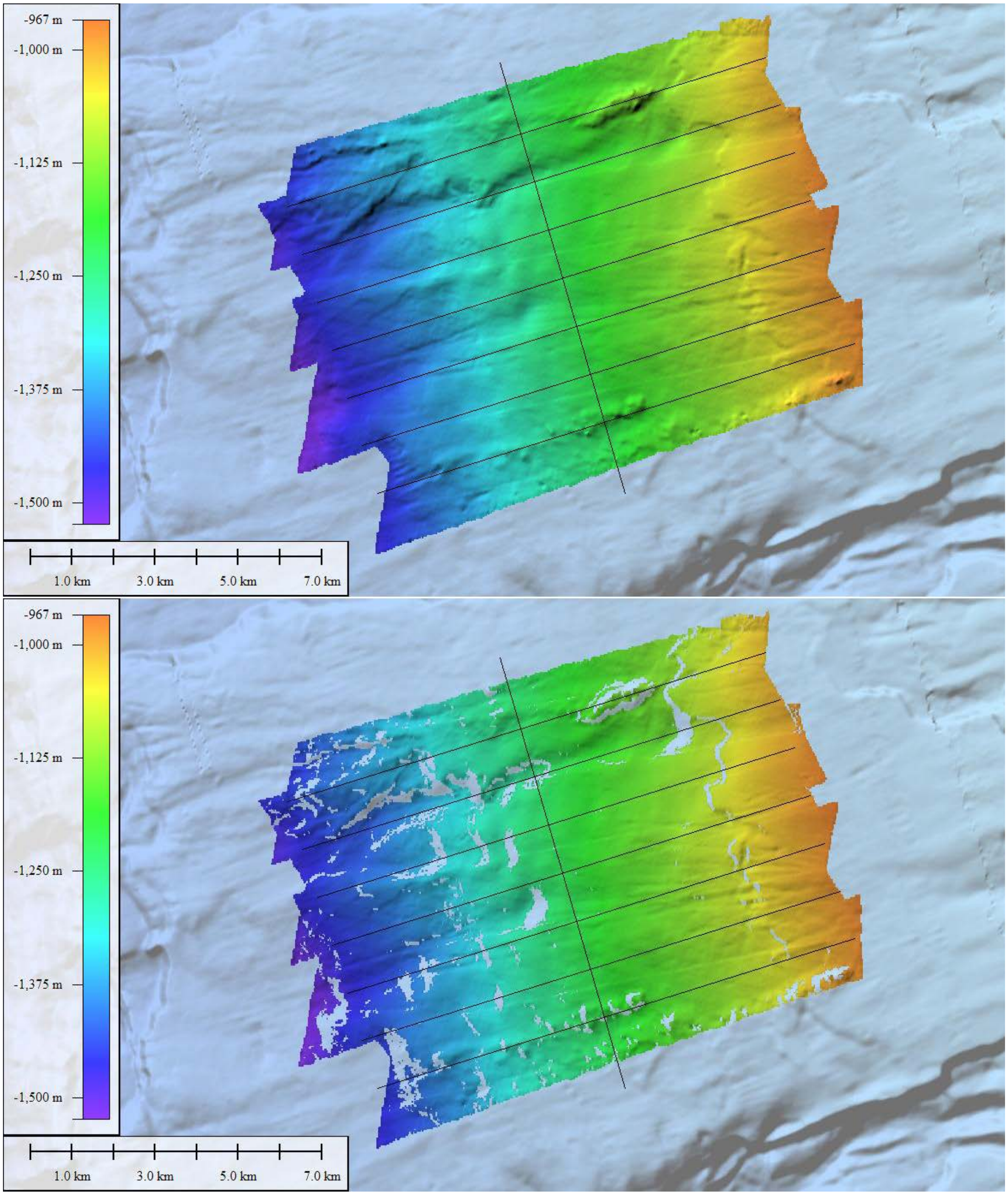

Figure 6. Overview of the reference surface area. Top figure shows all reference surface lines (lines trending SW/NE) gridded at a 30m resolution. Lower figure shows the results of masking the surface based on slope to remove regions with rugged topography.

A reference surface gridded at 30 m was prepared from the main survey lines (lines trending SW/NE) by utilizing only beams in the angular sector from +45° to -45° (see Fig. 6, top). A slope filter was then applied to the data to exclude areas having slopes greater than 5° from the cross line statistical analyses (see Fig. 6, bottom).

Cross lines were run in the orthogonal direction (SE/NW) from the surface collection lines with a vessel speed between 6 knots and 9 knots over ground, depending upon current. The desirable vessel speed of 6 knots was intentionally reduced to increase data density within the corridor for reference surface comparison. However, due to the extreme crabbing of the vessel in the currents in the area, speed increases were required for some lines.

