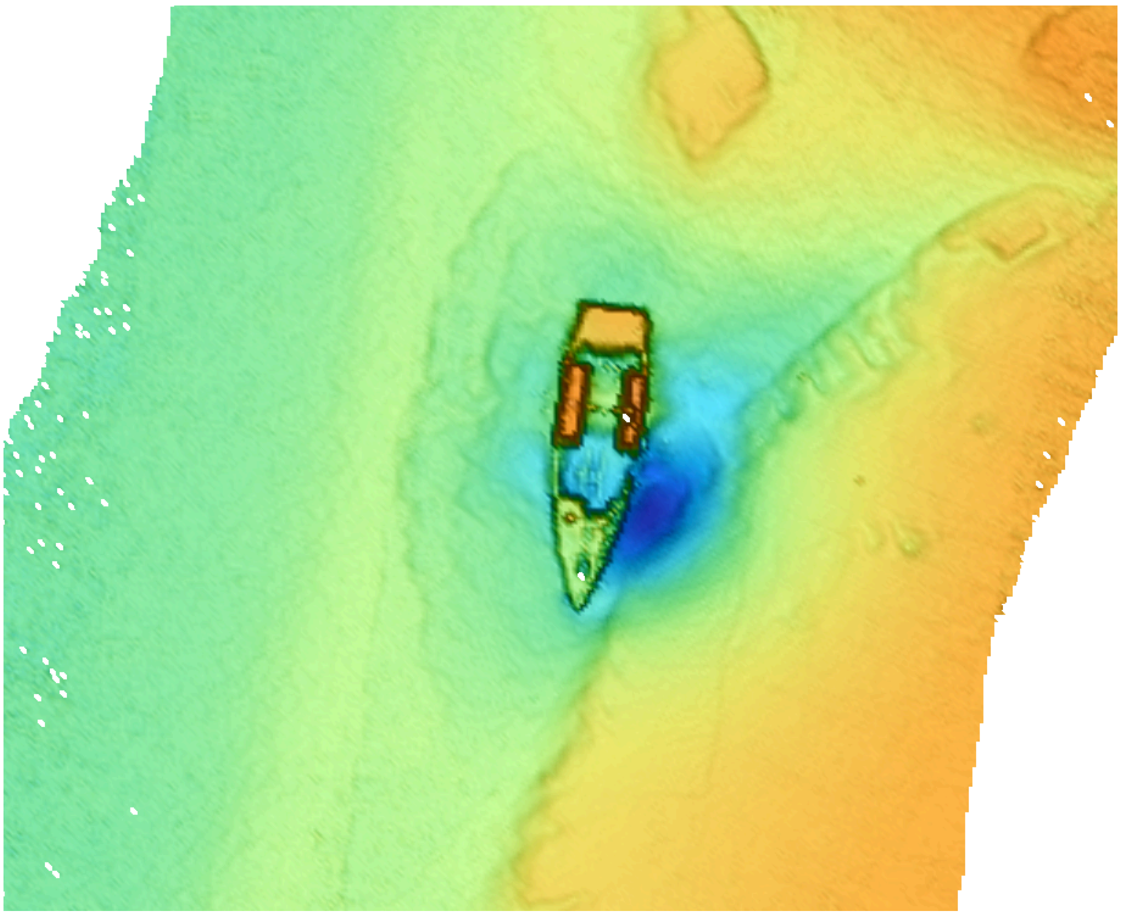
R/V *Bat Galim*
EM302 & EM2040
Multibeam Echosounder System Review
January 31 – February 4, 2016



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Cover image: EM2040 bathymetry of a wreck discovered during the shipboard acceptance testing.

Introduction

From January 31st to February 4th, 2016 a Shipboard Acceptance Testing (SAT) was conducted on the R/V *Bat Galim*, owned and operated by Israel Oceanographic and Limnological Research, on the newly installed Kongsberg Maritime (KM) EM302 (30 kHz) and EM2040 (200 kHz, 300 kHz, and 400 kHz) multibeam echosounders. These systems were thoroughly reviewed for system geometry, calibration, configuration, and performance during this acceptance period.

Documented in this report are:

1. Review of the system geometry for the multibeam echosounder systems
2. Examination of the EM302's RX and TX transducer "health"
3. Determination of any residual angular offsets between the multibeam echosounders and the primary MRU through a patch test
4. Evaluation of the depth accuracy across the swath using a reference surface
5. Calculation of the achieved swath coverage over a wide range of depths

Survey System Components

The mapping system consists of the following primary components:

1. KM EM302 MBES (30 kHz, 2° TX by 2° RX)
2. KM EM2040 MBES (200 kHz, 300 kHz, 400 kHz, 0.7° TX by 0.7° RX)
3. KM Seafloor Information System (SIS)
4. KM Seapath 330 vessel navigation system
5. Seapath 330 GNSS antennas
6. Seatex MRU-5
7. Valeport miniSVS

Overview of System Geometry

In this report, we use the term 'system geometry' to mean the reference frame of the vessel and the linear and angular offsets of the primary components of the multibeam mapping systems, including the TX arrays, RX arrays, and motion sensors. These parameters are critical for data collection in an unbiased and repeatable manner.

Geometry Review

The 2015 Parker Maritime AS vessel survey report established the primary reference frame used by the multibeam echosounders and ancillary sensors. This is a right-handed coordinate system with its origin at the center top of the primary motion sensor (Seapath MRU-5), with the X axis positive toward the bow, Y axis positive toward starboard, and Z axis positive downward. Angles are provided according to the Kongsberg Maritime sign convention, with pitch positive with bow up (right-hand rule about the +Y axis), roll positive with port side up (right-hand rule about the +X axis), and yaw positive with bow movement toward starboard (compass convention). Review of the survey reports and the EM302, EM2040, and Seapath 330 configurations revealed no discrepancies in the transformation of linear offsets from the Parker survey report to each systems respective installation parameters. Tables 3-5 in the Calibration Results section of this report provides summaries of the linear and angular offsets pre-for the EM302, EM2040, and Seapath 330 configurations.

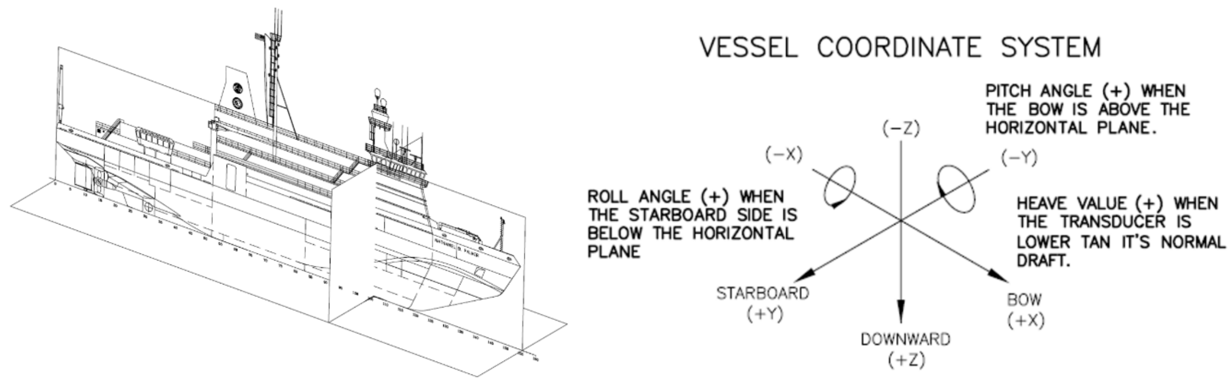

Figure 1 Illustration of the vessel coordinate system used by the Kongberg EM302, EM2040, and SeaPath 330 systems. The image adapted from the RVIB Nathaniel B Palmer's ship survey drawing 881-121282.

Geometric Calibration

After a review and confirmation of all system and sensor geometry linear offsets, a patch test was conducted on the EM302 and EM2040 multibeam systems to determine any remaining residual angular offsets.

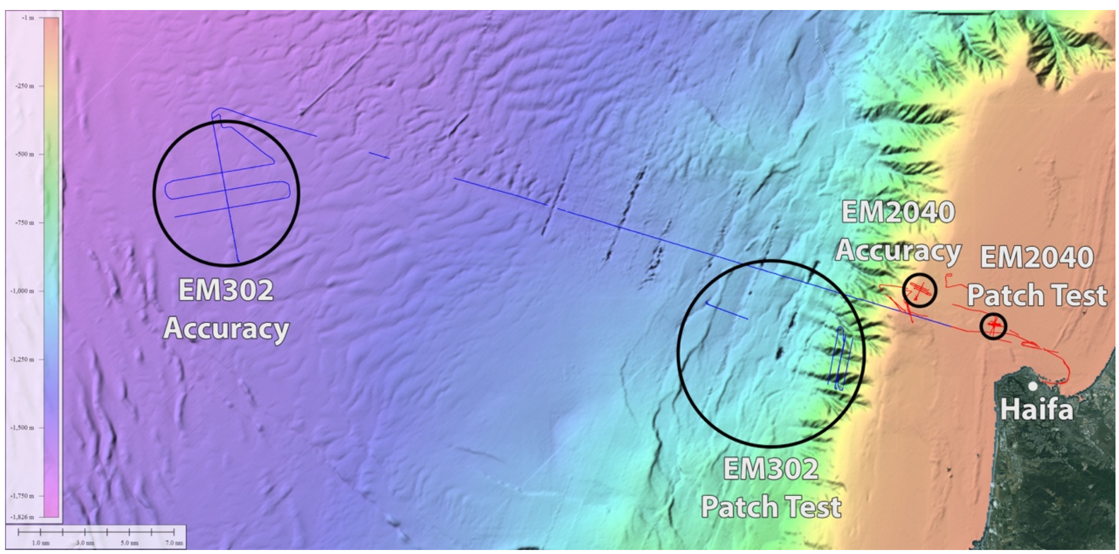

Figure 2. Calibration and accuracy testing sites northwest of Haifa, Israel. These sites were selected based on availability of suitable seafloor features in the operational depth ranges of the EM302 and EM2040 multibeam echosounders. Swath coverage (acoustic extinction) data were collected up and down the slope in addition to over these test sites. Blue trackline shows navigation from EM302 data. Red trackline shows navigation from EM2040 data.

Site Selection

Figure 2 shows overview line plan for the calibration and reference areas northwest of Haifa, Israel. Figure 3 and Figure 4 show the actual features used for the roll, pitch and yaw calibration. The EM302 calibration site had depth ranges between approximately 400-1100m, on the shallower end of what is normally used for a 30 kHz system, but was selected due to the lack of suitable seafloor geometry in the surrounding deeper water. Residual angular offsets were determined in the order of roll first, pitch second, and yaw third. 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 following offset calibration. The procedure was then repeated after initial calibration to verify the angular offset results in SIS and make final adjustments as necessary.

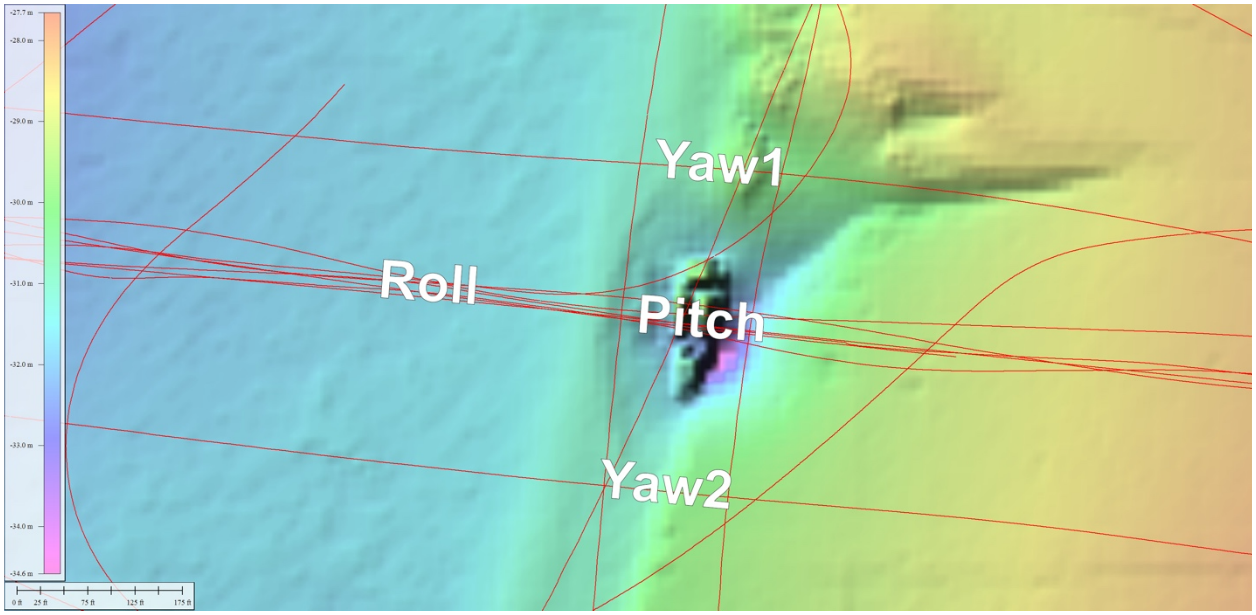

Figure 3. EM2040 patch test site. Red lines are ship tracks of acquired data.

