1. The University of Hawaii’s UNOLS vessel R/V Kilo Moana (KM) is equipped with Kongsberg Maritime EM122 and EM710 multibeam echosounders and an Applanix POS MV-320 V5 Ocean Master navigation system.


3. Because no hardware changes were made to the mapping systems since the 2022 post-shipyard QAT, the limited time available for the 2023 QAT was used to conduct deepwater accuracy testing and noise testing to build on the 2022 QAT (i.e., no new patch tests).

4. Pre- and post-shipyard noise testing conducted in March and May 2022 had indicated elevated but stable noise levels the previous field season (see 2022 report).

5. RX noise testing in October 2022 revealed significant increases in noise levels; additional testing in March-April 2023 confirmed the high (and worsening) noise levels detected in October 2022:
   a. Noise levels perceived by the EM122 and EM710 are higher in October 2022 and March 2023 across all speeds compared to the pre- and post-shipyard 2022 tests; the low-speed levels are similar between October 2022 and March 2023.
   b. The high-speed noise levels observed in March 2023 are ~10 dB higher than the October 2022 levels at 100 and 120 RPM, suggesting a major increase in the flow noise component at those speeds.
   c. Generator work was performed during the 2023 maintenance period; however, no major differences were noted across generator combinations at 120 RPM, likely ruling out any one unit causing the increases.
KM 2023 QAT Executive Summary

6. A diver inspection on April 3, 2023 showed significant biofouling on the hulls and arrays

7. Hull cleaning is necessary as soon as possible to reduce flow noise, providing the following benefits:
   a. probable improvements to swath coverage and accuracy at typical mapping speeds
   b. clearer assessment of machinery noise testing to determine whether recent generator maintenance may have had an across-the-board impact on noise levels

8. Kongsberg performed transducer impedance testing during the winter maintenance period, generally confirming the BIST TX and RX Channels data (see 2022 report); admittance plots have been generated from the impedance analyzer exports and are included in this report for reference

9. EM122 accuracy testing was conducted opportunistically by running a crossline in Deep mode over an existing 4700 m reference surface (used previously by several vessels); results indicated expected performance with no significant variability since the last test in this mode (2021)

10. Given the age of the EM122 and EM710 and the end of maintenance support from Kongsberg (e.g., decreasing availability of spare parts), the MAC recommends beginning to consider the replacement/upgrade planning process for the Kilo Moana’s multibeam mapping systems

11. The MAC is available to assist with additional testing and replacement planning as requested
KM 2023 QAT Planning Overview

1. EM122 and EM710 testing was incorporated into other deepwater gear testing on March 21-22 (local); due to scheduling conflicts, MAC personnel provided remote support for planning and data analysis from shore.

2. MAC communication with KM personnel (Lance Frymire) about the 2023 QAT commenced in early March 2023.

3. Because there had been no hardware changes since the 2022 QAT (aside from an EM122 TX board replacement), and due to the limited time available, the 2023 QAT plan skipped patch testing and included opportunistic testing of swath coverage, hardware health, and RX noise levels over a range of speeds to build on the 2022 QAT.

4. Additionally, an EM122 accuracy crossline was collected over an existing 4700 m reference surface (previously used by several vessels, including the KM in 2021).

5. This report describes the results for swath coverage, swath accuracy, system hardware health, and RX noise.
1. The 2022 QAT plan is shown below for reference; in 2023, only the 4700 m accuracy crossline was completed.
Swath Coverage Assessment

Overview

1. Coverage testing was conducted on two transit segments during the 2023 QAT:
   a. Segment 1: oriented SW, heading offshore and crossing contours perpendicularly with both systems logging, providing a useful dataset
   b. the second transit segment was oriented WNW and covered mostly flat terrain, with the starboard outer swath facing up slope; this segment is included to show the variability of coverage in the abyssal plain against previous years

2. Due to the high transit speed (11 kts) and associated high noise levels in 2023, the swath coverage plots shown here may under-represent the ‘typical’ coverage achieved at lower speeds
3. The EM122 and EM710 coverage data on the first segment are shown at left with different color scales (EM122 colorbar)