EM302 RUNTIME PARAMETERS	Cross Line Settings 1	Cross Line Settings 2	Cross Line Settings 3	Cross Line Settings 4
Sector Coverage				
Max. Angle (port)	70°	70°	70°	70°
Max. Angle (sbtd)	70°	70°	70°	70°
Max. Coverage (port)	5000 m	5000 m	5000 m	5000 m
Max. Coverage (stbd)	5000 m	5000 m	5000 m	5000 m
Ang. Coverage Mode	AUTO	AUTO	AUTO	AUTO
Beam Spacing	HD EQDST	HD EQDST	HD EQDST	HD EQDST
Depth Settings				
Force Depth	n/a	n/a	n/a	n/a
Min. Depth (m)	10	10	10	10
Max. Depth (m)	4000 m	4000 m	4000 m	4000 m
Dual Swath Mode	DYNAMIC	DYNAMIC	OFF	OFF
Ping Mode	DEEP	DEEP	DEEP	DEEP
FM Disable	Checked (CW)	Unchecked (FM)	Unchecked (FM)	Checked (CW)
Transmit Control				
Pitch Stabilization	ENABLED	ENABLED	ENABLED	ENABLED
Along Direction	0°	0°	0°	0°
Heading	0°	0°	0°	0°
Yaw Stab. Mode	REL. MEAN HDG.	REL. MEAN HDG.	REL. MEAN HDG.	REL. MEAN HDG.
Heading	0°	0°	0°	0°
Heading Filter	MEDIUM	MEDIUM	MEDIUM	MEDIUM

NOTE: Unchecked FM Disable means that FM is on.

Table 3. SIS Runtime Parameters settings for each cross line survey run over the reference surface.

Table 3 shows the Runtime Parameters settings for each of the cross lines. All tests were run in the DEEP ping mode, as the mean water depth in this area of 1250 meters was too deep for the MEDIUM mode (which is best utilized in 250 – 750 m water depth) and too shallow for the VERY DEEP mode (which is best utilized in 3300 – 5000 m water depth). The initial plan had been to run each test setting twice, up and down the line. This plan was changed mid-collection of the cross lines because processing of the shipboard noise data revealed a problem with the pump that supplies seawater to the surface sound speed sensor. Pump noise was decreased by throttling the flow of seawater through the pump. Unfortunately, this change was made late in the acquisition of the cross line data (almost all lines had been run), leaving time for only a single pass with each of the cross line settings 1 and 2 with the “fixed” pump.

Soundings from each of the cross line tests were compared on a beam-by-beam basis against the reference surface. This was done by sampling the reference surface grid depth at the coincident point reported by each beam. A table of beam depth, beam angle, and reference surface depth was compiled using this cross line sampling method.