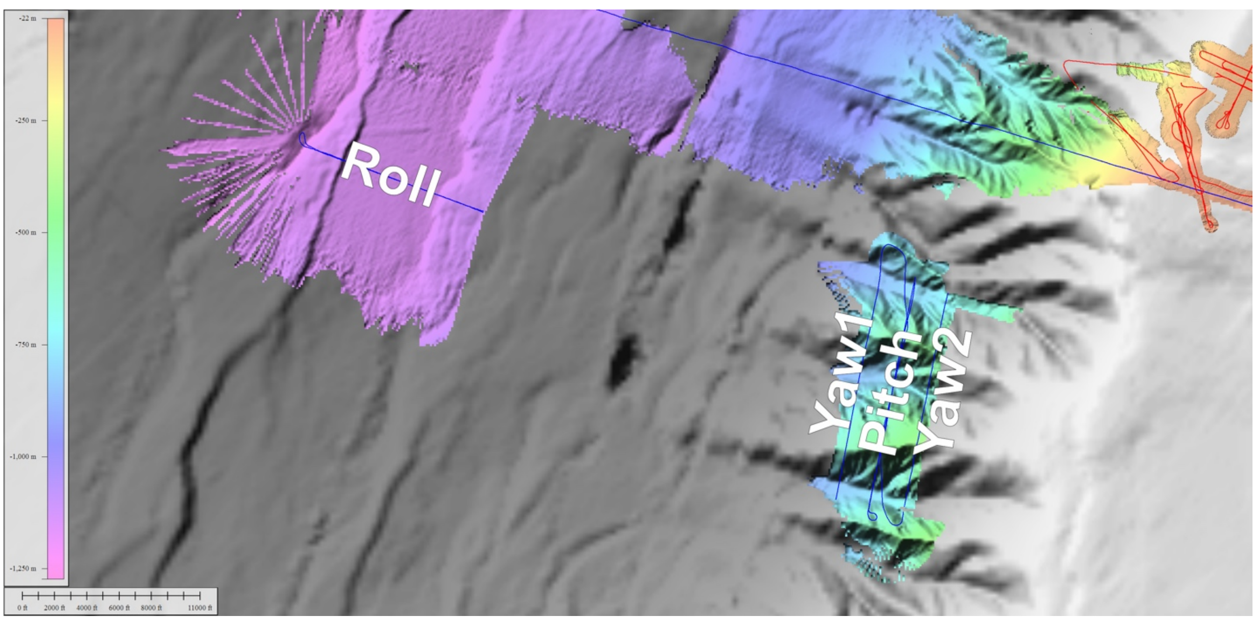

Figure 4 EM302 patch test site. Blue lines are ship tracks of acquired data.

SVP profiles were acquired, processed in SVP Editor, and applied in SIS prior to the first roll line and thereafter as deemed necessary. All SVPs throughout the SAT were processed using SVP Manager to remove spurious sound velocities, apply salinity data from the World Ocean Atlas, and prepare the profile for SIS. To achieve high ping rate and sounding density, the ship was operated at 6 kts for all calibration lines.

The EM302 was configured as shown in Table 1 for all calibration data collection:

Table 1. EM302 runtime parameters for the SAT Patch Test

SONAR RUN TIME PARAMETERS						
Sector Coverage	**Roll pass 1**	**Roll pass 2**	**Pitch pass 1**	**Pitch pass 2**	**Heading 1 (East)**	**Heading 2**
Max angle (port)	70	70	25	25	15	60
Max angle (sbtd)	70	70	25	25	60	15
Max Coverage (port)	5000	5000	5000	5000	5000	5000
Max Coverage (stbd)	5000	5000	5000	5000	5000	5000
Angular Coverage Mode	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO
Beam Spacing	HD EQDST	HD EQDST	HD EQDST	HD EQDST	HD EQDST	HD EQDST
Depth Settings	**Roll pass 1**	**Roll pass 2**	**Pitch pass 1**	**Pitch pass 2**	**Heading 1 (East)**	**Heading 2**
Force Depth	n/a	n/a	n/a	n/a		n/a
Min depth (m)	500	500	300	300		
Max depth (m)	1500	1500	1000	1000		
Dual swath mode	DYNAMINC	DYNAMINC	DYNAMIC	DYNAMINC	DYNAMINC	DYNAMINC
Ping mode	DEEP	DEEP	AUTO	AUTO	AUTO	AUTO
FM disable	Unchecked	Unchecked	Unchecked	Unchecked	Unchecked	Unchecked
Transmit Control	**Roll pass 1**	**Roll pass 2**	**Pitch pass 1**	**Pitch pass 2**	**Heading 1 (East)**	**Heading 2**
Pitch stabilization	ENABLED	ENABLED	ENABLED	ENABLED	ENABLED	ENABLED
Along direction	0	0	0	0	0	0
Auto Tilt	OFF	OFF	OFF	OFF	OFF	OFF
Yaw stab. Mode	OFF	REL. MEAN HDG	REL. MEAN HDG	REL. MEAN HDG	REL. MEAN HDG	REL. MEAN HDG
heading	n/a	n/a	n/a	n/a	n/a	n/a
heading filter	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM
Min Swath Dist	0	0	0	0	0	0
Enable Scanning	Off	Off	Off	Off	Off	Off

The EM2040 was configured as shown in Table 2 for all calibration data collection:

Table 2. EM2040 runtime parameters for the SAT Patch Test

SONAR RUN TIME PARAMETERS						
Sector Coverage	**Roll Pass 1**	**Roll Pass2**	**Pitch1**	**Pitch2**	**Heading 1**	**Heading 2**
Max angle (port)	70	70	70	70	70	70
Max angle (sbtd)	70	70	70	70	70	70
Max Coverage (port)	500	500	500	500	500	500
Max Coverage (stbd)	500	500	500	500	500	500
Angular Coverage Mode	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO
Sectore Mode	Normal	Normal	Normal	Normal	Normal	Normal
Beam Spacing	HD EQDST	HD EQDST	HD EQDST	HD EQDST	HD EQDST	HD EQDST
Depth Settings	**Roll Pass 1**	**Roll Pass2**	**Pitch1**	**Pitch2**	**Heading 1**	**Heading 2**
Force Depth	n/a	n/a	n/a	n/a	n/a	n/a
Min depth (m)	1	1	1	1	1	1
Max depth (m)	200	200	200	200	200	200
Ping Mode	300 kHz	300 kHz	300 kHz	300 kHz	300 kHz	300 kHz
Pulse Type	Auto	Auto	Auto	Auto	Auto	Auto
Detector Mode	Normal	Normal	Normal	Normal	Normal	Normal
FM disable	Unchecked	Unchecked	Unchecked	Unchecked	Unchecked	Unchecked
Transmit Control	**Roll Pass 1**	**Roll Pass2**	**Pitch1**	**Pitch2**	**Heading 1**	**Heading 2**
Pitch stabilization	ENABLED	ENABLED	ENABLED	ENABLED	ENABLED	ENABLED
Along direction	0	0	0	0	0	0
Auto Tilt	OFF	OFF	OFF	OFF	OFF	OFF
Yaw stab. Mode	OFF	OFF	OFF	OFF	OFF	OFF
Max Ping Freq (hz)	50	50	50	50	50	50
Min Swath Dist	0	0	0	0	0	0
Enable Scanning	Off	Off	Off	Off	Off	Off

Calibration tools in Qimera and SIS were used separately to evaluate each set of calibration lines for both echosounders while at sea, and then verified with Caris during post-cruise analysis. Results from independent examinations of each set of calibration lines by the Kongsberg Field Engineers and Johnson and typically fell within 0.05° of each other and frequently agreed to within 0.02°; final values were agreed upon after additional scrutiny before modification were made in SIS.

All calibration results for each motion sensor were verified by repeating the roll, pitch, and yaw calibration procedure after application of the initial results in SIS.

Calibration Results and Current Configuration

Tables 3-5 summarize the post-SAT configurations for the multibeam echosounders and motion sensor. These results are based on careful review of the survey documentation and calibration datasets and are to be used until sensors are modified or another calibration becomes necessary. To demonstrate the calibration results, Figures 5-10 depicts transects of the roll, pitch, and yaw verification data sets in the CARIS HIPS Subset Editor calibration tool with the final adjustments for each offset applied (note that the value applied in the calibration tool is only the final adjustment, not the offset recorded in the corresponding table of offsets).

Table 3. EM302 sensor offsets after system geometry review and calibration.

EM302 Origin at Seapath MRU-5	X	Y	Z	Roll	Pitch	Yaw
	BOW +	STBD +	DOWN +	PORT UP +	BOW UP +	COMPASS +
EM302 TX	3.526	0.517	4.831	-0.17	1.20	359.81
EM302 RX	2.397	0.143	4.853	0.23	1.32	359.87
Pos, COM1 (Seapath 330)	0.000	0.000	0.000	-	-	-
Pos, COM3	0.000	0.000	0.000	-	-	-
Attitude 1, COM2/UDP5 (Seapath 330)	0.000	0.000	0.000	-0.09	0.00	0.00
Attitude 2, COM3/UDP6	0.000	0.000	0.000	0.00	0.00	0.00
Waterline	-	-	0	-	-	-

Table 4. EM2040 sensor offsets after system geometry review and calibration.

EM2040 Origin at Seapath MRU-5	X	Y	Z	Roll	Pitch	Yaw
	BOW +	STBD +	DOWN +	PORT UP +	BOW UP +	COMPASS +
EM2040 TX (Port Orientation)	3.007	-0.129	4.857	0.34	1.16	359.84
EM2040 RX (Aft Orientation)	3.310	-0.234	4.836	0.40	1.03	359.83
Pos, COM1 (Seapath 330)	0.000	0.000	0.000	-	-	-
Pos, COM3	0.000	0.000	0.000	-	-	-
Attitude 1, COM2/UDP5 (Seapath 330)	0.000	0.000	0.000	-0.07	0.30	-0.10
Attitude 2, COM3/UDP6	0.000	0.000	0.000	0.00	0.00	0.00
Waterline	-	-	0.00	-	-	-
Depth Sensor	0.00	0.00	0.00			

Table 5. Seapath 330 sensor offsets after system geometry review.

Seapath 330	X	Y	Z	Roll	Pitch	Yaw
	BOW +	STBD +	DOWN +	PORT UP +	BOW UP +	COMPASS +
Seapath Forward Antenna	-0.175	0.182	-19.581	-	-	-
Seapath Aft Antenna	-2.676	0.150	-19.651	-	-	-
MRU-5 Plate	0.000	0.000	0.000	1.600	-0.690	-0.46

EM302 with Seapath 330

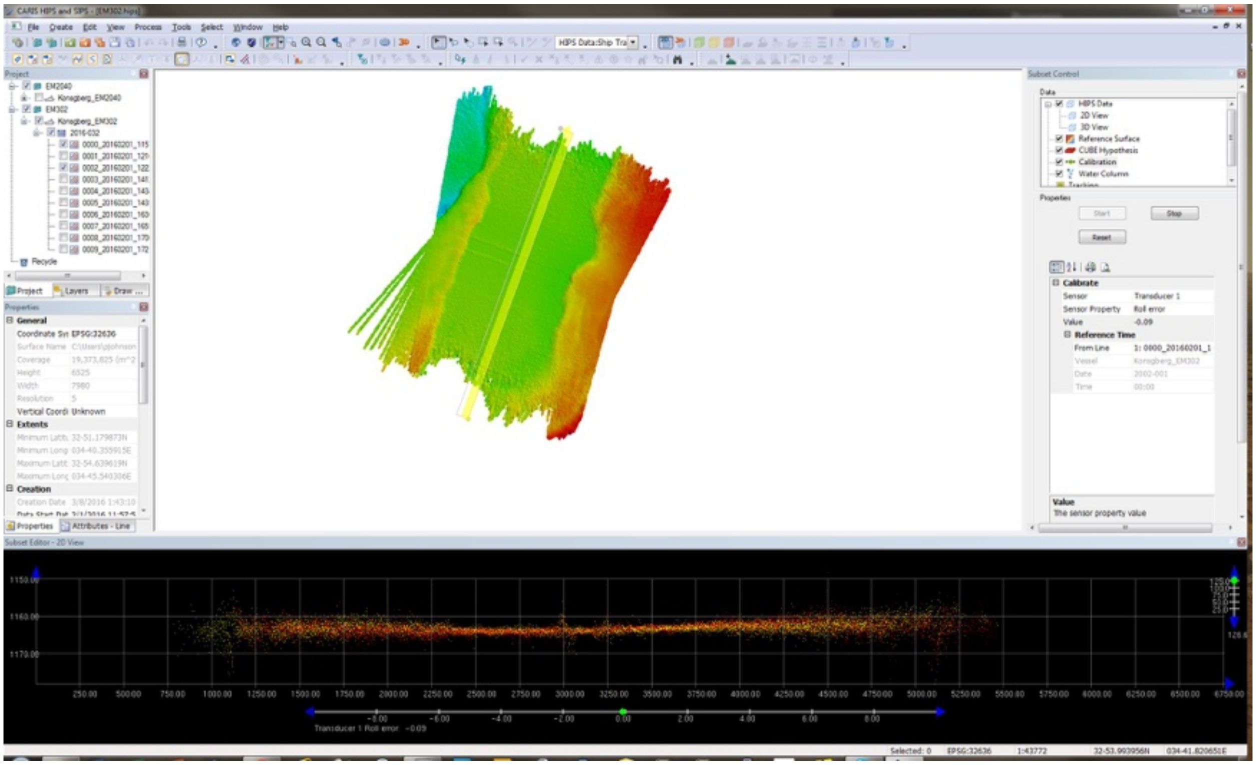

Figure 5. EM302 / Seapath roll verification in CARIS, with a final offset of -0.09°.

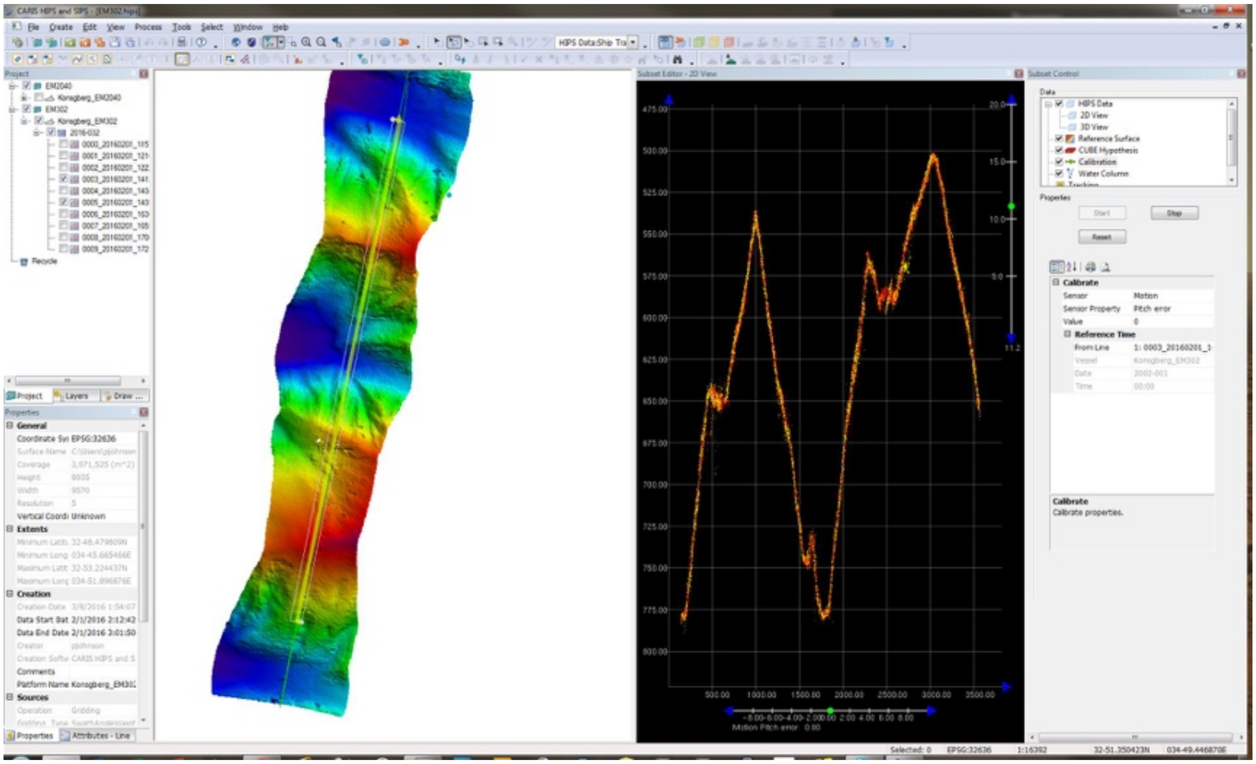

Figure 6. EM302 / Seapath pitch verification in Caris showing no apparent pitch bias.