4. The results suggest that swath coverage for both systems was reduced compared to 2022 data over similar depth ranges (see 2023 vs. 2022 coverage colored by backscatter on following slides)

5. These reductions are likely due to higher vessel noise caused by biofouling and higher speed (11 kts in 2023 vs 8 kts in 2022)
EM122 Swath Coverage

2023 (Depth)

Swath Width vs. Depth
EM 122 - R/V Kilo Moana - 2023 QAT

Results

2023 (Mode)

Swath Width vs. Depth
EM 122 - R/V Kilo Moana - 2023 QAT
EM122 Swath Coverage

2023 (Pulse Form)

Results

2023 (Swath Mode)
EM122 Swath Coverage

Results

2023 (Backscatter)

2017 (Backscatter) vs. 2012 (Gray)

Left: 2023 coverage trends (colored by reported reflectivity)
Right: 2017 results (colored by reported reflectivity) versus 2012 (gray)
EM122 Swath Coverage

Results

2023 vs. 2022
(Backscatter)

Left: 2023 trends (colored by reported reflectivity) are reduced from 2022 (gray)

Right: 2017 results (colored by reported reflectivity) versus 2012 (gray)

2023 results generally show a ~1X WD coverage reduction at depths >2000 m
EM710 Swath Coverage

2023 (Depth)

Results

2023 (Mode)
EM710 Swath Coverage

2023 (Pulse Form)

Results

2023 (Swath Mode)
EM710 Swath Coverage

2023 (Backscatter)

Results

2023 vs. 2022 (Backscatter)

Left: 2023 trends (colored by reported reflectivity)
Right: 2023 results are reduced from 2022 (gray)
Overview

1. Accuracy (in the sense of self-consistency) of a multibeam echosounder under ‘normal’ survey conditions can be assessed by examining soundings collected during single-pass survey lines over a trusted bathymetric surface (a reference surface).

2. Reference surfaces typically cover flat or gently sloping terrain that has been carefully and densely surveyed, providing a large sample count and high degree of confidence in the depth of each grid cell.

3. Accuracy assessments provide a baseline for each mode and can help to reveal both changes to the system (e.g., reduced accuracy due to low transmit power from a degraded array) as well as changes to the operation environment (e.g., impacts of noise on the distribution of soundings and achievable swath width).
Overview

4. With routine assessments, accuracy testing can provide a critical window into performance over the system’s service life and may help to identify early signs of component failure.

5. An EM122 crossline was collected during over an 4700 m EM122 reference surface surveyed during the Kilo Moana’s EM122 SAT in 2012.

6. This site has been used repeatedly for Kilo Moana (last 2021) and other vessels.

7. Due to scheduling constraints, the crossline was shortened from 25 km to 10 km for the 2021 QAT (see 2021 report); because the schedule allowed a single pass during the 2023 QAT, priority was given for Deep mode (the ‘default’ mode for this depth).

8. The selected crossline mode represents the typical configurations that may be used at this depth (left); Very Deep mode (tested in 2021) was not included.

<table>
<thead>
<tr>
<th>Crossline Setting</th>
<th>Ping Mode</th>
<th>Swath Mode¹</th>
<th>Pulse Form</th>
<th>Yaw Stab.²</th>
<th>Pen. Filter</th>
<th>Crossline Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Deep</td>
<td>Dual</td>
<td>Mix</td>
<td>RMH</td>
<td>Off</td>
<td>1</td>
</tr>
</tbody>
</table>

¹Dynamic for all dual swath modes
²RMH = Relative Mean Heading
1. The crossline was oriented north-south for simplicity and agreement with previous crossline orientations; the reference surface (surveyed in 2012) includes north-south and east-west lines, reducing concerns over potential coupling of echosounder biases across the swath.

2. A sound speed profile was collected ahead of the crossline and applied during data collection and processing (nearest in time scheduling).

