R/V *Sikuliaq*

EM304 MKII / EM710 Quality Assurance Testing SKQ202503S

Multibeam Advisory Committee
Feb 3-6, 2025

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Executive Summary

1. In Feb 2024, UAF and MAC personnel conducted sea acceptance testing (SAT) of R/V *Sikuliaq's (SKQ)* new EM304 MKII multibeam mapping system, Seapath 380-R3 navigation system, and EM710 RX array
2. Seasonal readiness testing off Hawaii in Feb 2025 expanded on the 2024 SAT work with access to deeper seafloor regions, supporting a more complete characterization of EM304 MKII performance
3. UAF and MAC personnel planned a series of tests following the standard MAC SAT/QAT checklist, with consideration for post-SAT priorities and backup options to suit the weather and sea state conditions
4. Small but critical updates were made to all sensor XYZ offsets, reflecting the final survey report provided by Westlake (after the 2024 SAT) and maintaining consistency of the mapping system origin at the granite block
5. Calibrations for both systems revealed small residual biases, suggesting a high-accuracy vessel and sensor survey by Westlake Consultants and correct implementations across the mapping system configurations
6. Built-In Self-Tests were carried out throughout the Factory Acceptance, Harbor Acceptance, and Sea Acceptance Tests to verify hardware health and document the baseline conditions for the new EM304 MKII
7. The EM304 showed a number of new 'high Z' results for TX Channels and both systems showed higher variability in their RX Channels results compared to historic BIST trends; these tests should be conducted routinely to continue monitoring these behaviors, and the MAC is available to plot data as they are recorded
8. Following the QAT, technicians discovered EM710 TX cables #8 and #10 had been swapped at the TRU, likely during the last impedance analysis in 2024; the cables were returned to the correct order on March 2

Executive Summary

9. While the TX cable order issue would have impacted TX beamforming and beamsteering processes (with associated degradation of signal strength, coherence, and bottom detection during RX), the bulk geometric calibration results (i.e., angular offsets) are not expected to have been seriously impacted; the MAC is available to help plan an opportunistic calibration during the field season in order to check these results / expectations
10. Additional TX and RX Channels data collected after cleaning the ice windows (March 2025) showed a general return toward baseline and reduction in the variability across channels; however, the EM304 TX Channels test still fails due to phase results, which may indicate fouling on the array faces (inaccessible until dry dock in 2026)
11. RX Noise Level BISTs were recorded across a wide range of speeds during the QAT to characterize machinery- and flow-related noise trends perceived by each EM system; compared to last year, both systems suffered from higher noise levels at speeds above approx. 5 kn
12. The higher noise levels observed during this QAT likely stem from increased biofouling / flow noise near the arrays at the time, as the hull could not be cleaned in port due to local restrictions
13. Additional noise testing was collected during the transit to Seward on April 13, showing a significant improvement from the pre-cleaning noise results and a return toward the 2024 SAT/QAT levels
14. EM304 swath coverage testing was conducted on most transits and a dedicated test line out to 4800 m, reaching twice the maximum depth observed in 2024 (a major goal of this QAT)

Executive Summary

15. The EM304 coverage data shows approximately a ~1X WD reduction in coverage compared to a benchmark dataset (Okeanos Explorer EM304 MKII data from the Puerto Rico Trench, also used for comparison in the 2024 SAT report); these reductions are easily attributable to the higher noise and increased attenuation of Sikuliaq's ice-protected system, which otherwise achieved the expected performance across this depth range
16. EM304 accuracy testing was completed for a variety of modes at 2800 m and 4800 m, including Extra Deep (not tested in 2024); the results are generally as expected for an ice-protected system, with zero mean bias and variable outer swath biases (e.g., possibly induced by yaw stabilization while 'crabbing' at the 2800 m site)
17. Accuracy results clearly suggest that operators may benefit from 'forcing' transitions to deeper modes sooner than automatically selected by the EM304, in order to achieve higher swath quality without limiting coverage
18. The final EM304, EM710, and Seapath configurations reflect a well-integrated mapping system and stable system geometry since 2024; the current settings should be maintained until any mapping sensors are modified or another calibration becomes necessary for other reasons (e.g, seasonal readiness testing)

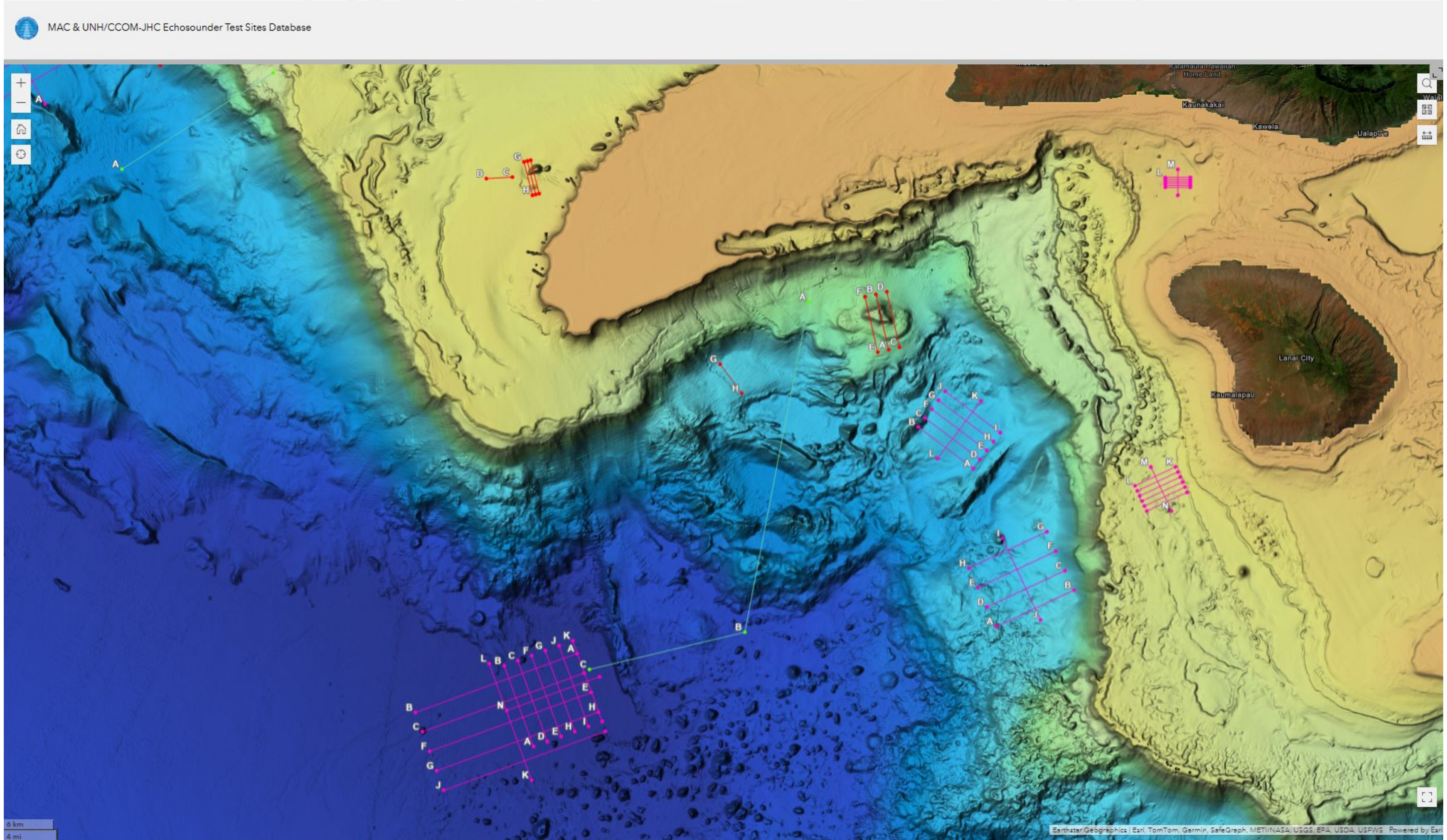
Mapping System Components

The primary mapping system components are:

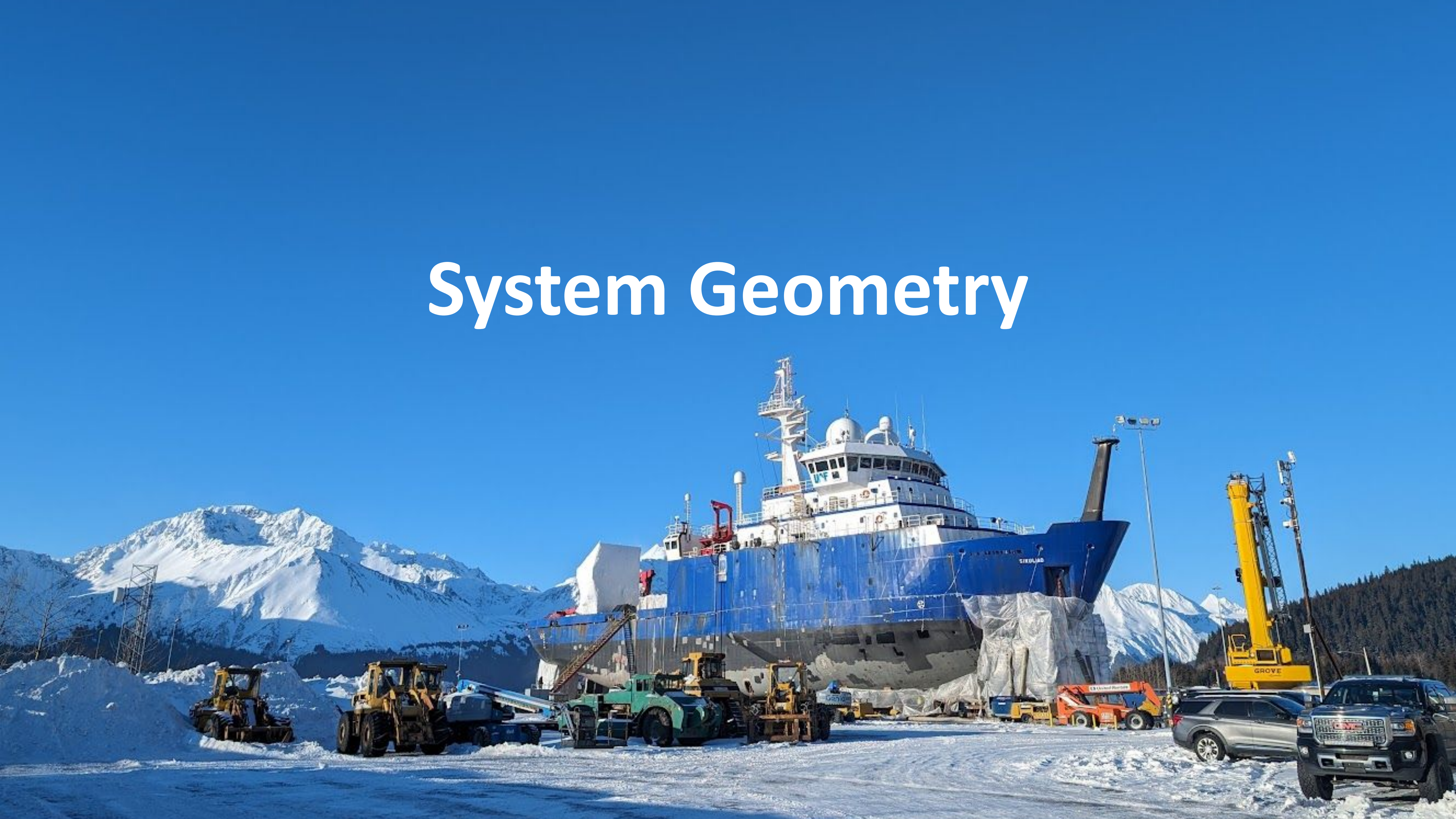
1. Kongsberg EM304 MKII multibeam echosounder (20-32 kHz, 0.5° TX x 1.0° RX), s/n 11017
2. Kongsberg EM710 multibeam echosounder (70-100 kHz, 0.5° TX x 1.0° RX), s/n 224
3. Kongsberg Maritime Seafloor Information System (SIS)
    a. EM304 MKII: v5.14.0
    b. EM710: v4.3.2
4. Kongsberg Seapath 380-R3 navigation system
    a. NovaTel GNSS-850 antennas
    b. Seatex MGC-R3 inertial navigation unit
5. AML Micro-X SV-Xchange surface sound speed sensor
6. Sippican XBT sound speed profiling system
7. Seabird SBE 9plus CTD profiling system

Planning Overview

1. As the *Sikuliaq* is an ice-breaking hull (with associated susceptibility to bubble sweep), QAT activities were planned in the lee of Moloka'i and Lanai to provide protection from northeasterly trade winds and swell



System Geometry



System Geometry Review **Overview: History**

The term 'system geometry' means the linear and angular offsets of the primary components of the multibeam mapping systems, including the transmit arrays (TX), receive arrays (RX), GNSS antennas, and motion sensors (MGC); these are measured and reported from a common mapping system origin

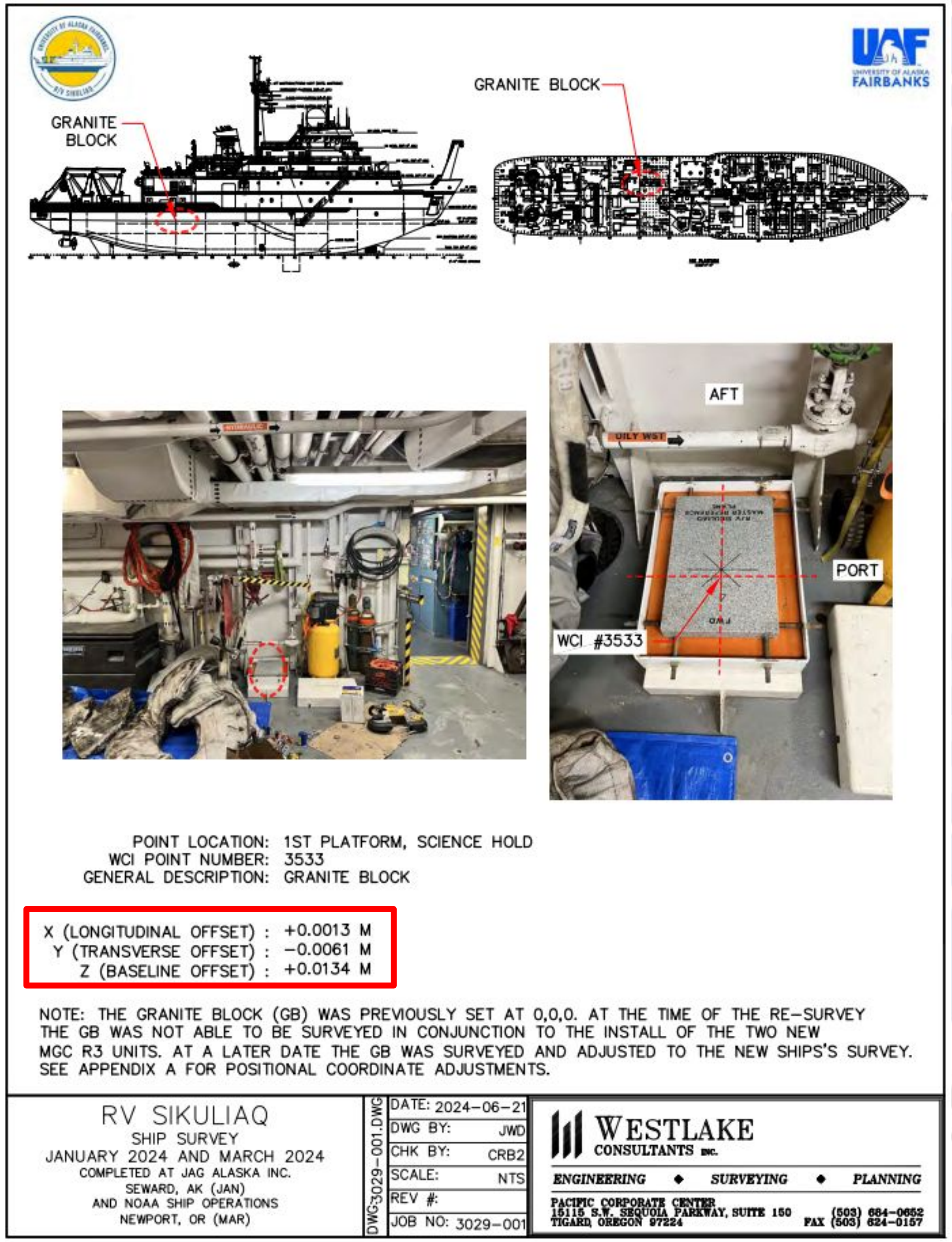
Because the 2024 SAT/QAT involved a completely new survey and updated mapping system configurations, the table below presents only the most recent survey and system geometry updates through the 2025 QAT

See the 2024 SAT report for more details of the mapping system reference frame, conventions, and configurations

Date	Location	Event	References
2023-24	Seward, AK	Westlake performed multiple surveys throughout winter 2023-24 to establish the vessel frame, new and old benchmarks, and offsets for all mapping sensors. All results were reported using the Kongsberg axis and sign conventions with origin at the granite block (in agreement with previous mapping system configuration). *NOTE: See the 2024 report for details of survey complications (e.g., shipyard conditions) and adjustments made after the SAT*	Preliminary Westlake results from *3029-001-WCI INITIAL NUMBERS SHIP PRELIMINARY COORDINATES_r2.pdf* were applied during the SAT/QAT
2024-02-27 to 2024-03-08	Seattle, WA to Newport, OR	EM304 MKII, EM710, Seapath 380-R3 configuration updates using Westlake preliminary results; Seapath GNSS antenna baseline calibration; Waterline update in SIS; EM304 MKII and EM710 calibrations and verifications	2024 Sikuliaq SAT report
2024-06-21	Newport, OR	Final survey report with updated granite block location of [+0.001 m, -0.006 m, +0.013 m] in the mapping system reference frame used during SAT; planning to adjust all sensor XYZ to this final origin during the next QAT	3029-001(0) UAK RV Sikuliaq Final Report r0 2024-06-21.pdf
2025-02-03 to 2025-02-06	Honolulu, HI	Configuration updates to reflect the final Westlake report; all XYZ values adjusted to final origin location by subtracting [+0.001 m, -0.006 m, +0.013 m] (see later slides); Seapath GNSS antenna baseline calibration; EM304 MKII and EM710 calibration verifications ('patch tests')	This document

System Geometry Review

Mapping Reference Frame Update

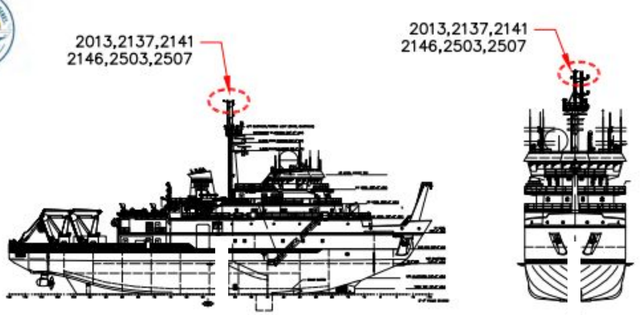


1. The 2024 Westlake survey followed Kongsberg axis/sign conventions and maintained the nominal origin at the granite block
2. Due to shipyard conditions and access limitations, Westlake was forced to estimate the granite block origin location by best-fit of other benchmarks in order to provide sensor offsets for the 2024 SAT
3. Westlake returned to the ship in Newport, OR, following the SAT to survey the granite block (report provided 2024-06-21)
4. The granite block was located at [+0.001 m, -0.006 m, +0.013 m] (rounded to 1 mm) in the same reference frame used during the SAT
5. This result confirms the estimated location used during the SAT is on the order of 0.001-0.01 m from the final surveyed position, and is not expected to have an appreciable impact on any of the 2024 results
6. In order to expressly define the granite block as the origin at [0, 0, 0], all offsets were shifted by subtracting [+0.001 m, -0.006 m, +0.013 m]
7. This change was described in the 2024 SAT report, discussed by UAF and MAC personnel on board, and applied prior to 2025 calibrations to ensure a clear and consistent origin moving forward

System Geometry Review

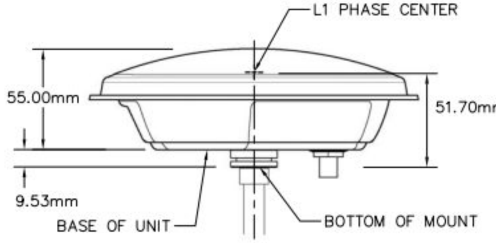
Seapath Antenna Lever Arms

1. Seapath antennas are NovAtel GNSS-850 models installed in an alongship orientation with the aft antenna as primary
2. In 2024, Westlake reported the L1 phase centers, adjusting from the surveyed location using the antenna specification, as expected for Seapath configuration
3. For 2025, the results shown at right were shifted to the final granite block origin by subtracting [+0.001, -0.006, +0.013] m, as discussed in previous slides
4. Note that results are rounded to the nearest mm in Seapath GNSS configuration
5. **Antenna 1** (aft) height at the L1 phase center (m, Z+ down from final origin at granite block and rounded by Seapath):
   a. **X = +12.822 m; Y = +2.073 m; Z = -30.543 m**
6. **Antenna 2** (fwd) offsets following the same approach:
   a. **X = +15.314 m; Y = +2.086 m; Z = -30.562 m**



WCI REF #	LONGITUDINAL OFFSET (X) POSITIVE FORWARD	TRANSVERSE OFFSET (Y) POSITIVE TO STARBOARD	BASELINE OFFSET (Z) POSITIVE DOWN	SENSOR DESCRIPTION AND NOTES
2507	14.0696	2.0710	-30.5304	℄ C-NAV X1 @ L1 PHASE CENTER
2013	15.3146	2.0795	-30.5485	℄ SEAPATH 2 (FWD) @ L1 PHASE CENTER
2503	12.8234	2.0666	-30.5295	℄ SEAPATH 1 (AFT) @ L1 PHASE CENTER
2146	14.1313	0.8695	-29.1406	℄ DGPS #2 (PORT)
2141	14.1333	1.3756	-29.1420	℄ DGPS #1 (STRBRD)
2137	13.6097	2.1697	-29.3189	℄ C-NAV 3050 @ L1 PHASE CENTER

Westlake results before adjustment to define granite block as [0,0,0]



NOVATEL SEAPATH ANTENNA
L1 PHASE CENTER OFFSET
PER KONGSBERG SEAPATH 380 MANUAL

RV SIKULIAQ
SHIP SURVEY
JANUARY 2024 AND MARCH 2024
COMPLETED AT JAG ALASKA INC.
SEWARD, AK (JAN)
AND NOAA SHIP OPERATIONS
NEWPORT, OR (MAR)

DWG3029-001.DWG

DATE: 2024-06-21
DWG BY: JWD
CHK BY: CRB2
SCALE: NTS
REV #:
JOB NO: 3029-001

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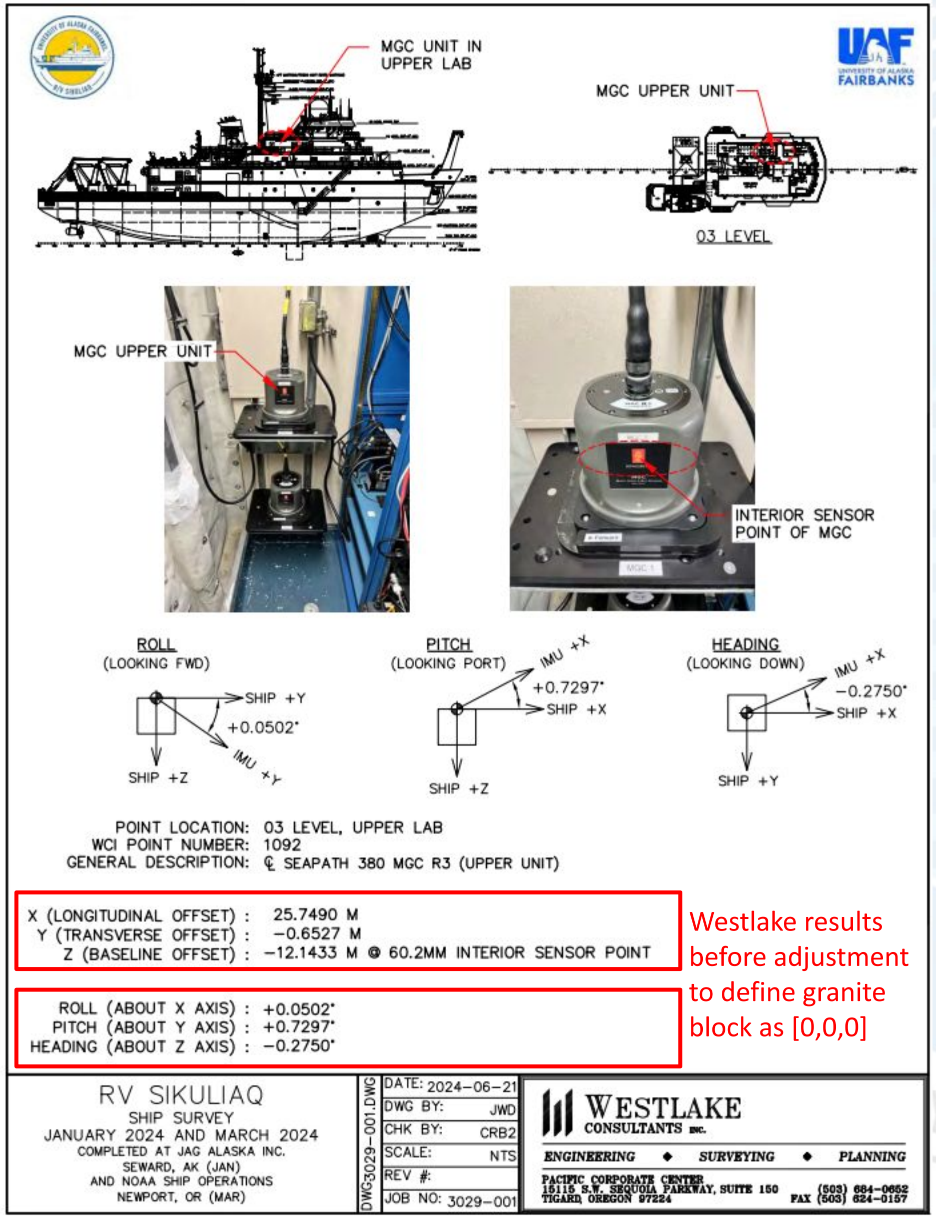
System Geometry Review

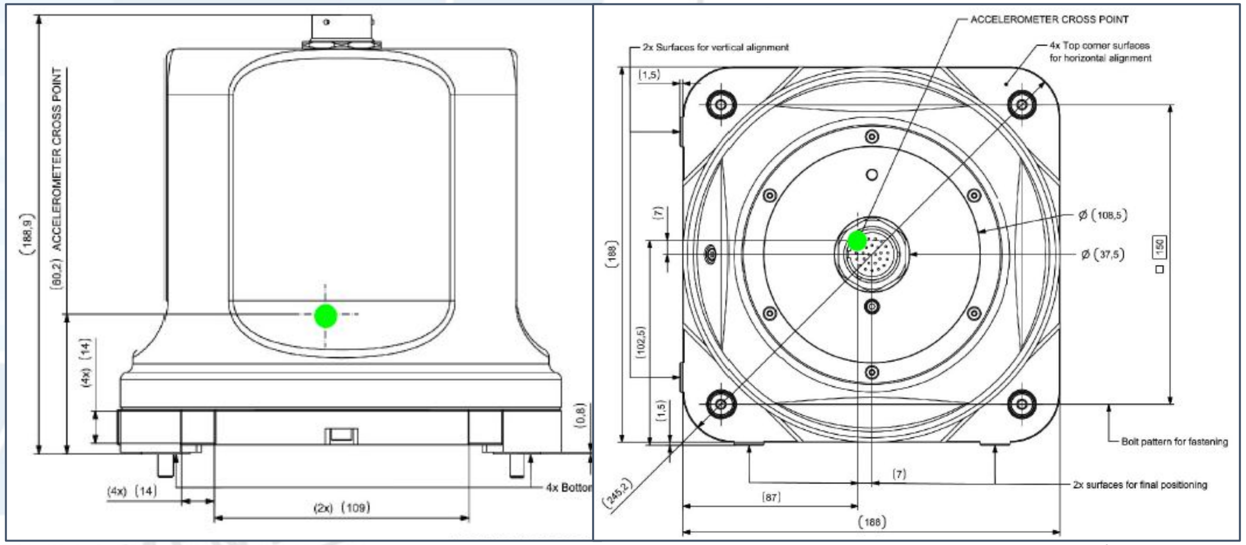
Seapath MGC Lever Arms



Westlake results before adjustment to define granite block as [0,0,0]

1. The top MGC serves the Seapath 380-R3 and mapping system
2. The sensing center was calculated and reported by Westlake using a Seapath MGC diagram (below), with a small X adjustment in the final report received after the SAT; these results were adjusted to the final origin location by subtracting [+0.001, -0.006, +0.013] m
3. MGC sensing center offsets in Seapath, from Granite Block at [0,0,0]

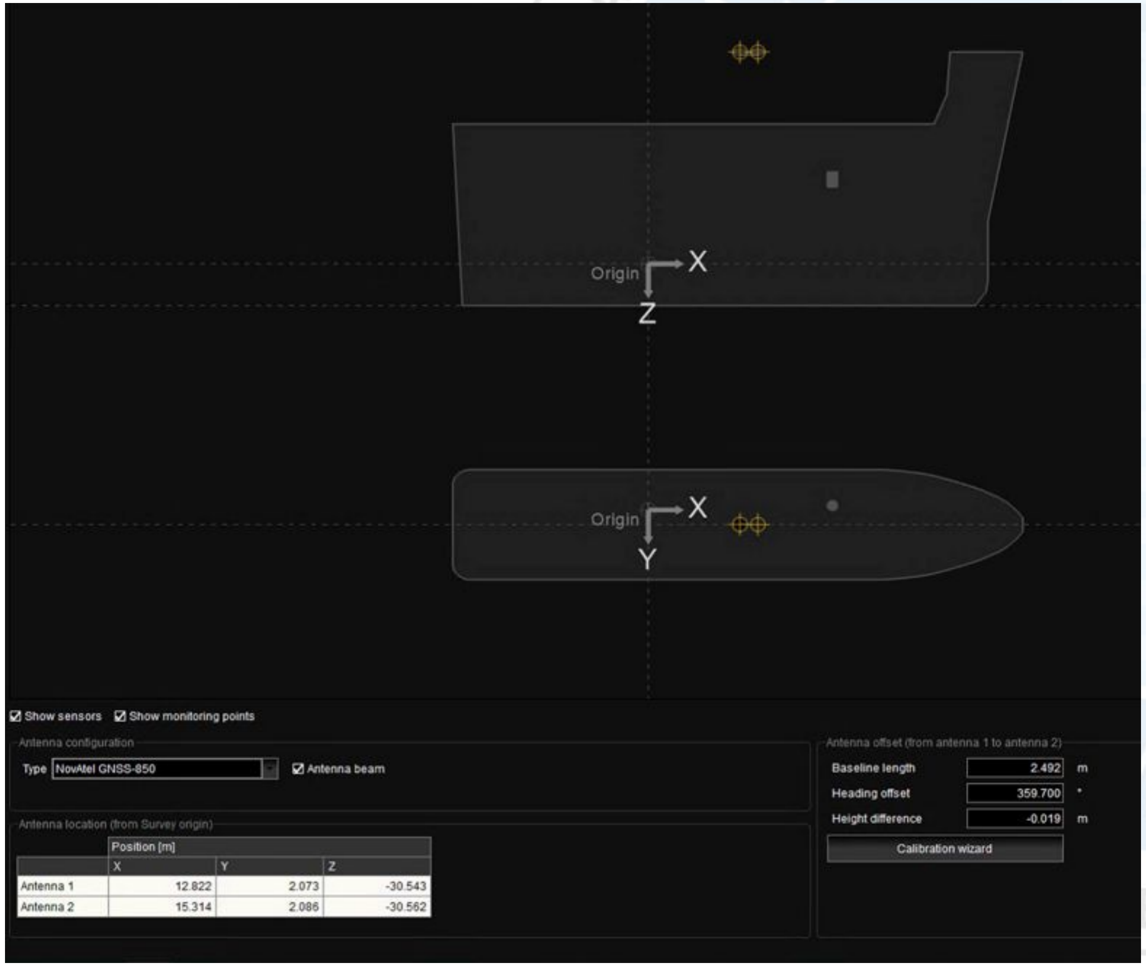
X: +25.748 m	**Roll: -179.950° (+0.05° - 180°)**
Y: -0.647 m	**Pitch: +0.730°**
Z: -12.157 m	**Heading: -0.275°**