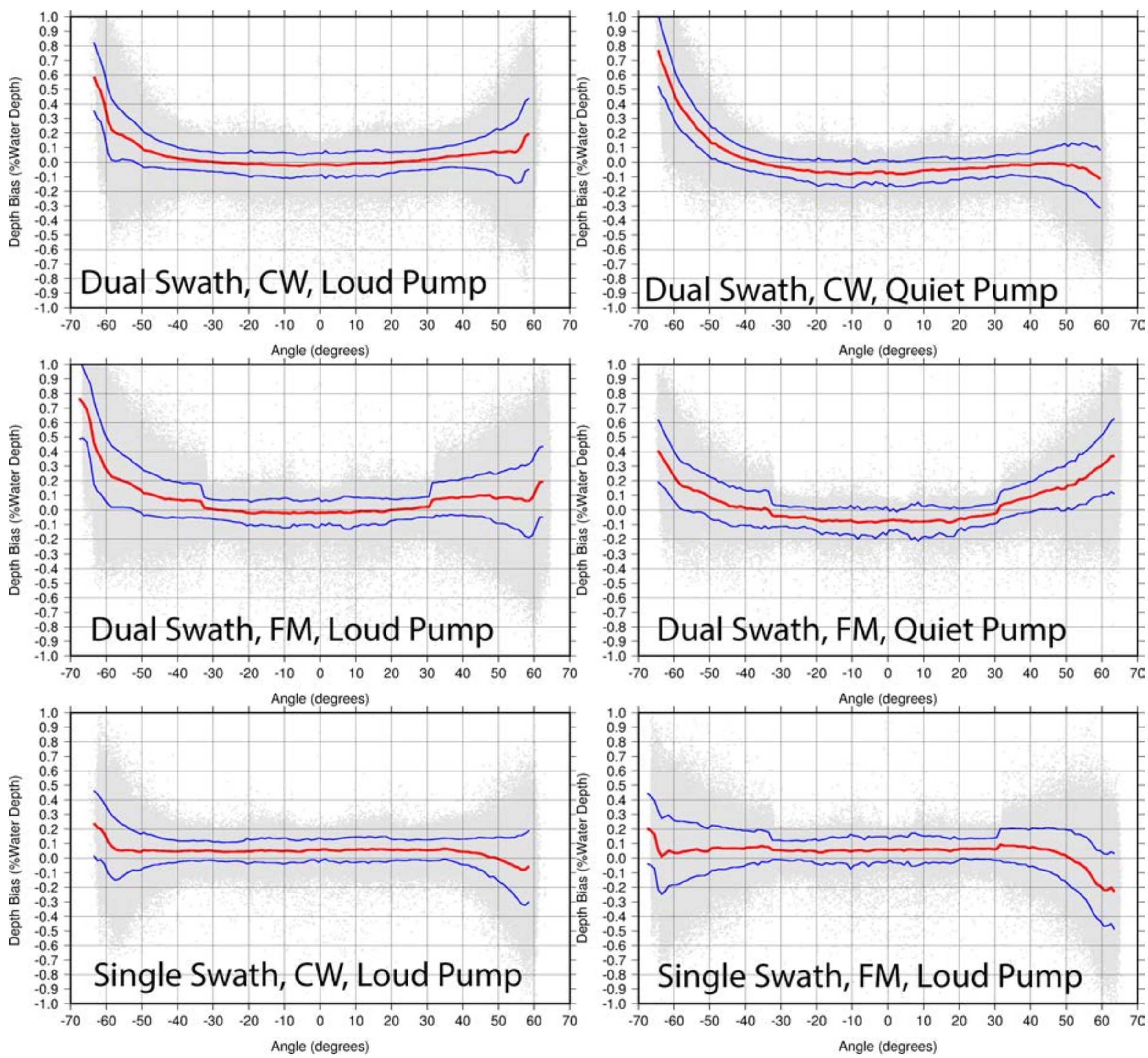

Figure 7. Sounding biases for cross lines with different Runtime Parameters and pump conditions.

Results from the cross line analyses were then tallied in 1° bins with the mean bias and standard deviation about the mean calculated for each bin. A scatter plot (grey points) of the beam wise biases are plotted against incidence angle along with the mean (solid red line) and standard deviation (solid blue line) from each 1° bin in Fig. 7. Fig. 8 shows only the standard deviation about the mean bias against beam angle.

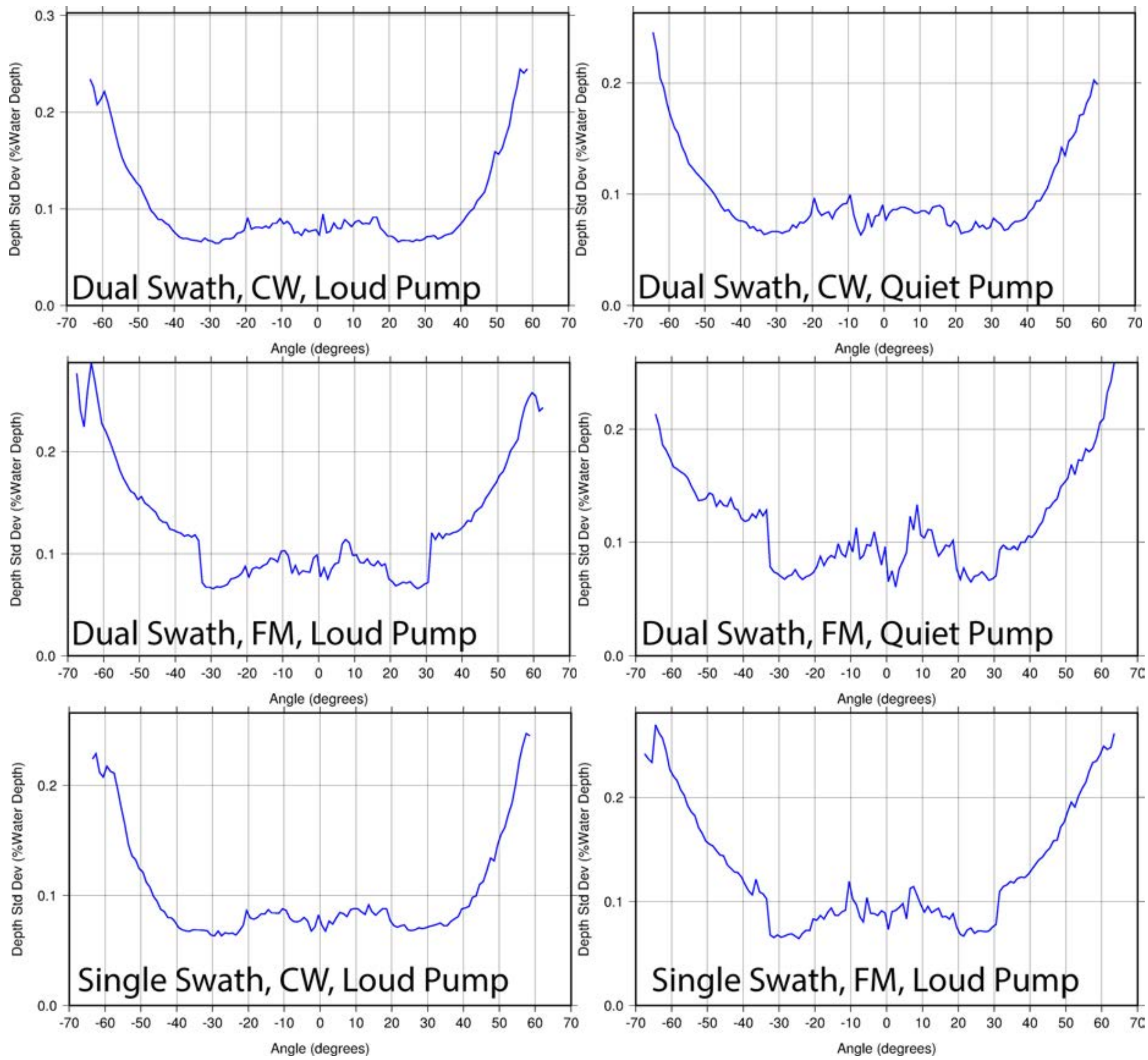

Figure 8. Soundings standard deviations by beam angle for cross lines with different Runtime Parameters.