3. The reference surface was gridded with the CUBE algorithm in QPS Qimera at appropriate resolution, then filtered by slope in the NOAA/MAC accuracy plotter app (density and uncertainty were omitted from the available 4700 m ref. surf. grids).
4. No tide data was applied to the reference surface or crosslines, as the expected amplitudes (<1 m) are insignificant as a portion of water depth and vertical distribution of the EM122 soundings

5. Only reference surface cells meeting the slope criterion were used for analyses of crossline data

<table>
<thead>
<tr>
<th>Reference Surfaces</th>
<th>4700 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal depth (m)</td>
<td>4700</td>
</tr>
<tr>
<td>Grid size (m)</td>
<td>200</td>
</tr>
<tr>
<td>Min. soundings/cell</td>
<td>NA</td>
</tr>
<tr>
<td>Max. slope (deg)</td>
<td>5</td>
</tr>
<tr>
<td>Max. uncertainty (m)</td>
<td>NA</td>
</tr>
<tr>
<td>Crossline max. diff. (m)</td>
<td>NA</td>
</tr>
<tr>
<td>Crossline max. diff (%WD)</td>
<td>5</td>
</tr>
</tbody>
</table>
Testing Procedure

6. Examples of the reference surface filter results and the final grid used for comparison are shown at left on this and preceding slides

7. Crossline soundings (e.g., gray points at left; track line in black) were filtered to remove outliers based on distance from the reference grid, excluding soundings that are not representative of the normal swath behavior and would be readily flagged during routine processing; other systemic behavior of the echosounder was not edited or impacted

8. Sounding depths were compared to reference grid depths (interpolated onto the sounding horizontal position); mean depth bias 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)
EM122 Accuracy Testing

1. The EM122 Deep mode crossline mean curve generally agrees well with the reference surface, aside from possible outer refraction issues and a ~0.05%WD shallow bias in some port sectors.

2. The standard deviation trends are slightly elevated compared to the ranges typically seen with other EM122 systems, even after excluding soundings based on a depth-appropriate distance from the reference surface (e.g., soundings more than 5% of water depth from the reference surface that would be readily flagged during routine processing).

3. The distribution of soundings broadens rapidly toward the outer swath in Deep mode; this depth is on the far end of the intended depth range, and Very Deep mode may provide higher accuracy at the cost of narrower swath width.

4. Elevated standard deviations near nadir seen in 2021 seem to have been reduced in 2023; these may have been related to sea state near-nadir mistracking due to the penetration filter.

Swath accuracy as a percentage of water depth
Examples from 2021 and 2023 shown on next slides
EM122 Accuracy Testing

4700 m: **Deep/Dual/Mix/RMH**

2021 Deep

Pass 1: file 9
2021-05-15 (UTC)

Filtered to remove soundings >5%WD from ref. surface

EM122 Accuracy Testing

4700 m: Deep/Dual/Mix/RMH

2023 Deep

Pass 1: file 6
2023-03-22 (UTC)

Filtered to remove soundings >5%WD from ref. surface
Hardware Health

Overview

• Built-In Self-Tests (BISTs) were run for the EM710 and EM122 on 16 March 2023 to document system health
• BISTs provide impedance measurements of the transmitter elements, receiver elements, and receiver
• These types of test results may be used as proxies for the health of transducer elements and receivers
• Routine RX and TX Channel BISTs may aid early detection of element degradation; this is important to monitor, as arrays have been observed to degrade with time, causing reductions in swath coverage and accuracy

• **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 by direct measurements, e.g., Kongsberg Cypher tool)**
  • A Kongsberg field engineer visited the Kilo Moana in Feb 2023 to conduct direct impedance measurements; the results and report are provided separately by Kongsberg, and also presented here (admittance loops)
• The EM122 RX Channels BIST format includes receiver data but no transducer data (resulting in empty plots)
• All BISTs available on the EM710 and EM122 work stations are plotted here to provide an overview of proxy impedance measurements through time
• EM122 TX Channels data were collected through a BIST telnet session on 2023-03-16
• **Note for EM710 BIST telnet sessions:** the EM710 TX Channels BIST menu via telnet includes options to test Slots 11-15 and 16-20, which do not exist for a 1.0° TX system; ‘extra’ tests beyond Slot 10 caused the BIST plotter to fail and were removed in order to generate the plots shown here
1. TX Channels BISTs were collected via telnet on 2023-03-16 (EM122) and 2023-06-02 (EM710).