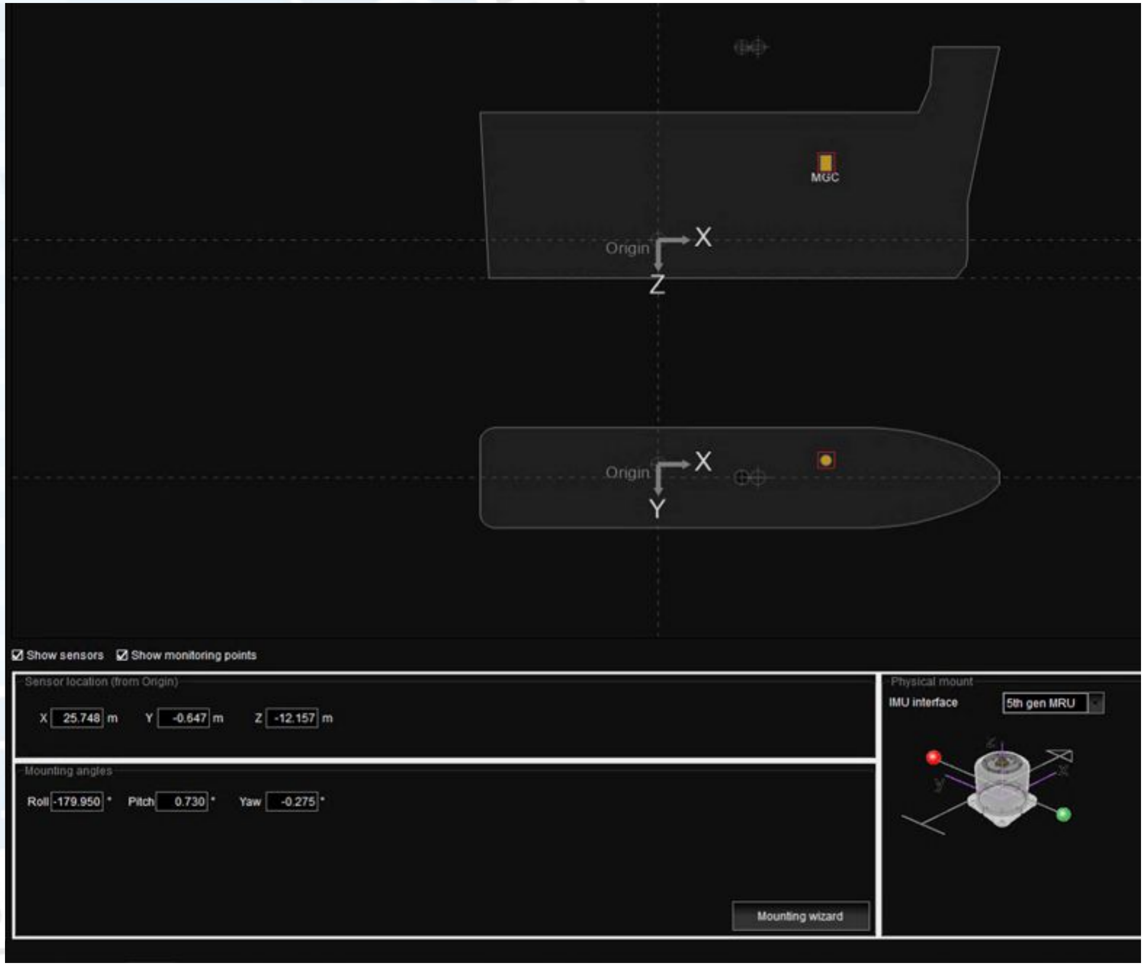


Sensing center location (Seapath MGC Installation Manual MGC-D-115/1 p. 30)

System Geometry Review **Seapath 380-R3 Configuration**

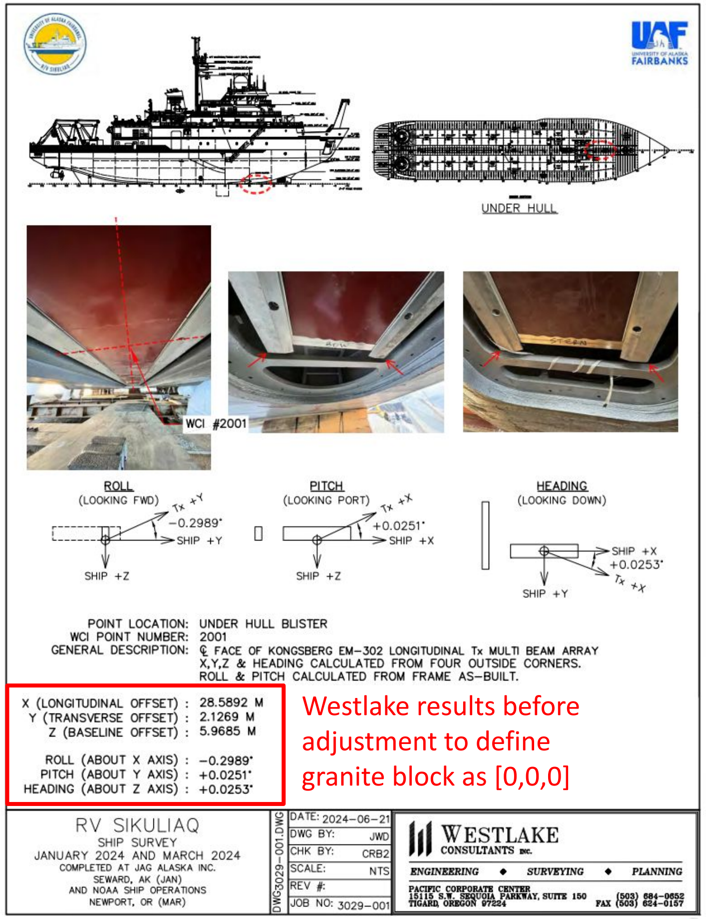
1. The configurations below reflect the final survey results with adjustments to define the granite block origin at [0,0,0]; these values should remain unchanged until the MGC or antennas are moved (and re-surveyed)
2. Initial **Attitude 1** installation angles in SIS were left unchanged from their post-SAT values prior to calibration (i.e., verification)

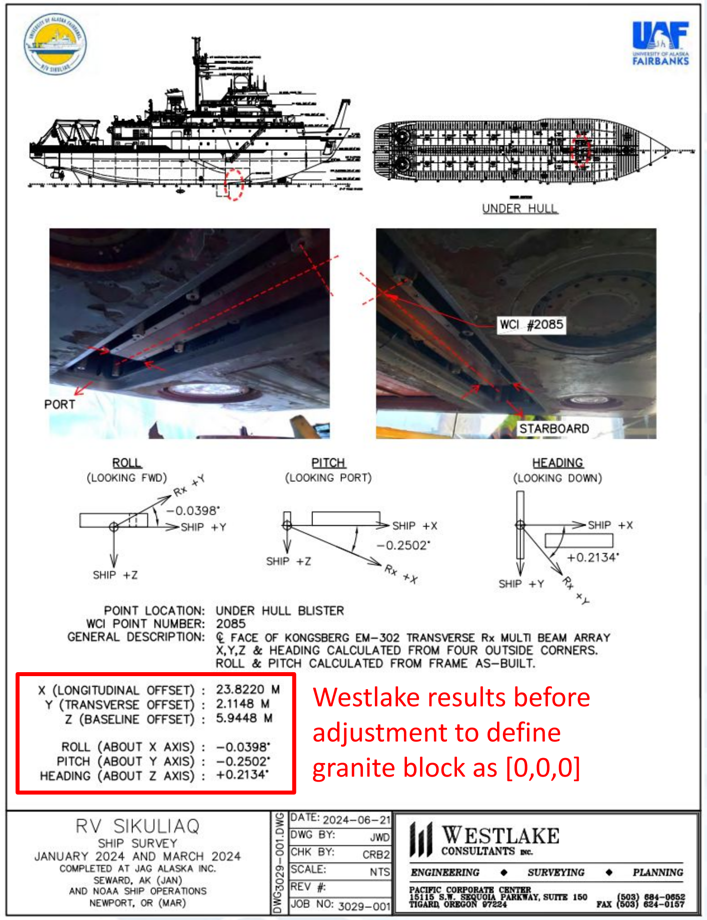


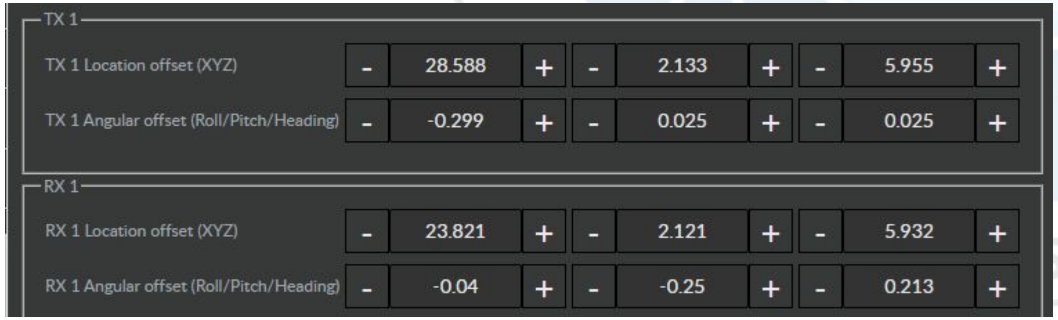


System Geometry Review

EM304 TX & RX Offsets







- Prior to SKQ202503S, linear offsets of the **EM304** array face centers were adjusted using the final Westlake report (2024-06-21) to define the granite block at [0,0,0], as described for the Seapath and EM710 systems as well
- Angular offsets remain unchanged from the 2024 SAT configuration review and final report
- EM304 array Installation Parameters were configured in SIS as follows for SKQ202503S:

EM304 TX Transducer from Granite Block at [0,0,0]

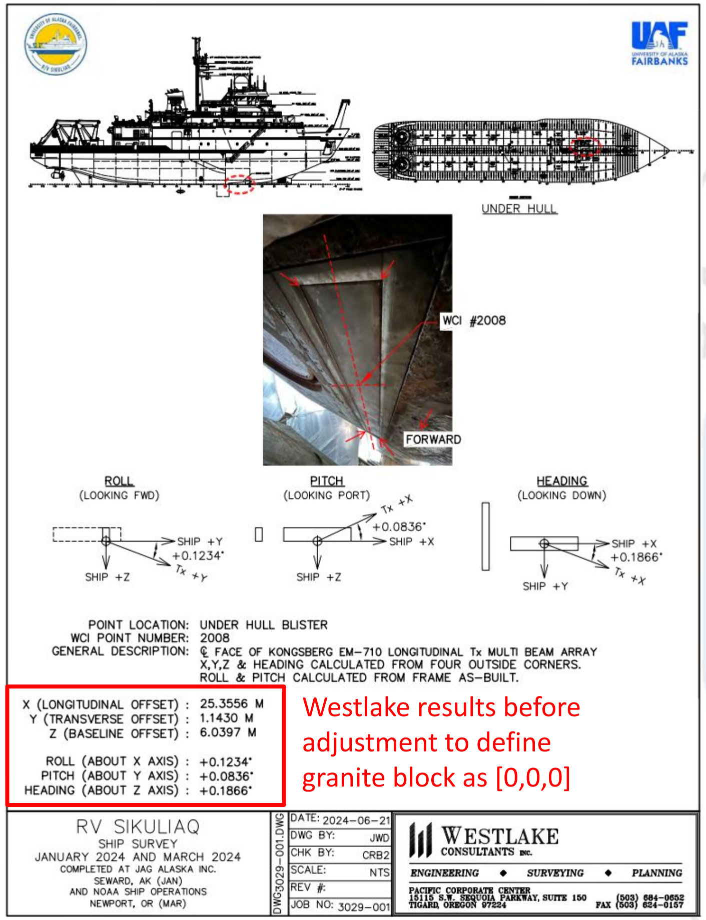
X: +28.588 m	**Roll: -0.299°**
Y: +2.133 m	**Pitch: +0.025°**
Z: +5.955 m	**Heading: +0.025°**

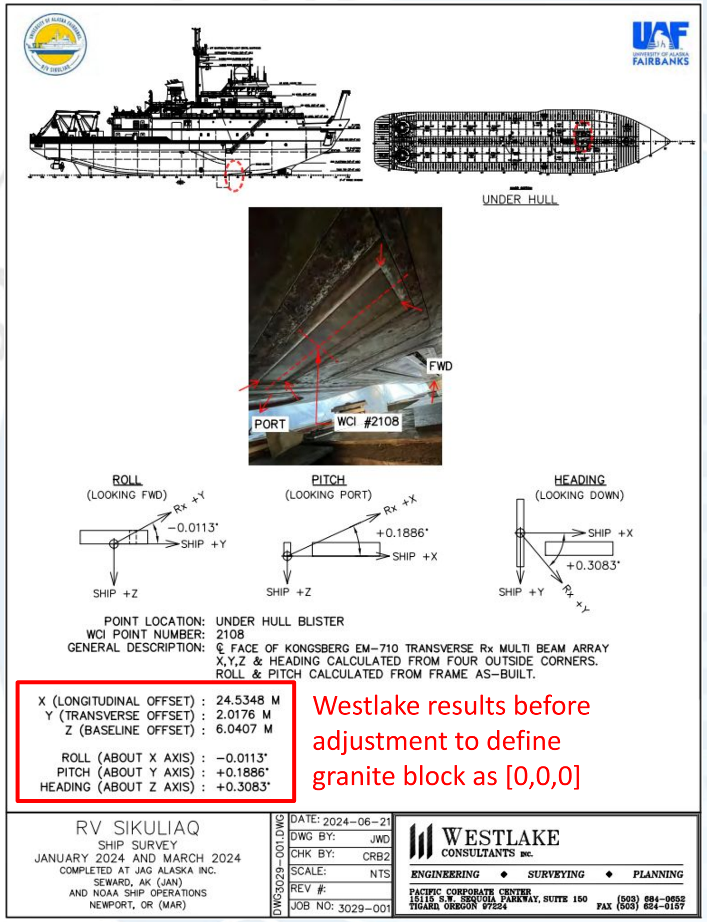
EM304 RX Transducer from Granite Block at [0,0,0]

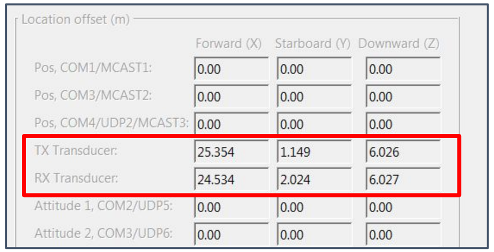
X: +23.821 m	**Roll: -0.040°**
Y: +2.121 m	**Pitch: -0.250°**
Z: +5.932 m	**Heading: +0.213°**

System Geometry Review

EM710 TX & RX Offsets

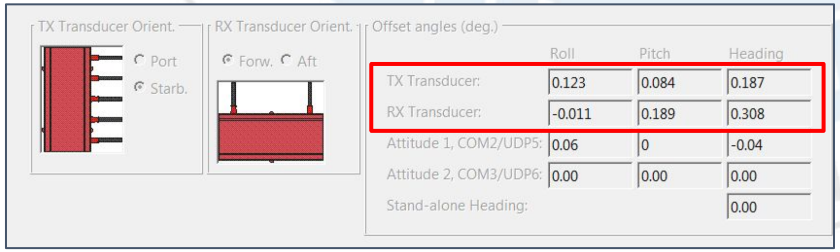






Location offset (m)

	Forward (X)	Starboard (Y)	Downward (Z)
Pos, COM1/MCAST1:	0.00	0.00	0.00
Pos, COM3/MCAST2:	0.00	0.00	0.00
Pos, COM4/UDP2/MCAST3:	0.00	0.00	0.00
TX Transducer:	25.354	1.149	6.026
RX Transducer:	24.534	2.024	6.027
Attitude 1, COM2/UDP5:	0.00	0.00	0.00
Attitude 2, COM3/UDP6:	0.00	0.00	0.00



TX Transducer Orient. ○ Port ⊙ Starb.

RX Transducer Orient. ⊙ Forw. ○ Aft

Offset angles (deg.)

	Roll	Pitch	Heading
TX Transducer:	0.123	0.084	0.187
RX Transducer:	-0.011	0.189	0.308
Attitude 1, COM2/UDP5:	0.06	0	-0.04
Attitude 2, COM3/UDP6:	0.00	0.00	0.00
Stand-alone Heading:			0.00

- Prior to SKQ202503S, linear offsets of the **EM710** array face centers were adjusted using the final Westlake report (2024-06-21) to define the granite block at [0,0,0], as described for the Seapath and EM304 systems as well
- Angular offsets remain unchanged from the 2024 SAT configuration review and final report
- EM710 array Installation Parameters were configured in SIS as follows for SKQ202503S:

EM710 TX Transducer from Granite Block at [0,0,0]

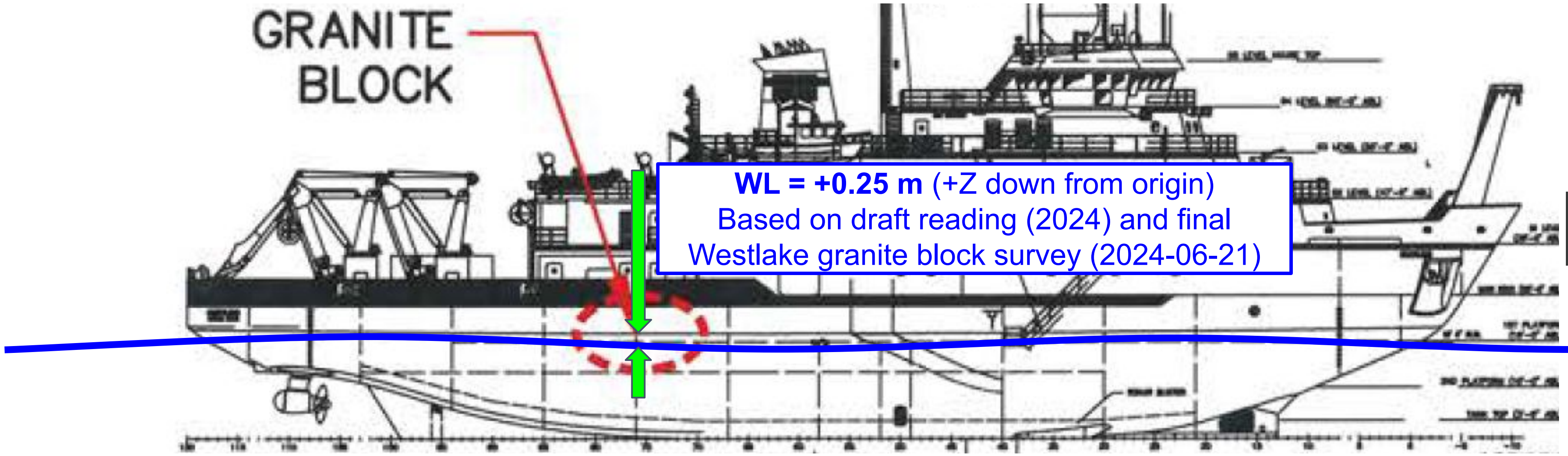
X: +25.354 m	**Roll: +0.123°**
Y: +1.149 m	**Pitch: +0.084°**
Z: +6.026 m	**Heading: +0.187°**

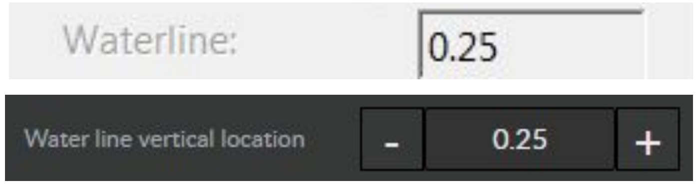
EM710 RX Transducer from Granite Block at [0,0,0]

X: +24.534 m	**Roll: -0.011°**
Y: +2.024 m	**Pitch: +0.189°**
Z: +6.027 m	**Heading: +0.308°**

Waterline Calculation

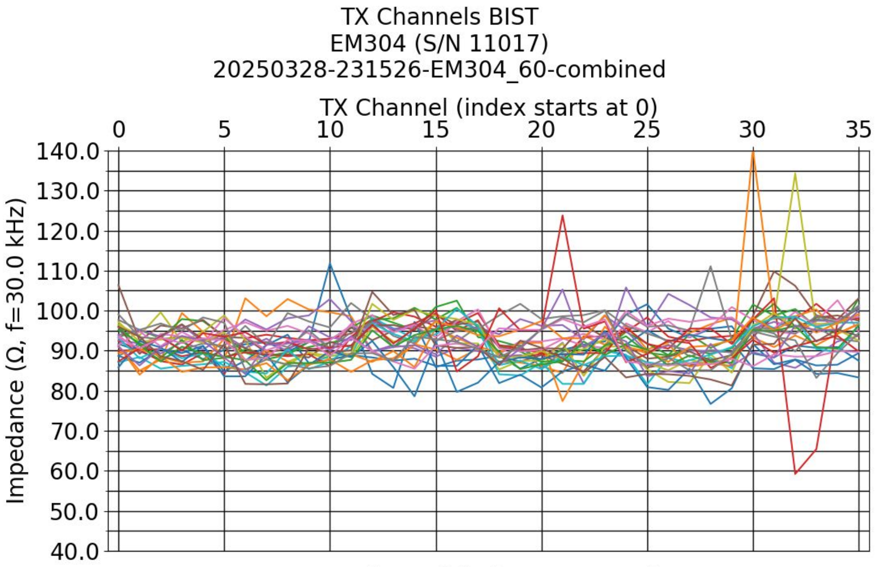
1. Waterline relative to the origin was calculated from dockside draft readings using the publicly available MAC Waterline Worksheet during the 2024 SAT; no new draft readings were taken during the 2025 QAT
2. Waterline was adjusted to reflect the final granite block survey, defining it as the origin at [0,0,0]; *because all mapping sensor configurations were updated consistently to maintain the same reference system, there is no net change in reported depths associated with this waterline parameter adjustment in SIS*
3. The completed worksheet can be updated with new draft readings as loading changes for the vessel
4. Bow and stern draft readings were taken in 2024 and translated into an updated SIS WL for SKQ202503S
   - 2024-02-26 Bow: 19.50 ft Stern: 18.75 ft **Waterline: +0.25 m** (+Z down from origin)

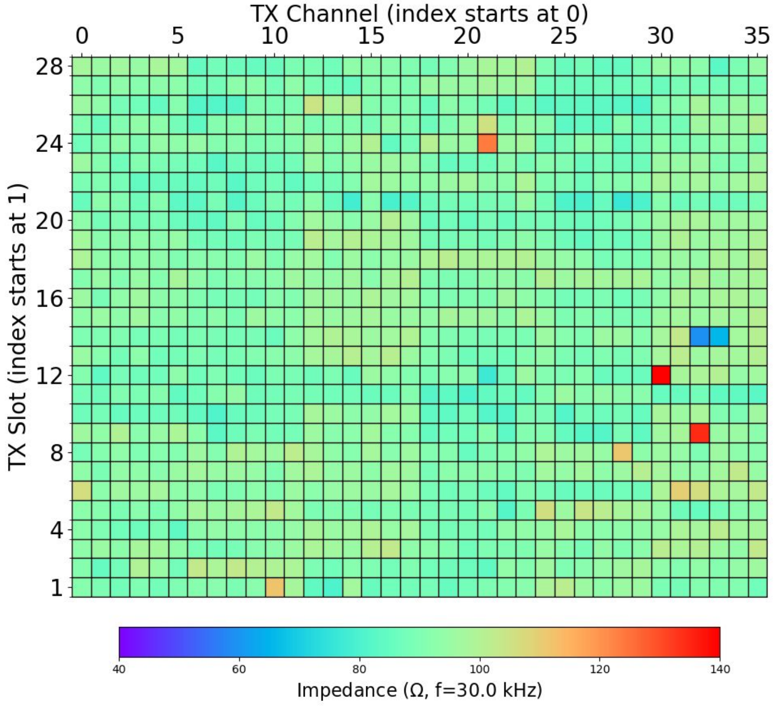




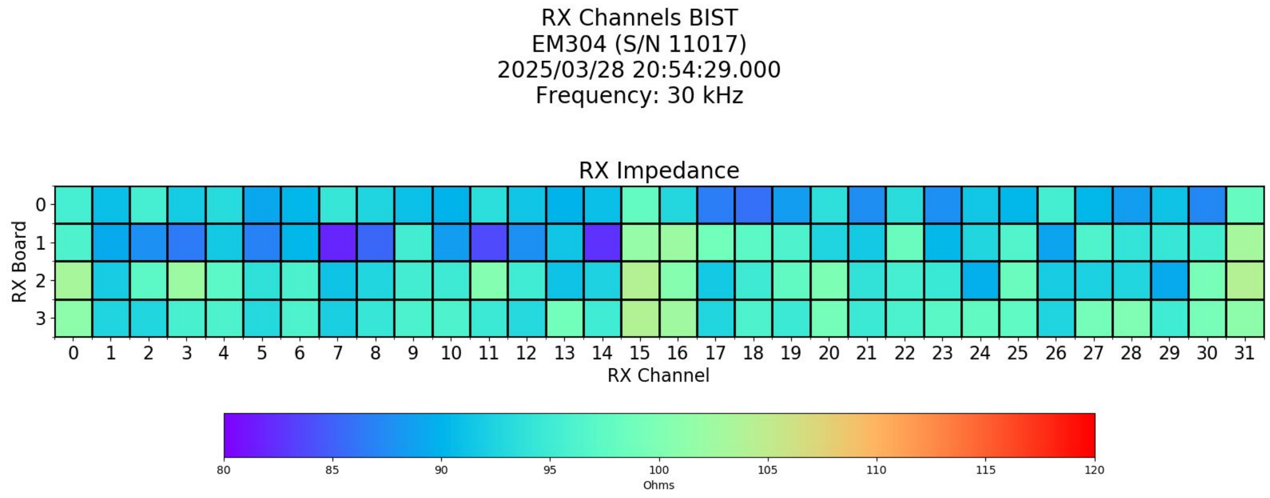
Hardware Health

EM304 Hardware Health TX/RX Channels





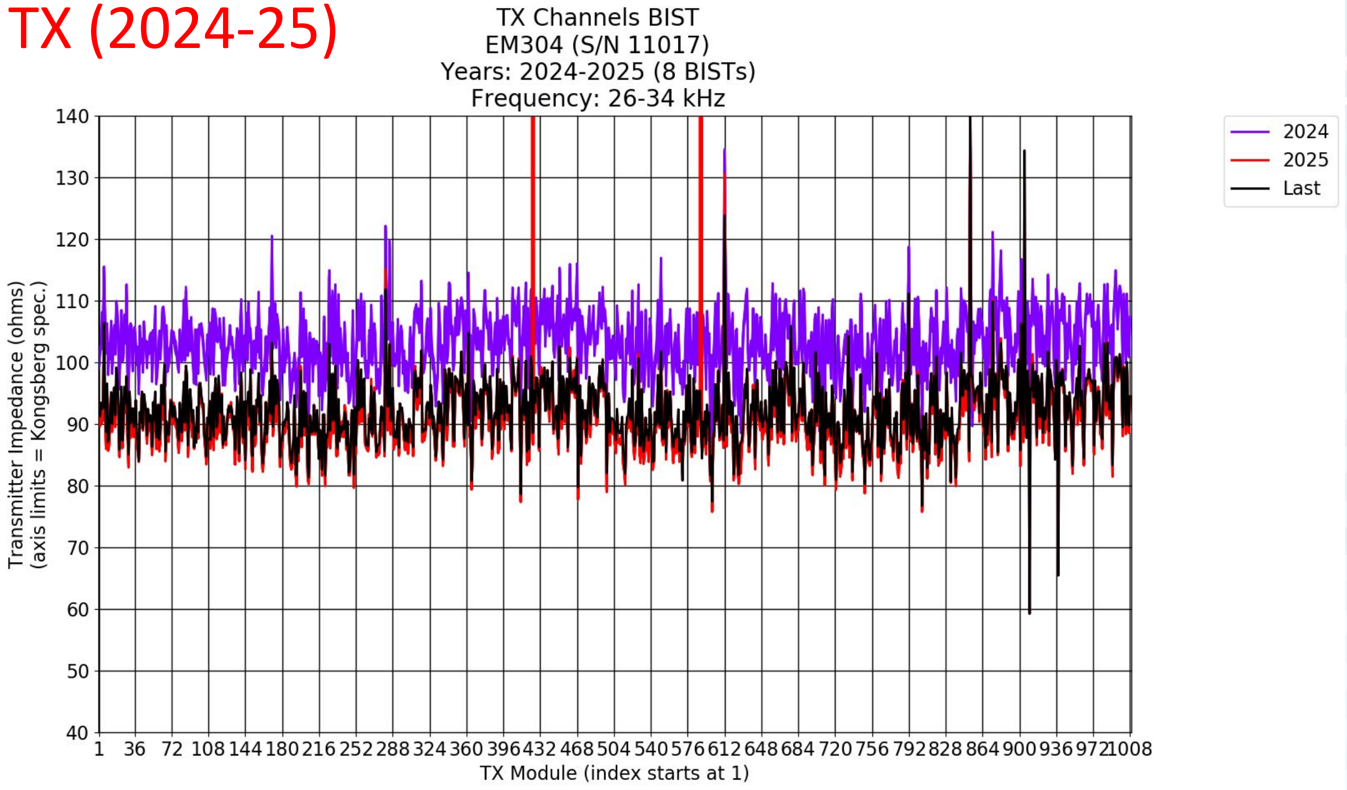
1. Built-In Self-Tests (BISTs) were collected throughout the QAT and after array cleaning (shown here), including TX and RX Channels as proxies for hardware health
2. The color scale on each plot is based on the acceptable impedance range to pass a BIST, as defined by Kongsberg
3. The 2025 results show some variability from 2024 that should be monitored with routine TX and RX Channels BISTs (e.g., at the start and end of every cruise)