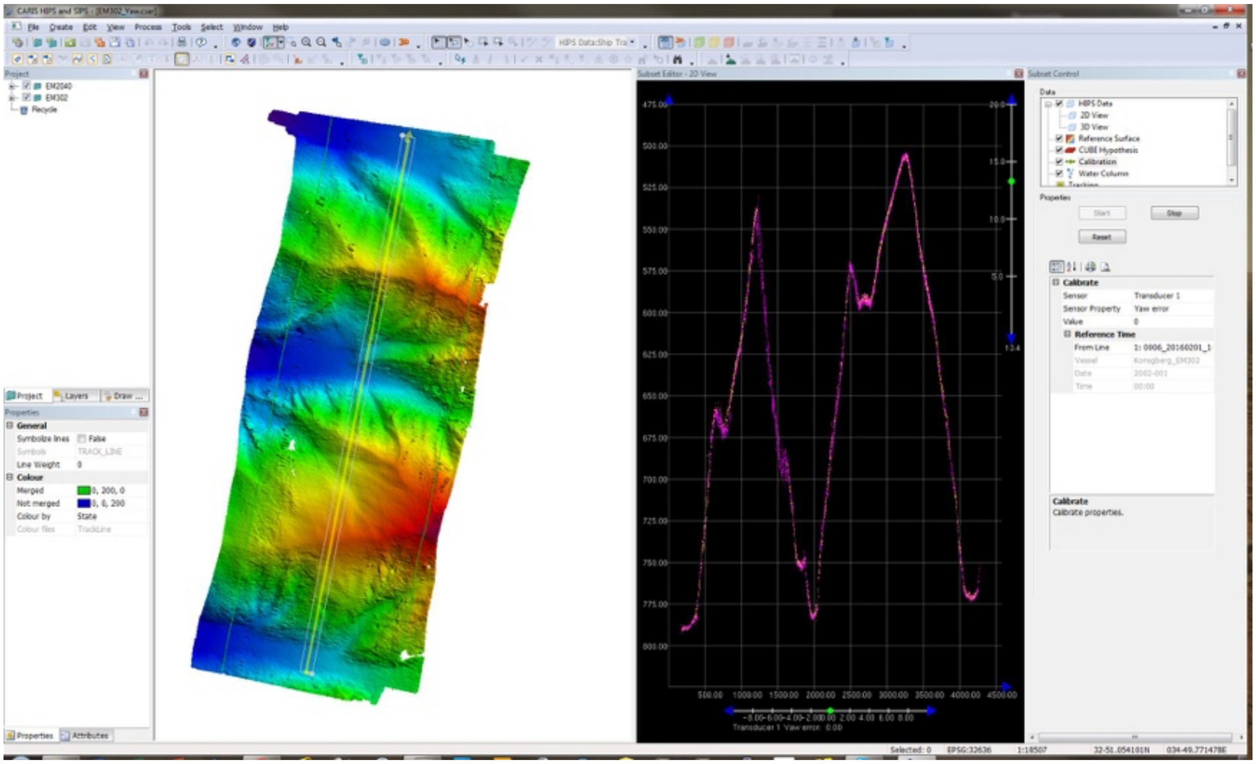

Figure 7. EM302 / Seapath yaw verification in CARIS showing no apparent yaw bias.

EM2040 with Seapath 330

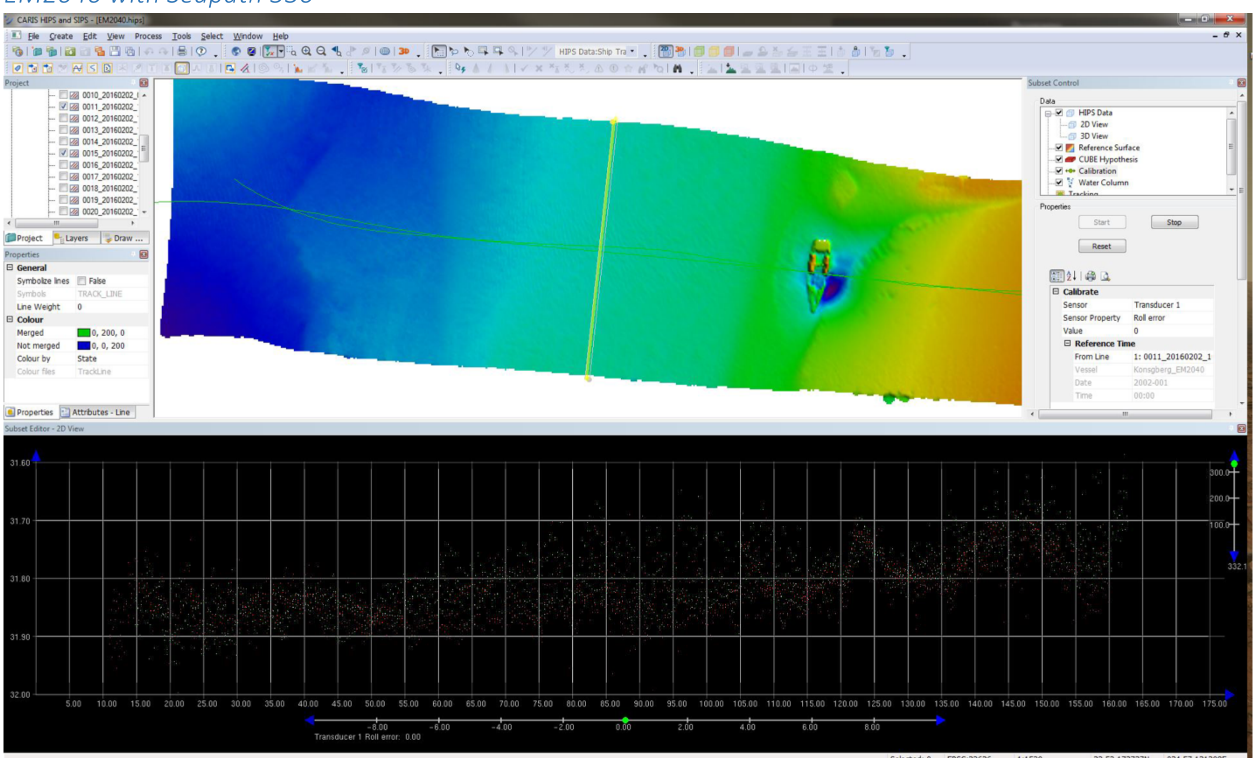

Figure 8. EM2040 / Seapath roll verification in CARIS, applying an adjustment of -0.07° for the final offset.

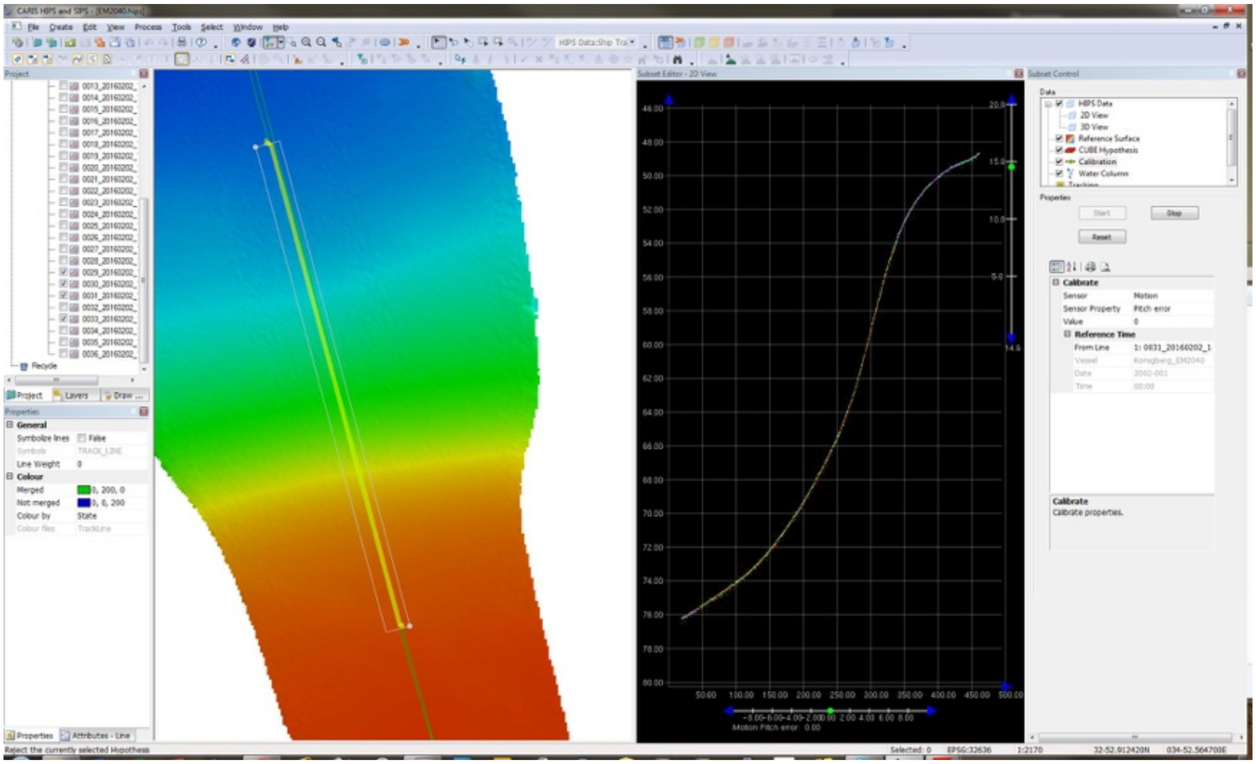

Figure 9. EM2040 / Seapath pitch verification in CARIS, applying an adjustment of +0.30° for the final offset.

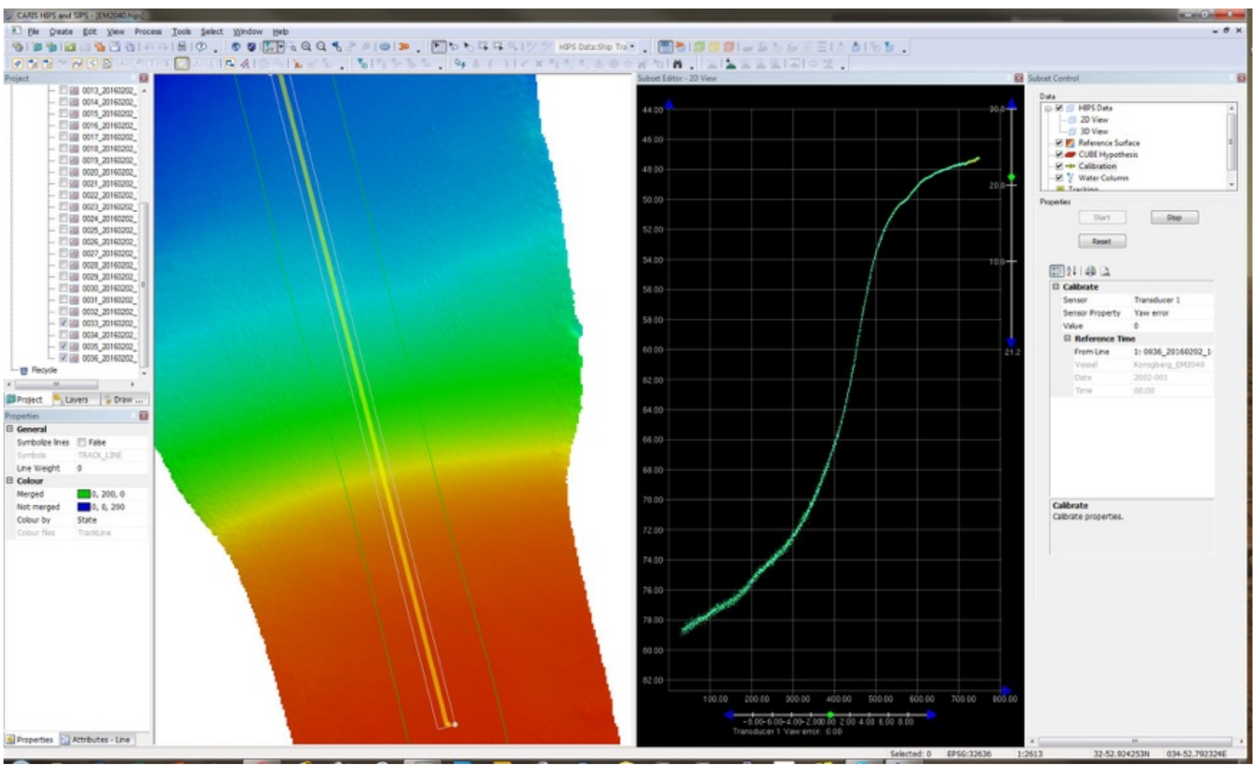

Figure 10. EM2040 / Seapath yaw verification in CARIS, applying an adjustment of -0.10° for the final offset.