Examining Fig. 7 and Fig. 8, it can be seen that the system provides fairly unbiased soundings over the majority of the swath. A small non-linear refraction-like bias is apparent in the outermost sectors for almost all test cases. This type of artifact is likely the result of improper sound speed profiles being applied during data collection. An examination of the SVP 'weather map' for this region indicated high variability of the water mass during NA040. The refraction-like biases could be minimized with more frequent collection of XBT profiles or the selection of an alternative area with a more stable water mass for data collection.

Despite the refraction artifact across the swath, the observed mean biases and standard deviations are within the expected performance tolerances of the system as a whole. A majority of the swath shows beam-wise depth biases of less than 0.1% of water depth. The standard deviations about the mean bias are typically within +/-0.15% to +/-0.25% water depth (1-σ) across the majority of the swath with higher uncertainties at the limits of the swath, as expected.

It is interesting to note that the difference between the "Loud Pump" test modes and the "Quiet Pump" test modes show that the pump noise made little difference for the central portions of the swath and only a small difference in the outer portions of the swath. Also, as expected, the CW modes perform more consistently across the entire swath than the FM modes.

Achieved Coverage

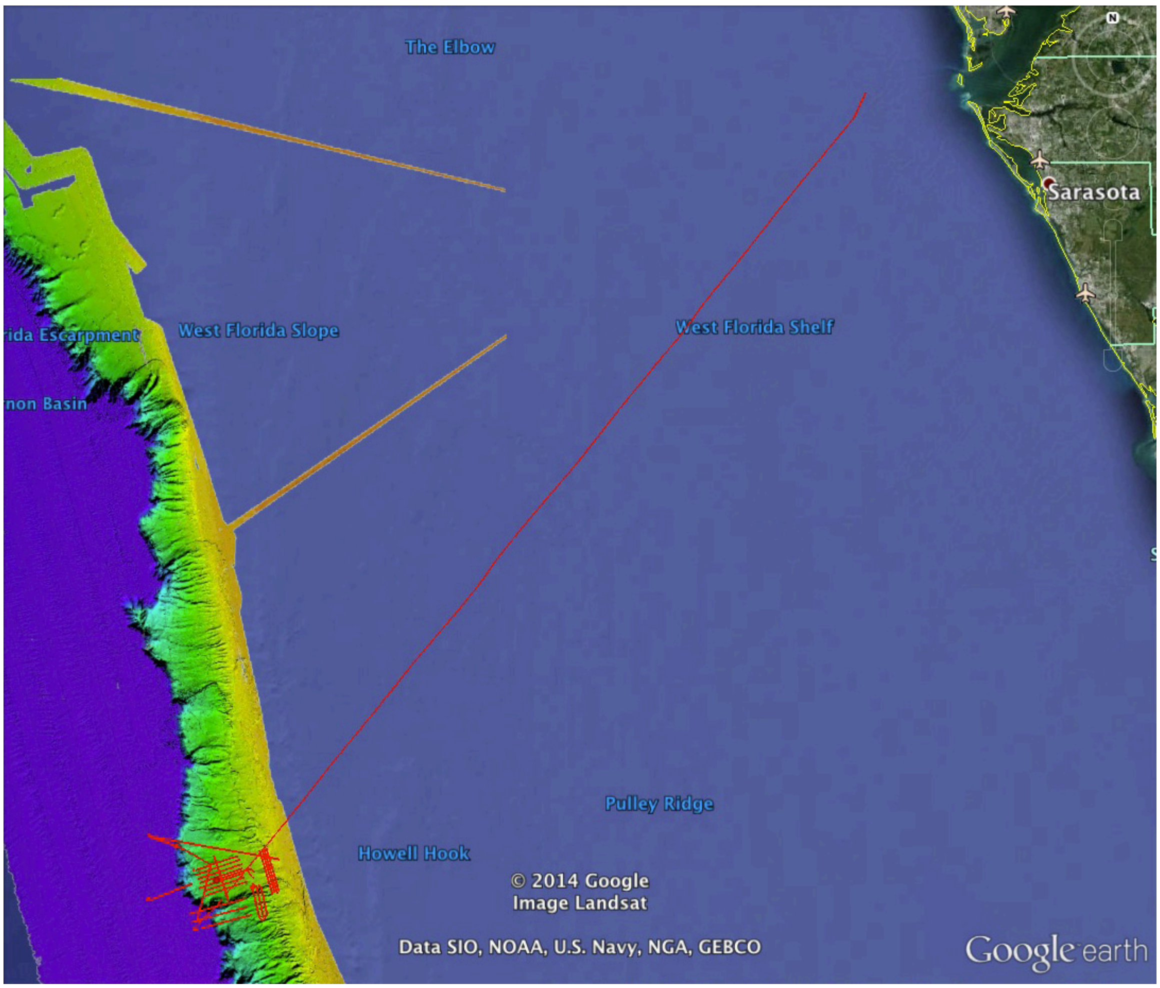

Figure 9. Red lines show ship navigation extracted from the EM302 data included in the swath coverage calculation.

Coverage plots (Figs. 10, 11) were prepared using the outermost port and starboard soundings from all data acquired during the patch test, reference surface collection, extinction tests, training exercises, and during the transit back to St. Petersburg (Fig. 9). Ideally, all data included in the swath coverage analysis should have been collected in automatic angular coverage mode, automatic depth mode, and FM in order to calculate the swath width as a function of depth using settings selected by the EM302 for maximum coverage. However, as other test activities were being undertaken during the cruise, the data utilized to produce the coverage plots were collected with many different Runtime Parameters set, including limitations to the angular coverage (during patch testing only), changes to the depth mode, and both CW and FM modes.

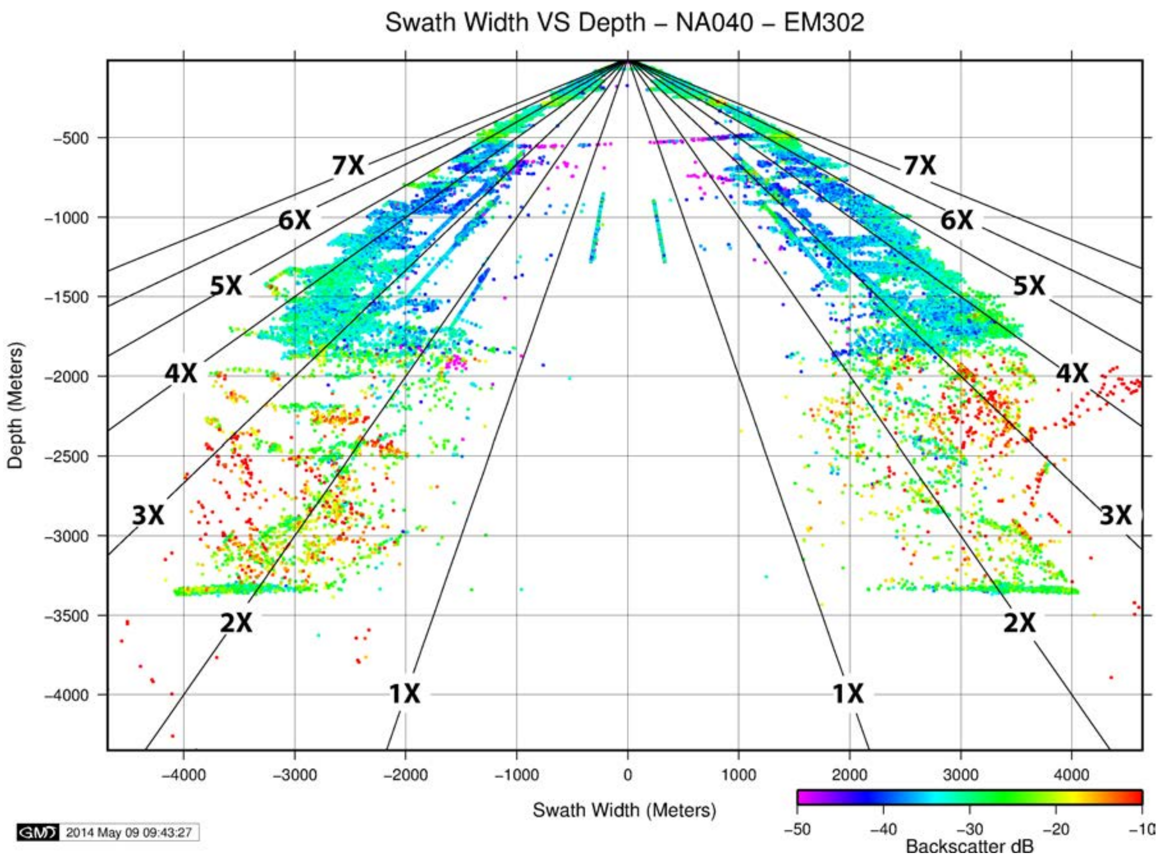

Figure 10. EM302 coverage evaluation plot showing swath width versus depth. Colors of the plotted beams are based on the backscatter strengths of the beam.