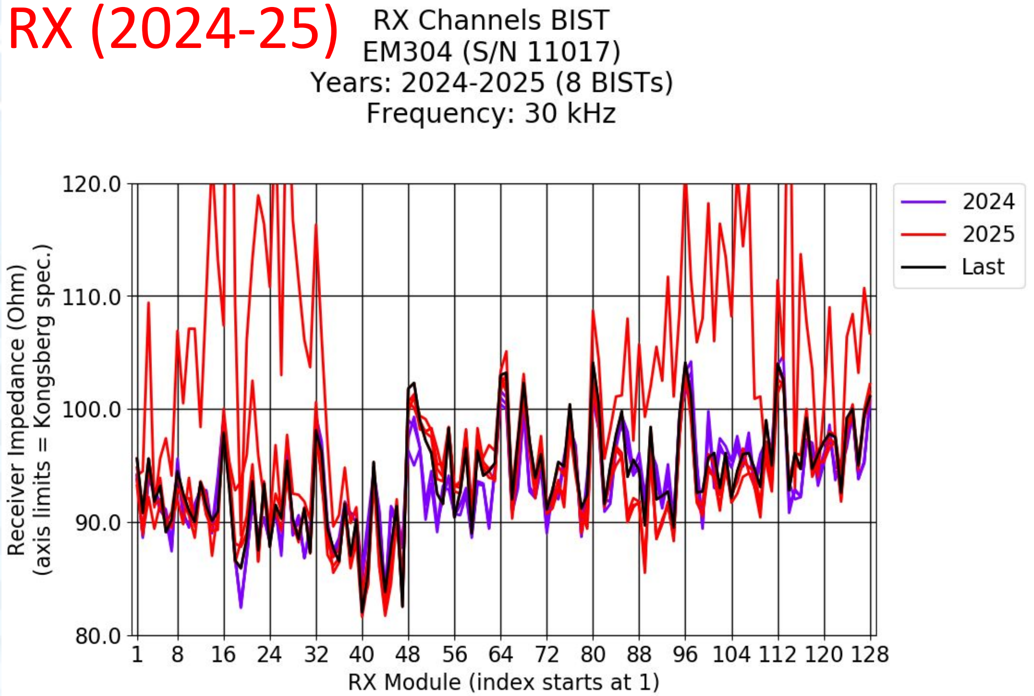
EM304 Hardware Health

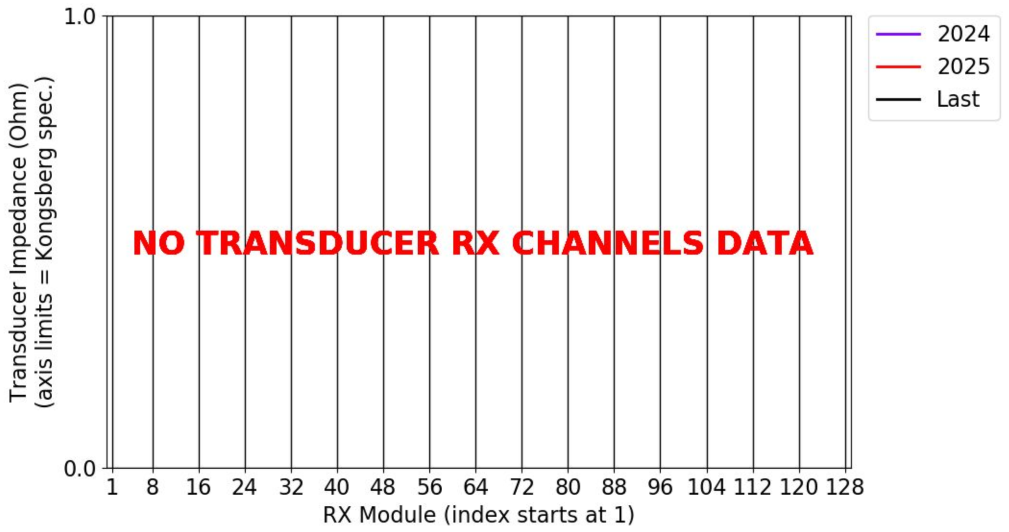
TX/RX Channels History

TX (2024-25)



RX (2024-25)





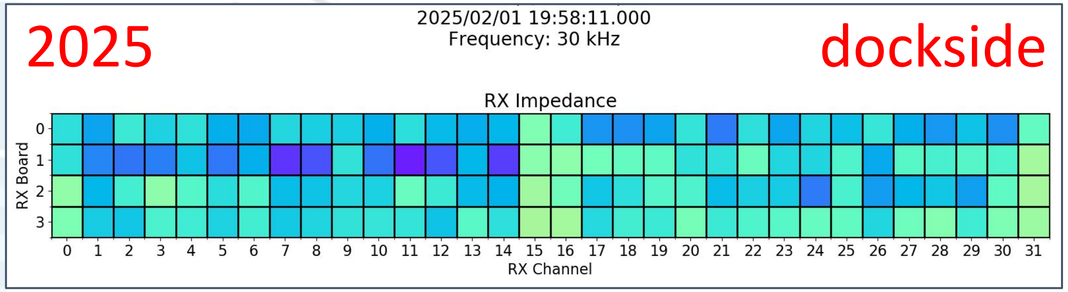
1. The 2025 TX Channels results show a few anomalous elements not present in 2024; these should be monitored with routine BISTs
2. RX Channels tests show variable results during SKQ202503S; although these 'passed' the Kongsberg thresholds, and the trends improved after cleaning in March, the variable nature warrants monitoring with routine BISTs (see next slides)

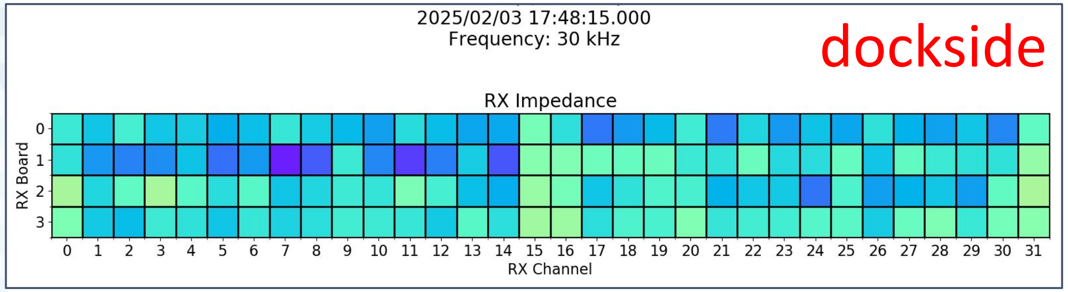
**Note: the SIS 5 BIST format does not include separate transducer results*

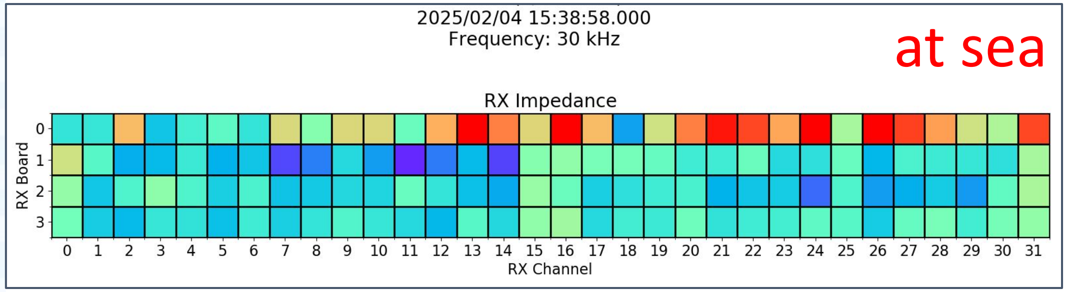
EM304 Hardware Health

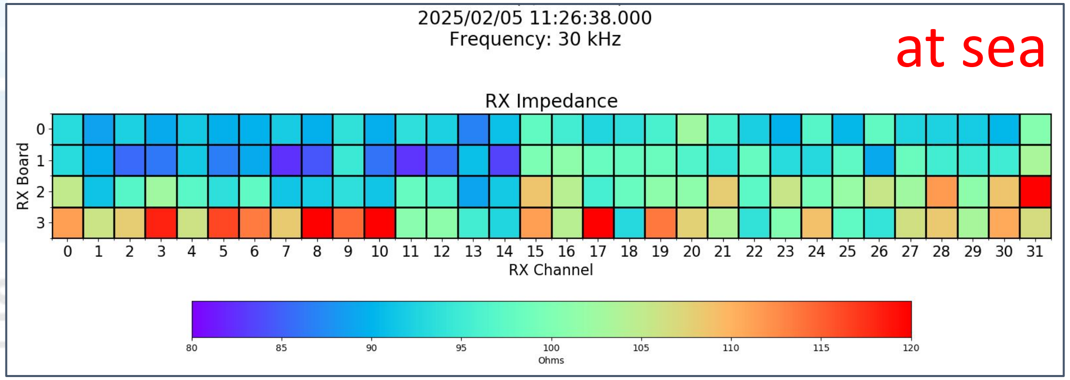
RX Channels Variability (pre-clean)

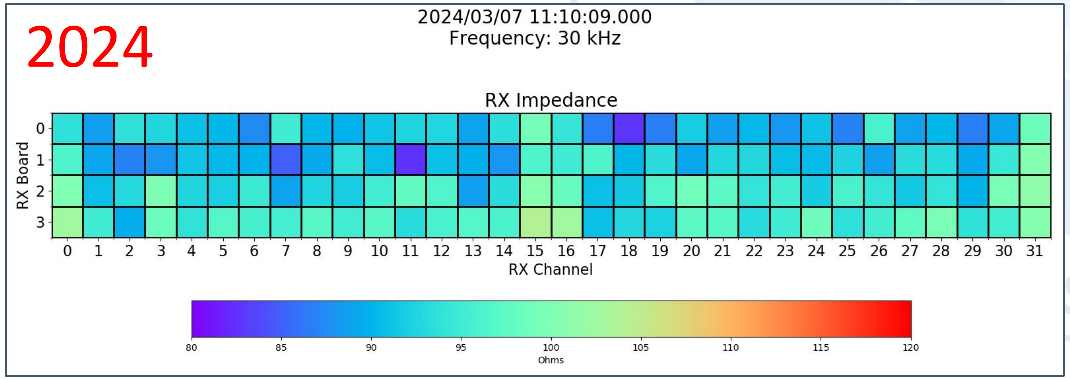
1. The last RX Channels result from the 2024 SAT is shown below for reference; four tests from the 2025 QAT are shown at right
2. The first two tests (2025 Feb 1 and 3) were collected dockside and resemble the last 2024 tests below
3. The two at-sea tests (2025 Feb 4 and 5) show high-Z results along the varying groups of channels; the root cause of these is not clear, but may be related to bubbles or sea state while underway, potentially complicated by heavy biofouling
4. BISTs collected after array cleaning in March show a return toward normal (see previous slides)
5. Routine BISTs should be collected ('run all BISTs') and may be sent to the MAC for monitoring or plotted on-board with the [MAC BIST Plotter]





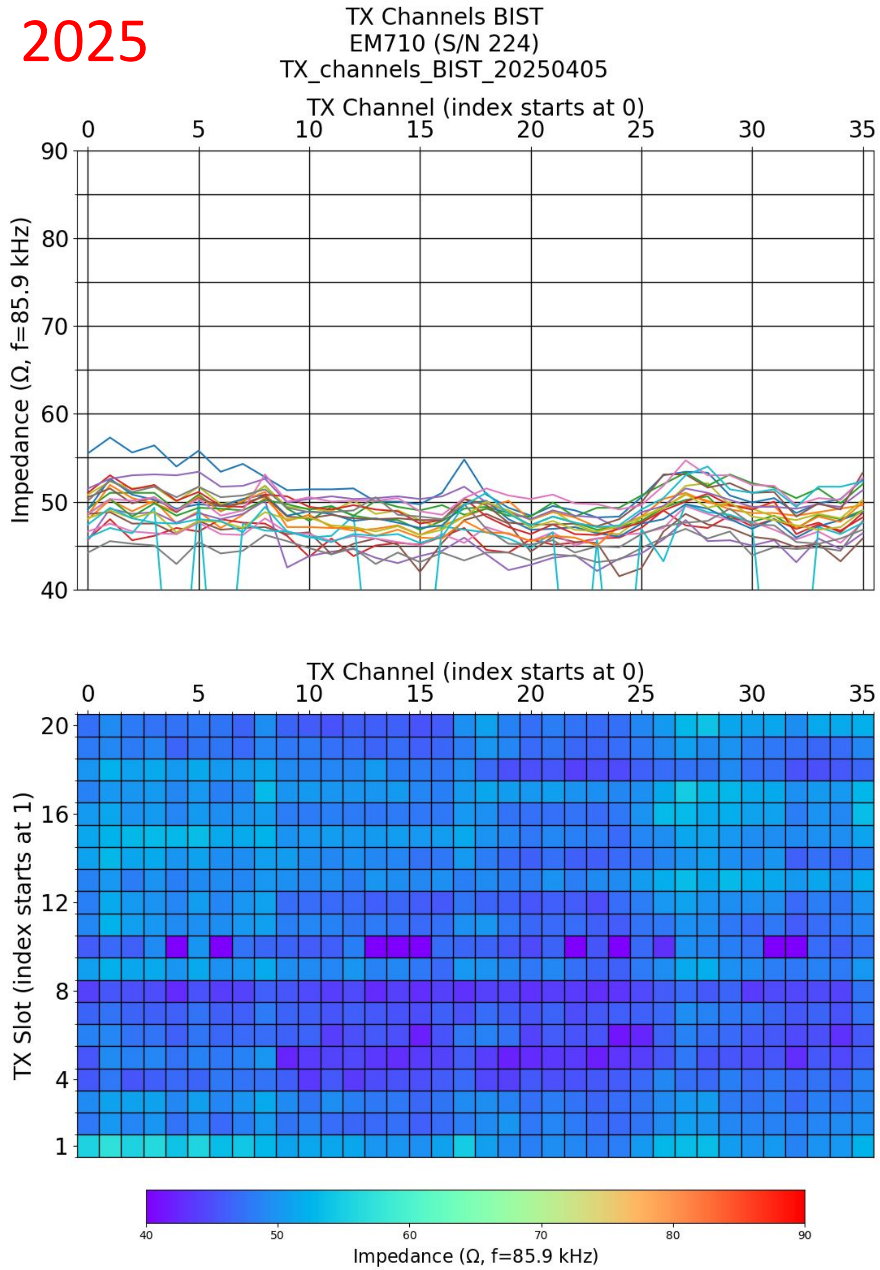




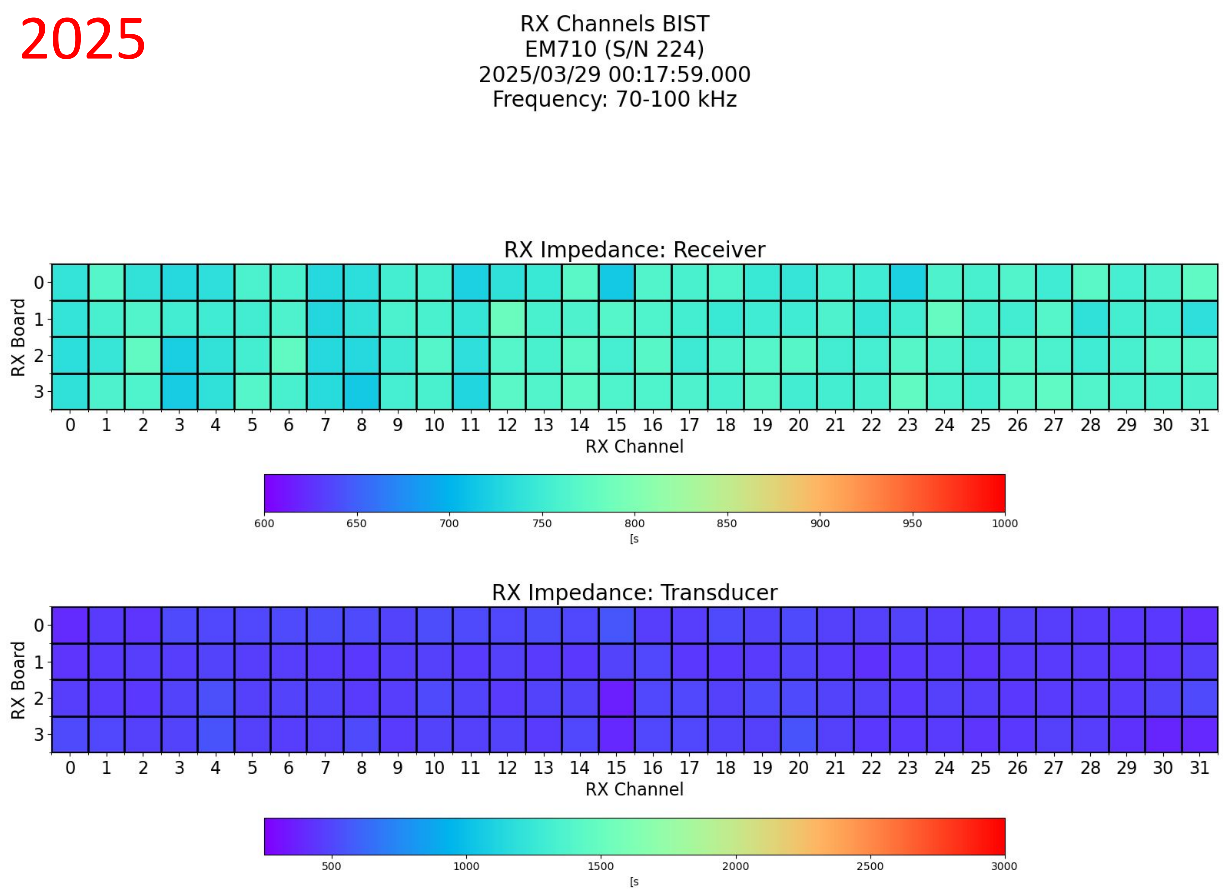


EM710 Hardware Health

TX/RX Channels



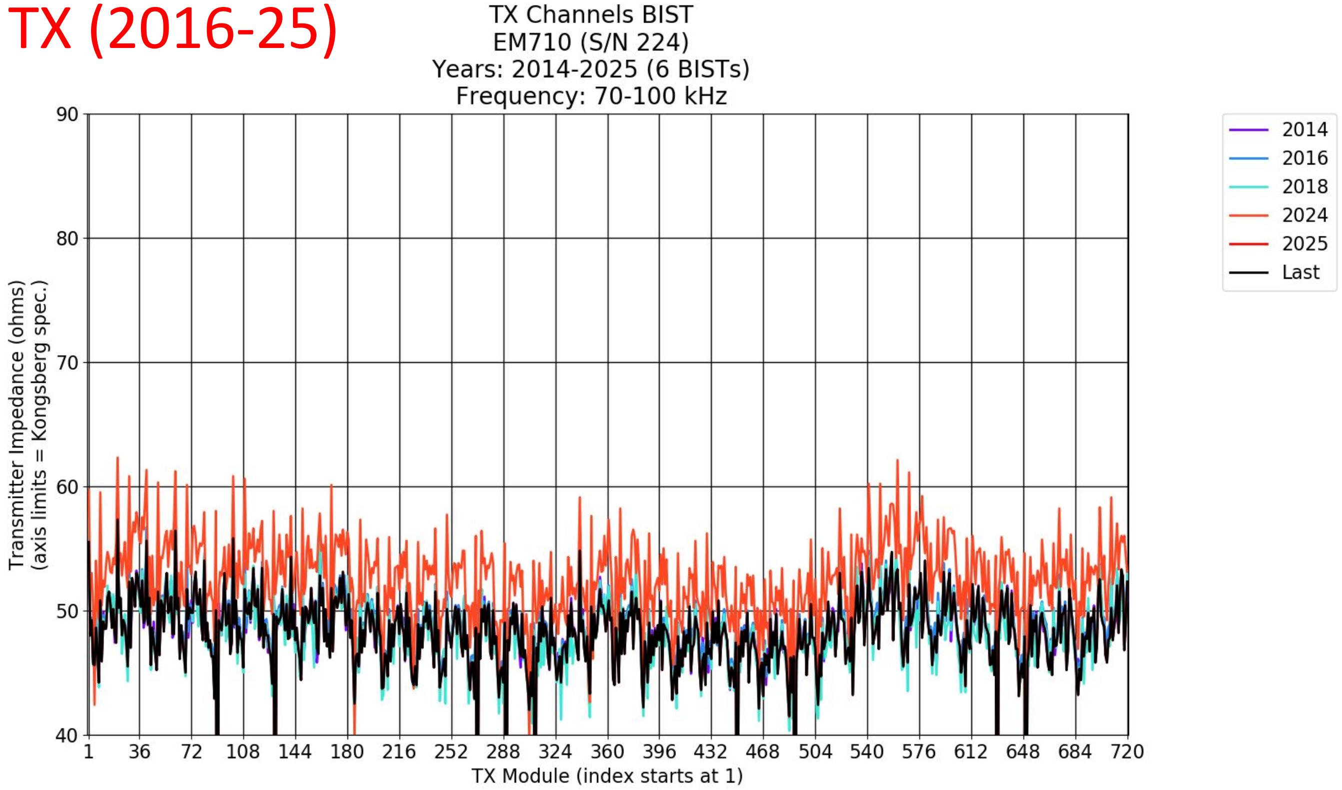
1. EM710 TX/RX Channels BISTs were run after cleaning the arrays and correcting a TX cable error (see executive summary)
2. The EM710 hardware is showing signs of degradation that are expected for its age; fortunately, some anomalous channels observed during the QAT appear resolved in this latest test



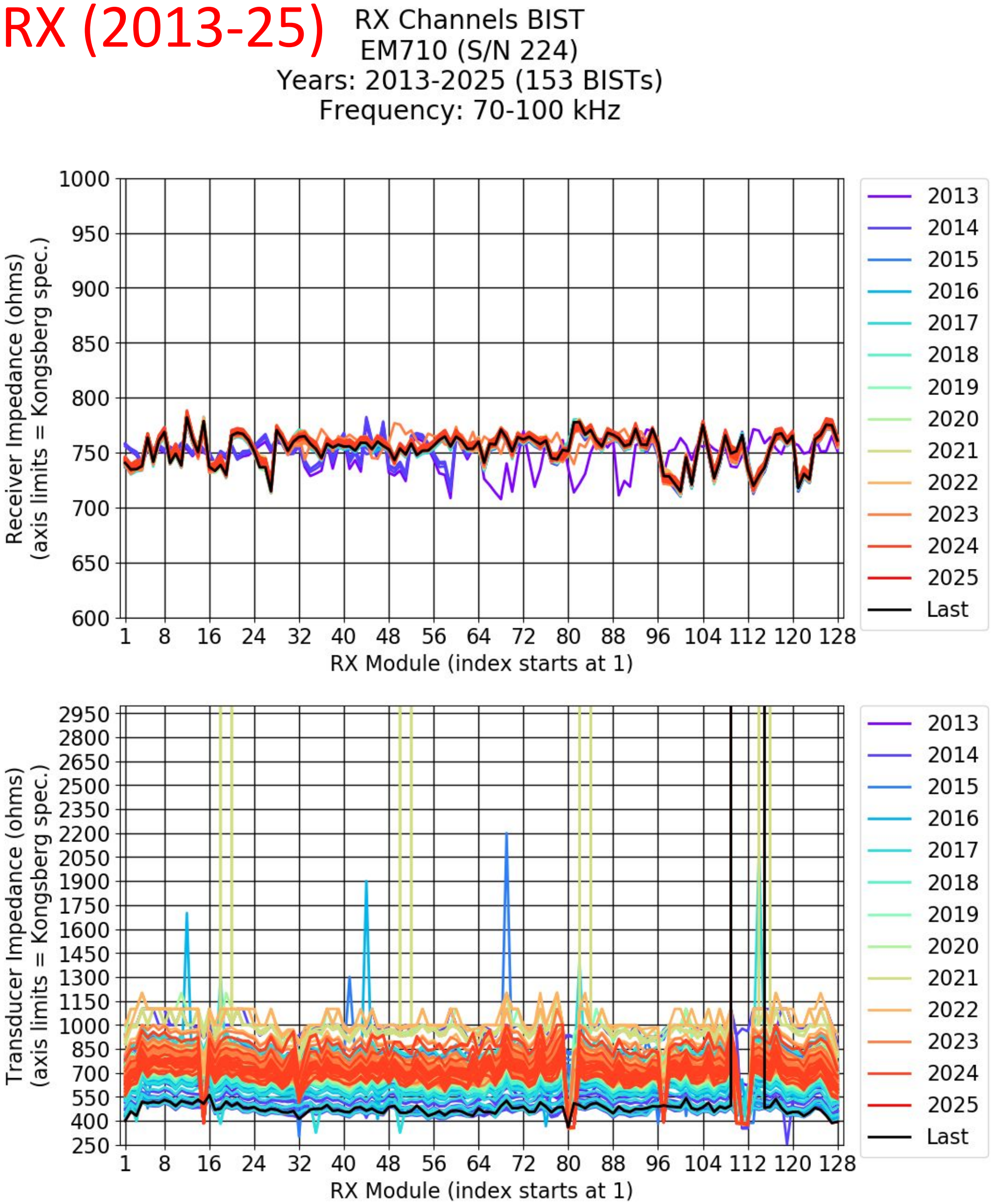
EM710 Hardware Health

TX/RX Channels History

TX (2016-25)



RX (2013-25)



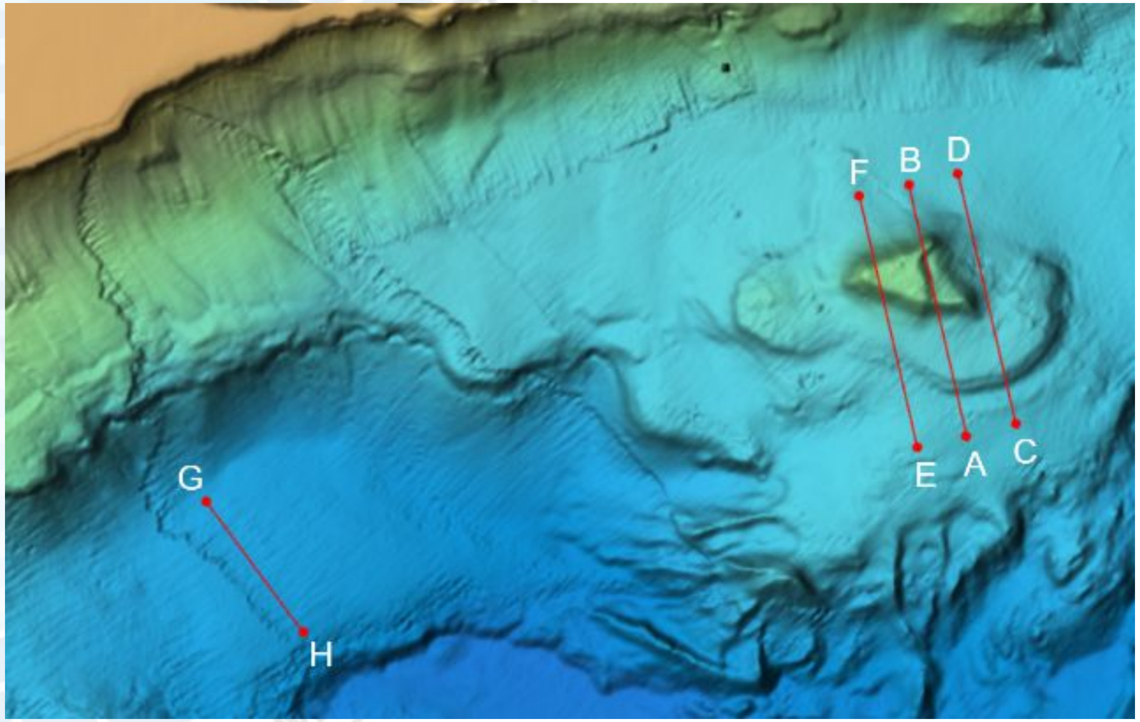
1. TX Channels are run through telnet for SIS 4 (hence the small number of tests over the service life); TX results show increasing counts of 'low' element values over the available history (2016-25)
2. RX Channels tests are included in the EM710 BIST archive from installation (2013), showing the downward trend in RX Z toward the lower limit from Kongsberg; compared to the 2024 report, this plot includes many additional tests that were found in the archive

Calibration

EM304 Calibration **Planning**

1. Calibration planning for both systems revolved around weather protection in the prevailing winter winds / swell
2. A calibration site was developed for E/V *Nautilus* (see NA136 report) in 2022 in the lee of Molokai and Lanai for these same reasons; this site was reoccupied with R/V *Sikuliaq* for EM304 calibration (verification) as the first priority in 2025

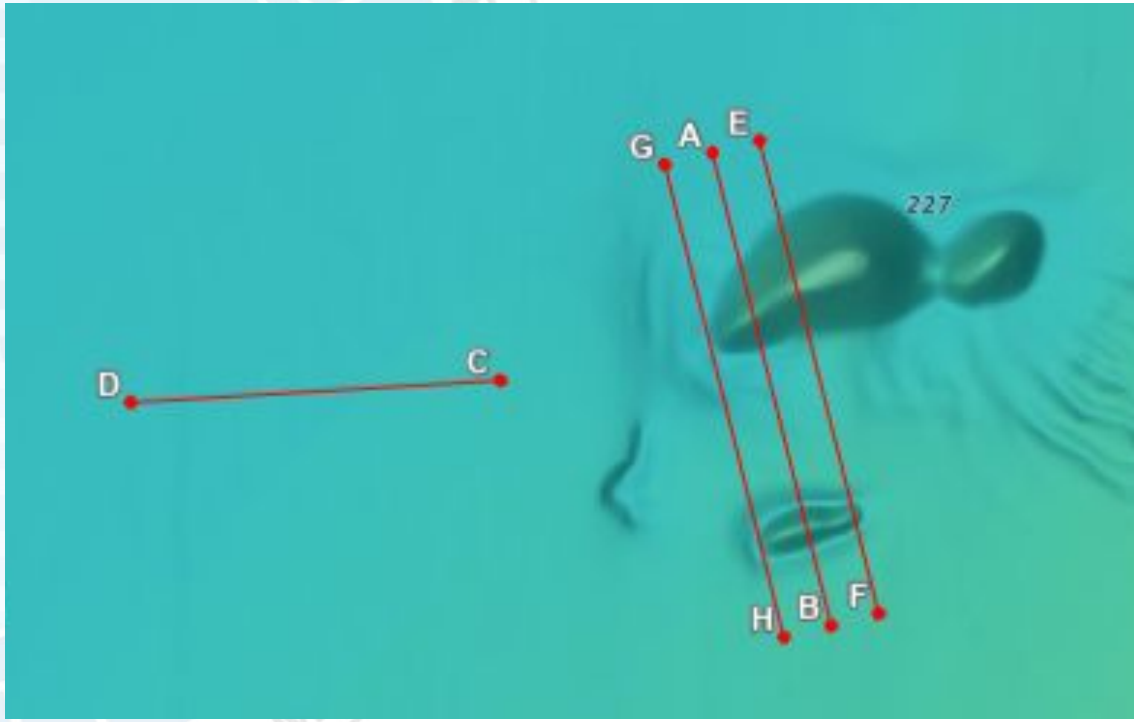
	Waypoint	Decimal Degrees		Degrees Decimal Minutes			
		Lat.	Lon.	Lat. Deg.	Lat. Min.	Lon. Deg.	Lon. Min.
Pitch	A	20.834800	-157.372700	20	50.088	-157	22.362
	B	20.892633	-157.386992	20	53.558	-157	23.220
Roll	C	20.837430	-157.360511	20	50.246	-157	21.631
	D	20.895263	-157.374803	20	53.716	-157	22.488
Heading 1	E	20.832170	-157.384888	20	49.930	-157	23.093
	F	20.890003	-157.399179	20	53.400	-157	23.951
Heading 2	G	20.819680	-157.560778	20	49.181	-157	33.647
	H	20.789344	-157.536762	20	47.361	-157	32.206



EM710 Calibration **Planning**

1. EM710 calibration (verification) was carried out at a proven site that has been used repeatedly by other vessels (e.g., *Kilo Moana* and *Falkor*)
2. This site is more exposed than the EM304 site, and EM710 calibration was scheduled later in the QAT for the calmest weather window (i.e., lower priority than EM304 SAT follow-up in deep water)

	Waypoint	Decimal Degrees		Degrees Decimal Minutes			
		Lat.	Lon.	Lat. Deg.	Lat. Min.	Lon. Deg.	Lon. Min.
Pitch	A	21.031712	-157.775900	21	1.903	-157	46.554
	B	20.996824	-157.766507	20	59.809	-157	45.990
Roll	C	21.014919	-157.792590	21	0.895	-157	47.555
	D	21.013300	-157.821740	21	0.798	-157	49.304
Heading 1	E	21.032589	-157.772162	21	1.955	-157	46.330
	F	20.997701	-157.762769	20	59.862	-157	45.766
Heading 2	G	21.030835	-157.779638	21	1.850	-157	46.778
	H	20.995947	-157.770245	20	59.757	-157	46.215