Transducer and System Health

A full Built-In Self-Test (BIST) diagnostic routine was run through the SIS acquisition software prior to departure, while in Haifa Harbor, with both systems passing all tests. Additionally, a TX Channels impedance BIST was run through a telnet session on April 3, 2016 by Tomer Ketter, IOR. The BIST provides the ability to perform impedance measurements of the RX and TX array. However, it should be noted, that only the EM302 has the ability to record the RX array impedance values to a file for analysis, as the EM2040 only reports pass/fail through a telnet session. 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 with just normal use. It is important to note that the BIST impedance measurements do not provide a full characterization of transducer properties as a function of frequency as performed by Ifremer in 2012 (Le Gall and Pacault, 2012). However, the BISTs provide useful indicators of overall transducer health over their lifetime, especially when conducted on a routine basis.

The BIST output for the RX module lists two sets of impedance measurements for the EM302, the first set being referred to as the receiver impedance and the second set being the transducer impedance. From this point forward, we will refer to the first as the receiver channel impedance and the second as the transducer impedance.

EM302 impedances, for both receiver channels, Figure 11, and receiver transducers, Figure 12, are consistent when compared to other well functioning EM302 which have been previously evaluated. Conducting regular RX channel BISTs through the SIS interface and comparing the results to this should be done with some regularity in order to verify that the arrays have not undergone any form of change.

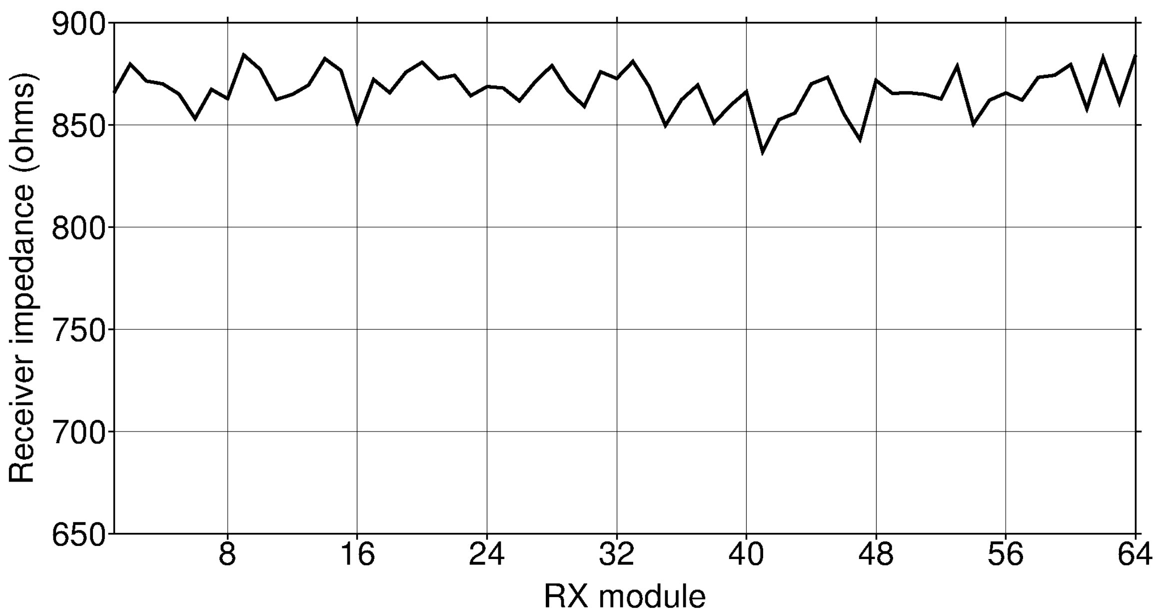

Figure 11 EM302 receiver impedance measurements taken during the EM302 SAT.

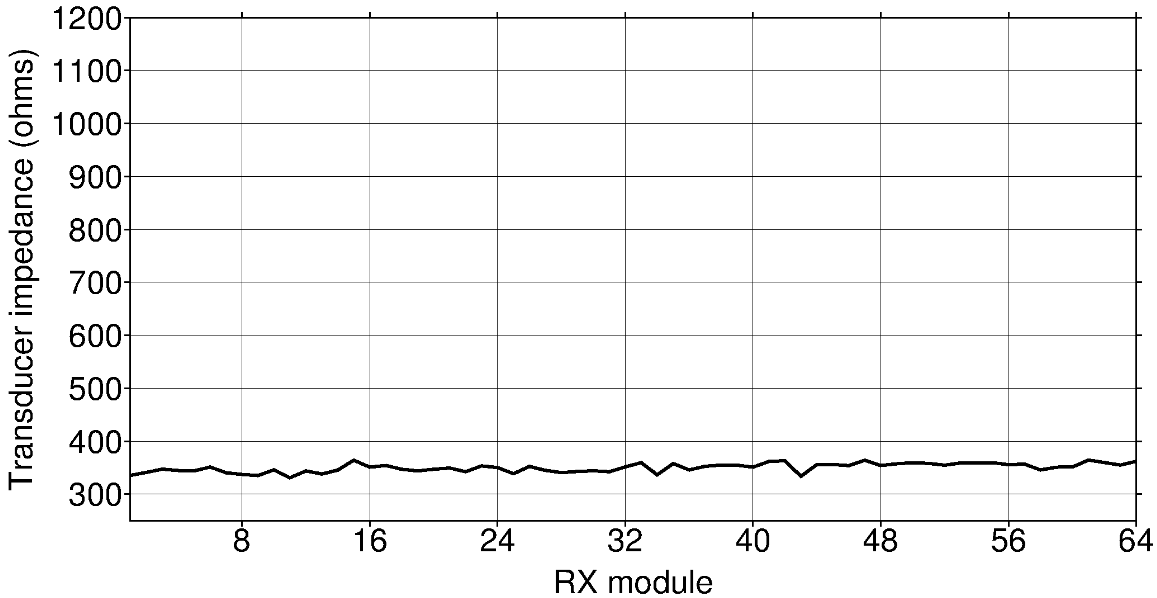

Figure 12 EM302 transducer impedance measurements taken during the EM302 SAT.

The transmitter channel impedance tests (not to be confused with receiver transducer impedances tests discussed above) passed for both systems, however as mentioned above, module level granularity of impedance values are not available through the BIST routines when run in SIS and must instead be acquired through a telnet session. The data from this test shown in Figure 13 and Figure 14 show consistent acoustic impedance across all channels and slots, indicating a well functioning array.

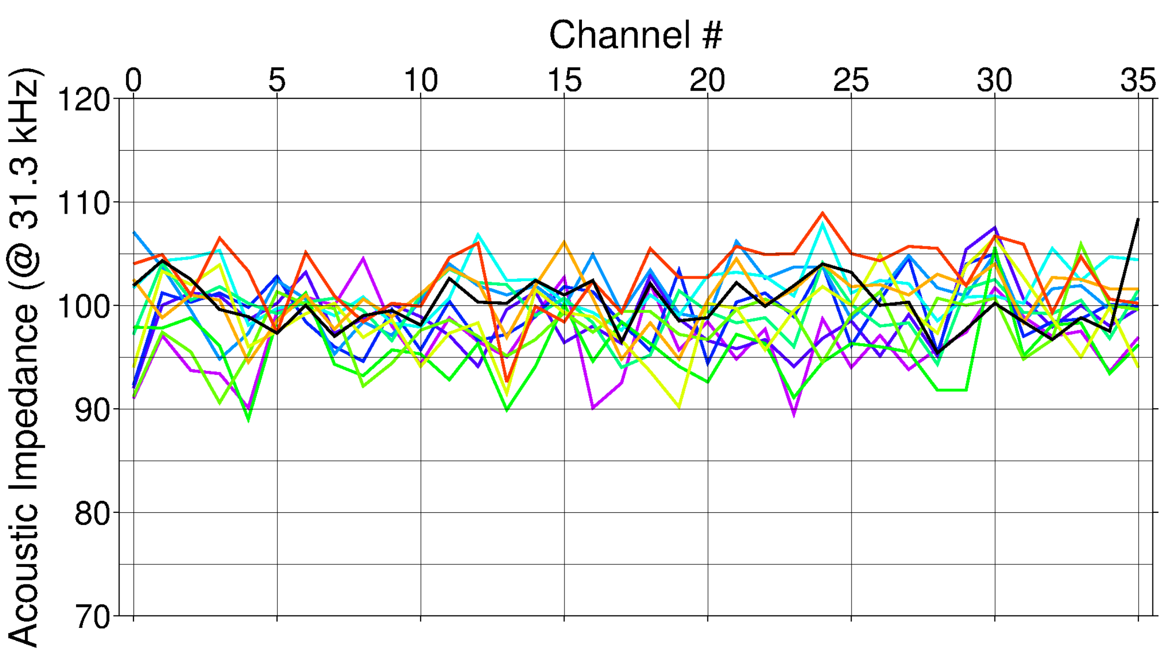

Figure 13. R/V Bat Galim EM302 Transmitter Acoustic Impedances collected through a telnet session. Each colored line represents a different TX slot (12 total).

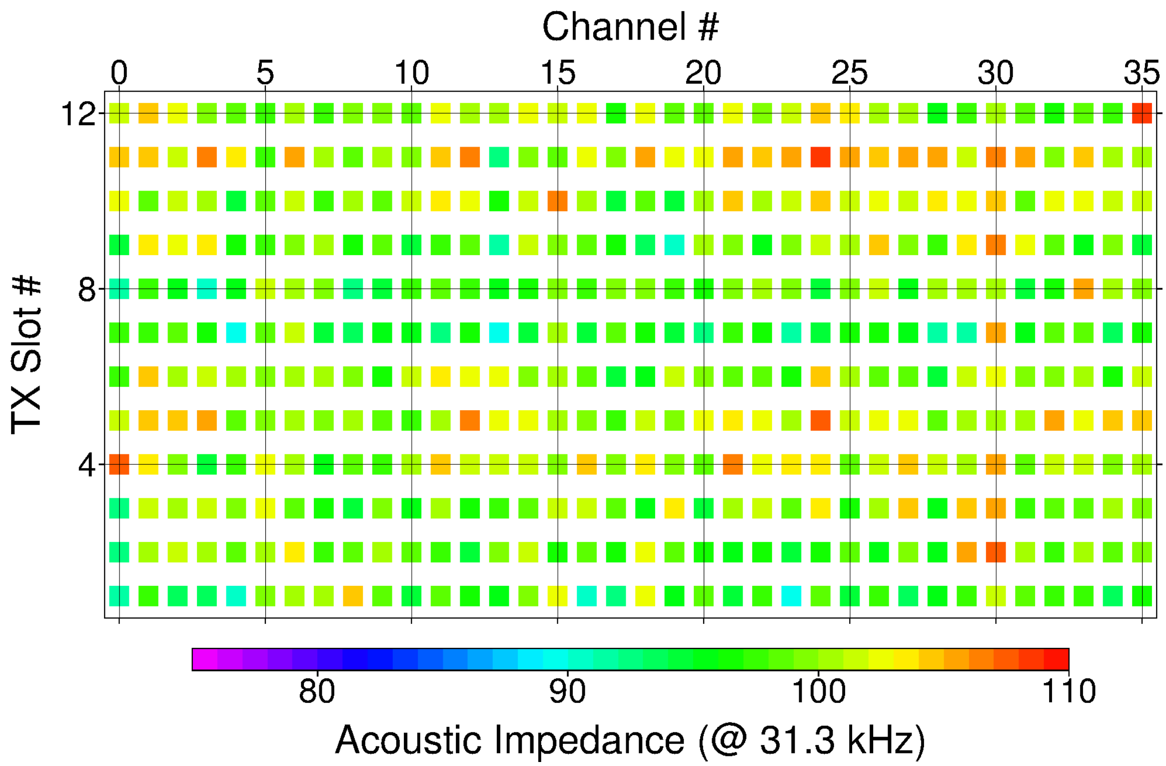

Figure 14. R/V Bat Galim EM302 Transmitter Acoustic Impedances collected through a telnet session. Acoustic impedance value (colored squares) are plotted with relationship to channel number (0 to 35) and TX slot (1 to 12).

Accuracy Testing

Overview

Accuracy testing was conducted for both echosounders, using a shallow site (Figure 15) for the EM2040 and deep water site (Figure 16) for the EM302. For both sites, reference surfaces were constructed using data collected during the SAT; each surface consists of 3 survey lines with a 1 water depth (WD) spacing. Vessel speed was limited to 6 kts during the collection of the EM2040 reference surface and 7 knots during acquisition of the EM302 surface. Sound speed profiles were collected and applied from a SVP cast acquired immediately before reference surface data was collected.

All soundings in the reference surfaces and accuracy cross lines were corrected for tide using data from a sensor at Qishon port and applied through Qimera. Furthermore, bathymetric slopes were computed for the reference surfaces and used as a mask to exclude areas of significant topography (>5°) from the crossline analysis. Finally references surfaces were masked to only include areas where multiple sounding contributed to the gridded node. All cross lines were run orthogonally to the reference surface main lines to reduce the effects of any biases compounding or cancelling across the swath. Fortunately, noise due to ship heading relative to the prevailing seas was not a major factor on either the reference surface lines or cross lines headings. To reduce refraction artifacts, an SVP profile was collected, processed with SVP Manager, and loaded into SIS for each echosounder prior to cross line data collection for each settings configuration.

Outliers (such as bottom detections at constant range across the swath due to interference) were removed from the accuracy analysis, as these would clearly be edited during normal bathymetric processing. In all cases, the mean depth bias and depth bias standard deviations as a percentage of water depth were computed in 1° angular bins across the swath for each configuration. EM302 and EM2040 configurations and accuracy results are presented in the following sections.