Discounting the effects of changes in acquisition modes, the system tracked the seafloor routinely out to 4 to 5 times water depth to depths of ~1500 m. At depths greater than ~1500-1800 m, the system tracked very well to about 2.5 times water depth at the maximum observed depth of ~3,300 meters. Soundings deeper than ~3,300 m in this plot are outliers and do not represent the observed maximum depth during testing. The coverage achieved up to ~3,300 m depth is comparable to other EM302 installations and indicates that the system is performing well.

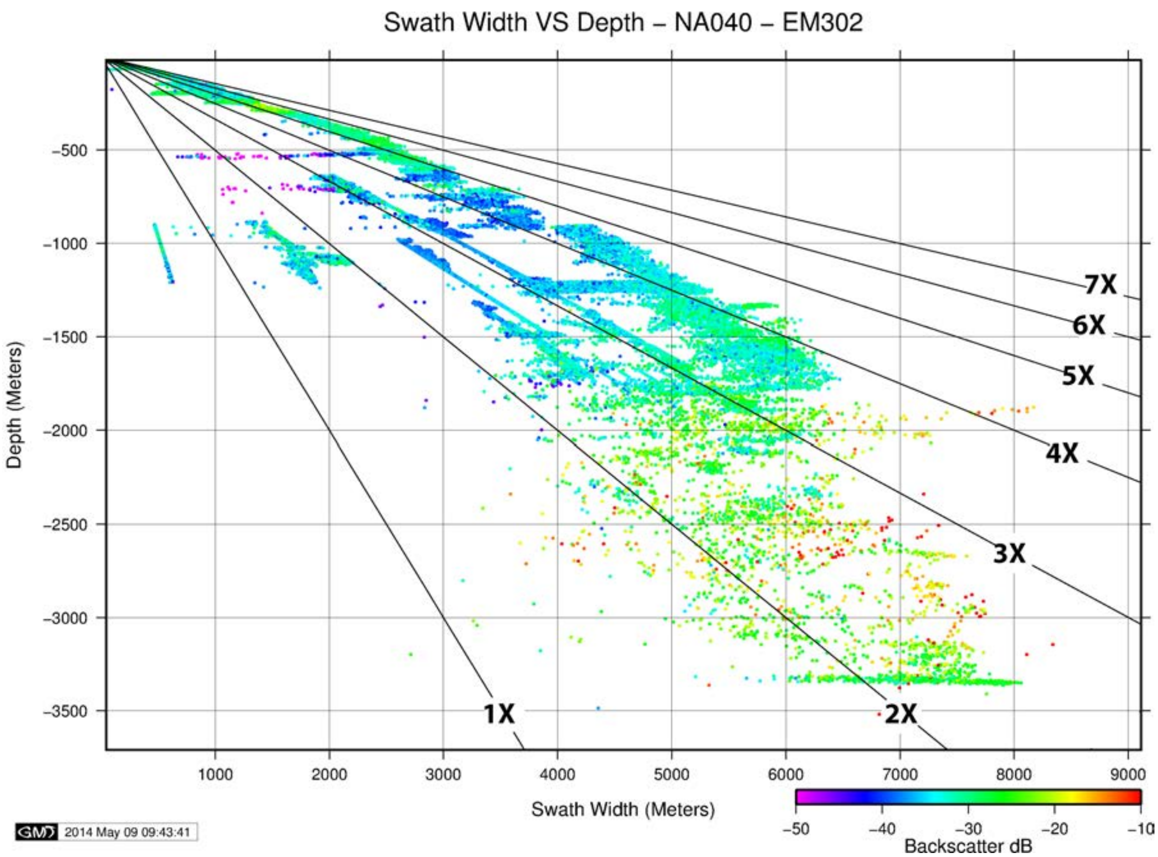

Figure 11. EM302 coverage evaluation plot showing swath width vs. depth. This figure is similar to figure 9, except it wraps all values from the port and starboard sides into a single curve.

Noise Level Assessment

As mentioned above, the pump for the surface sound speed sensor was determined by Tim Gates and Marisa Yearta to be a significant source of noise during NA040 data collection. The pump was discovered to be operating at a much higher flow rate than expected and was turned down to ~14 GPM, a flow rate used successfully during previous mapping missions.

Because this adjustment noticeably reduced the pump noise, it was decided to re-run reference surface cross lines for a qualitative assessment of the effects of the pre- and post-adjustment pump noise on water column data. Due to time constraints, only two cross line re-runs were completed. Cross Line Settings 1 and 2 (Table 3) were used to examine the effect of pump noise in both CW and FM modes, both in Dual Swath.

Figure 12 includes water column imagery collected during each cross line appropriate for pump noise comparison. In each case, the imagery presented below is from the first swath collected north of latitude 25° 41’ 30’’ N, the parallel bisecting the NNW-SSE cross line track at approximately its midpoint. The bottom detections are included to highlight any significant effects of pump noise on seafloor tracking.

Qualitatively, these images suggest a very slight reduction in noise associated with pump adjustment. This reduction is most apparent in the outermost sectors for CW mode, though the pre-adjustment noise did not appear to significantly affect bottom detections across the swath in either mode. Likewise, the pre-adjustment pump noise would likely not have significantly obscured water column features such as plumes of gas bubbles or the deep scattering layer. Nonetheless, any reduction in shipboard noise is a welcome improvement to the EM302 operating environment.