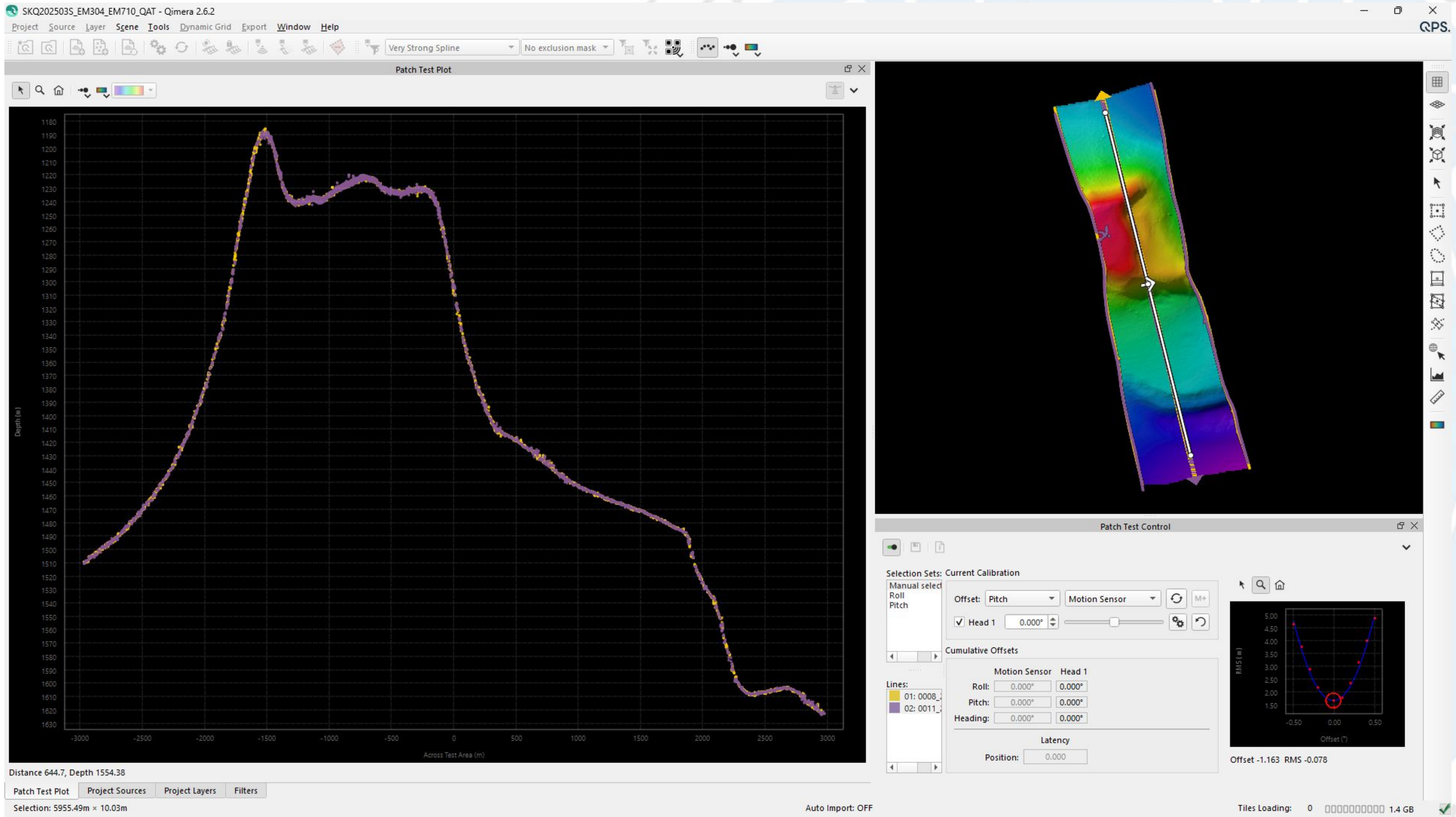


EM304/EM710 Calibration **Data Collection and Processing**

1. As no physical modifications were made to the mapping system since the 2024 SAT, the SKQ202503S calibrations were carried out to verify consistency of the 2024 results after updating all sensors with the final (post-SAT) surveyed granite block location as the origin
2. Sound speed profiles were acquired with CTDs, processed in Sound Speed Manager, and applied in SIS throughout the calibration steps for each system
3. Calibration data were examined by MAC and UAF personnel on board in SIS and Qimera to determine results
4. During Qimera analysis, files were processed with nearest-in-time sound speed scheduling, edited to remove outlier soundings, and then scrutinized with the patch test tool using a combination of
   a. visual assessment and adjustment of the biases across a wide variety of data subsets
   b. ‘Autosolver’ method to confirm minimum RMS differences between suitable subsets
5. The result of each calibration step was updated in the *SIS Installation Parameters* prior to data collection of the subsequent test (e.g., applying the pitch result before roll calibration)
6. Results were small, suggesting stable system geometry since the 2024 SAT and no obvious complications associated with the final granite block survey adjustments
7. Final results applied in the EM304 and EM710 should remain unchanged until sensors are modified, routine assessment, or the need for additional patch testing is indicated by bathymetric artifacts

EM304 Calibration

Results: Pitch (Seapath)

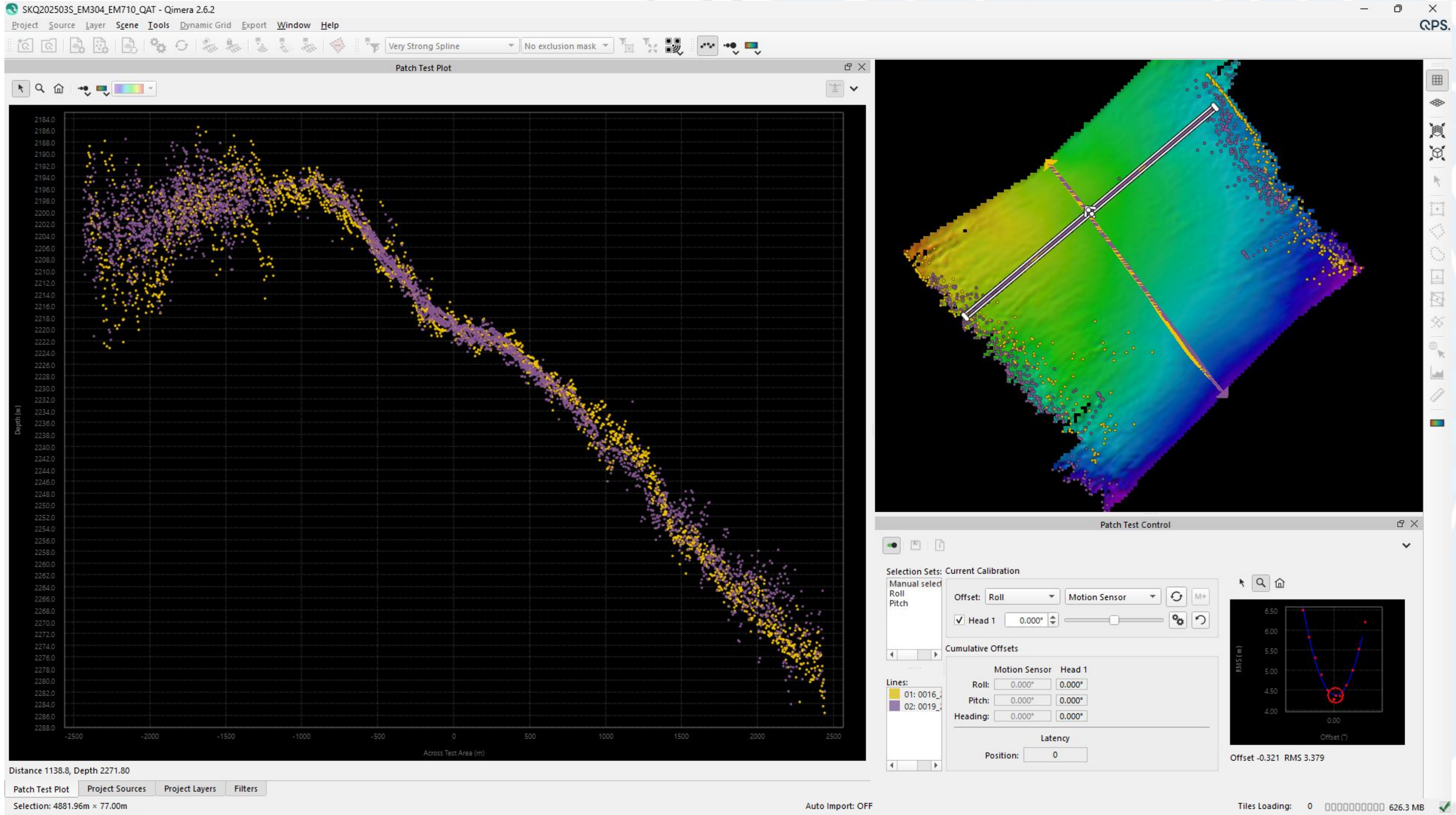


Pitch verification lines shown at left in the Qimera Patch Test Tool

1. Attitude 1 initial setting: -0.01°
2. Verification adjustment: -0.01°
3. **Final pitch offset: -0.02° in SIS**

EM304 Calibration

Results: Roll (Seapath)



Roll verification lines shown at left in the Qimera Patch Test Tool

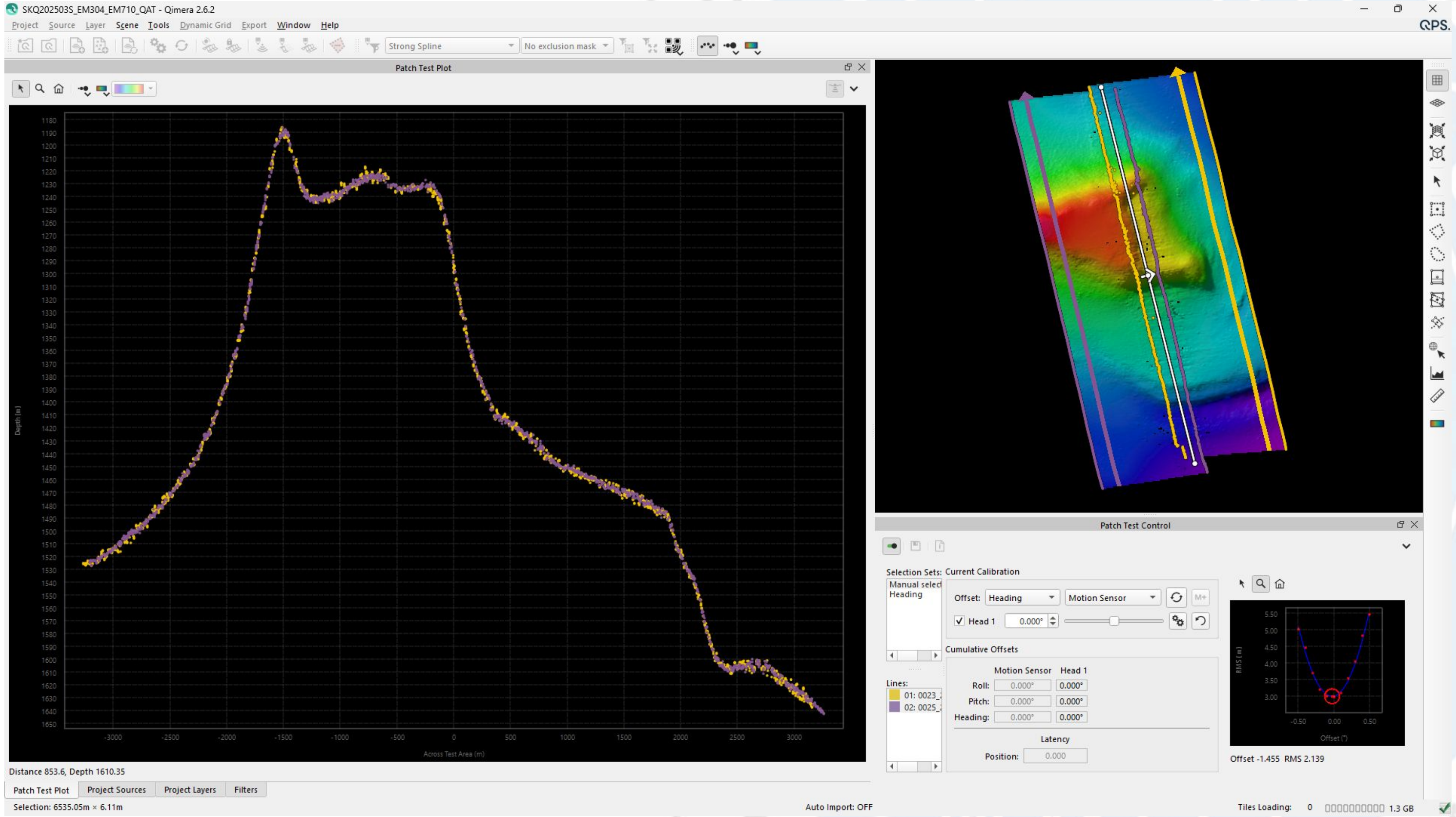
1. Attitude 1 initial setting: +0.09°
2. Verification adjustment: -0.02°
3. **Final roll offset: +0.07° in SIS**

Note: multiple small and large subsets were used for Qimera processing, with the final adjustment providing the minimum RMS difference between calibration passes; the small subset at left shows short-period outer swath variability (possibly from a dynamic sound speed environment and bubble sweep along the hull) that complicates analysis but does not change the mean final result

Left subplot: 30X vertical exaggeration

EM304 Calibration

Results: Heading (Seapath)

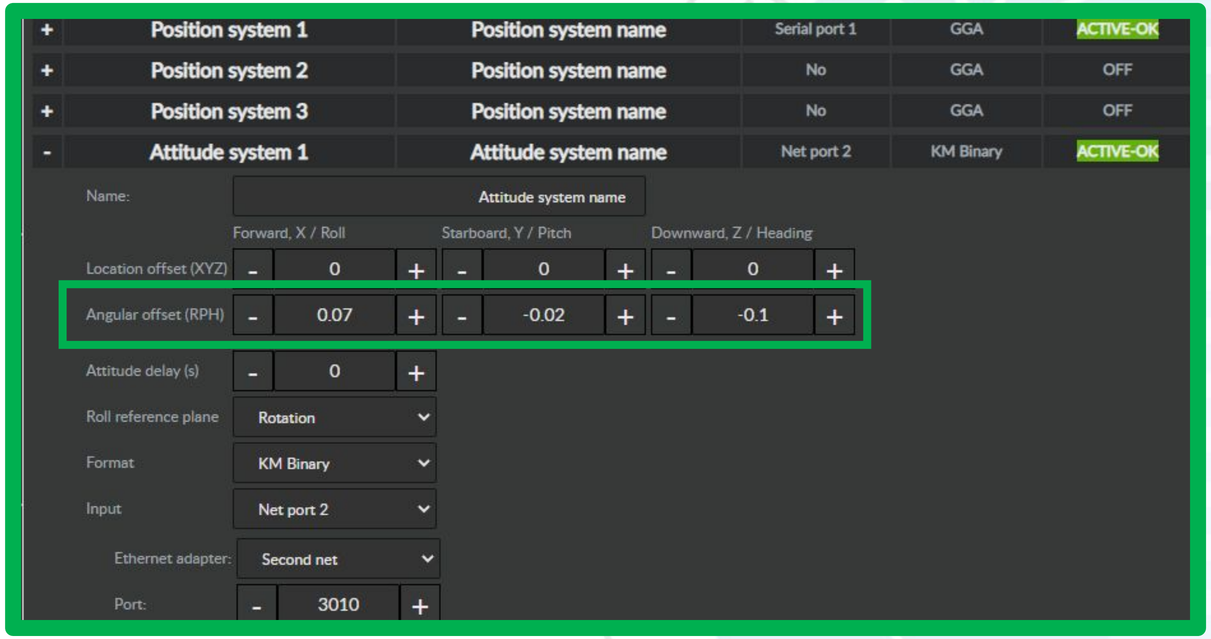


Heading verification lines shown at left in the Qimera Patch Test Tool

1. Attitude 1 initial setting: 0.00°
2. Verification adjustment: -0.10°
3. **Final heading offset: -0.10° in SIS**

EM304 Calibration

POST-CALIBRATION (EM304)

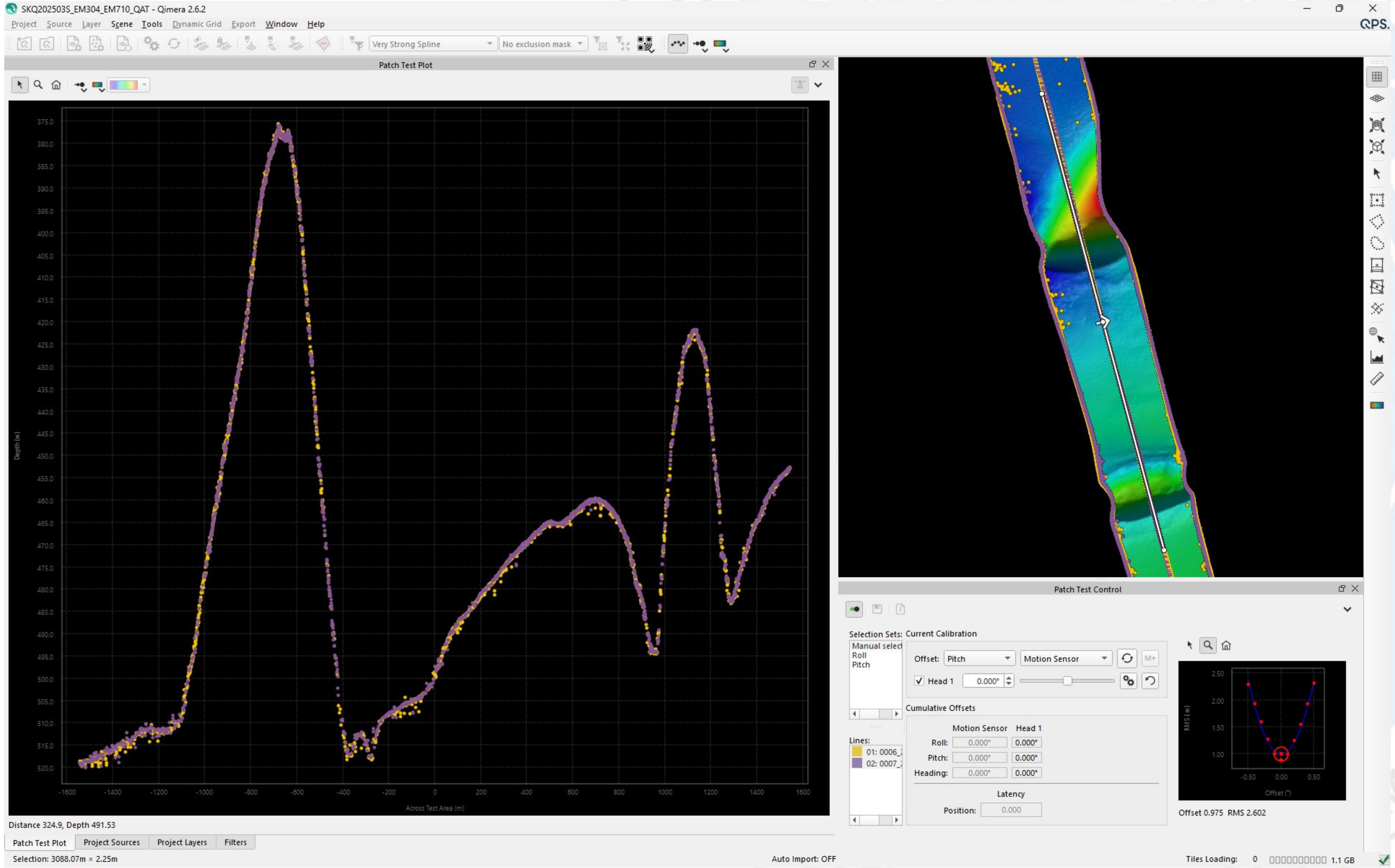


Post-Calibration Configuration

1. The EM304 *Attitude 1* adjustments made during SKQ202503S are small, suggesting stable system geometry and consistent sensor integration
2. The *Installation Parameters: Angular Offsets* shown at left should be maintained until any modification is made to the EM304 or Seapath, or a new calibration becomes necessary for other reasons

EM710 Calibration

Results: Pitch (Seapath)

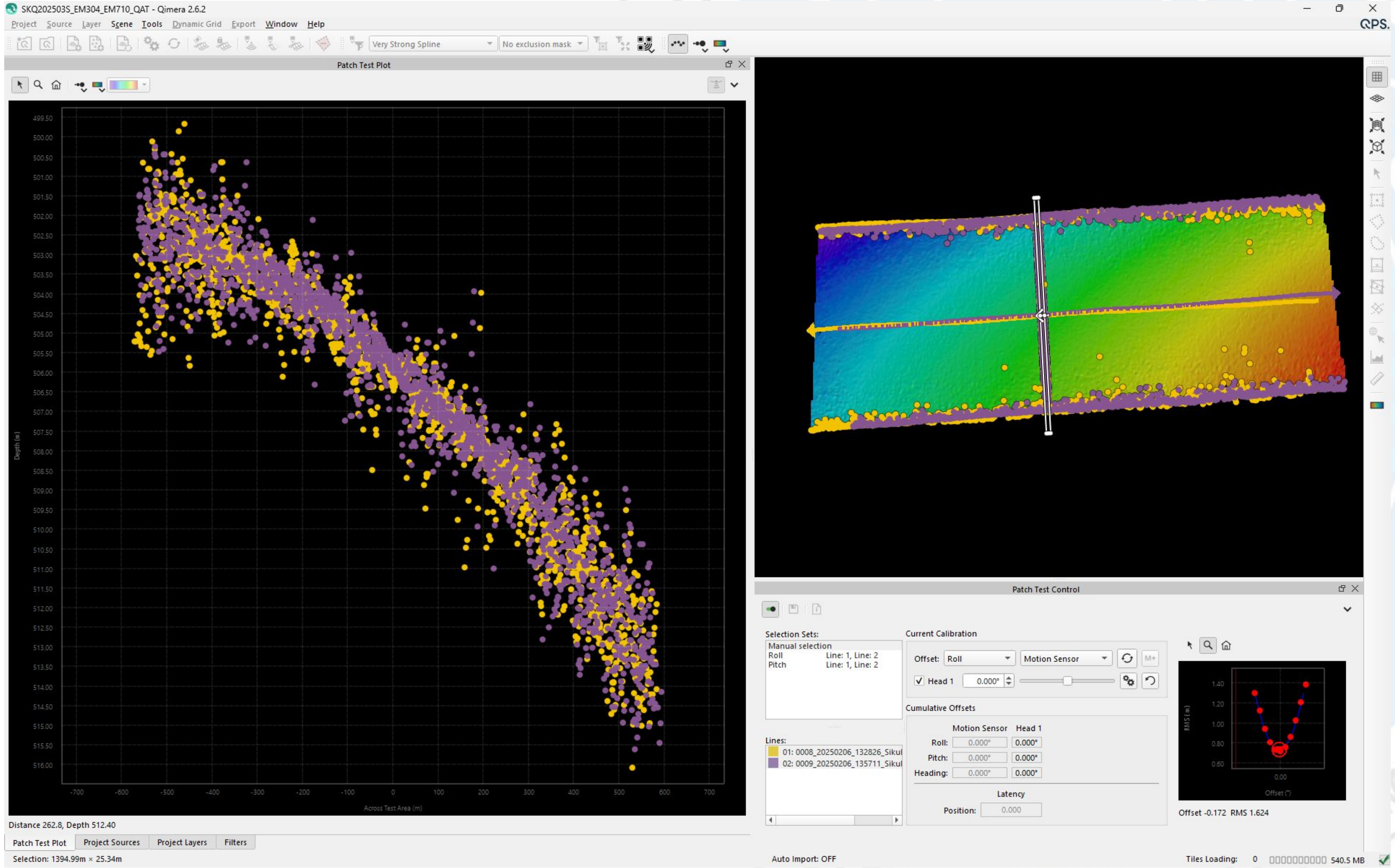


Pitch verification lines shown at left in the Qimera Patch Test Tool

1. Attitude 1 initial setting: 0.00°
2. Verification adjustment: 0.00°
3. **Final pitch offset: 0.00° in SIS**

EM710 Calibration

Results: Roll (Seapath)



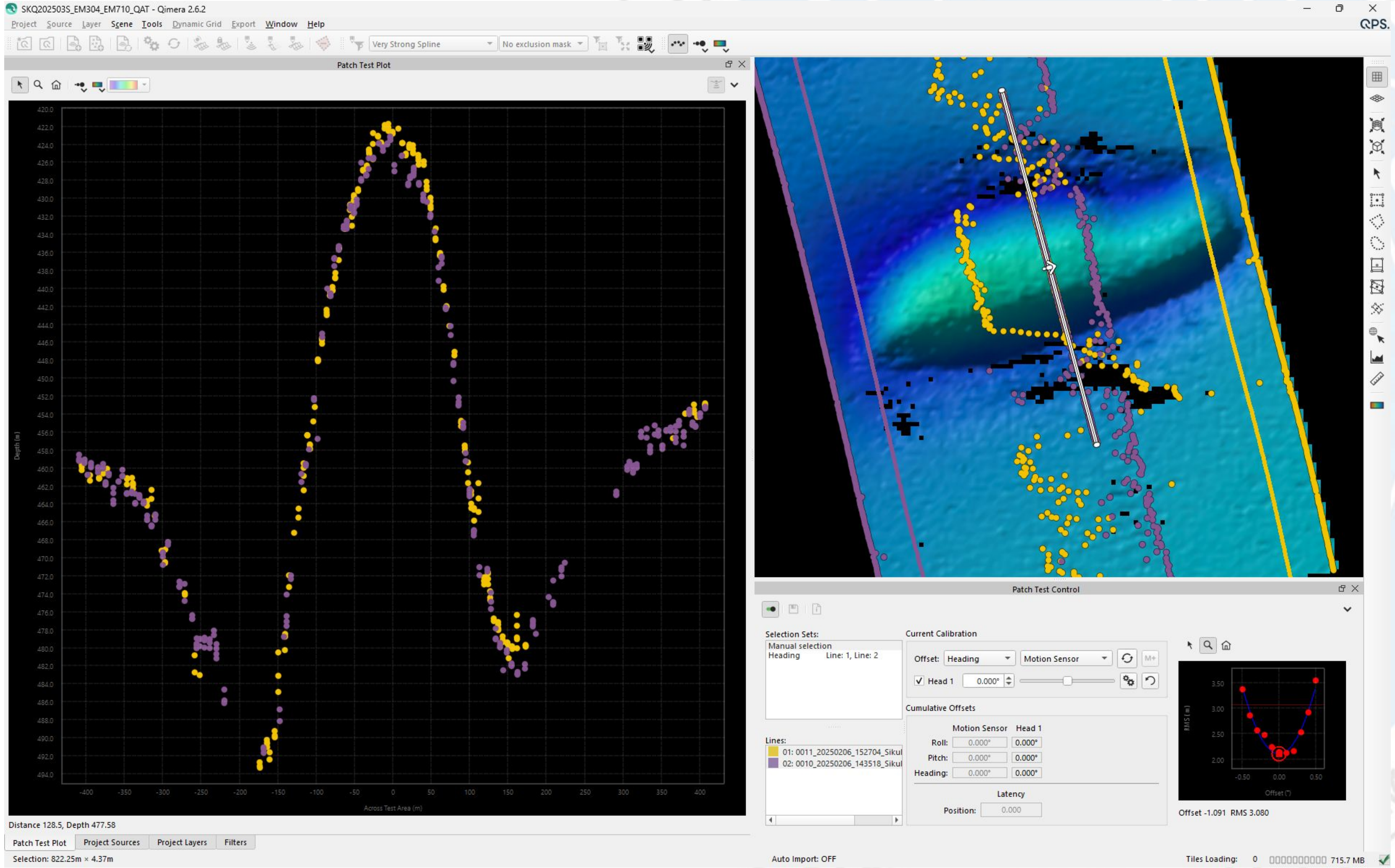
Roll verification lines shown at left in the Qimera Patch Test Tool

1. Attitude 1 initial setting: +0.07°
2. Verification adjustment: -0.01°
3. **Final roll offset: +0.06° in SIS**

Left subplot: 50X vertical exaggeration

EM710 Calibration

Results: Heading (Seapath)



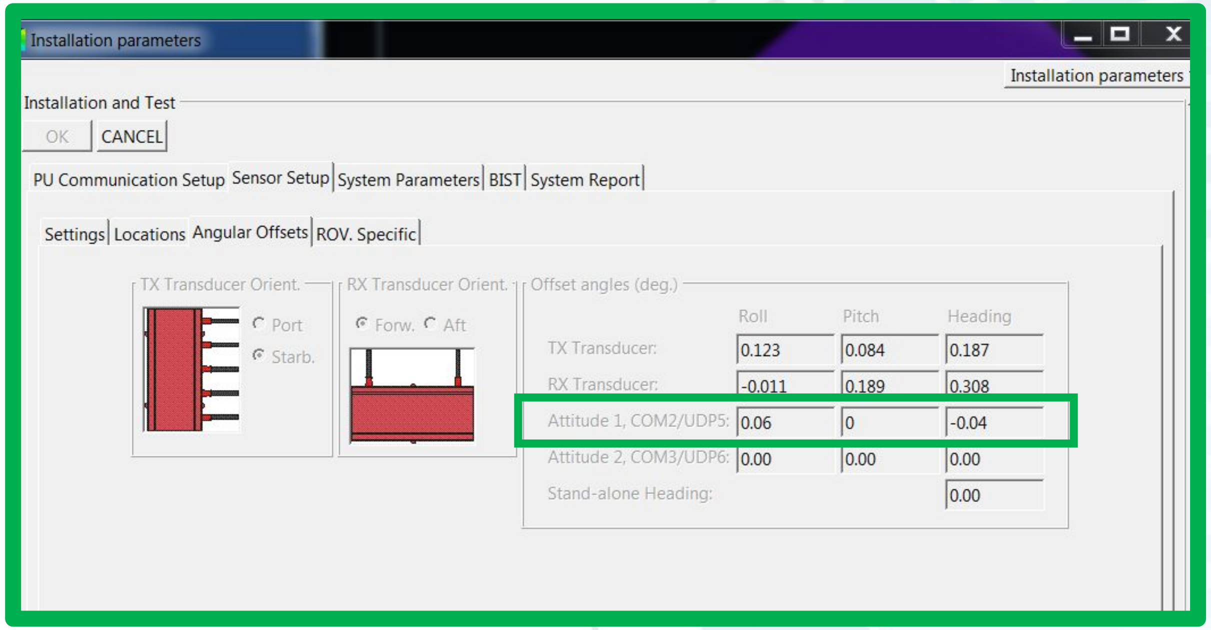
Heading verification lines shown at left in the Qimera Patch Test Tool