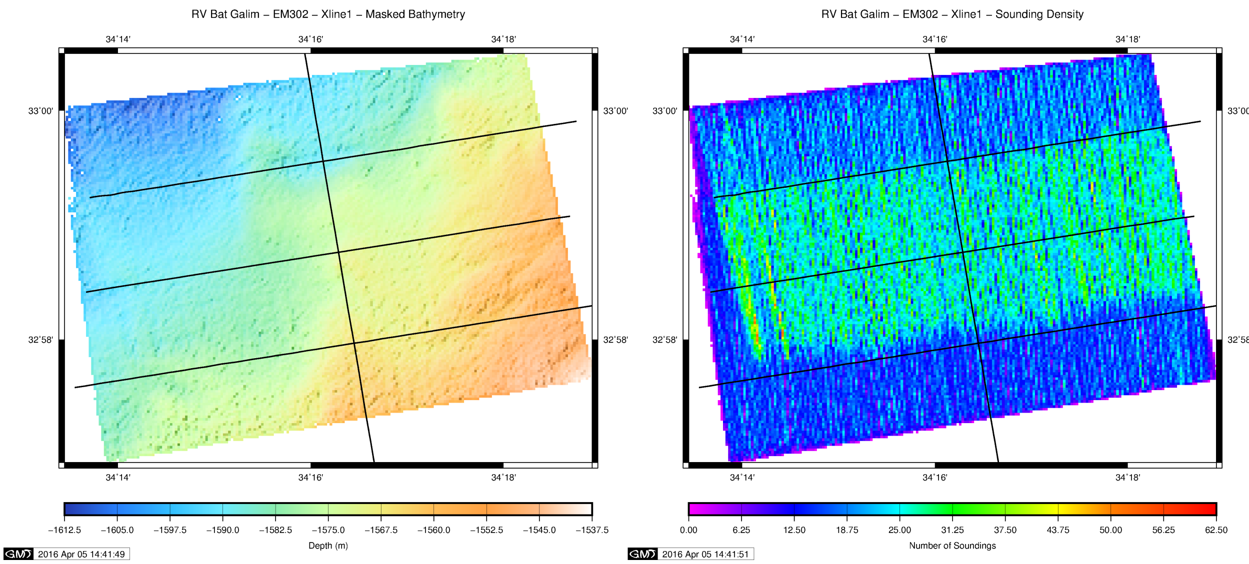

Figure 15. The deep water reference site used for assessing the accuracy of the EM302 multibeam echosounder. The colored bathymetry shown on the left is gridded at 40m and masked to remove any slopes greater than 5°. The sounding density plot on the right shows the number of soundings per cell for the reference surface. Black lines show navigation for acquisition lines (WSW to ENE direction) and for the cross line (NWN to SES direction).

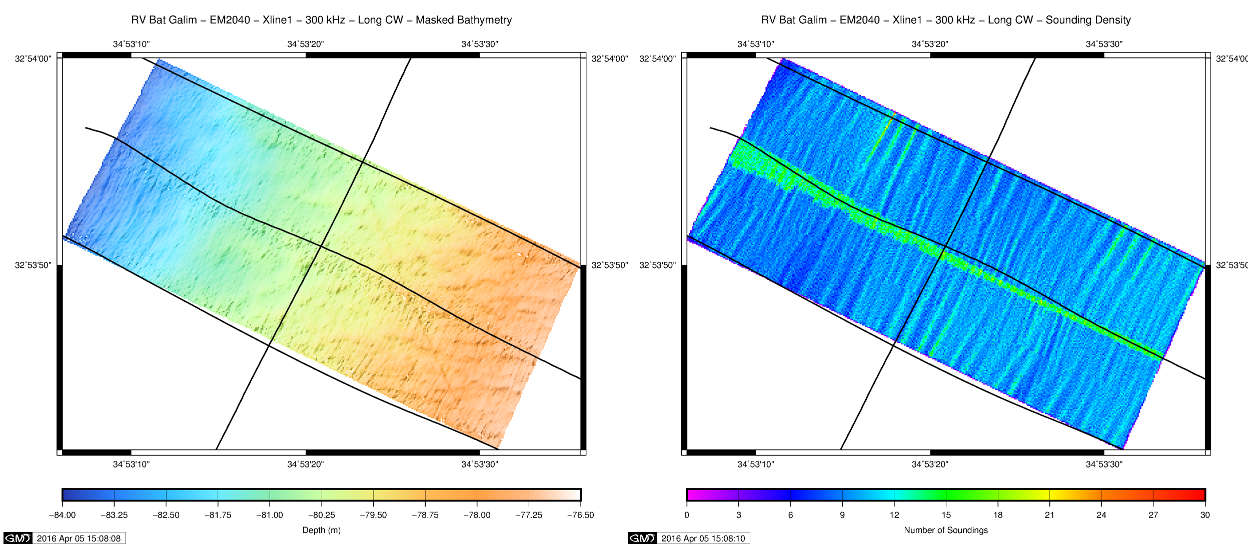

Figure 16. The shallow reference site used for assessing the accuracy of the EM2040 multibeam echosounder. The colored bathymetry shown on the left is gridded at 2m and masked to remove any slopes greater than 5°. The sounding density plot on the right shows the number of soundings per cell for the reference surface. Black lines show navigation for acquisition lines (WSW to ENE direction) and for the cross lines (NWN to SES direction).

EM302 Accuracy Testing

The EM302 accuracy evaluation was conducted at a deep reference site (1650-1533 meters water depth) in an area of no significant bathymetric features, Figure 15. Table 6 presents the runtime parameters used for the collection of the acquisition lines and the 2 crosslines. During acquisition of all lines, the mode was set to Deep with FM enabled, meaning that the system operated in a Mixed CW/FM TX Pule Form mode. The only difference in data collection between the reference surface lines and the 2 crosslines was the difference in speed of the ship. All reference surface lines were collected at 7 knots, the first crossline was collected at 6 knots, and the second crossline was collected at 7.5 knots. The reason the crosslines were collected at different speeds was the Acoustic Noise Testing team had previously identified a significant increase in ship self noise around 7.5 – 8 knots and it was decided to examine how this increase in noise affected the accuracy of the collected data.

As shown in Figures 17-18, the EM302 exhibits the expected increase in depth bias standard deviation with increased beam angle due to reduced SNR and increased scatter of the bottom detection at larger ranges and shallow angles of incidence on the seafloor. The observed mean biases and standard deviations are within the expected performance tolerances of the system as a whole when compared to other EM302s operating with FM on and with a soft bottom type. A majority of the swath shows beam-wise depth biases of less than 0.1% of water depth with no large steps present at the sector boundaries. The standard deviations about the mean bias are typically within +/-0.15% to +/-0.20% water depth (1-σ) across the majority of the swath with higher uncertainties at the limits of the swath, as expected and as typical for these systems. Also, as expected, the faster speed of crossline 2 when compared to crossline 1 exhibited greater depth variability when comparing soundings from the crossline to the reference surface. This data compares well to the E/V *Nautilus*'s EM302 data, Figure 19, collected during a 2015 Quality Assurance Visit in similar water depths and operating conditions.

For both crosslines, the port and starboard sides do differ in their outer beam bias trends, with the port side tending to showing a slight shallow bias at the extreme end of the swath, while the starboard side shows a a slightly more apparent deeper depth bias. This type of behavior has been noted during other EM302 assessments, and is not consistent with typical errors in sensor offsets or sound speed; at present, no concrete explanation is readily apparent.

Ideally, if more time had been available during the SAT, the system should have been tested in the CW mode to assess the effect of changing the TX pulse form on accuracy. Changing from FM (Mixed Mode), which the system was run in during the 2 crosslines, to CW mode (FM Disabled) would have likely yielded a decreased swath width, but would have also likely have shown an increase in system accuracy. If data is collected over this reference site in the future, please provide it to Johnson for analysis as this step can be done fairly quickly and this report can be updated to reflect this information.

Table 6. EM302 deep accuracy cross line settings (parameter changes are italicized).

SONAR RUN TIME PARAMETERS	Main Lines	Xline 1	Xline 2
Sector Coverage			
Speed	7	6	7.5
Max angle (port)	70	70	70
Max angle (sbtd)	70	70	70
Max Coverage (port)	5000	5000	5000
Max Coverage (stbd)	5000	5000	5000
Angular Coverage Mode	AUTO	AUTO	AUTO
Beam Spacing	HIDENS EQDIST	HIDENS EQDIST	HIDENS EQDIST
Depth Settings			
Force Depth	n/a	n/a	n/a
Min depth (m)	1200	1200	1200
Max depth (m)	2500	2500	2500
Dual swath mode	DYNAMIC	DYNAMIC	DYNAMIC
Ping mode	DEEP	DEEP	DEEP
TX Pulse Form	FM (Mixed)	FM (Mixed)	FM (Mixed)
Transmit Control			
Pitch stabilization	ENABLED	ENABLED	ENABLED
Along direction	0	0	0
Auto Tilt	OFF	OFF	OFF
Yaw stab. Mode	REL. MEAN HDG	REL. MEAN HDG	REL. MEAN HDG
Heading	n/a	n/a	n/a
Heading filter	MEDIUM	MEDIUM	MEDIUM
Min Swath Dist	0	0	0
Enable Scanning	Off	Off	Off
heading filter	MEDIUM	MEDIUM	MEDIUM
Min Swath Dist	0	0	0
Enable Scanning	Off	Off	Off

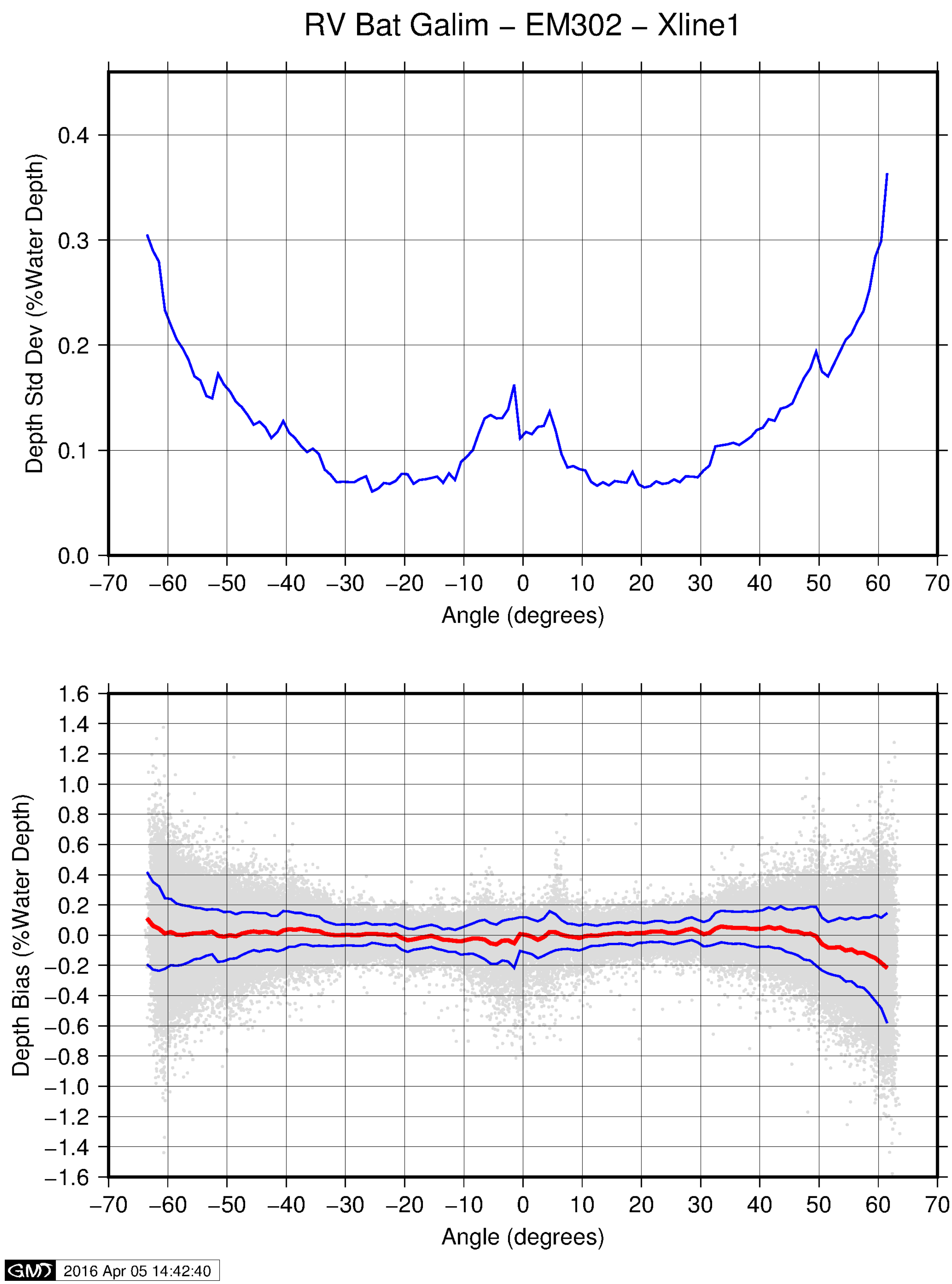

Figure 17. EM302 cross line 1 accuracy results (Deep, Dual Swath Dynamic, FM, 6 knots). Top: depth bias standard deviation as a percentage of water depth. Bottom: mean depth bias (red) as a percentage of water depth +/- one standard deviation (blue).