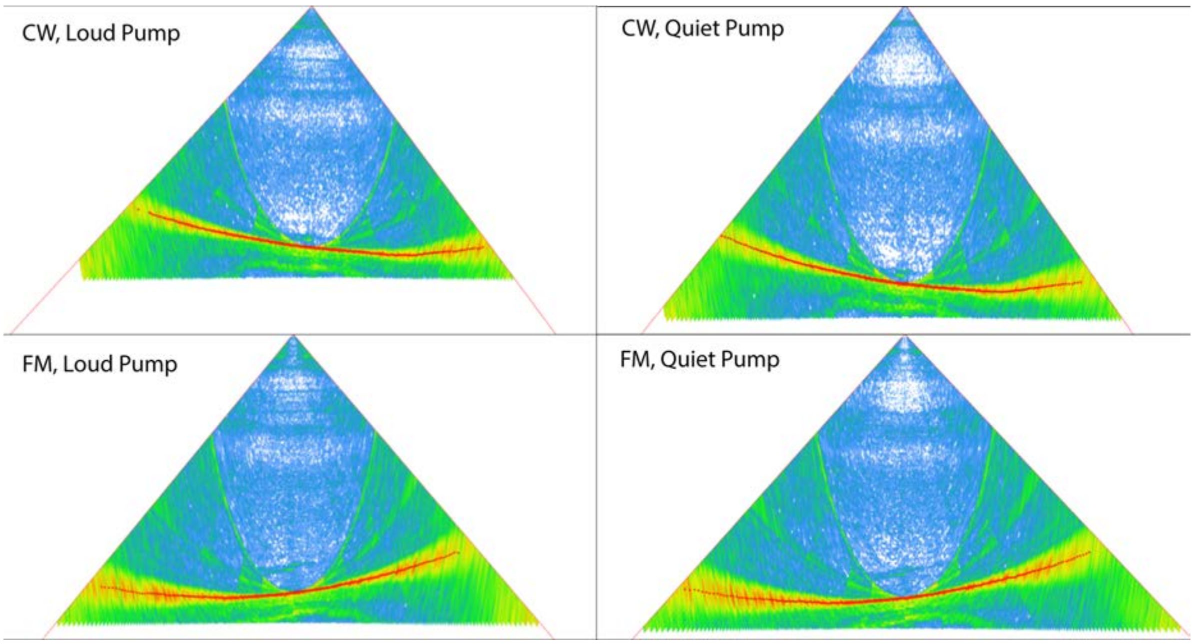

Figure 12. Water column plots showing effects of the loud pump in CW and FM modes. Color scale is amplitude from -80 (blue) to +40 dB (red). Red squares are bottom detections.

Transducer and System Health

A full Built-In Self Test (BIST) diagnostic routine was run while underway. Among other tests, the BIST provides the ability to perform impedance measurements of the RX and TX arrays. These tests are useful in establishing the health of the transducers, as these components of the mapping system have been known to degrade with time. It is important to note that the BIST impedance measurements do not provide a full characterization of transducer properties as a function of frequency, however, they are believed to be good indicators of overall transducer health over their lifetime, especially when conducted on a routine basis.

The EM302 receiver impedances and receiver transducer impedances, as measured through the BIST routines available in SIS, were compared to measurements made during the system acceptance tests in 2013 and to routine BISTs collected during the 2013 field season and were found to be within the nominal acceptable range expected by the manufacturer (Fig. 12 and Fig. 13). This is a very good sign as the impedance levels have basically not changed for the receive arrays from the initial delivery of the system.