1. Attitude 1 initial setting: -0.14°
2. Verification adjustment: +0.10°
3. **Final heading offset: -0.04° in SIS**

EM710 Calibration

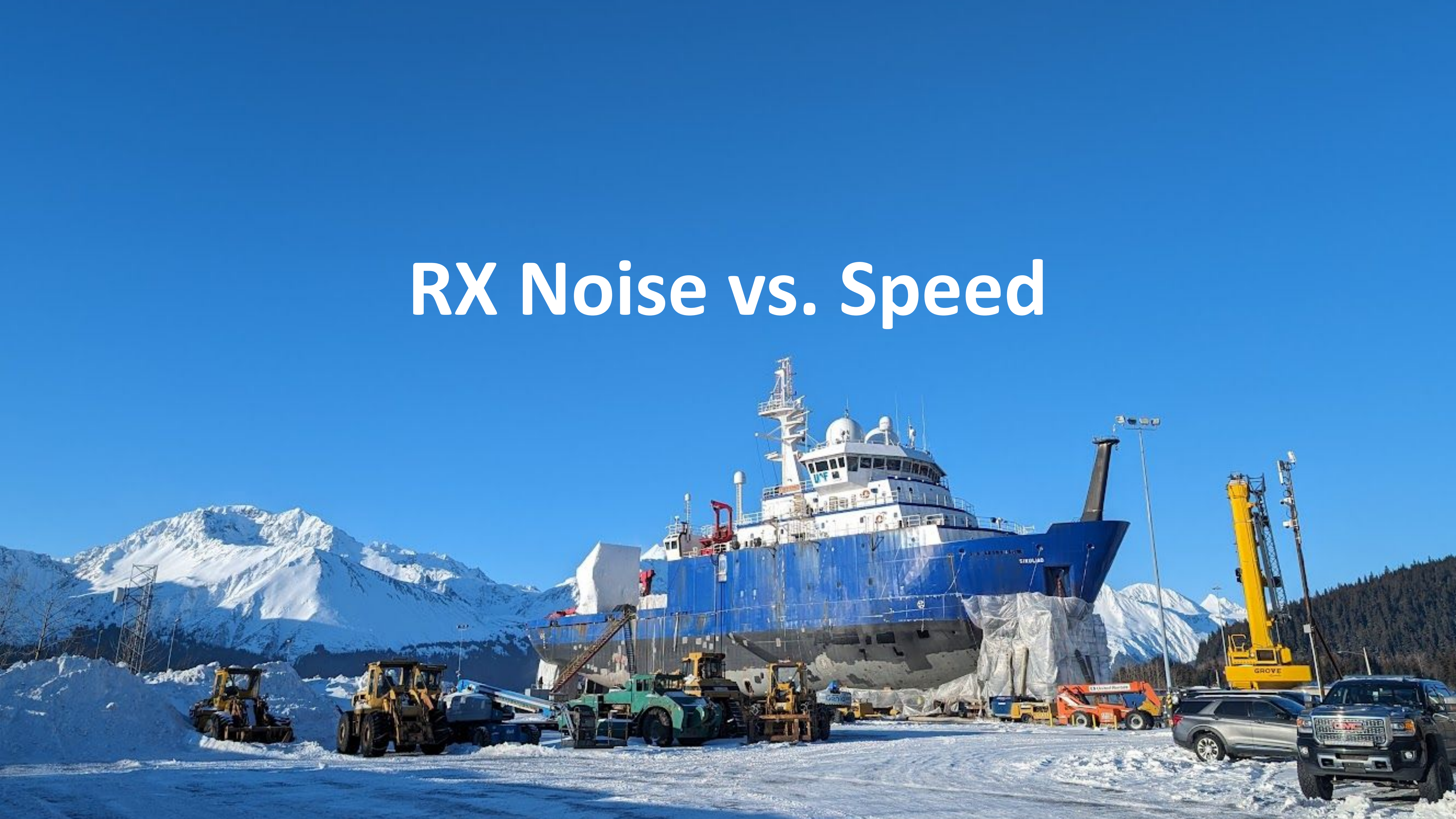
Post-Calibration Configuration

POST-CALIBRATION (EM710)



1. The EM710 *Attitude 1* adjustments made during SKQ202503S are small, suggesting accurate vessel survey results and consistent sensor integration
2. The *Installation Parameters: Angular Offsets* shown at left should be maintained until any modification is made to the EM710 or Seapath, or a new calibration becomes necessary for other reasons

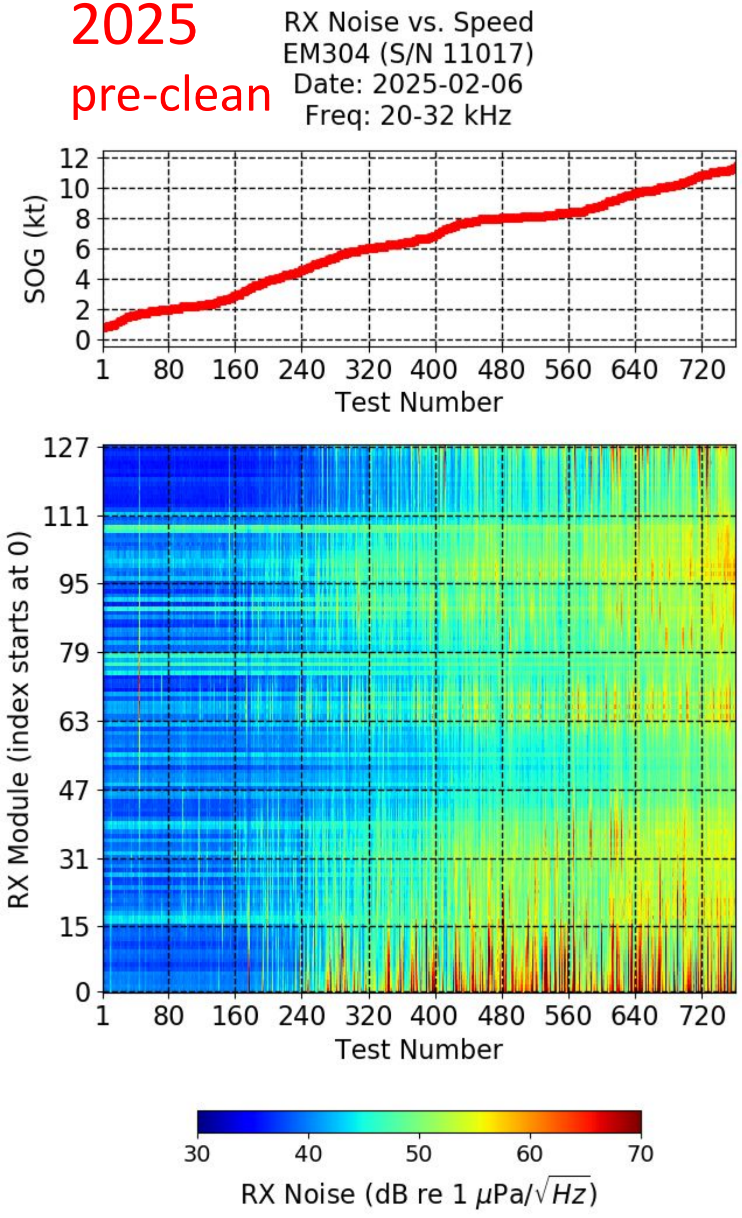
RX Noise vs. Speed



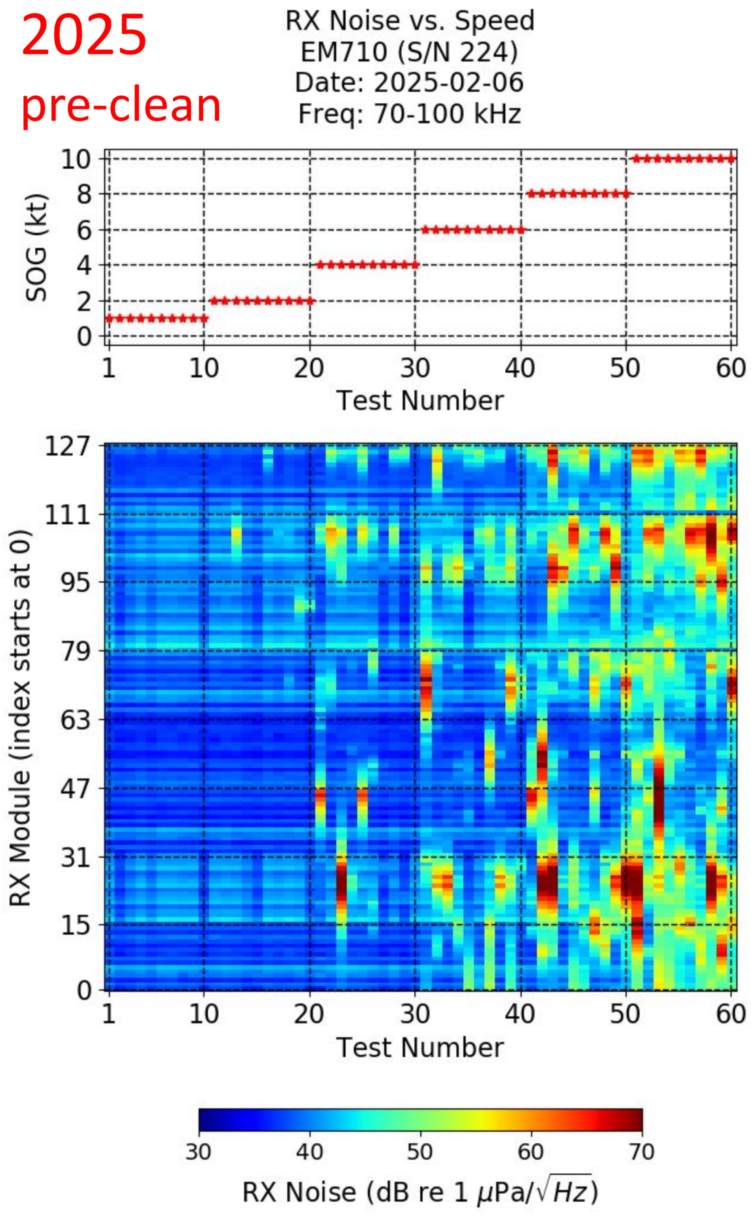
RX Noise BIST Assessment

Noise Level vs. Speed

2025
pre-clean

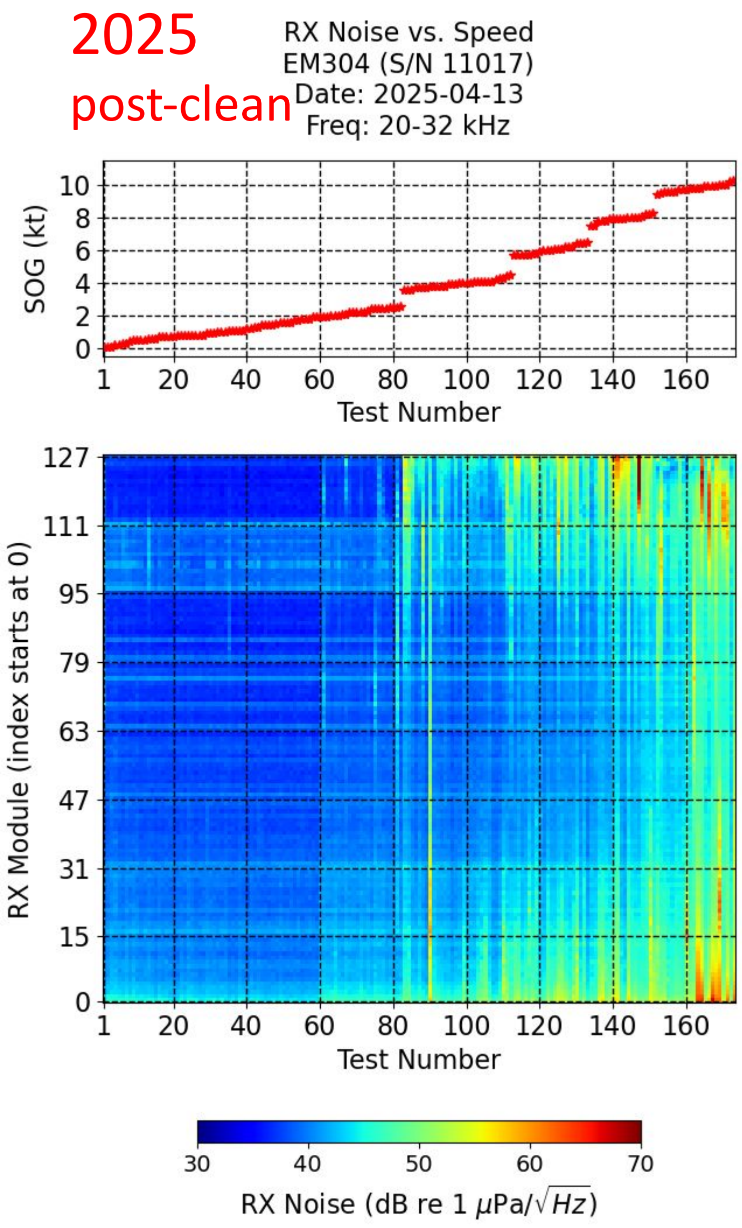


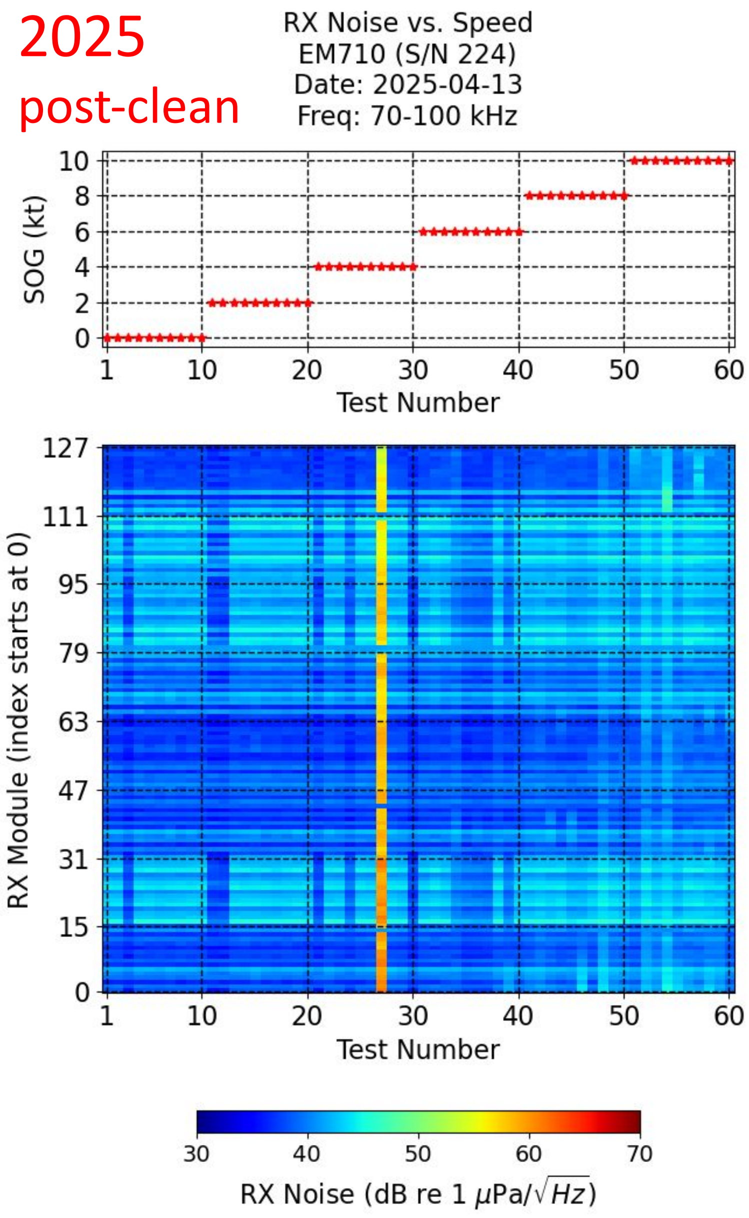
2025
pre-clean



1. Major limitations of multibeam performance can stem from elevated noise levels due to hull design, engines and other machinery, sea state, biofouling, electrical interference, etc.
2. EM304 and EM710 RX noise tests were run in deep water (2600 m) and calm seas (<2’ waves and <5 kn winds)
3. These tests show noticeable increases in RX noise for both systems (see following slides)
4. As the low-speed trends are similar to 2024 and no major machinery work has been done since then, these levels are likely due to higher flow noise from biofouling as the vessel operated in warm water for several months without cleaning (due to port rules)
5. These tests were repeated after cleaning during the transit to Seward (April 13; see following slides)

RX Noise BIST Assessment **Noise Level vs. Speed**



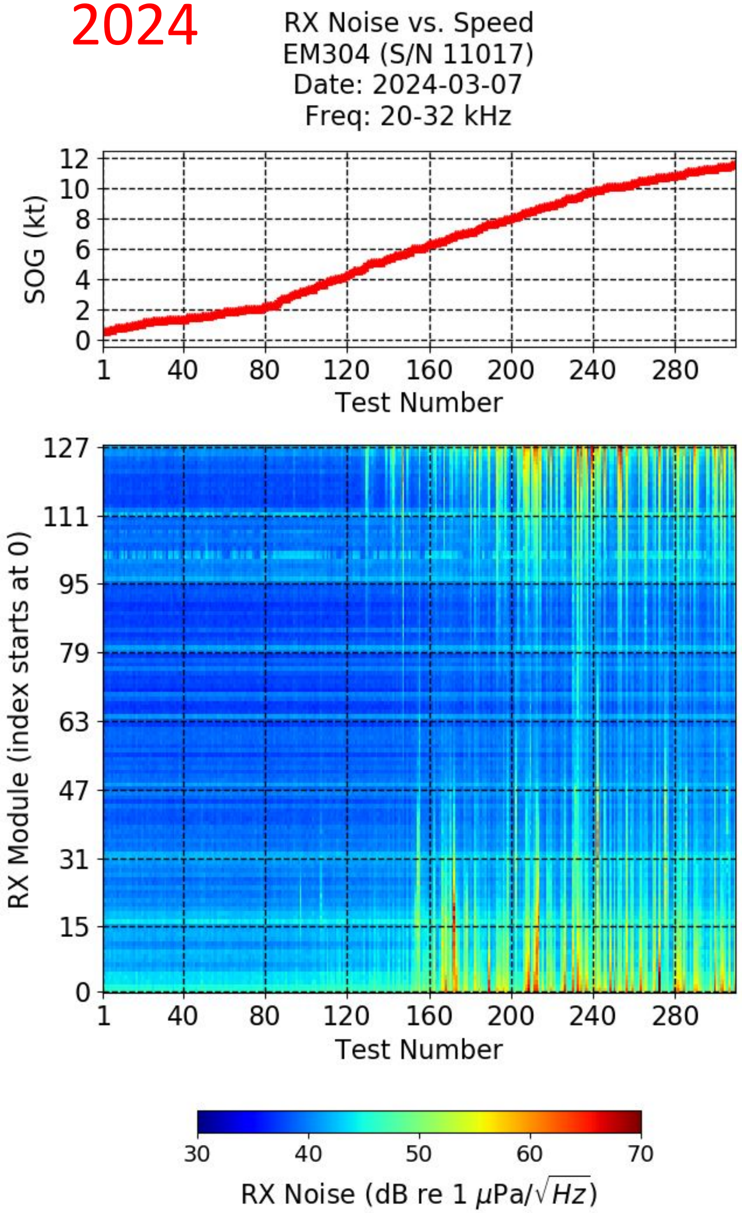


1. After cleaning the ice windows, EM304 and EM710 RX noise tests were repeated in deep water (6000+ m) and slightly elevated seas (3-4' waves and 15 kn winds) on April 13 during the transit to Seward
2. These tests show significant decreases in RX noise for both systems compared to the pre-cleaning tests; results compare more favorably with 2024 tests (following slides), though there may be residual biofouling on the array faces that impact RX Noise and TX Channels (see Hardware Health)

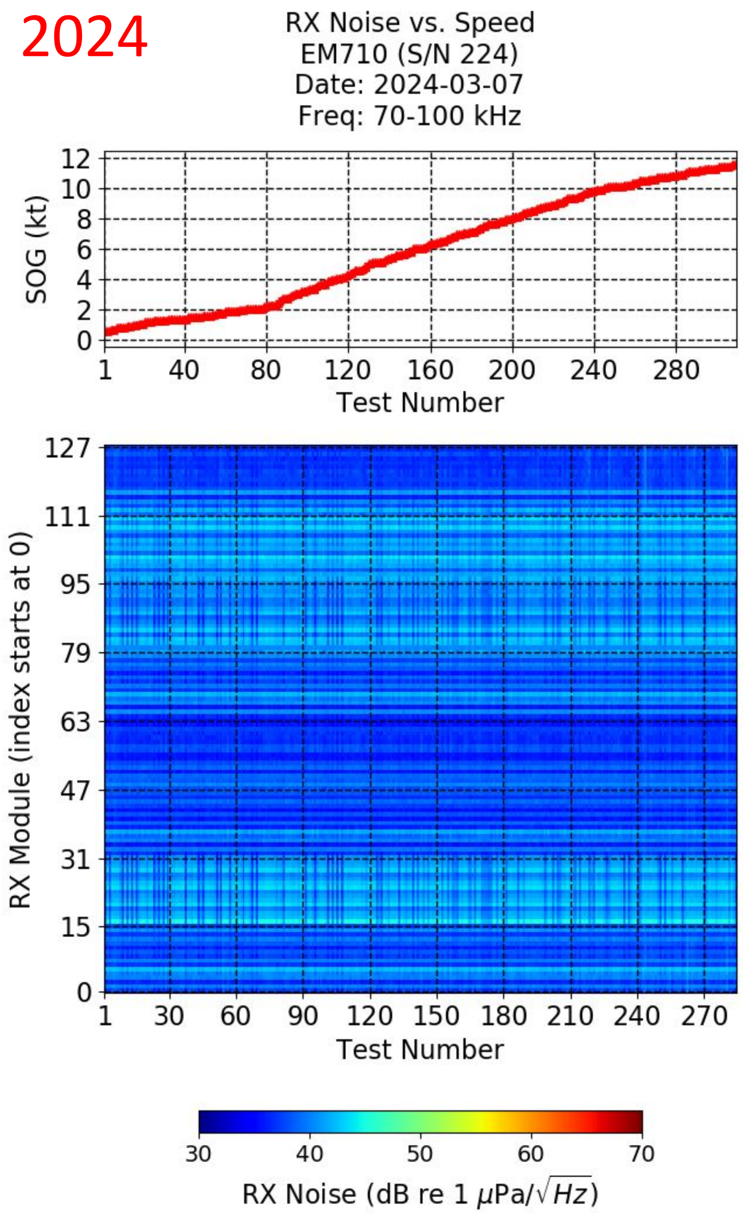
RX Noise BIST Assessment

Noise Level vs. Speed (2024)

2024



2024



1. RX Noise vs. speed examples from the 2024 SAT are shown for comparison with the higher 2025 levels
2. *Note: The SIS 4 BIST format does not include SOG; due to BIST format and plotter limitations, the 2024 EM710 plot at left is a composite of the EM304 SIS 5 speeds (upper subplots) and simultaneous EM710 RX noise levels (lower subplots) over the same interval*

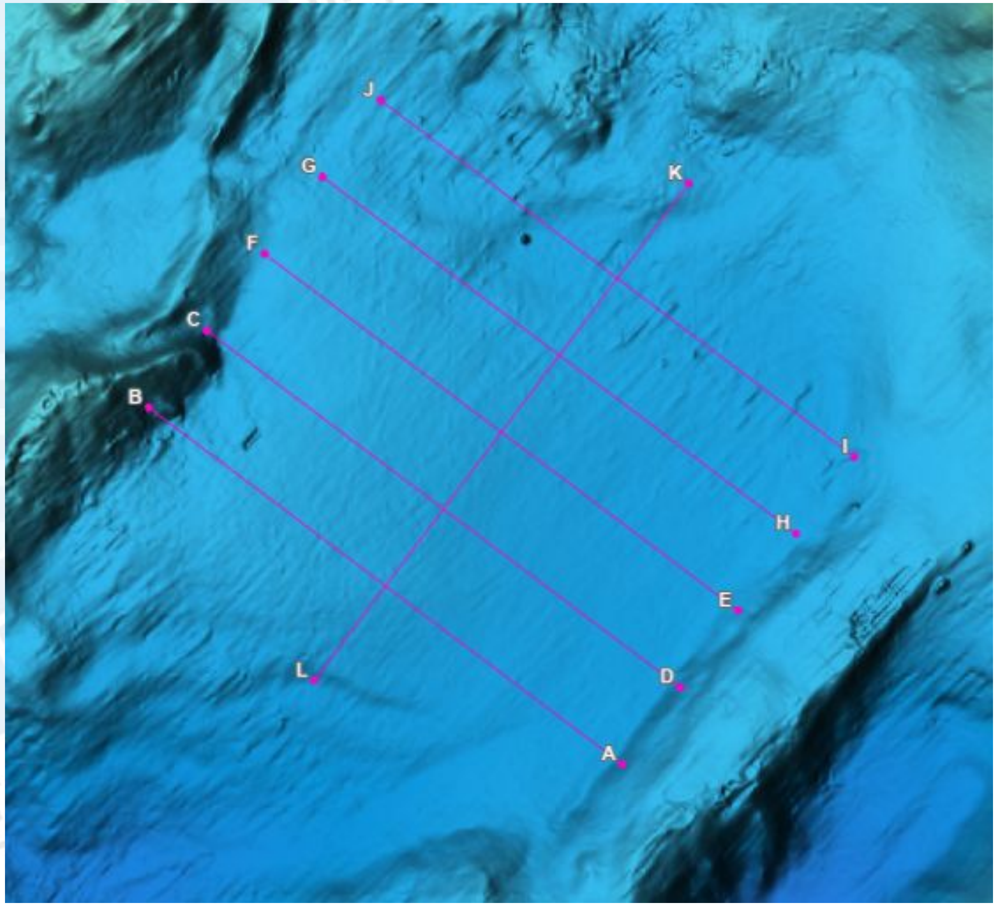
EM304 Accuracy Testing

Accuracy Testing

EM304 - 2800 m Penguin Bank

1. A 2800 m accuracy test site was developed near Penguin Bank over an existing *Nautilus* accuracy test site; the reference surface was re-surveyed with in Very Deep mode and crosslines were run in Very Deep and Deeper modes (both modes were tested during the 2024 SAT at 2400 m)
2. See Penguin Bank 2800 m accuracy for waypoints and settings

	Waypoint	Decimal Degrees		Degrees Decimal Minutes			
		Lat.	Lon.	Lat. Deg.	Lat. Min.	Lon. Deg.	Lon. Min.
Line 1	A	20.710836	-157.278247	20	42.6502	-157	16.6948
	B	20.754123	-157.339693	20	45.2474	-157	20.3816
Line 2	C	20.763460	-157.332168	20	45.8076	-157	19.9301
	D	20.720151	-157.270736	20	43.2091	-157	16.2442
Line 3	E	20.729488	-157.263213	20	43.7693	-157	15.7928
	F	20.772775	-157.324666	20	46.3665	-157	19.4800
Line 4	G	20.782112	-157.317141	20	46.9267	-157	19.0284
	H	20.738803	-157.255701	20	44.3282	-157	15.3421
Line 5	I	20.748140	-157.248178	20	44.8884	-157	14.8907
	J	20.791427	-157.309638	20	47.4856	-157	18.5783
Crossline	K	20.781277	-157.269641	20	46.8766	-157	16.1785
	L	20.720990	-157.318224	20	43.2594	-157	19.0934

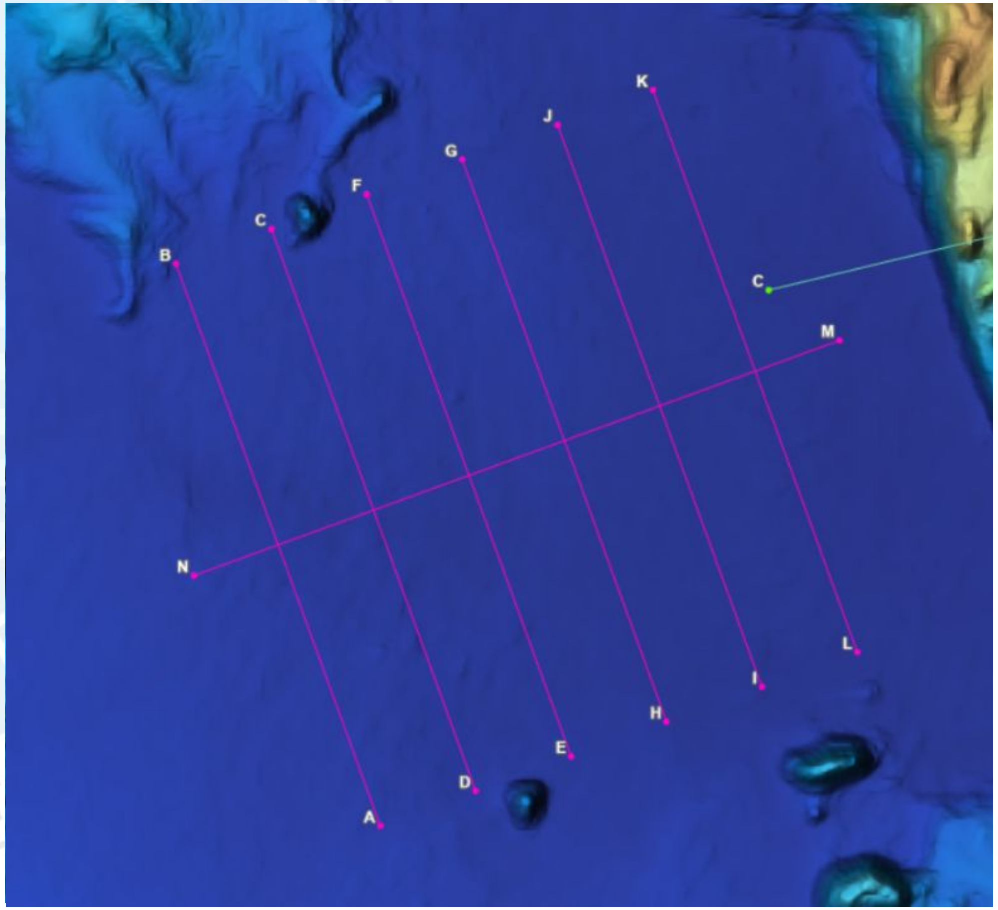


Accuracy Testing

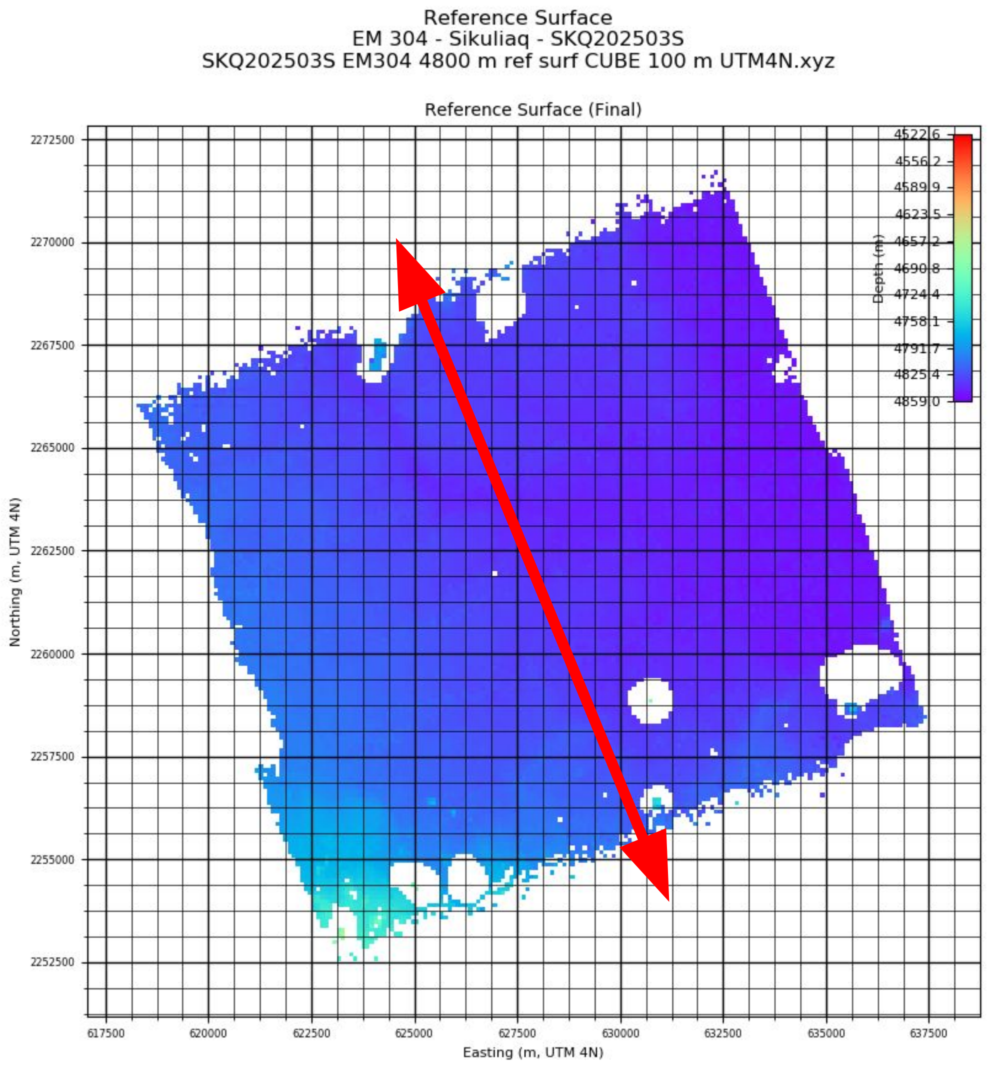
EM304 - 4800 m Penguin Bank

1. A 4800 m accuracy test site was developed over a *Nautilus* reference surface with slight changes to provide a surface width of 3X water depth; the reference surface was surveyed in Extra Deep and crosslines were run in Very Deep and Extra Deep modes (only Very Deep was tested in 2024 at 2400 m, the deepest available region)
2. See [Penguin Bank 4800 m (3X WD)]() for waypoints and settings