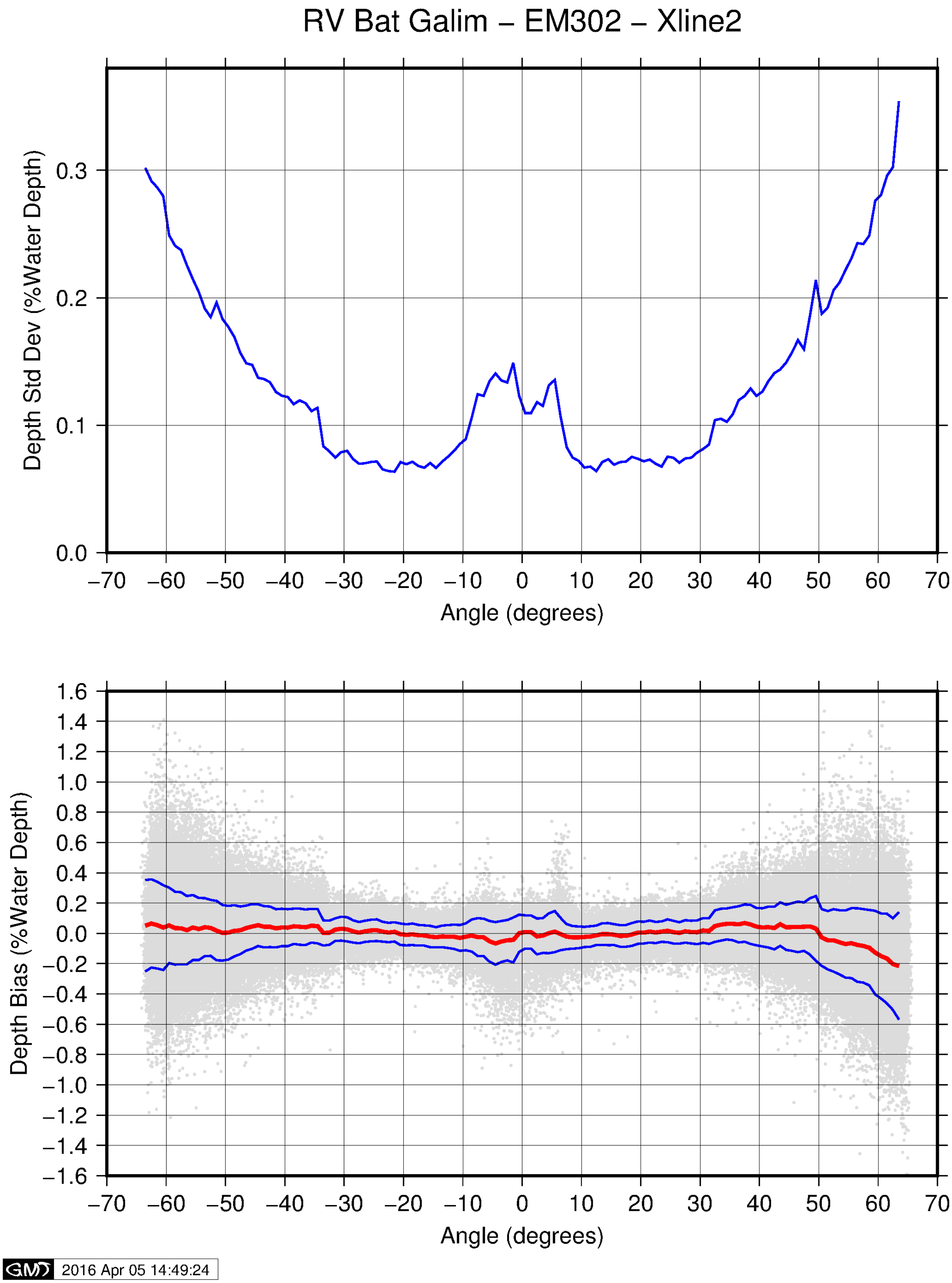

Figure 18. EM302 cross line 2 accuracy results (Deep, Dual Swath Dynamic, FM, 7.5 knots). Top: depth bias standard deviation as a percentage of water depth. Bottom: mean depth bias (red) as a percentage of water depth +/- one standard deviation (blue).

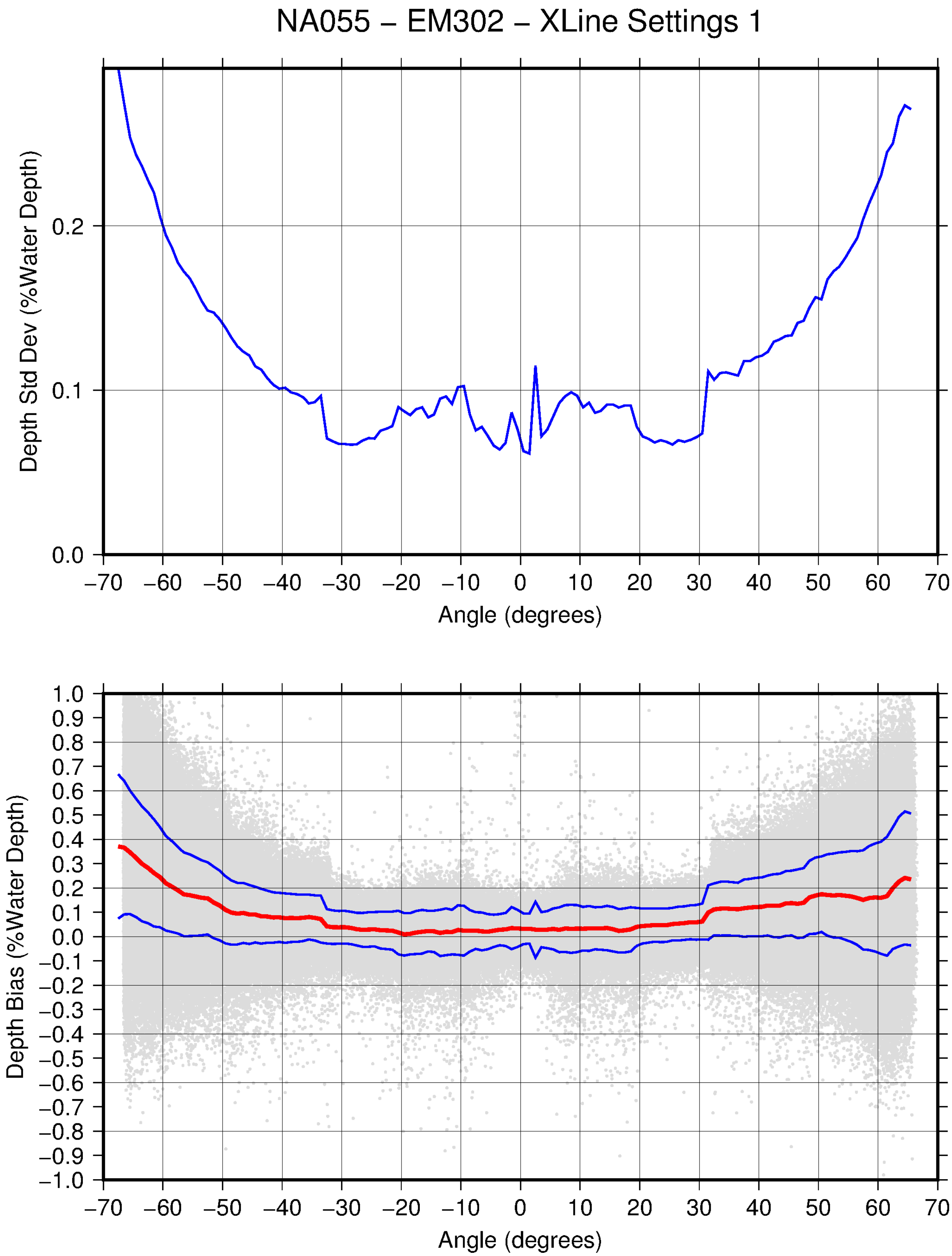

Figure 19 EM302 accuracy results from the E/V Nautilus's 2015 Quality Assurance Visit. Data was collected between 1000-1500 meters water depth at 8 knots and with runtime parameters set to Deep, Dual Swath Dynamic, and FM. Top: depth bias standard deviation as a percentage of water depth. Bottom: mean depth bias (red) as a percentage of water depth +/- one standard deviation (blue).

EM2040 Accuracy Testing

The EM2040 accuracy evaluation was conducted at a shallow reference site (85-75 m water depth) in an area of relatively benign bathymetry (Figure 16). Table 7 presents the runtime parameters used for the collection of the reference surface acquisition lines and the 2 crosslines. Unlike the EM302 site, runtime parameters were varied during the collection of the acquisition and crosslines. All reference surface lines and crosslines were collected at 6 knots and in the 300 kHz ping mode. However, the reference surface and the first crossline were collected with a Long CW TX pulse and the second crossline was collected with FM enabled. This was done to look at the effects on accuracy of the EM2040 with different TX pulse types.

Table 7. EM2040 accuracy cross line settings.

SONAR RUN TIME PARAMETERS			
Sector Coverage	**Reference Lines**	**Xline1**	**Xline2**
Max angle (port)	65	70	70
Max angle (sbtd)	65	70	70
Max Coverage (port)	500	500	500
Max Coverage (stbd)	500	500	500
Angular Coverage Mode	AUTO	AUTO	AUTO
Sector Mode	Normal	Normal	Normal
Beam Spacing	HD EQDST	HD EQDST	HD EQDST
Depth Settings	**Reference Lines**	**Xline1**	**Xline2**
Force Depth	n/a	n/a	n/a
Min depth (m)	1	1	1
Max depth (m)	200	200	200
Ping Mode	300 kHz	300 kHz	300 kHz
Pulse Type	LONG CW	LONG CW	FM
Detector Mode	Normal	Normal	Normal
FM disable	Unchecked	Unchecked	Unchecked
Transmit Control	**Reference Lines**	**Xline1**	**Xline2**
Pitch stabilization	ENABLED	ENABLED	ENABLED
Along direction	0	0	0
Auto Tilt	OFF	OFF	OFF
Yaw stab. Mode	OFF	OFF	OFF
Heading Filter	Medium	Medium	Medium
Max Ping Freq (hz)	50	50	50
Min Swath Dist	0	0	0
Enable Scanning	Off	Off	Off

As shown in Figures 20-21, the EM2040 exhibits the same expected increase in depth bias standard deviation with increased beam angle due to reduced SNR and increased scatter of the bottom detection at larger ranges and shallow angles of incidence on the seafloor as seen with the EM302. The observed mean biases and standard deviations are within the expected performance tolerances of the system with a majority of the swath having a depth standard deviation as a percentage of water depth around 0.1. The standard deviations about the mean bias are typically within +/-0.1% to +/-0.15% water depth (1-σ) across the majority of the swath with higher uncertainties at the limits of the swath, as expected and as typical for these systems. Also, as expected, the Long CW TX pulse (Figure 20) type yields better data in this water depth than the FM pulse (Figure 21) did, with the FM data showing humps on either side of nadir with the depth standard deviation approaching 0.2 at the peak of the hump.

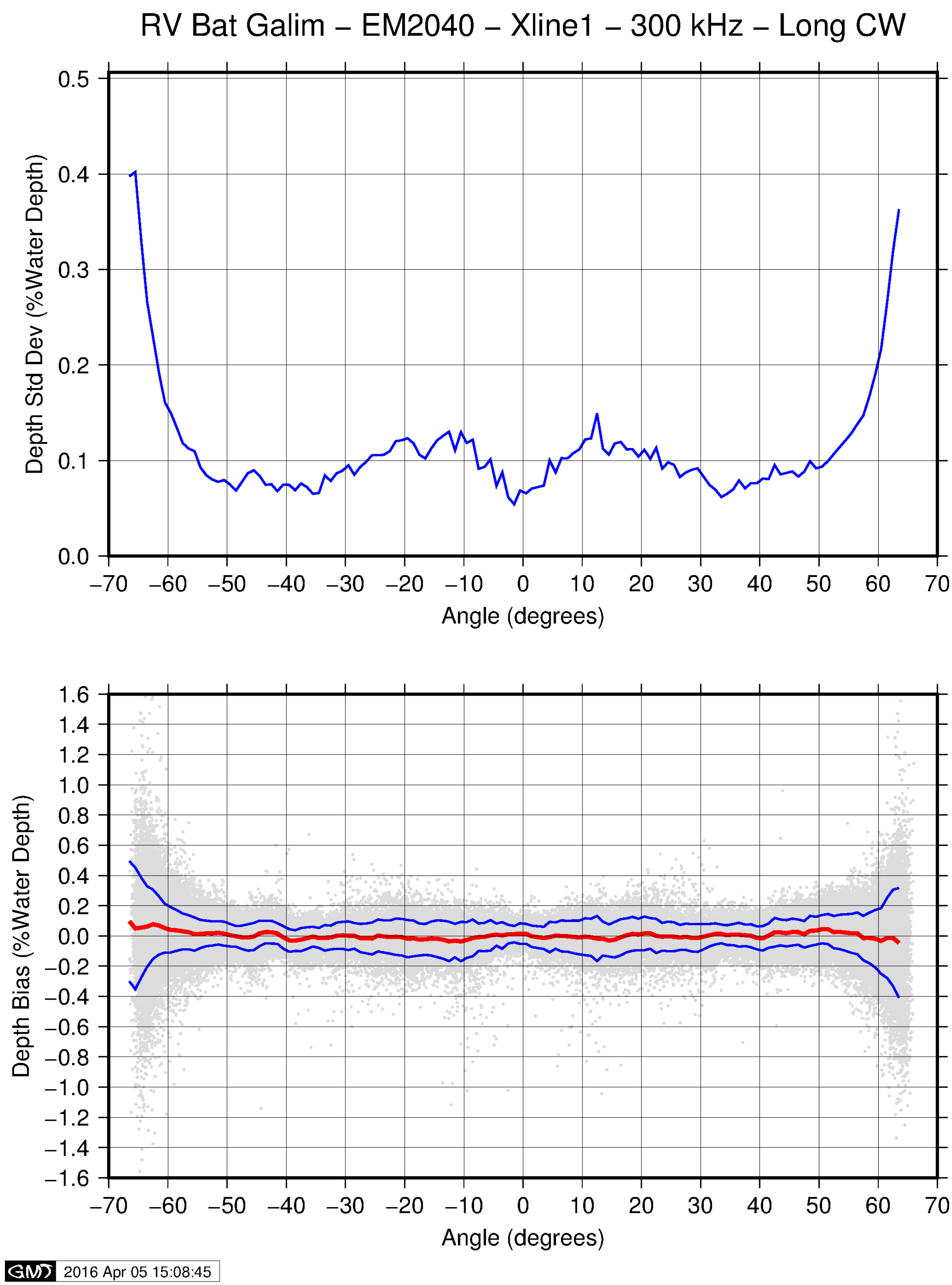

Figure 20. EM2040 accuracy results (300 kHz, Long-CW). Top: depth bias standard deviation as a percentage of water depth. Bottom: mean depth bias (red) as a percentage of water depth +/- one standard deviation (blue).