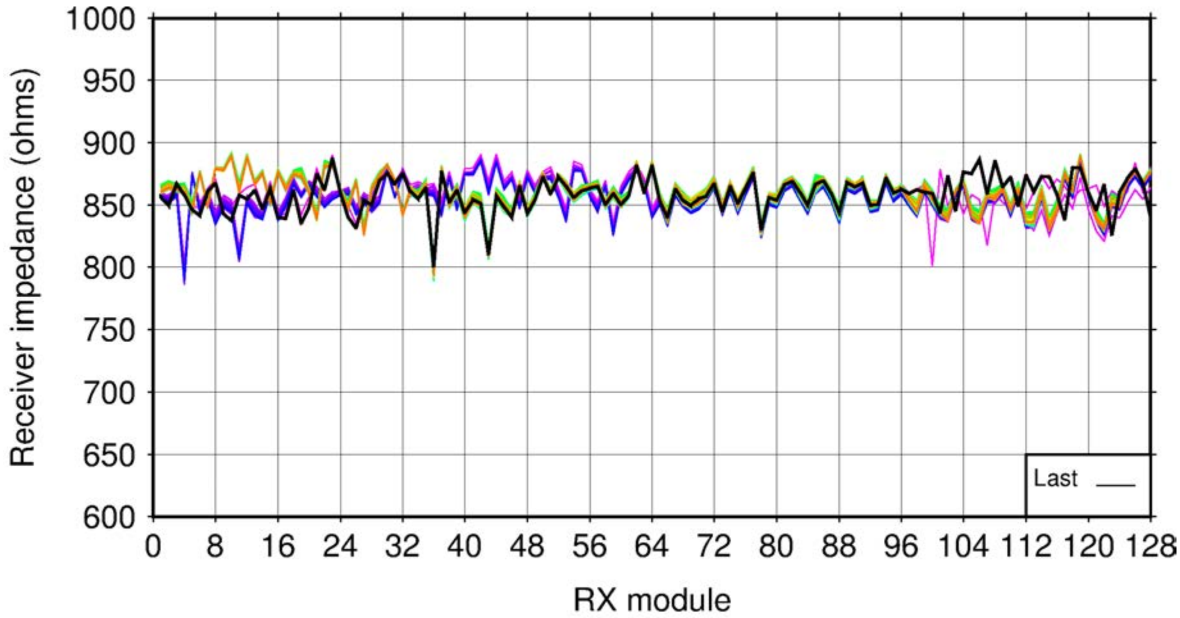

Figure 13. EM302 receiver impedance measurements. Historic measurements are colored and measurements from this evaluation in black.

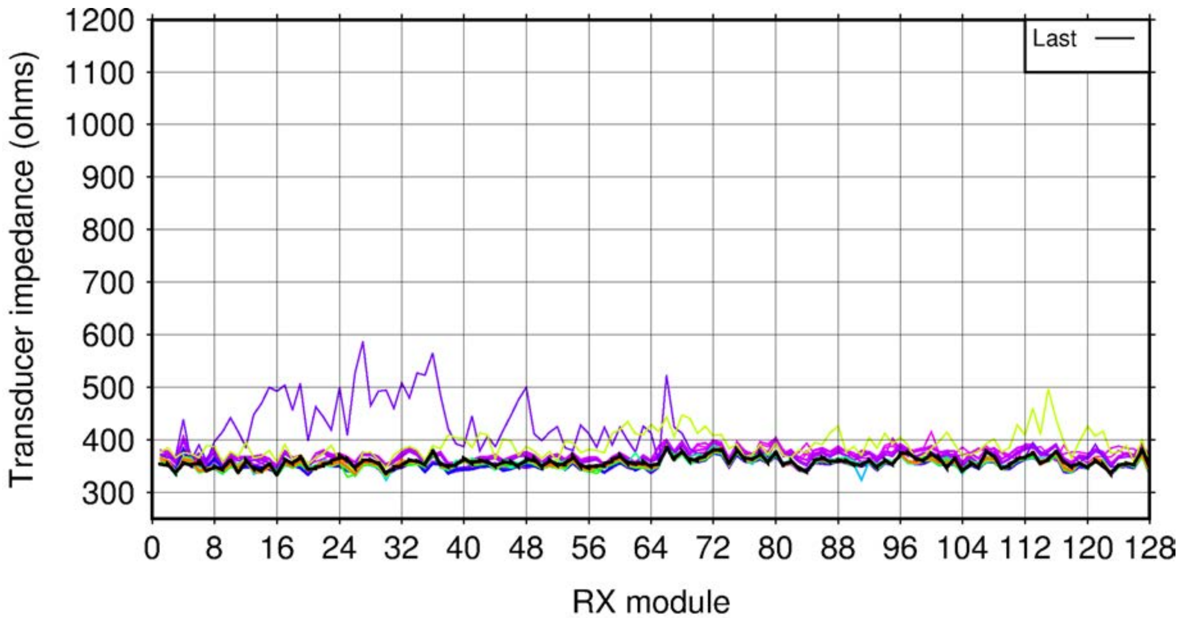

Figure 14. EM302 receiver transducer impedance measurements. Historic measurements are colored and measurements from this evaluation are in black.

Summary and Recommendations

- As it stands now, the EM302 and associated sensors are working well as compared to other EM302s evaluated recently. The patch test revealed very slight residual angular offsets, indicating a successful reinstallation of the MRU and no apparent change to any other component of the system.

- Refraction did play a role in limiting the ability to best quantify the accuracy of the system through the reference surface cross lines. When the survey site was selected, SVP 'weather maps' indicated a relatively stable water mass. Unfortunately, by the time of the test, the water mass had become relatively complex. During normal mapping missions (or future system testing) in regions of high water column variability, it will be necessary to collect XBT casts more frequently in order to collect higher quality bathymetric data with reduced refraction artifacts. This will be especially true for line spacing greater than 1 water depth (+/- 45° angular swath width).

- Sensor positions and SIS Installation Parameters should not be changed. A PU Parameters file containing all SIS Installation Parameters and Runtime Parameters was written to disk on the primary acquisition machine at the end of NA040. If any problems or questions arise with any parameters, this file can be reloaded to restore a functional configuration for SIS. Johnson and Jerram have a copy of this file and can provide it if required.

- Routine BIST collection should be continued as it provides a great resource for examining changes of the system through its lifetime.

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