	Waypoint	**Decimal Degrees**		**Degrees Decimal Minutes**			
		Lat.	**Lon.**	**Lat. Deg.**	**Lat. Min.**	**Lon. Deg.**	**Lon. Min.**
Line 1	A	20.457709	-157.768974	20	27.4626	-157	46.1384
	B	20.493060	-157.801813	20	29.5836	-157	48.1088
Line 2	C	20.446193	-157.786474	20	26.7716	-157	47.1885
	D	20.530705	-157.753652	20	31.8423	-157	45.2191
Line 3	E	20.525476	-157.738321	20	31.5286	-157	44.2993
	F	20.440971	-157.771163	20	26.4582	-157	46.2698
Line 4	G	20.435743	-157.755823	20	26.1446	-157	45.3494
	H	20.520254	-157.722999	20	31.2152	-157	43.3799
Line 5	I	20.515026	-157.707667	20	30.9015	-157	42.4600
	J	20.430520	-157.740510	20	25.8312	-157	44.4306
Line 6	K	20.425292	-157.725170	20	25.5175	-157	43.5102
	L	20.509804	-157.692343	20	30.5882	-157	41.5406
Crossline	M	20.504575	-157.695228	20	30.2745	-157	41.7137
	N	20.420070	-157.798919	20	25.2042	-157	47.9351



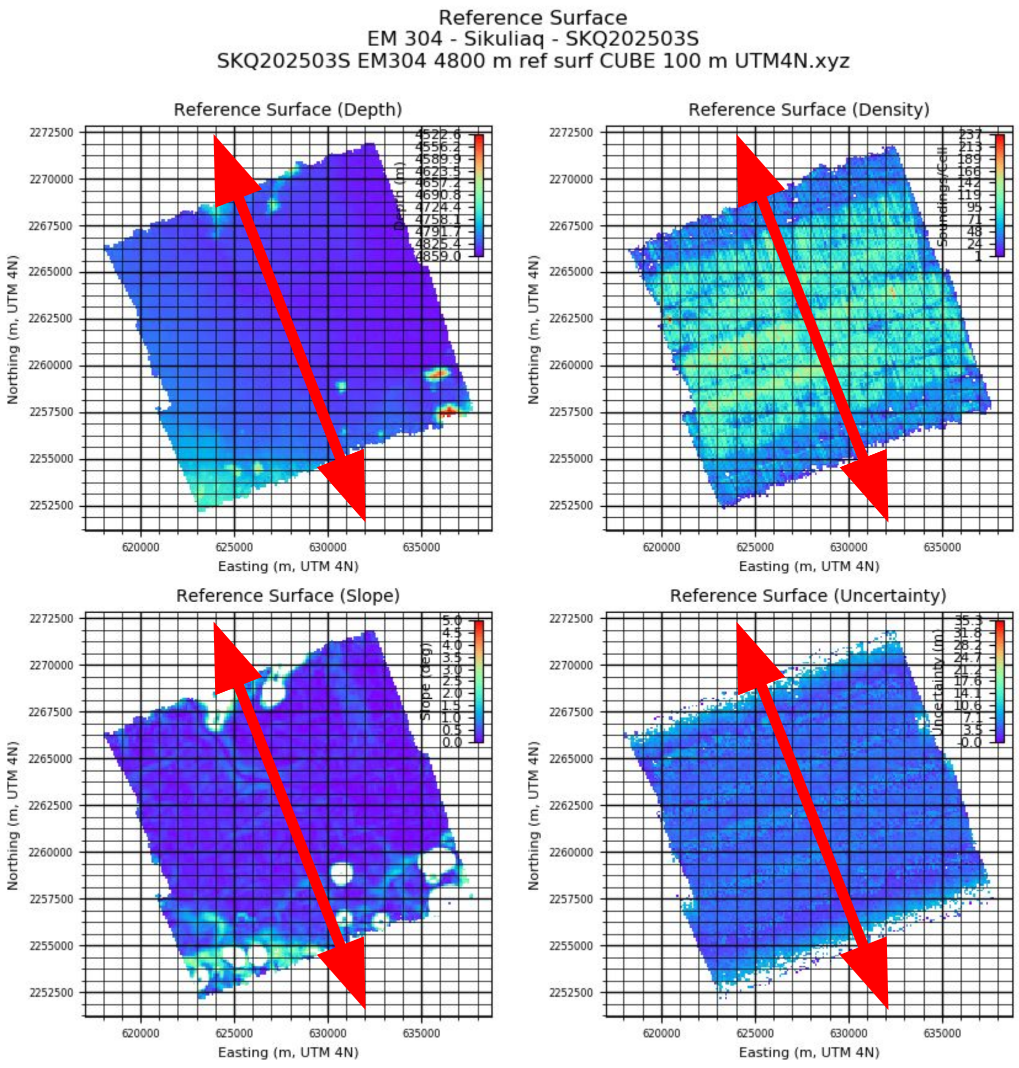
Accuracy Testing



Testing Procedure

1. Swath accuracy (i.e., self-consistency) and sounding distributions were assessed by surveying a reference surface and running crosslines (e.g., red line) in typical modes appropriate for each depth range
2. Two accuracy test sites were developed (see following slides) in order to assess several primary depth modes for the EM304, including Very Deep in its intended depth range and Extra Deep (not tested in 2024); EM710 accuracy was a lower priority under the schedule constraints and was ultimately not tested during SKQ202503S
3. At both sites, orientation of the ship relative to the wind and sea state was considered to try to minimize bubble sweep; fortunately, conditions were reasonably calm in the lee of Molokai and Lanai, as intended with these plans
4. Crosslines were oriented to maximize coverage across the reference surface; these lines were oriented orthogonal to the reference surface survey lines in order to reduce any potential coupling of echosounder biases across the swath

Accuracy Testing



Testing Procedure

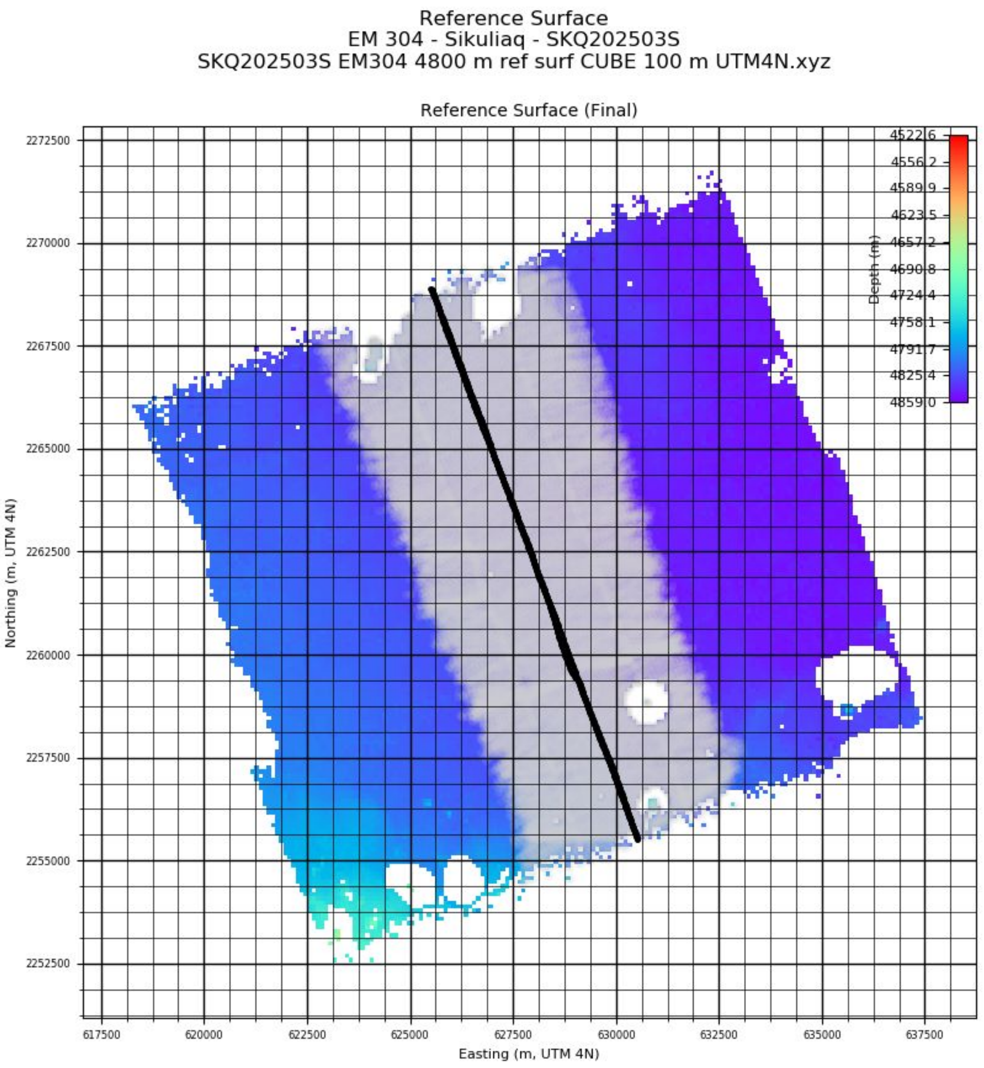
5. The reference surfaces were gridded with the CUBE algorithm in QPS Qimera at appropriate resolutions, then filtered by slope, sounding density, and uncertainty in the MAC accuracy plotter app

6. Only reference surface cells meeting the slope, density, and uncertainty criteria below were used for analyses of crossline data (e.g., filtered reference surfaces at left)

Ref. Surface	2800 m	4800 m
Mean Depth (m)	2800	4800
Grid size (m)	60	100
Min. soundings/cell	10	10
Max. slope (deg)	3	3
Max. uncertainty (m)	10	10
Crossline max. diff. (%WD)	5	5

7. Examples of reference grid filter results and the final grid for crossline tests are shown here and on preceding slides

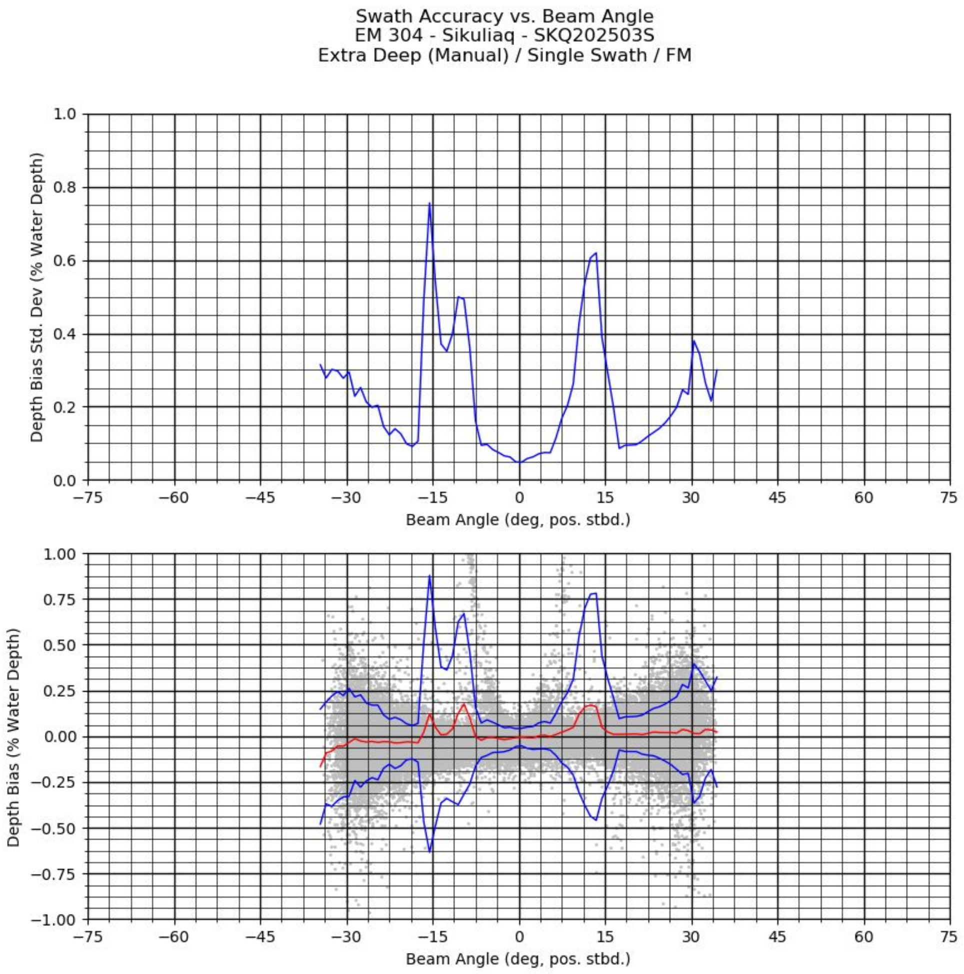
Accuracy Testing



Testing Procedure

8. Sound speed profiles were collected and applied in SIS during data collection (with ‘nearest in time’ scheduling during processing of reference surfaces)
9. Tide amplitudes were on the order of 0.5 m in the vicinity of Oahu and were not applied during accuracy processing
10. Crossline soundings (e.g., gray points at left; track line in black) were filtered to remove outliers that are not representative of the near-seafloor swath behavior and would be readily flagged during routine processing; other systemic behaviors of the echosounder were not edited or impacted by this depth difference filter
11. Sounding depths were compared to reference grid depths (interpolated onto the sounding horizontal position); mean depth biases and depth bias standard deviations as a percentage of water depth were then computed in 1° angular bins across the swath for each configuration (shown in following slides)

Accuracy Testing



Example of swath accuracy as a percentage of water depth
Results for each setting are presented in the following slides

Results Overview

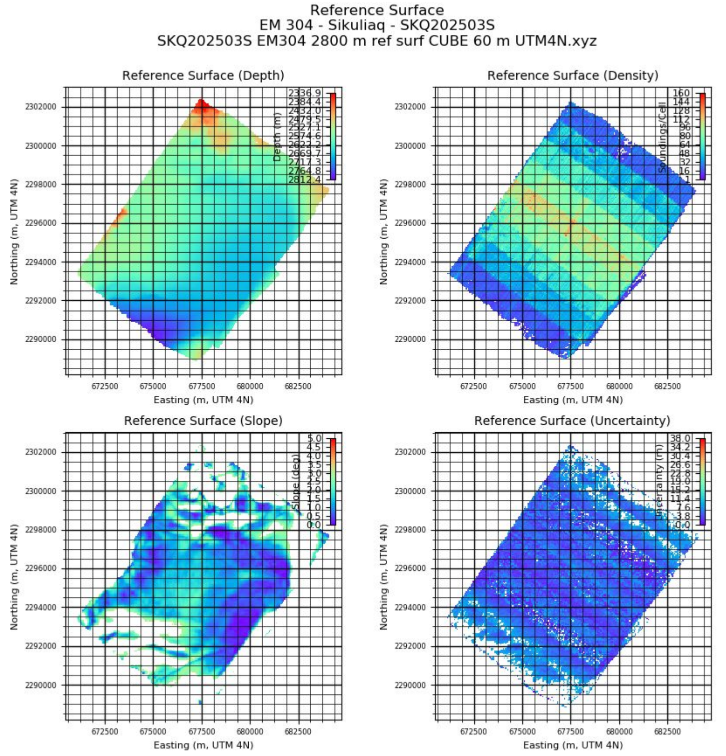
1. Results shown here include the 'default' modes at each depth, with FM enabled, yaw stabilization (rel. mean heading) enabled, and dual-swath (dynamic) enabled, as well as variations on these settings to demonstrate the effects of particular parameters on swath quality
2. The results appear to be impacted by flow noise, bubble sweep along the icebreaking hull, and additional acoustic attenuation due to ice protection windows
3. Compared to 2024, refraction issues were less of a complication due to a more stable sound speed environment and frequent CTD profiling; however, yaw stabilization while the vessel was 'crabbing' appears to have induced some shoal/deep biases in the outer sectors
4. Results are presented with both crossline passes for each mode (when available) in order of increasing depth
5. Note that Crossline Setting numbers in this report refer to the configuration identifiers used during planning; because the planning spanned multiple systems at each site, with certain prioritization to ensure efficient use of ship time, the Crossline Setting numbers reported here for each system may not be sequential for a given site

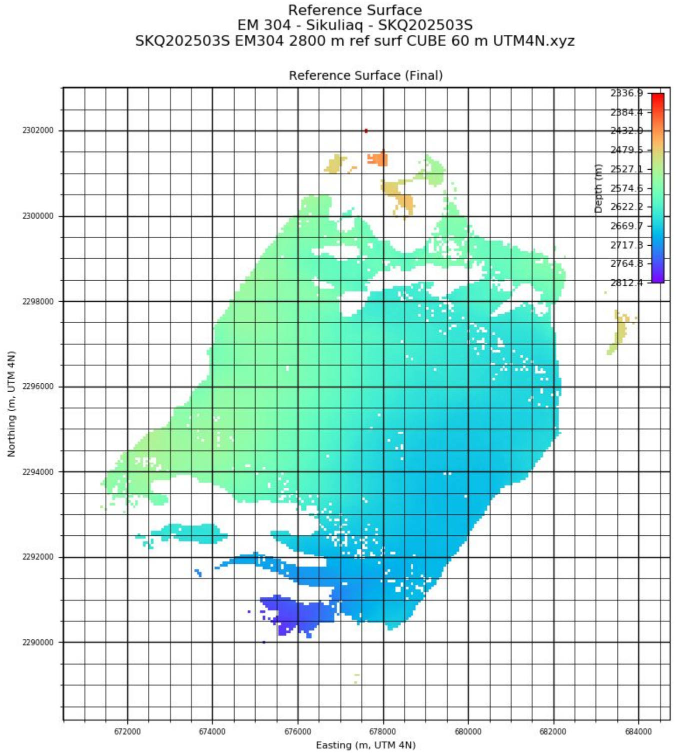
EM304 Accuracy Testing **2800 m Accuracy: Data Collection**

Crossline Setting	Depth Mode	Swath Mode	Pulse Form	Yaw Stabilization[1]	Conditions
Reference	Very Deep	Single[2]	FM	RMH	Relatively calm seas; moderate winds causing vessel 'crabbing'
1	Very Deep	Single[2]	FM	RMH	
2	Deeper	Dual	FM/CW Mix	RMH	

[1]RMH = Relative Mean Heading

[2]Very Deep is single swath by default

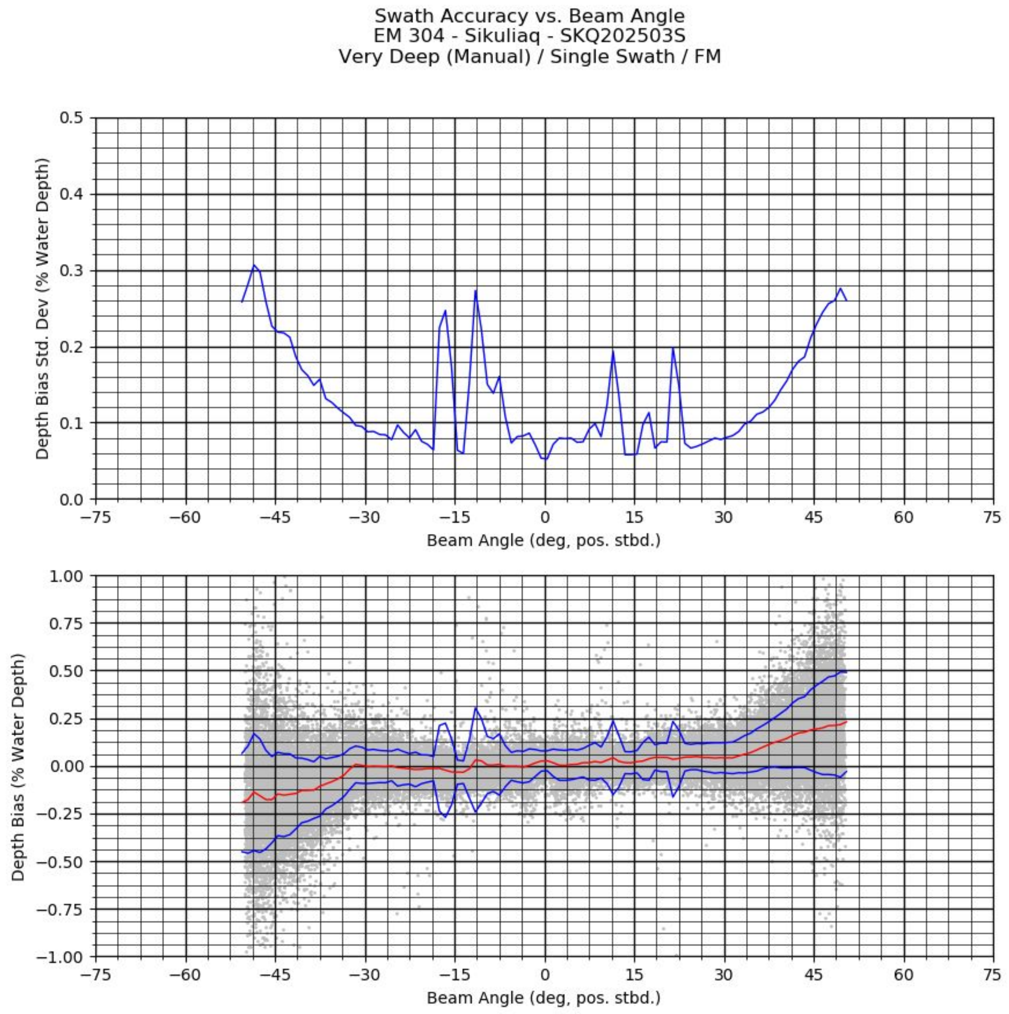




Left (clockwise from upper left): ref. surface bathymetry, sounding density, slope, uncertainty

Bottom: final surface after masking

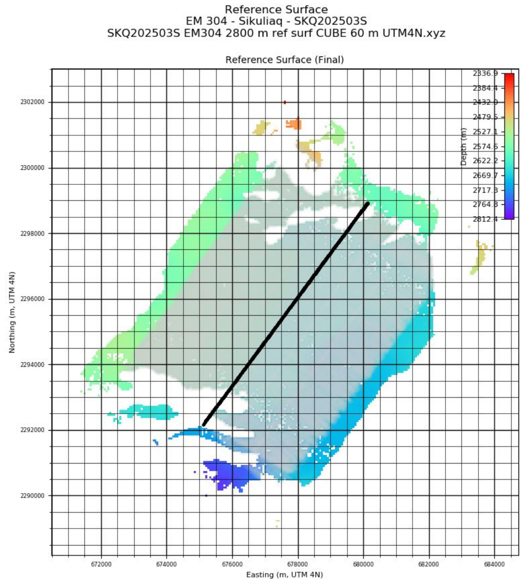
EM304 Accuracy Testing 2800 m Accuracy: Results Overview

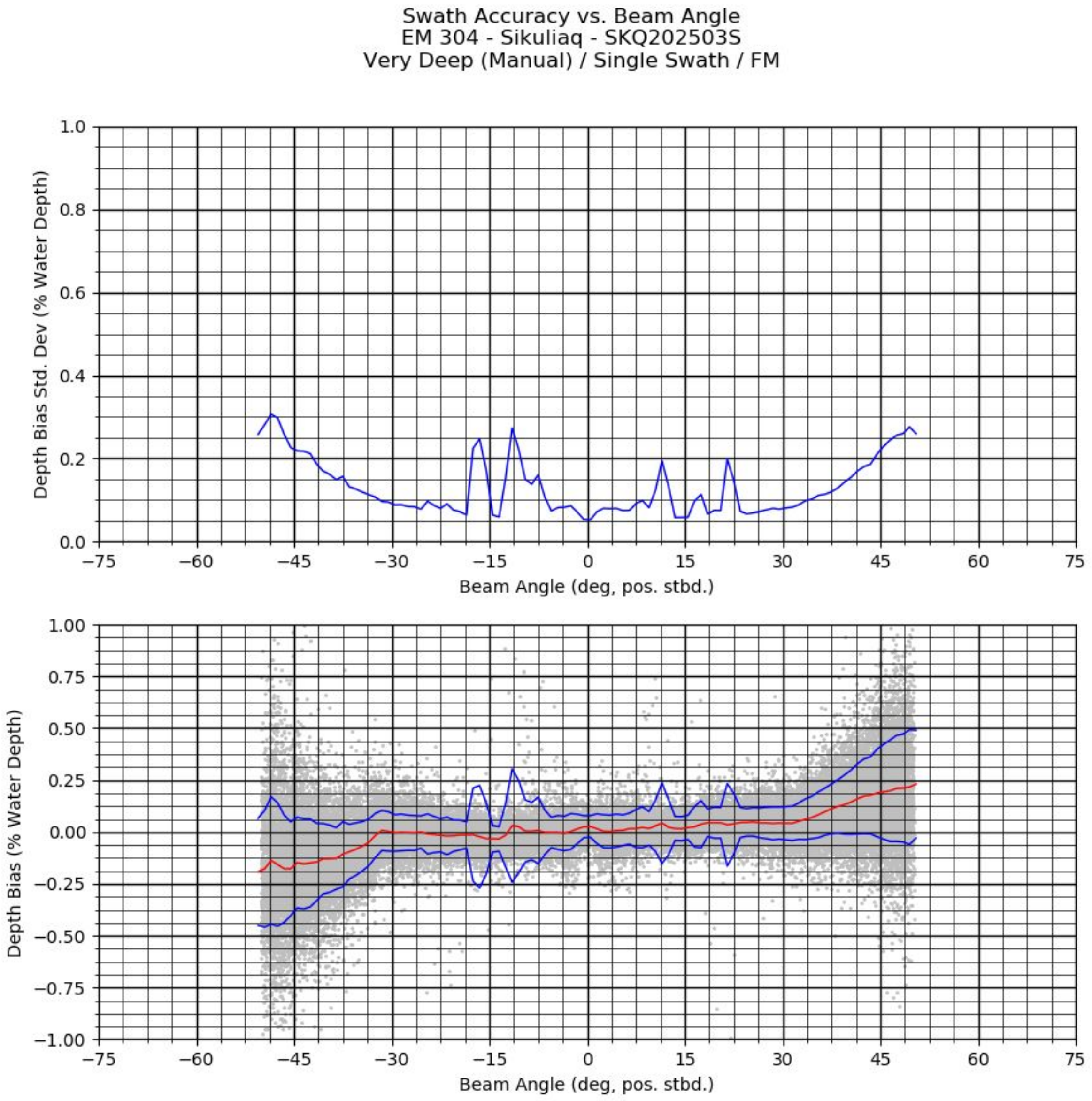


EM304 swath accuracy as a percentage of water depth

1. EM304 results at the 2800 m site are limited to Deeper and Very Deep modes, which are expected to be priority operating modes for the EM304 MKII in this depth range
2. The results clearly show the necessity to force Very Deep mode at this depth, which is earlier than the 'default' transition depth (~3300 m)
3. This behavior has been seen on other EM304 systems and is compounded by the higher noise levels of Sikuliaq (especially with potential biofouling causing higher flow noise) and increased attenuation of the ice protection windows
4. Although Very Deep mode is limited by the software to 52° /52° (versus 70°/70° for Deeper), it achieved wider coverage than Deeper with higher swath quality / lower std. dev.; one tradeoff is the single-swath limitation in Very Deep, which reduces alongtrack data density by half
5. Performance is plotted with max. +/- 1 %WD limits to show the significantly increased distribution of soundings along the outer swath edges in Deeper (i.e., 'noisy' edges)
6. The mean depth bias across the swath remains near zero, with noticeable shoal and deep biases on the outermost TX sectors that may be complicated by yaw stabilization while 'crabbing' in moderate winds