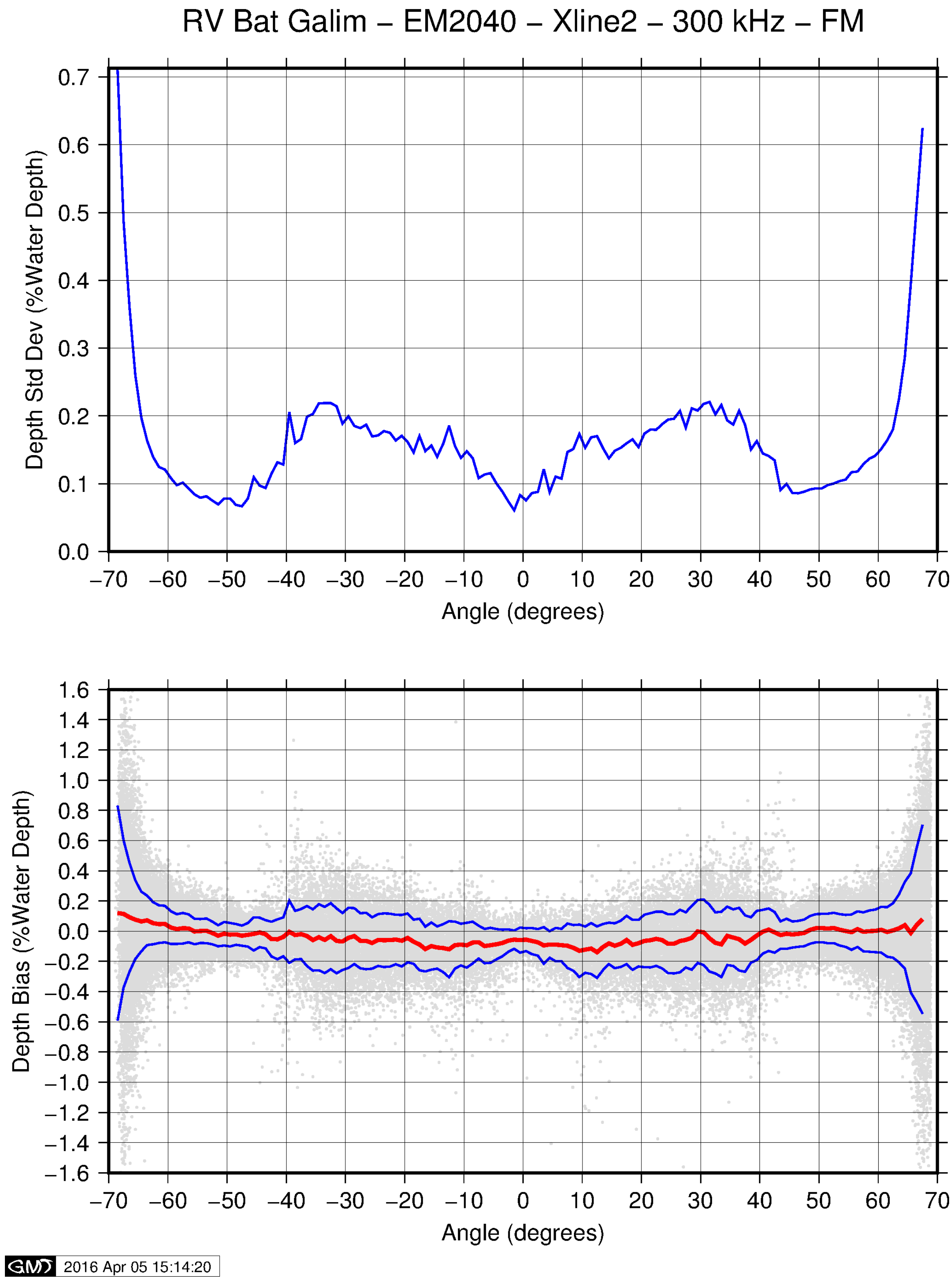

Figure 21. EM2040 accuracy results (300 kHz, FM). Top: depth bias standard deviation as a percentage of water depth. Bottom: mean depth bias (red) as a percentage of water depth +/- one standard deviation (blue).

Swath Coverage Performance

Overview

The noise and impedance evaluations test only some factors that control the performance, in terms of swath coverage, of a multibeam sonar. There are other factors at play and an overall assessment can be done by evaluating the achieved coverage and comparing this to a baseline performance level. This is sometimes a straightforward comparison. For example, when a ship always returns to the same home port, it is possible to build up a long time series of coverage performance as it leaves and returns to port over the same track line. Coverage can be compared from differing areas of similar water depths, however, one must recall that environmental conditions can affect the achievable coverage and caution must be exercised when interpreting or comparing results from areas with different oceanographic regimes and/or seafloor composition.

For the R/V Bat Galim SAT, system swath coverage was evaluated using data collected during transits between testing sites and at the testing sites themselves. Line speed varied depending upon the speed at the time, and unfortunately lines were not necessary run perpendicular to slope as is normally the case. The EM302 was run with the depth mode set to automatic during transits, this mode allows the system to chooses the proper depth mode automatically based on water depth observed by the sonar, and with runtime parameters set to maximum angular coverage (+/- 75°) and to maximum swath distance (+/-5000 m). The EM2040 data was evaluated from both 300 kHz data and 200 kHz data depending upon what mode was active at the time

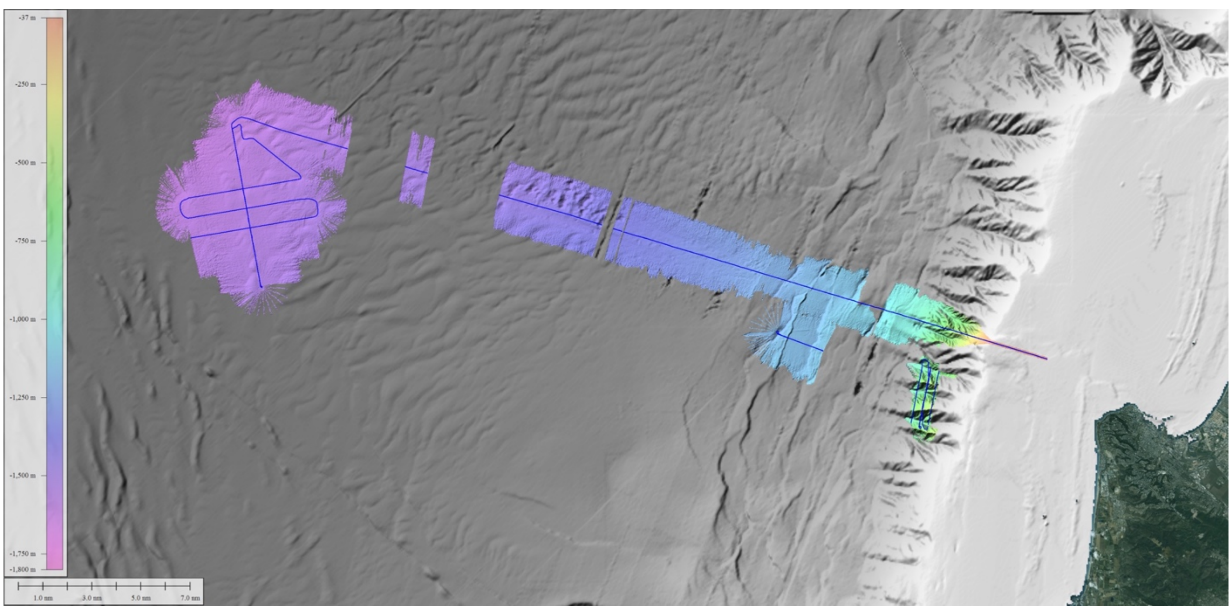

Figure 22. EM302 data contributing to the swath coverage curves below.

EM302 Swath Coverage

Figure 22 shows the EM302 data used to calculate the swath coverage performance curves and the results of the analysis of this data are plotted in Figure 23. Analysis of the data shows increasing swath width as a function of increasing depth, with the swath width being between 4 and 5 time water depth over the range of depths tested. This is on par with other systems which have been assessed, especially when considering the soft bottom type in the region of analysis and the higher speeds during much of the testing (typical transit speeds are 6 knots for testing achievable swath width). Figure 24 shows extinction data collected with the R/V Falkor's 1°x1° EM302 system during a September 2015 Quality Assurance Visit. Although the R/V *Bat Galim*'s swath performance as a function of depth is a bit smaller than the R/V *Falkor*'s, the Falkor test was run off of Hawaii in an area of volcanic rock with higher strength bottom returns and at a lower speeds and acoustically quieter speed. It should be noted, that the swath width of the R/V *Bat Galim*'s EM302 at ~1575 meters, of a little over 4X water depth is very similar to that of the *Falkor's*. This is because the *Bat Galim* data was collected at survey speeds from 6 to 7 knots, during acquisition of the reference surface and crosslines, an acoustically quieter operating speed. Also, the swath width of 6800 meters at 1580 meters water depth closely matches the modeled swath performance provided by Kongsberg Maritime (Figure 25).

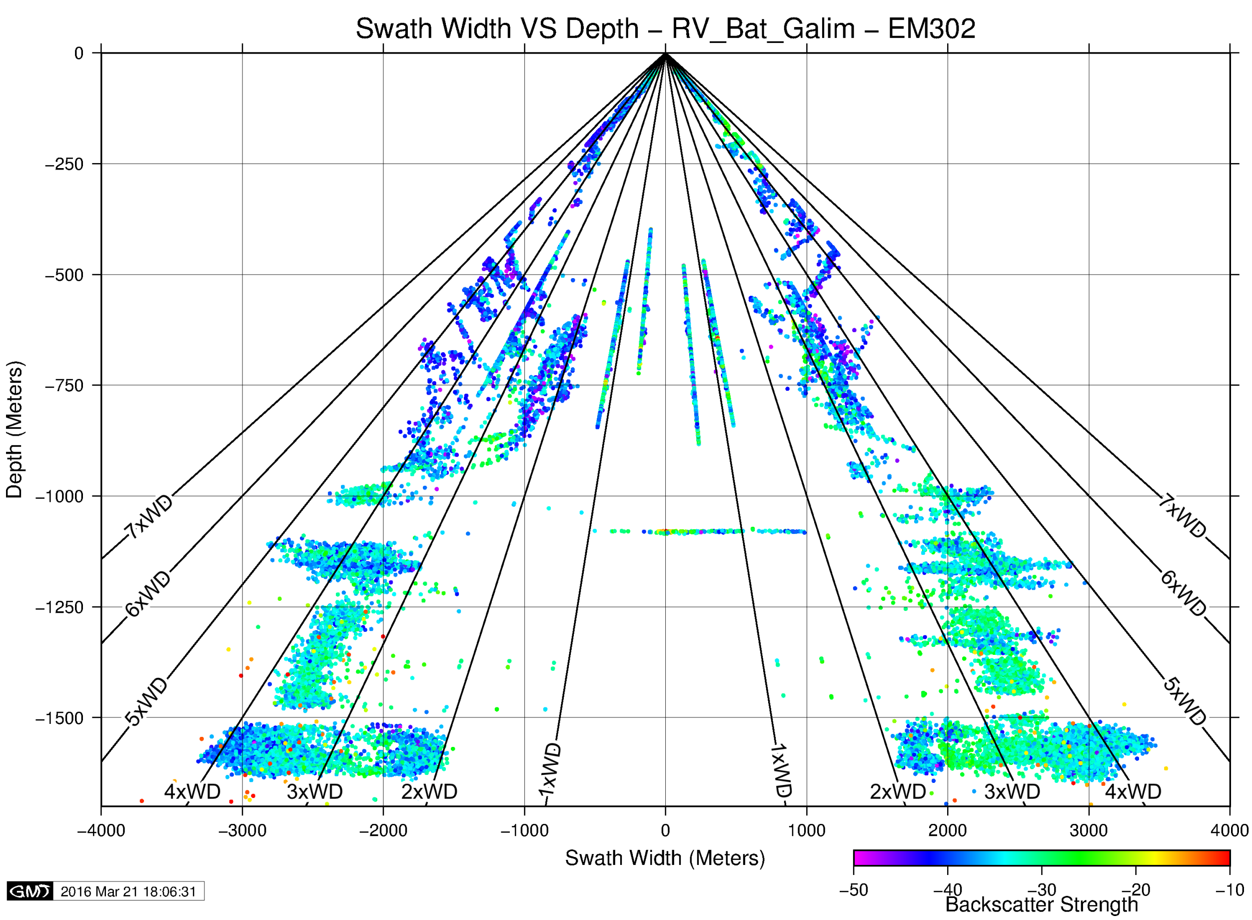

Figure 23. EM302 swath coverage performance during R/V Bat Galim shipboard acceptance test.

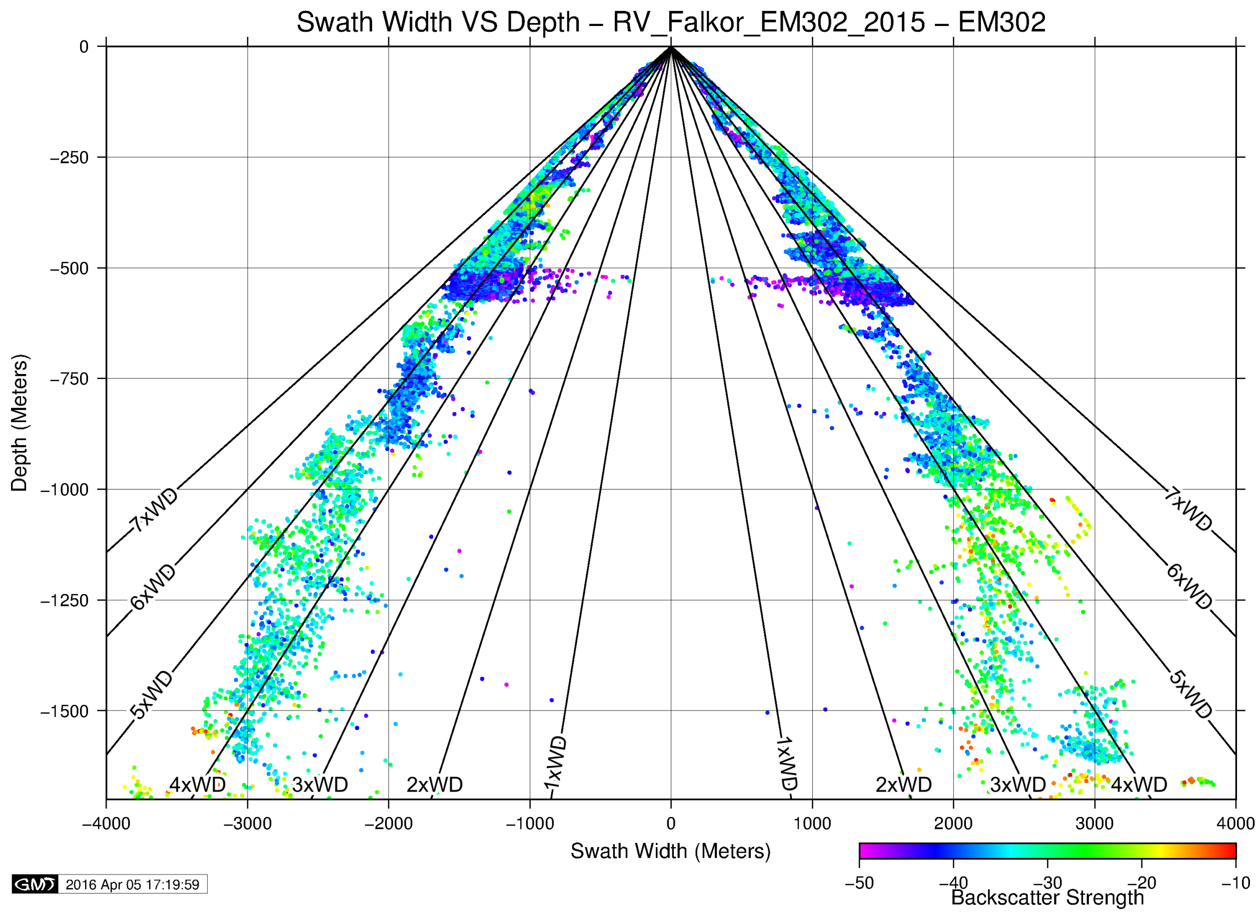

Figure 24. EM302 swath coverage performance from the 2015 R/V Falkor Quality Assurance Visit