EM304 Accuracy Testing 2800 m: Very Deep/Single/FM/RMH





Crossline setting 1

Depth Mode: Very Deep

Dual Swath: Off

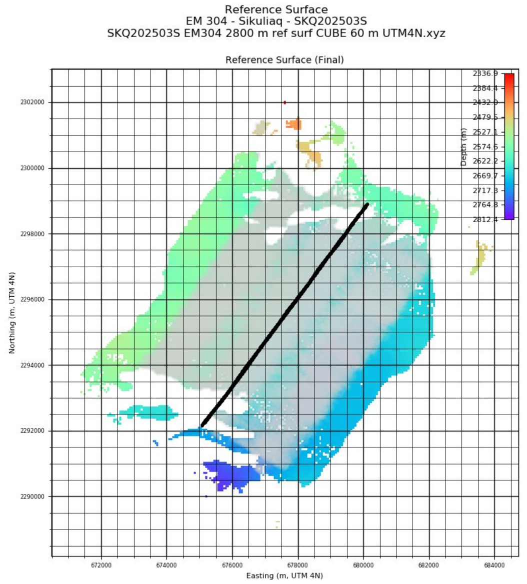
Yaw Stabilization: RMH

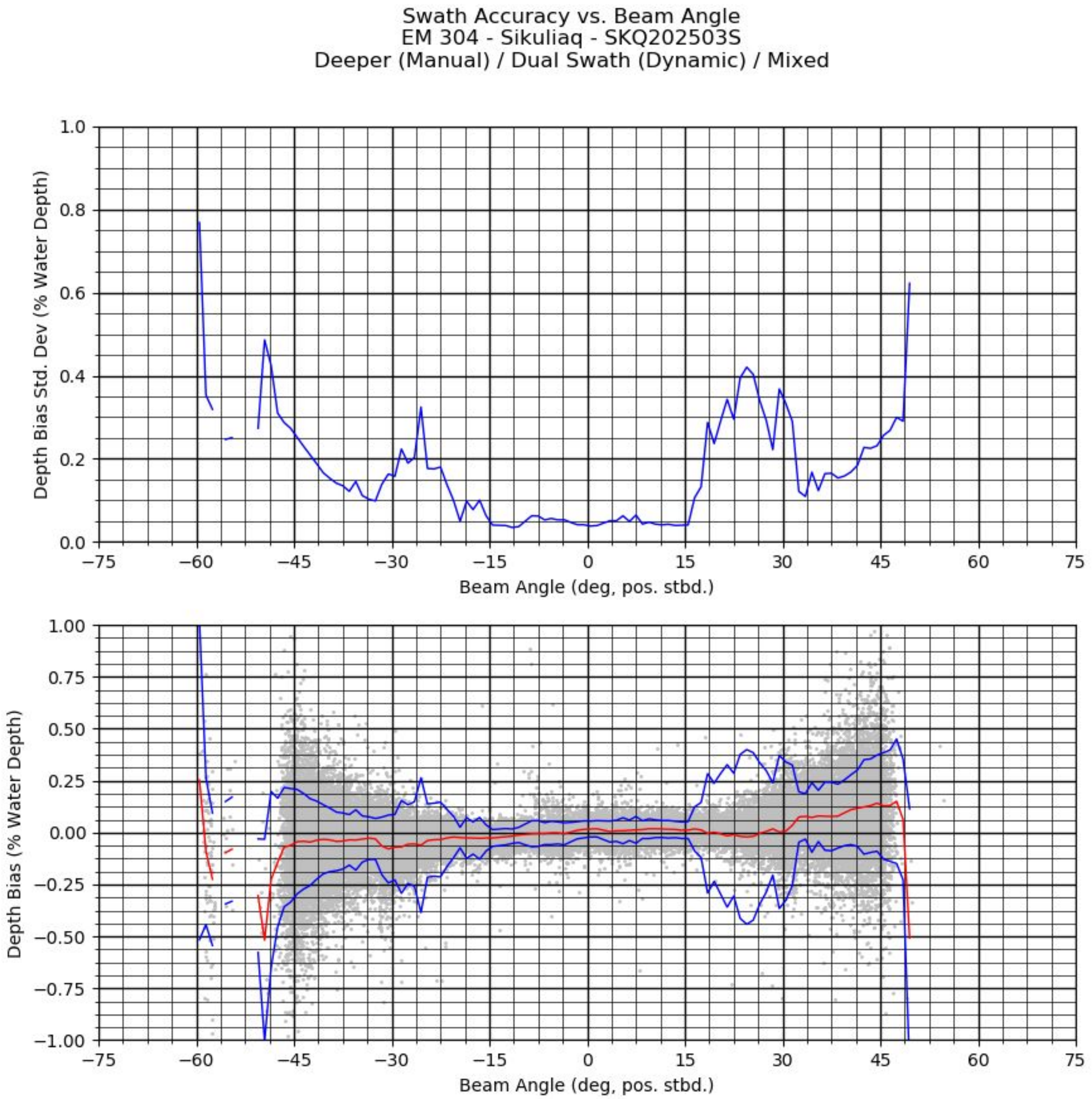
No. passes: 2

Files: 56, 57

2025-02-05

EM304 Accuracy Testing   2800 m: Deeper/Dual/Mix/RMH





Crossline setting 2

Depth Mode: Deeper

Dual Swath: Enabled

Yaw Stabilization: RMH

No. passes: 2

Files: 58, 59

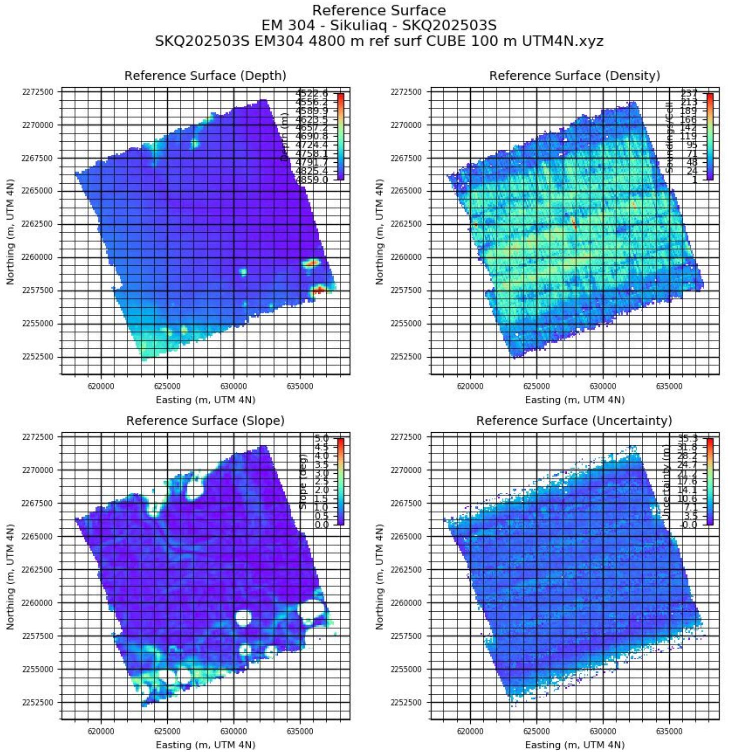
2025-02-05

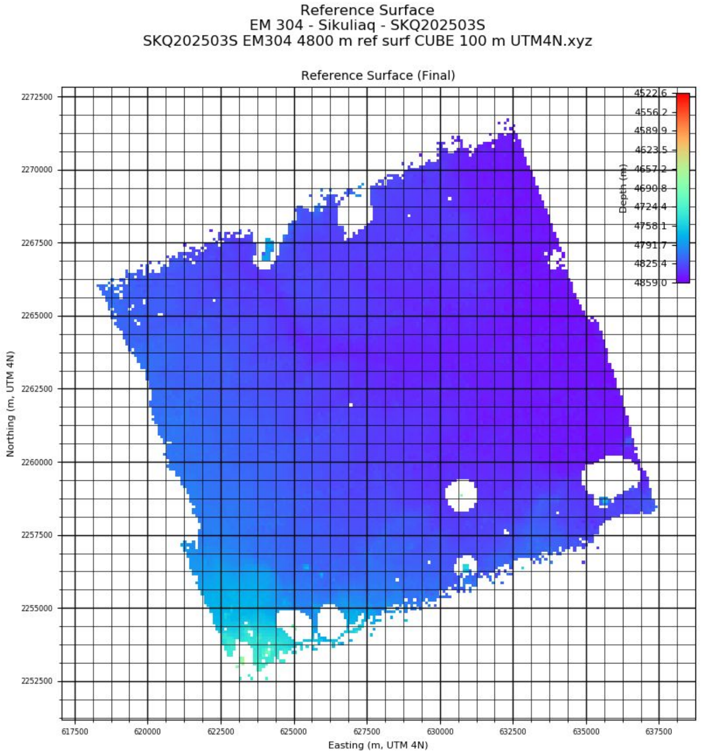
EM304 Accuracy Testing **4800 m Accuracy: Data Collection**

Crossline Setting	Depth Mode	Swath Mode	Pulse Form	Yaw Stabilization[1]	Conditions
Reference	Extra Deep	Single[2]	FM	RMH	
1	Extra Deep	Single[2]	FM	RMH	Relatively calm seas
2	Very Deep	Single[2]	FM	RMH	

[1]RMH = Relative Mean Heading

[2]Very Deep and Extra Deep are single swath by default

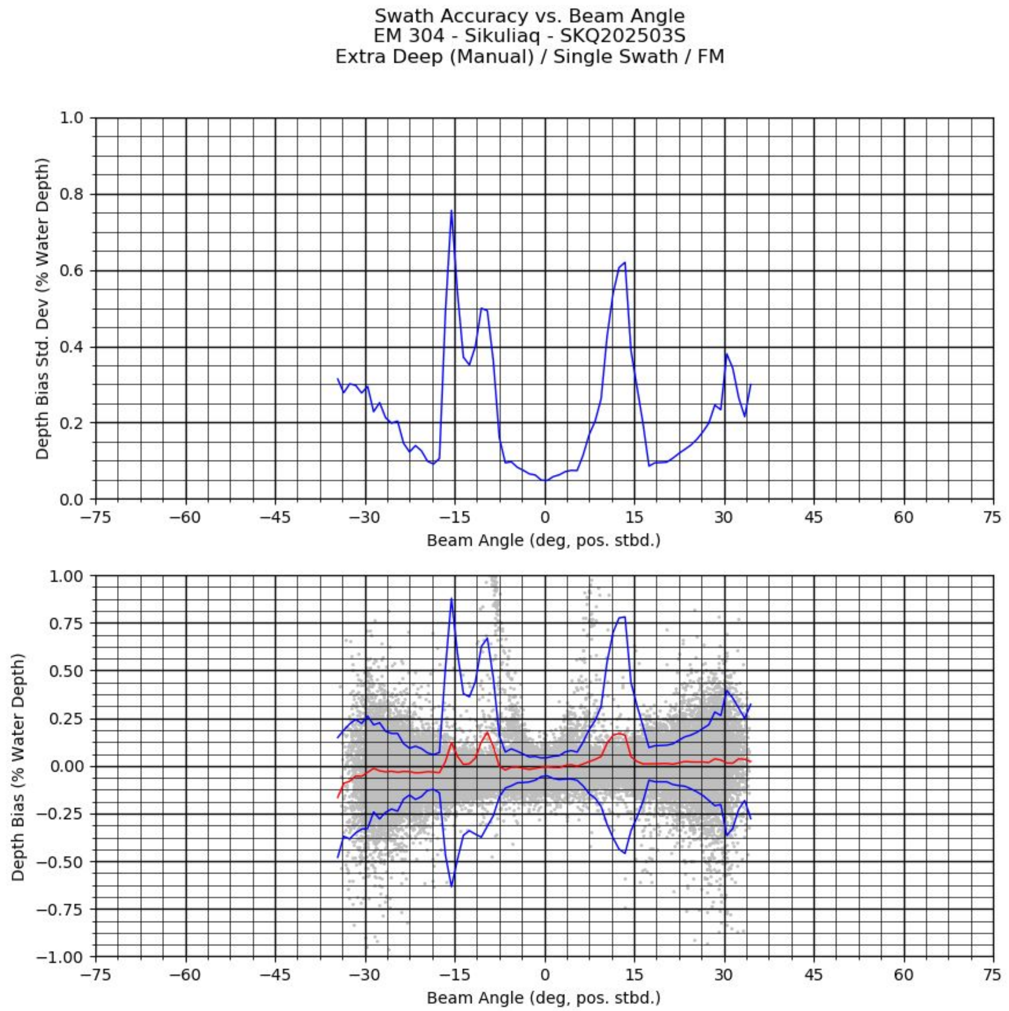




Left (clockwise from upper left): ref. surface bathymetry, sounding density, slope, uncertainty

Bottom: final surface after masking

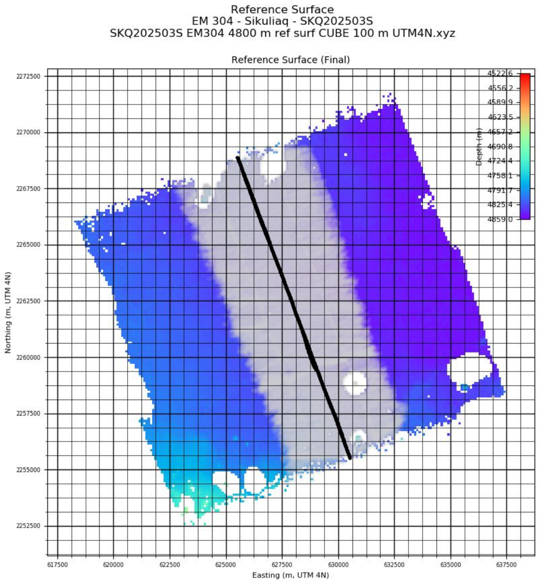
EM304 Accuracy Testing **4800 m Accuracy: Results Overview**

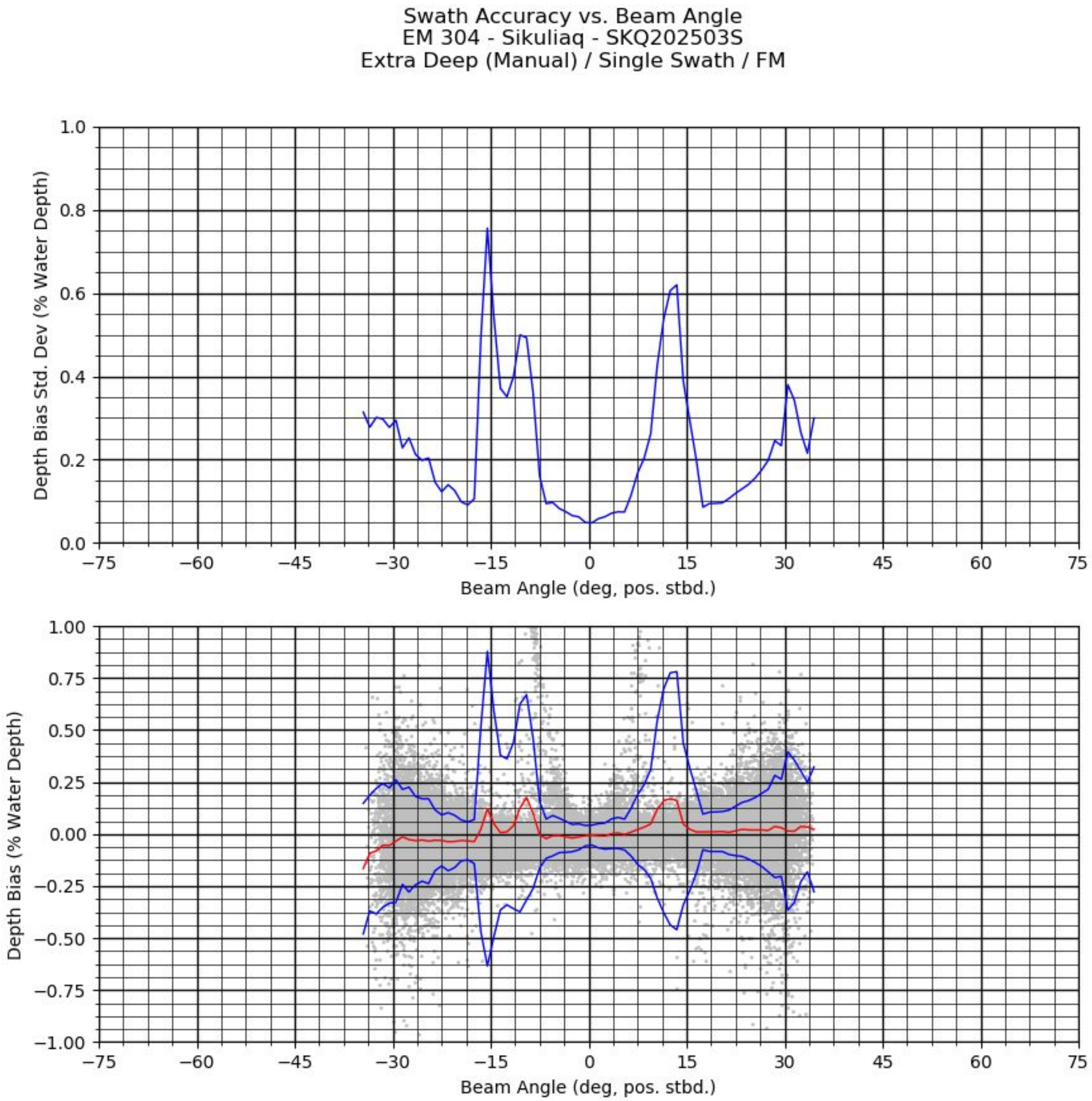


EM304 swath accuracy as a percentage of water depth

1. EM304 results at the 4800 m site are limited to Extra Deep and Very Deep modes, which are expected to be priority operating modes for the EM304 MKII in this depth range
2. These results clearly show the necessity to force Extra Deep mode at this depth; although Extra Deep mode is limited by the software to 35°/35° (versus 52°/52° for Very Deep), it achieved the same coverage and sounding density as Very Deep with higher swath quality / lower std. dev.
3. Performance at this depth is plotted with max. +/- 1 %WD limits owing to the significantly increased distribution of soundings around TX sector boundaries (as in 2024)
4. The mean depth bias across the swath remains near zero, with minor shoal and deep biases on each side that might be attributable to different acoustic penetration trends for each TX sector

EM304 Accuracy Testing **4800 m: Extra Deep/Single/FM/RMH**





Crossline setting 1

Depth Mode: Extra Deep

Dual Swath: Off

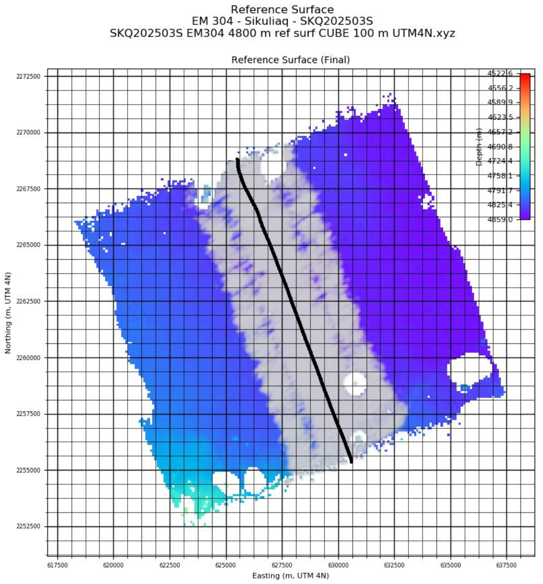
Yaw Stabilization: RMH

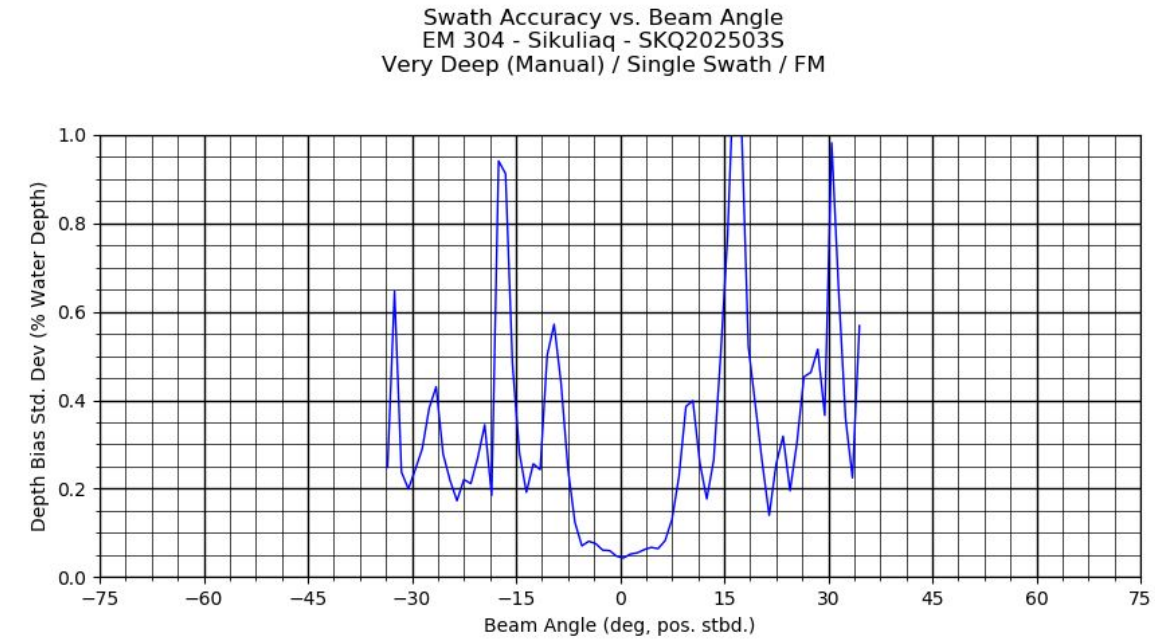
No. passes: 2

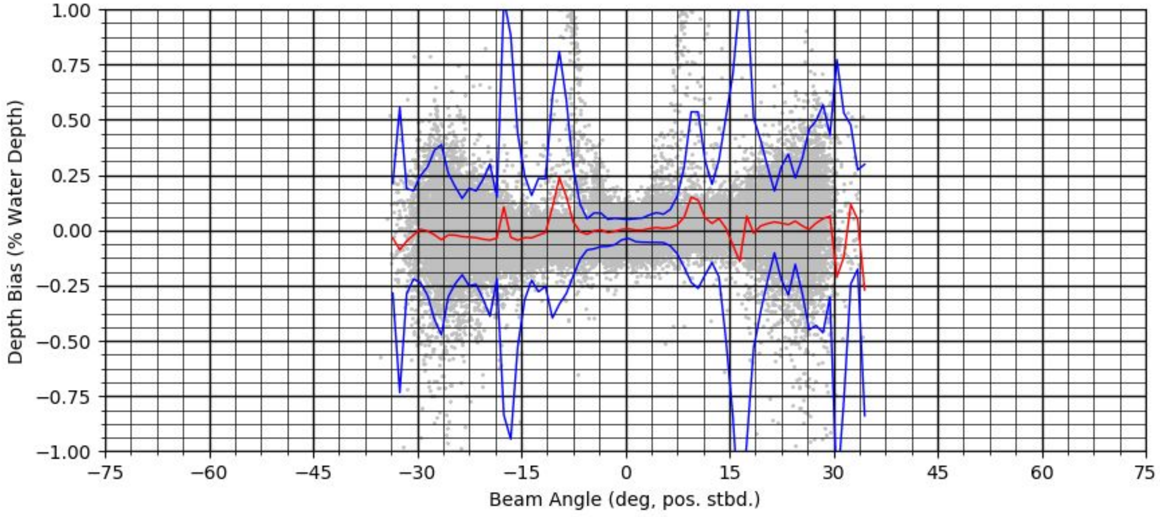
Files: 35-38

2025-02-04

EM304 Accuracy Testing **4800 m: Extra Deep/Single/FM/RMH**







Crossline setting 2

Depth Mode: Very Deep

Dual Swath: Off

Yaw Stabilization: RMH

No. passes: 1

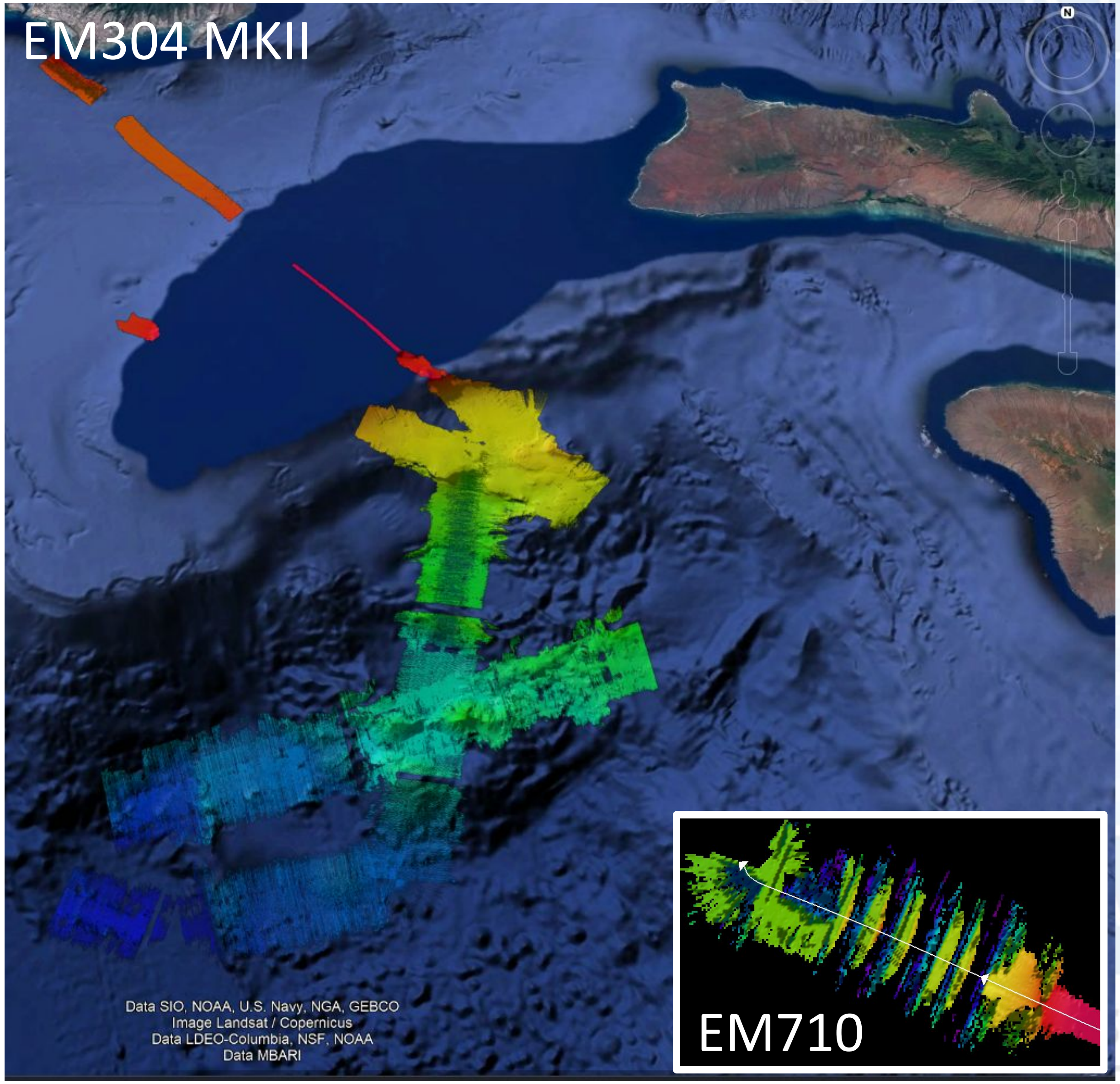
Files: 39-40

2025-02-04

Coverage Testing

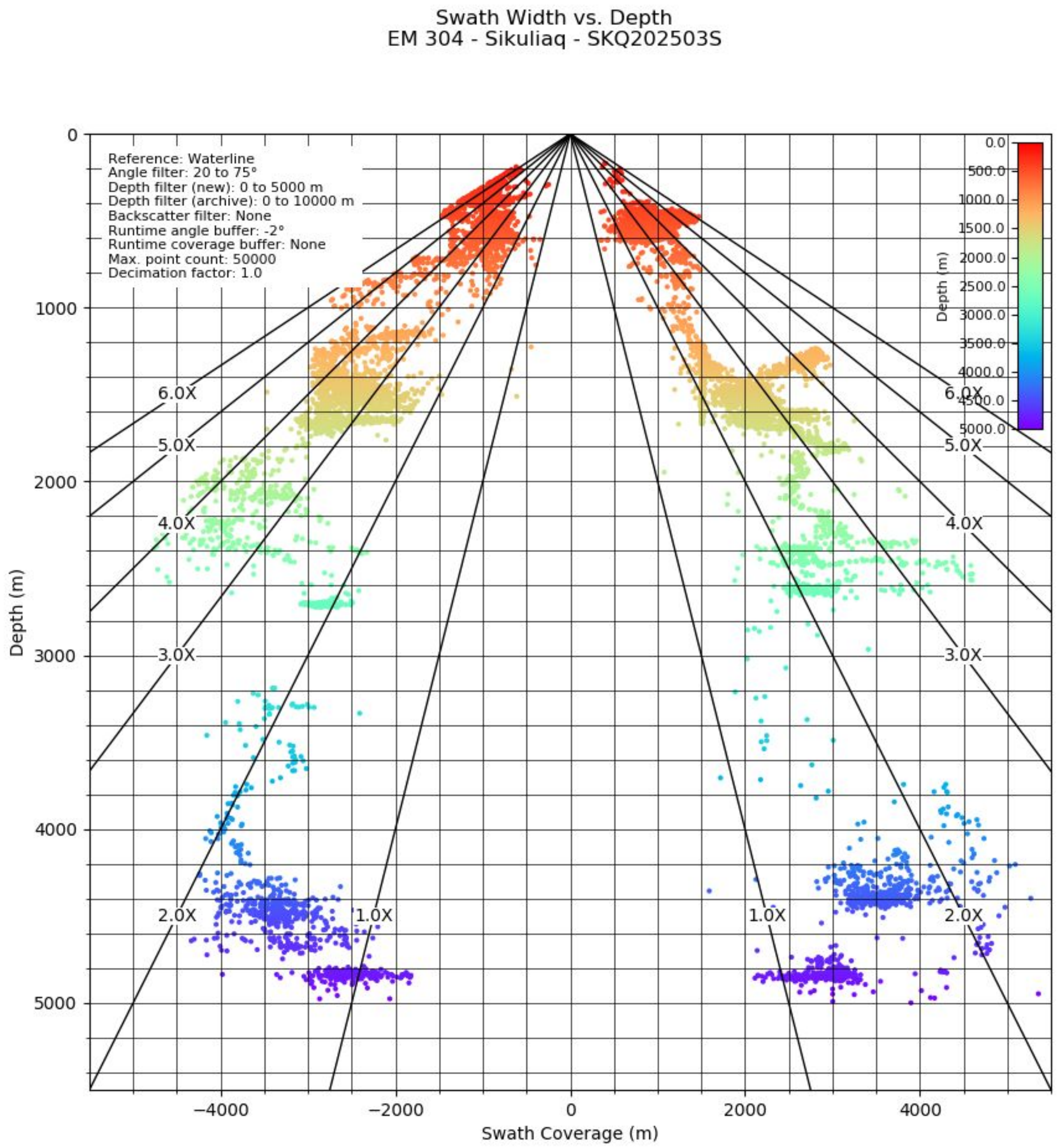
Swath Coverage Assessment

EM304 and EM710 Overview



1. Swath coverage data were collected for both systems while transiting and on a dedicated EM304 coverage test line down to a maximum depth of 4800 m south of Penguin Bank (as shown at left in Google Earth)
2. Both systems were operated with Auto depth mode and ±75° max. swath angles for the coverage test
3. The EM710 data were severely limited in data quality by bubble sweep (e.g., mistracking example shown at left in Qimera processing)and other ongoing tests (e.g., ADCP testing that did not impact the EM304)
4. Closer analysis of the available EM710 data suggest they would not be representative of typical coverage achieved during normal mapping work; as such, no EM710 coverage plots are presented in this report
5. The MAC is available to process any additional EM304 or EM710 swath coverage data that may be collected opportunistically on transits, especially into any available deeper waters; recommended settings are available on the [Ocean Mapping Community Wiki]()

EM304 Swath Coverage

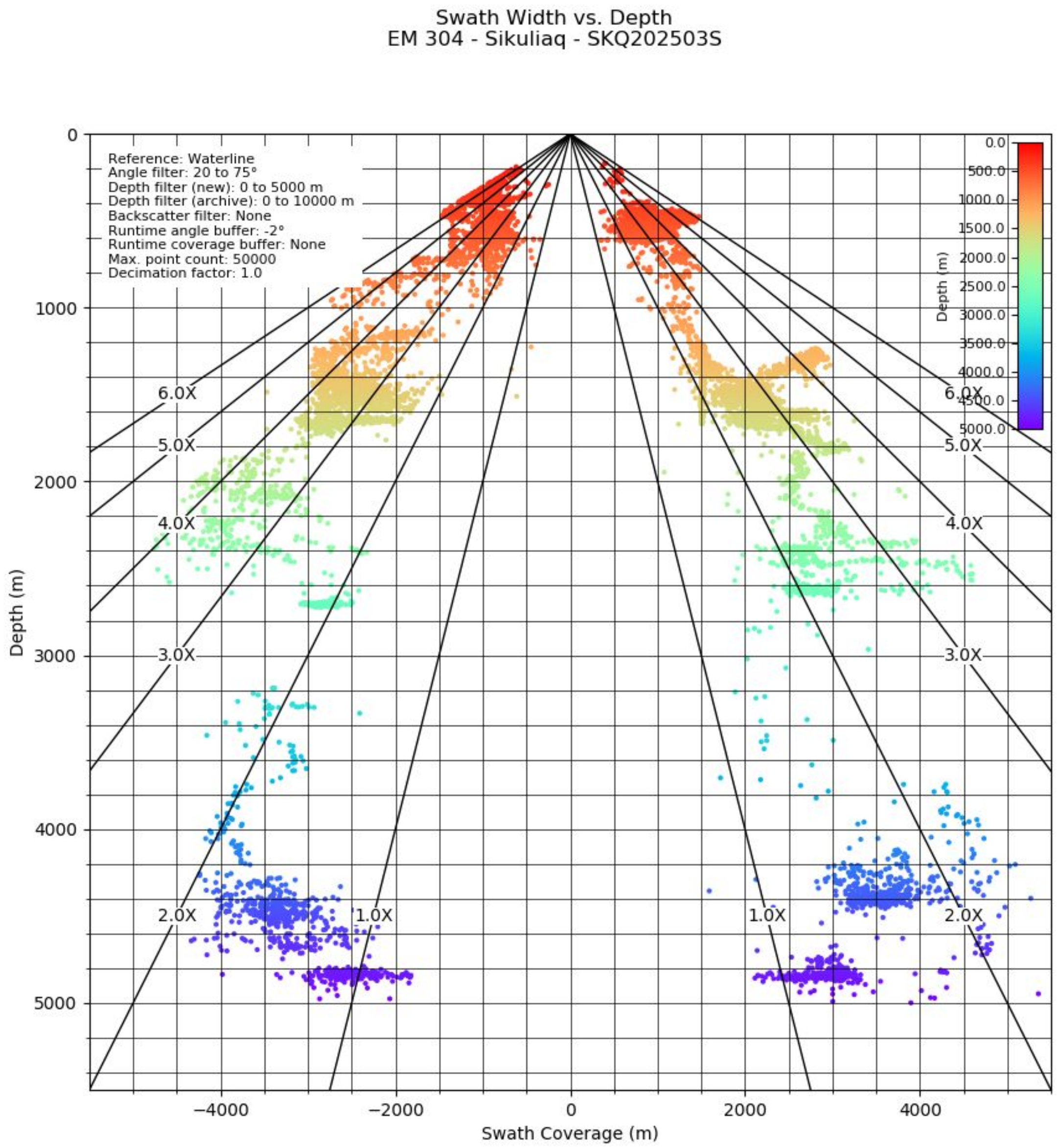


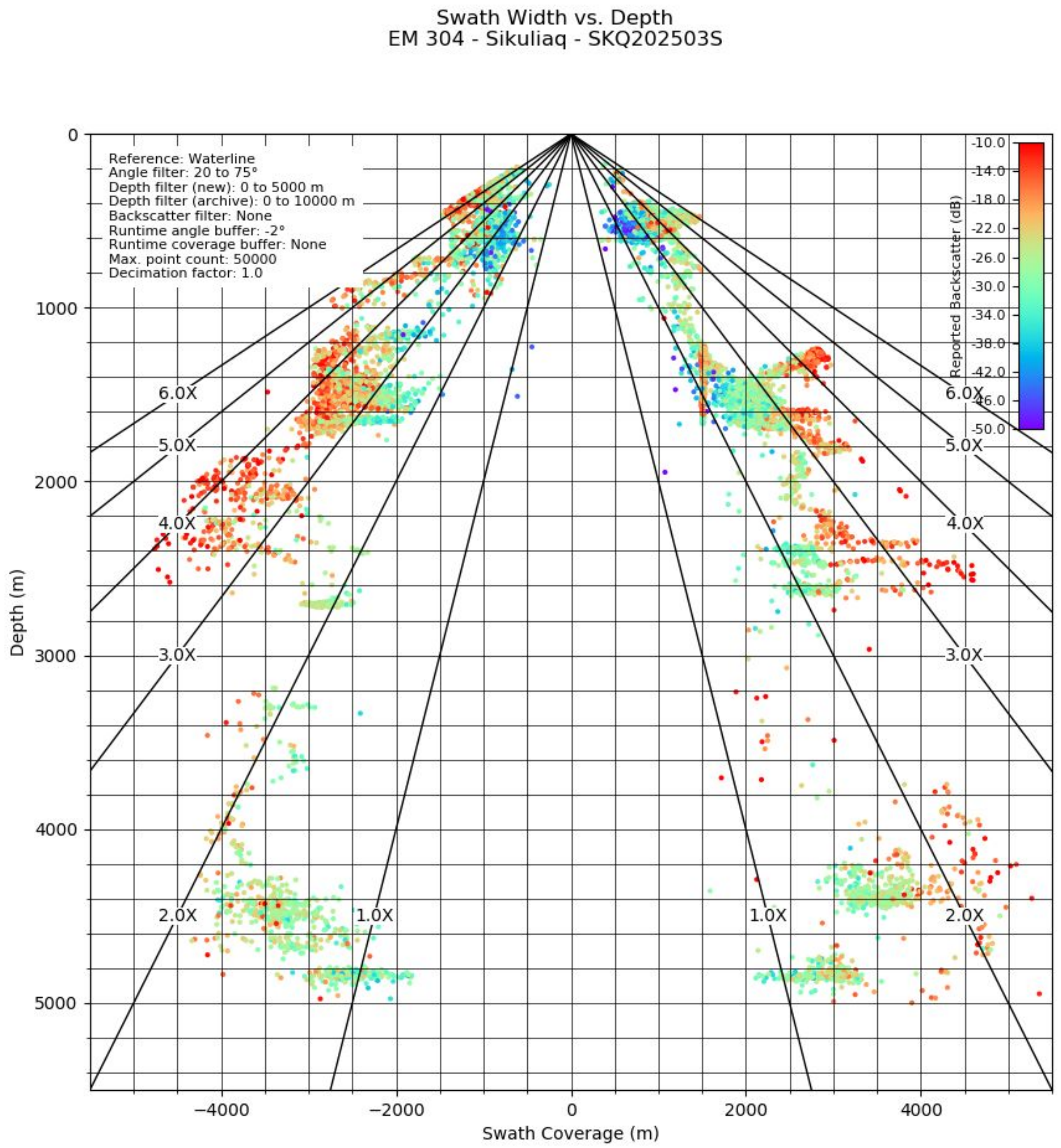
Overview

1. Across-swath distance from nadir was calculated for the outermost port and starboard ‘valid’ sounding for each ping and then plotted against depth to evaluate the achieved swath width versus depth
2. The following slides present the achieved EM304 swath coverage versus depth, colored by a variety of parameters to illustrate performance versus mode and compare against relevant benchmark datasets
3. Maximum depths observed during SKQ202503S was 4800 m, twice the max depth of the 2024 SAT; this was a major goal for 2025 and provides valuable insight into real-world coverage for this system on the deeper continental slope and abyssal plain

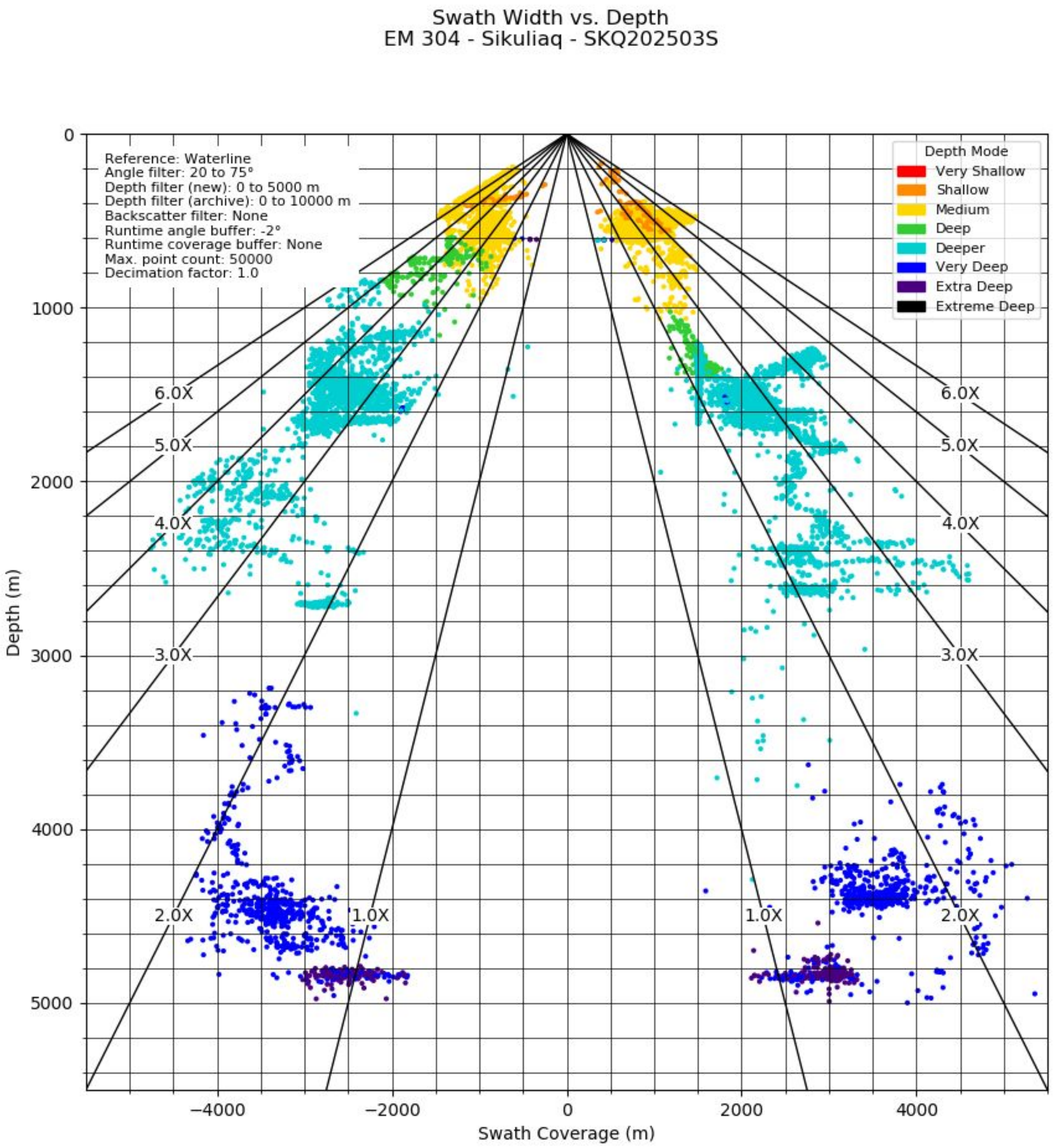
EM304 Swath Coverage

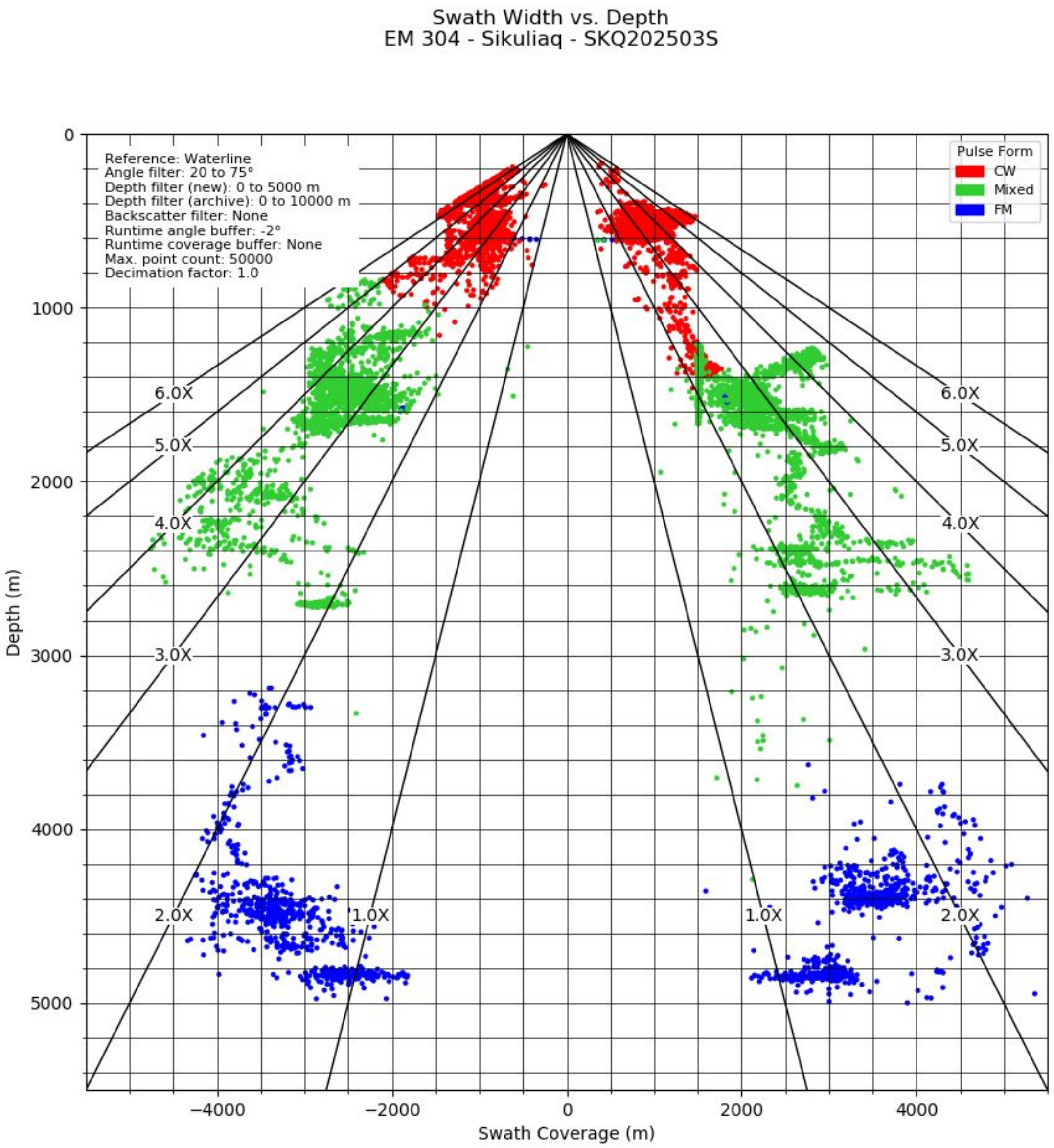
Results



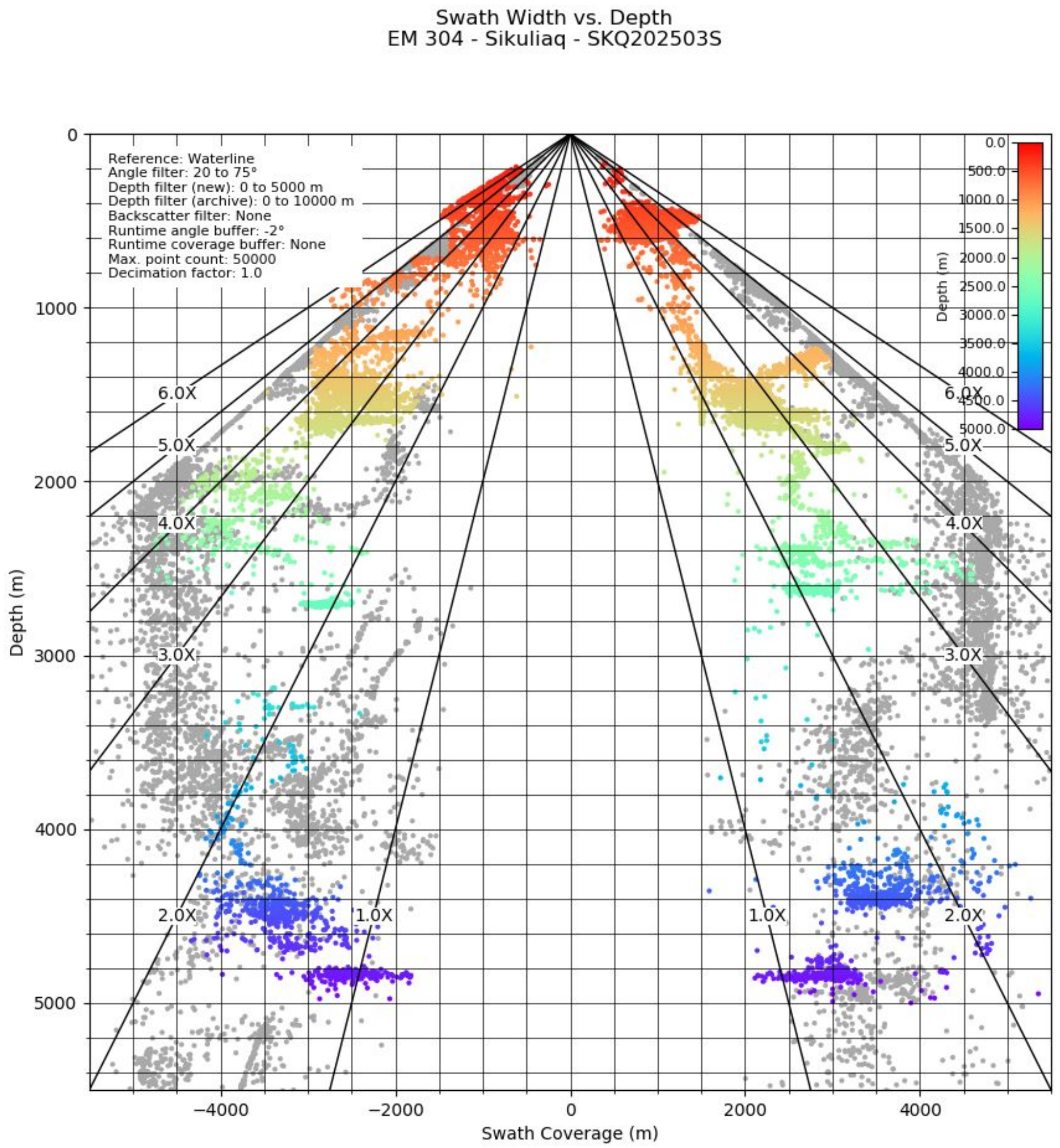


EM304 Swath Coverage **Results**





EM304 Swath Coverage

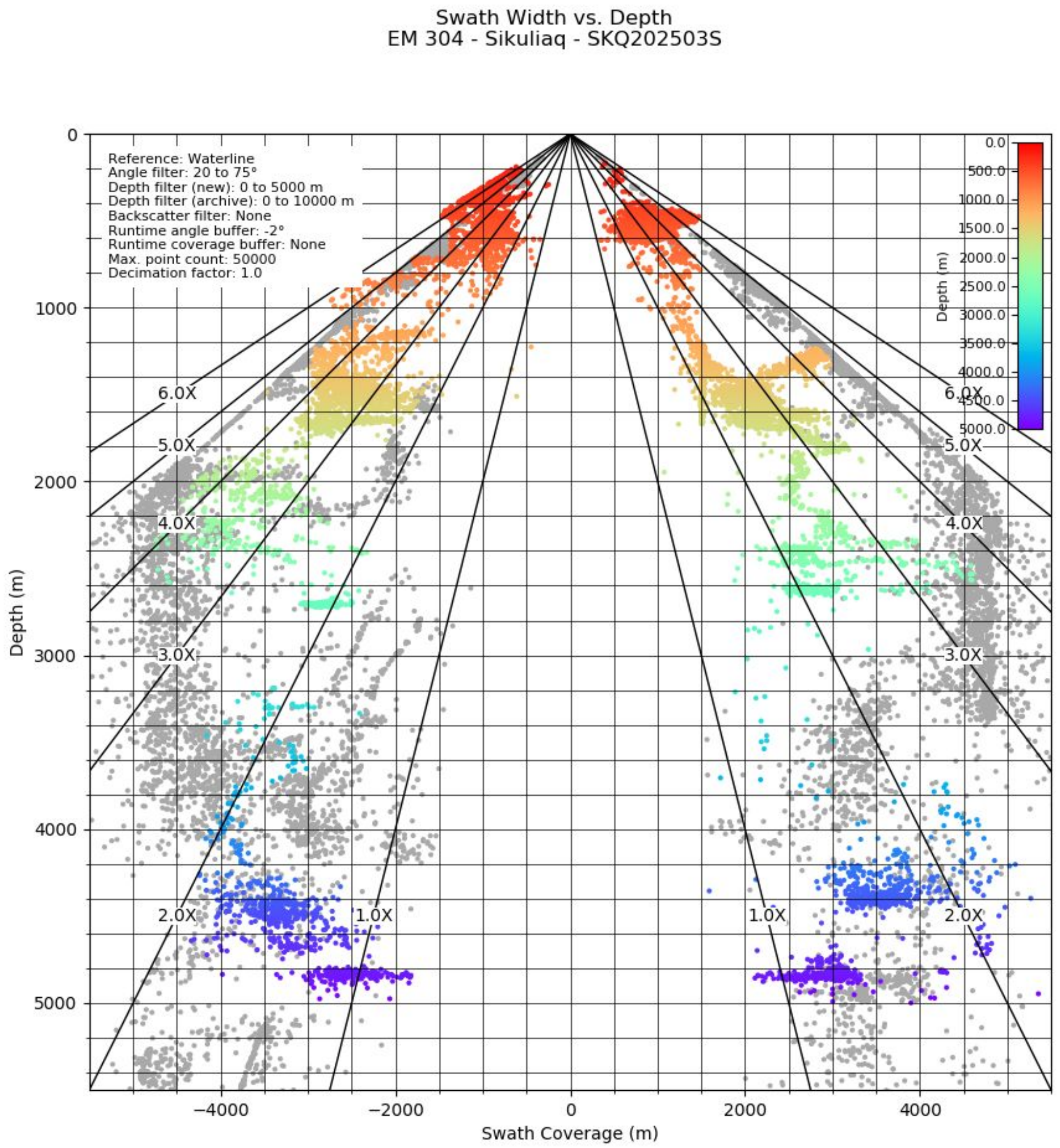


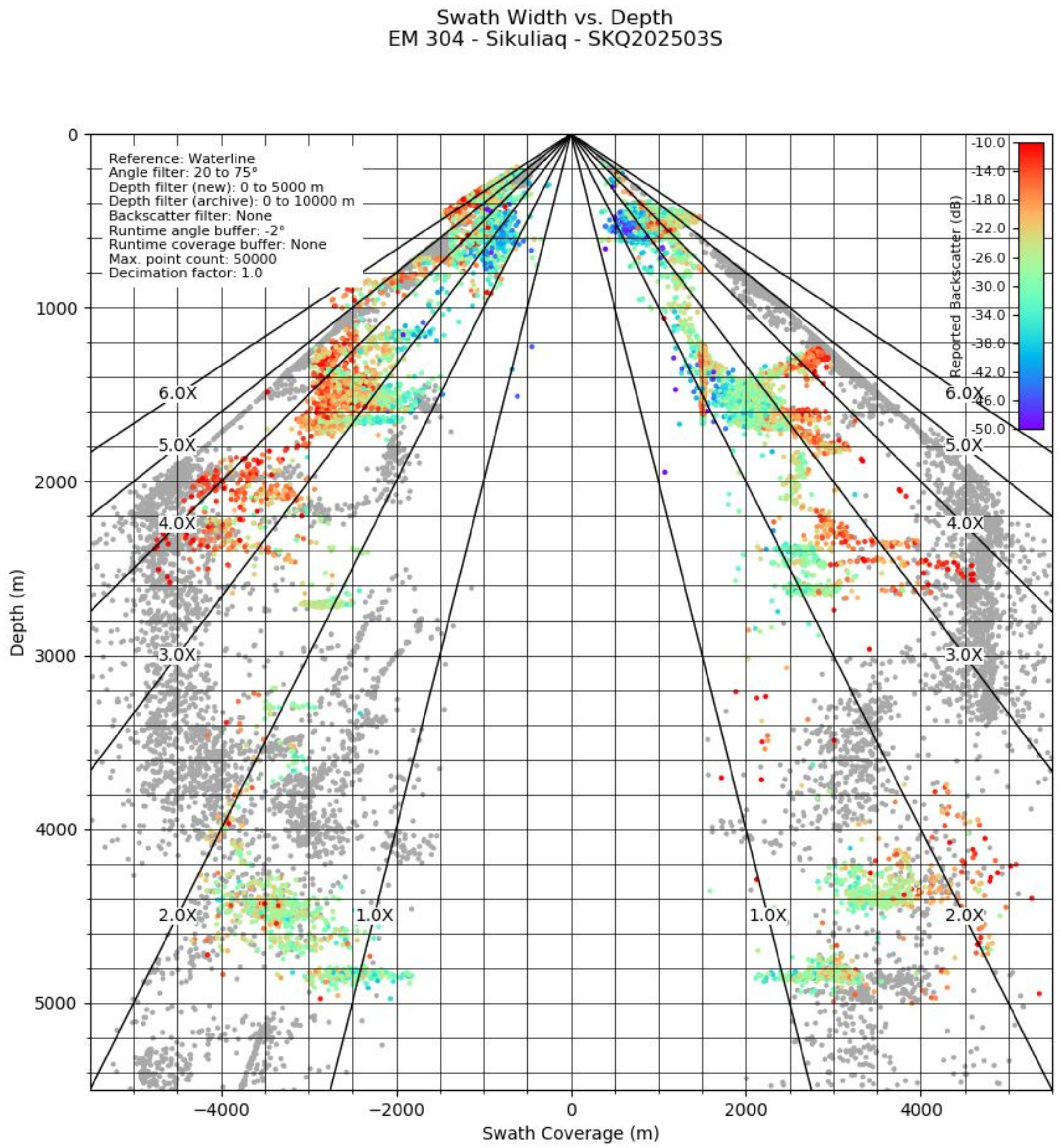
EM304 MKII Benchmark Data

1. Swath coverage can be an early indicator of noise limitations or other hardware health issues; baseline coverage trends observed early in the service life can be compared against future coverage tests to help detect these complications
2. The 2024 SAT report compared coverage against a benchmark EM304 MKII dataset collected by the *Okeanos Explorer* (same array sizes) over the Puerto Rico Trench in 2022 (EX2203); the benchmark data are shown at left (gray points) for reference
3. There are important differences that naturally reduce the *SKQ* coverage compared to the *EX* benchmark:
   a. TX High Voltage reduction required by Kongsberg
   b. Attenuation through ice protection windows
   c. Higher noise levels on *SKQ* than *EX,* possibly exacerbated in 2025 by biofouling / flow noise
4. Given these factors, SKQ coverage in the 2400-4800 m depth range (not tested in 2024) shows approximately a 1X WD reduction in coverage compared to EX

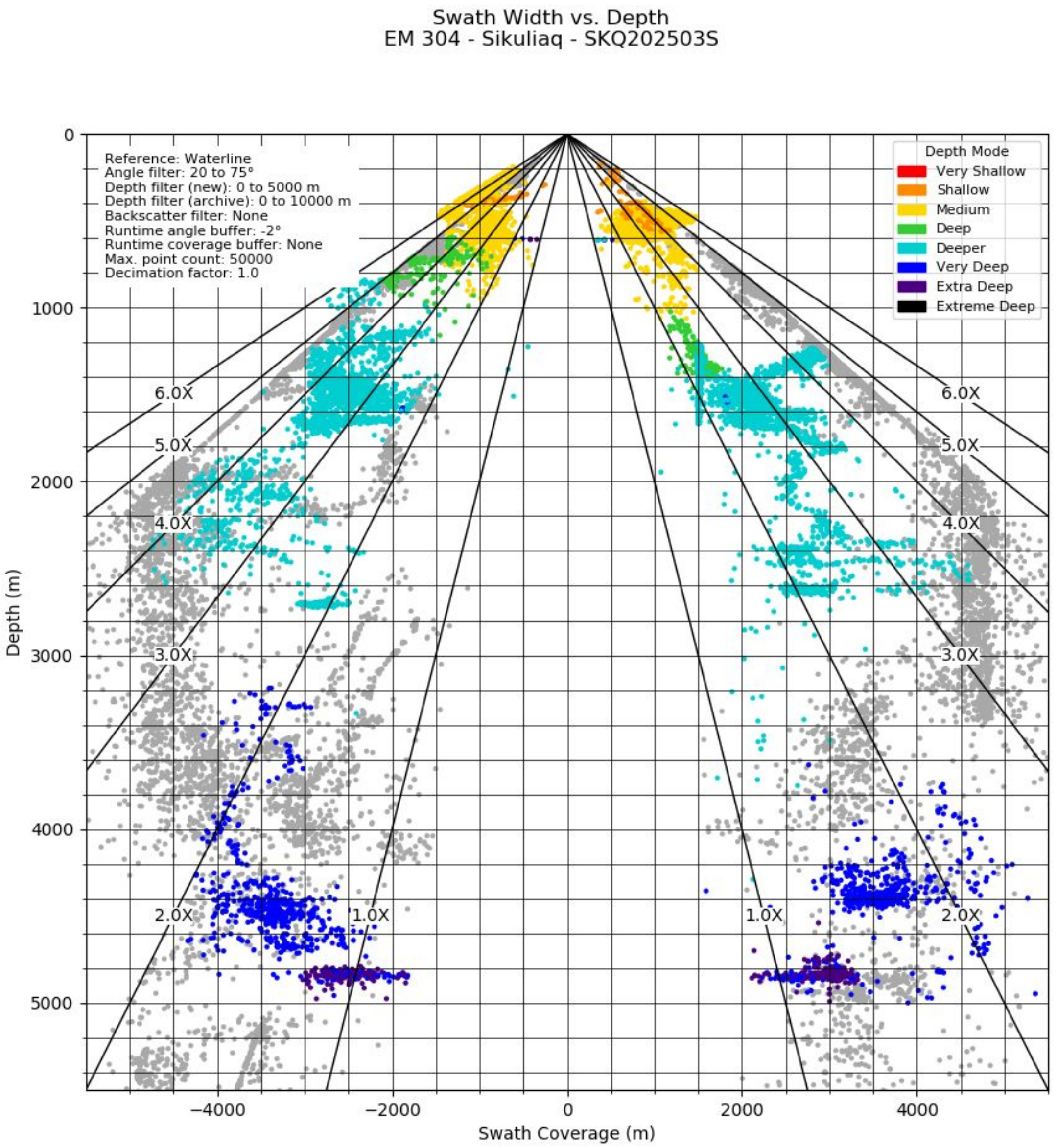
EM304 Swath Coverage

EM304 MKII Benchmark Data

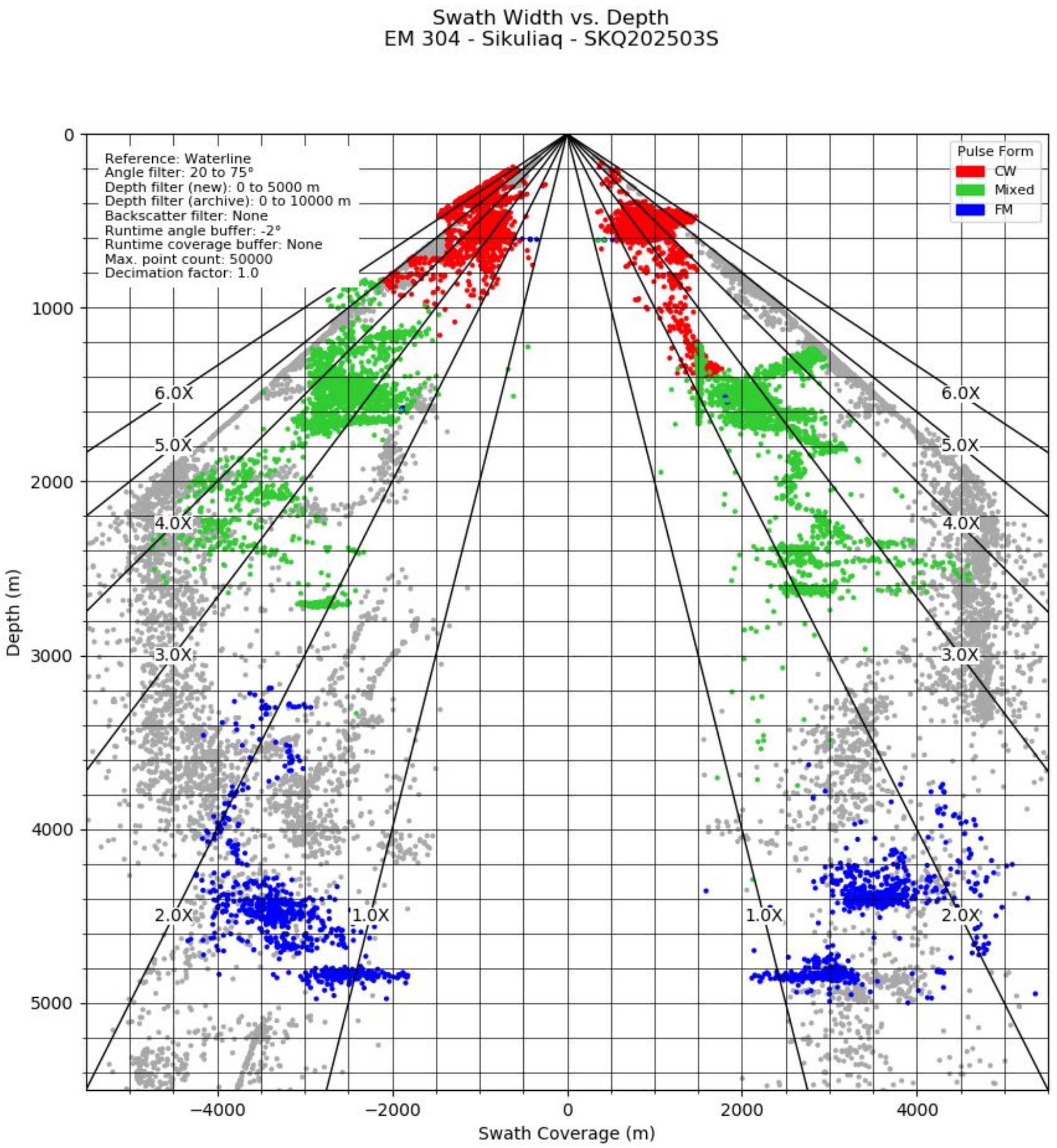




EM304 Swath Coverage



EM304 MKII Benchmark Data




GROVE