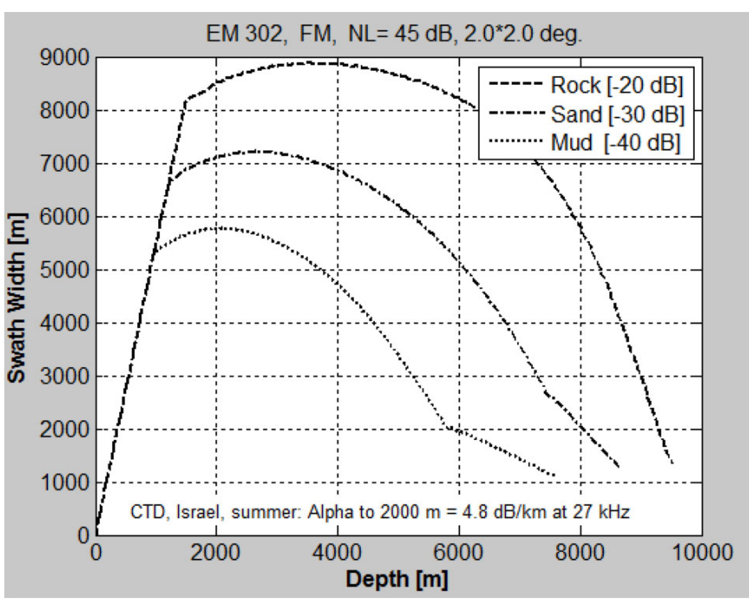

Figure 25. Kongsberg Maritime calculated swath performance for an EM302 as a function of depth, water temperature, and bottom type.

EM2040 Swath Coverage

Figure 22 shows the EM2040 data used to calculate the swath coverage performance curves and the results of the analysis of this data are plotted in Figure 27. Analysis of the data shows increasing swath width as a function of increasing depth until 120 meters water depth with the system achieving 5 to 7 times water depth over that range. Deeper than 120 meters the swath width as a function of depth decreases with the system going into extinction (no valid bottom return) at 375 meters water depth. Considering the sub-optimum geometry in relationship to slope during collection of the extinction lines, this performance actually exceeds expectations. As with the EM302, the achieved swath width as a function of depth closely matches the modeled swath performance provided by Kongsberg Maritime (Figure 25) and the system goes into extinction at a depth very close to that which as also modeled, although it should be noted that the for depths above 100 meters the swath width mostly closely follows the rock (-10dB) curve, while extinction more closely follows the sand (-25dB) curve. This is in contrast to the actual geology of the survey area, where the bottom type is likely closer to being mud.

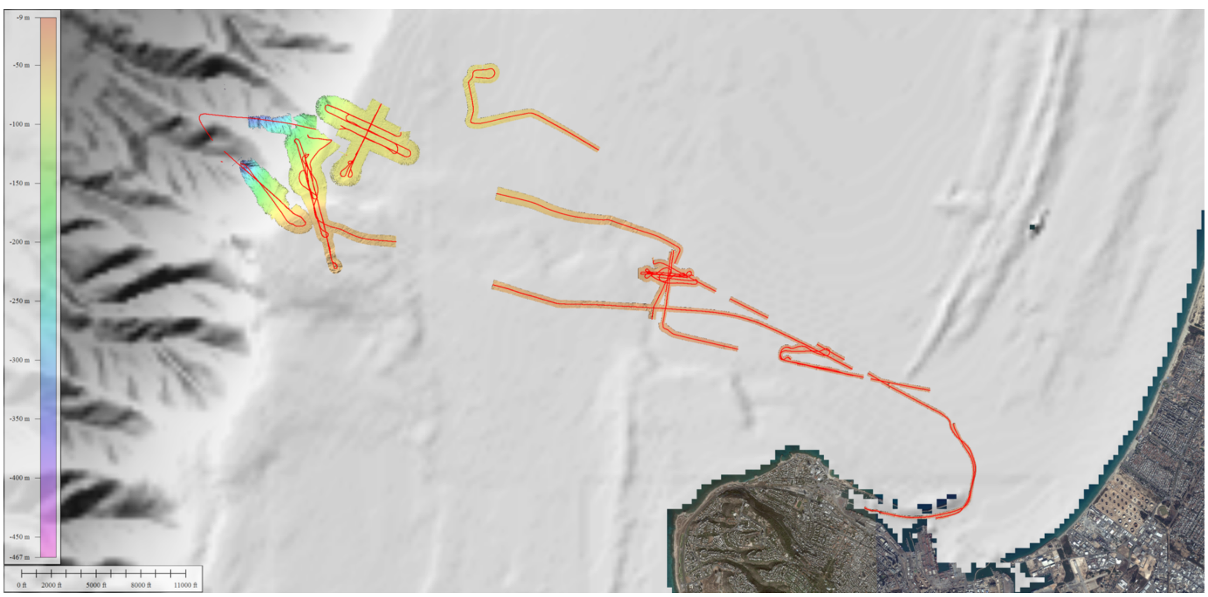

Figure 26. EM2040 data contributing to the swath coverage curves below.

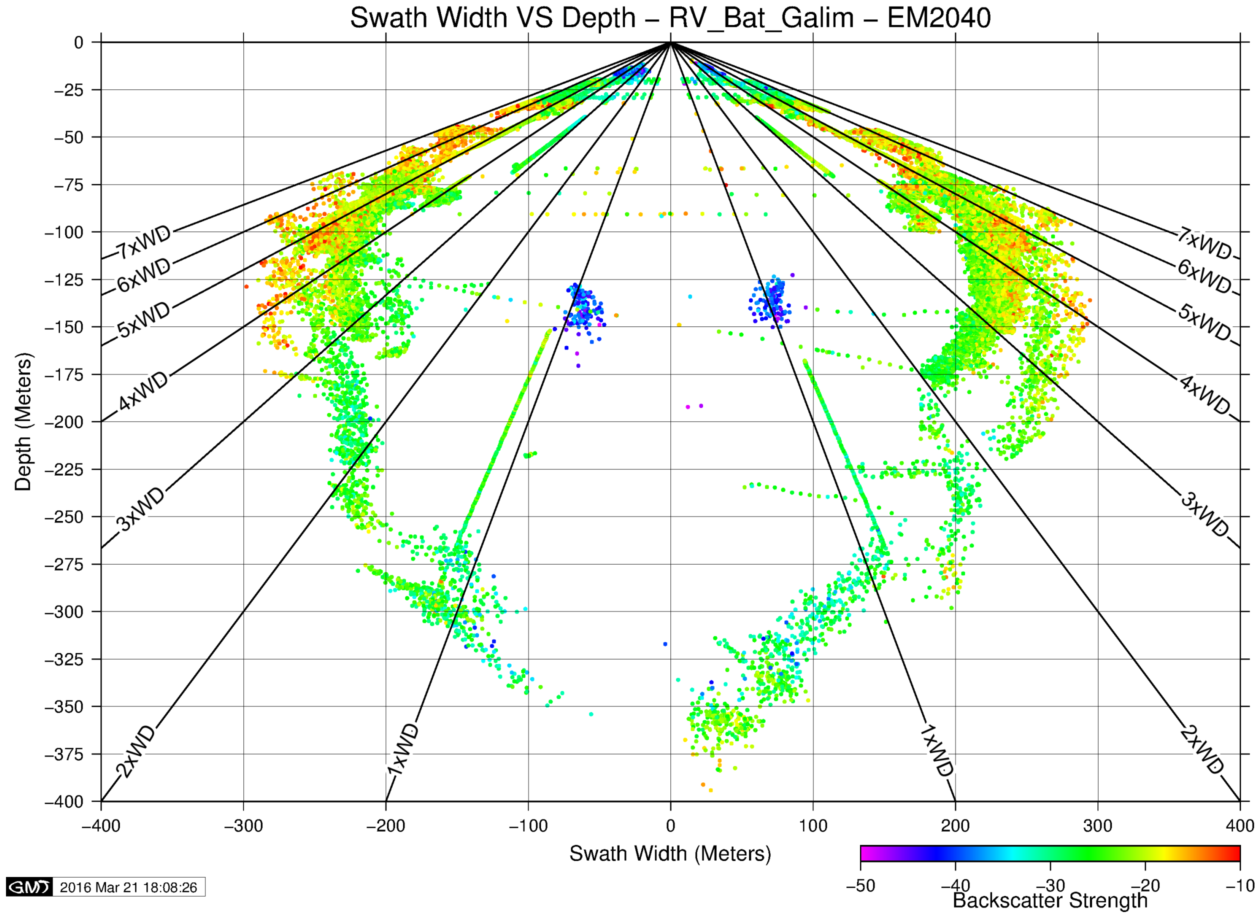

Figure 27. EM2040 swath coverage achieved during the R/V Bat Galim shipboard acceptance test.

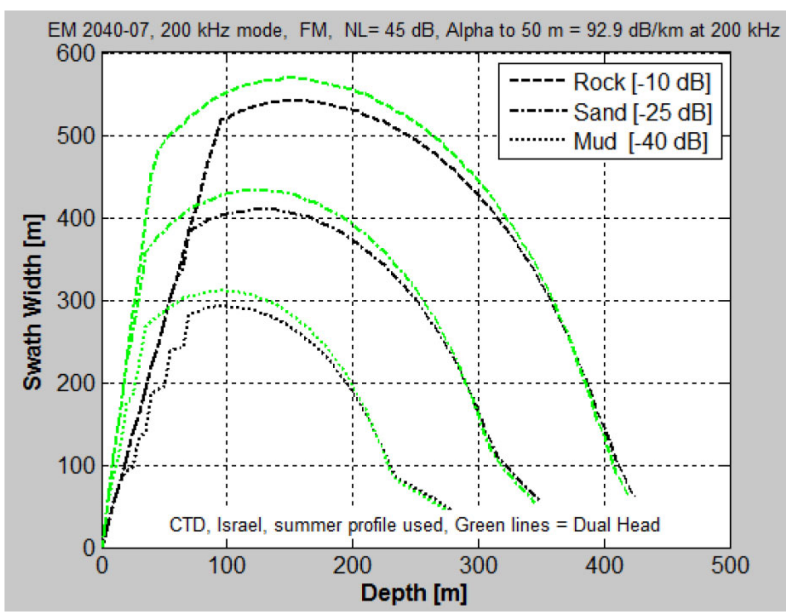

Figure 28. Kongsberg Maritime calculated swath performance for an EM2040 as a function of depth, water temperature, and bottom type.

Principal Findings & Recommendations

- The systems were successfully calibrated and verified. Positional accuracy was not as high hoped for during the SAT, therefore, when the process of integrating the positional correctors into the Seapath 330 have been worked out, a repeat verification patch test should be conducted to look for any small residual angular offsets. That said, the angular biases which were corrected for during the SAT are very small, indicating a quality survey of the installation.
- Both multibeam systems provide bathymetric measurements that are in agreement with their expected performances. However, if more data with different TX mode are collected, especially running the EM302 in CW over the existing reference surface, it would be ideal to analyze this data and to amend this report to include this information. From a processing side, this is not an onerous task, and would gladly be done.
- During the SAT it was noticed that a very small 5-10 cm "wobble" was noticeable over very flat seafloor. While the data quality, when this issue is observed, is in specification for the system, modern visualization software does makes it very easy to illuminate and highlight it. Post-SAT analysis of this issue by Glen Rice, NOAA, using a 'wobbleometer' routine revealed that this ripple is not related to latency or lever arms issues.
- As a whole, the two multibeam systems are in satisfactory working condition and I do not anticipate any obvious issues with either system for the 2016 mapping season.
- The transmit transducer impedances for both the EM302 and 2040 passed during the SAT. However, post-SAT analysis of the EM302's data proved unusable for analysis as the test did not log the full set of channels, and the EM2040 only reports a pass or fail through the telnet session. In order to monitor the EM302's TX impedance over the time, please conduct a test as documented earlier in this report and send it to Johnson for analysis and inclusion in this report.
- The swath performance as a function of depth (extinction data) closely matches other systems which have been previously evaluated. The collected data also closely matches the modeled data provided by Kongsberg prior to assessment of the systems. That said, the extinction curves can be more fully fleshed out with the inclusion of more data. If so desired, please provide Johnson with the additional data collected during normal operations for inclusion into the curves.
- The receiver transducer impedance BIST tests for the EM302 were collected during the SAT and logged for future comparison. They closely match other EM302 systems which have been assessed. Continued collection of BISTs through SIS is highly recommended in order to be able to monitor the array health.
- The survey report documenting the system offsets and angles is superb, especially when compared to other research vessel reports which have been reviewed. It is highly recommended that if any changes are made to the sensor geometry, that these changes are amended to the survey report so that a clear lineage is available for review during future patch tests, system reviews, or SIS modifications.

- It is highly recommended that an XBT system or underway CTD system be purchase as the ability to collect underway sound velocity profiles can save a large amount of time when working in deep water. While SVP profile casts can be highly accurate, the time it takes to stop the ship and perform the cast can be monetarily quite high when day rate of the ship is considered.