2. The color scales are based on Kongsberg specs included in the BIST files, with red (high Z, open) and purple (low Z, short) indicating element failure.
1. An EM122 TX Channels BIST was logged on 2023-03-16 for comparison to 2022 data; no pre-2022 TX Channels BISTs are available

2. As reported in 2022 and confirmed in 2023, the EM122 BISTs show 36 failures (out of 864 channels, or ~4%), in agreement with direct Z measurements taken by Kongsberg in Feb 2023

3. Degrading EM122 TX array health should prompt a discussion for hardware replacement planning
EM710 Hardware Health

1. No TX Channels data are available prior to 2022
2. The 2023 results indicated stable health across the EM710 TX hardware, with some failures apparently returning to normal
EM122 Hardware Health

RX Channels and Receiver

• EM122 RX channels data for the receiver (top) and transducer (bottom) were logged on 2023-03-16
• The color scale on each plot is based on the acceptable impedance range to pass a BIST, as defined by Kongsberg
• All receiver impedance values are well within spec
• For this EM122 BIST format, the text file does not include transducer element impedance data; this should be tested with direct measurements (e.g., Cypher tool) as the array elements may degrade without impacting receiver impedance results
EM122 Hardware Health

RX Channels and Receiver

Historic BISTs

- EM122 RX channels impedance data for the receiver (top) and transducer (bottom) are shown for all available BISTs (2019-2023); the last BIST plotted (black) is from 2023-03-16
- These plots show consistent trends for each module and no significant changes in the 15 available files
- For this EM122 BIST format, the text file does not include transducer element impedance data
EM710 Hardware Health

RX Channels and Receiver

- EM710 RX channels data for the receiver (top) and transducer (bottom) were logged on 2023-03-16
- The color scale on each plot is based on the acceptable impedance range to pass a BIST, as defined by Kongsberg
- Aside from a few clustered high values (e.g., elements 7-11 on board 2), the receiver and transducer impedance values are well within spec for all elements
EM710 RX Channels and Receiver

Historic BISTs

- EM710 RX channels impedance data for the receiver (top) and transducer (bottom) are shown for all available BISTs (2017-2023); the last BIST plotted (black) is from 2023-03-16

- These plots show consistent trends for each module and no significant changes for the receiver impedance in the 13 available files

- The transducer impedance history shows an increase across the array in 2020, possibly associated with temperature, that returned to its baseline in 2021

- The history also shows continued upward trends for two clusters in the middle of the array, which must be monitored
1. Cypher impedance files provided by Kongsberg were plotted as admittance loops in MATLAB for reference.

2. The ‘spread’ of these loops may indicate additional failure modes not capture in the TX or RX Channels BISTs.

3. The EM122 TX plot (upper left) is cropped to exclude one major outlier loop and preserve reasonable scaling for all other data.

4. See the Kongsberg service report for more information.
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.

To characterize the vessel’s noise environment as perceived by the EM710 and EM122, a series of RX Noise Level Built-In Self-Tests (BISTs) were recorded over a range of shaft speeds (0-120 RPM in 20-RPM increments)

Whereas previous tests were recorded at incremental speeds over ground (SOG), shaft speed (RPM) is used here as a more repeatable metric of engine load and speed through water (STW), given the uncertainty over currents and lack of direct STW information with all other acoustic systems secured (e.g., Doppler speed log); the top speed of 117 RPM / ~12 kts SOG is consistent across tests in 2020-23

The following slides present a history of 2020-23 tests to illustrate trends in each system’s noise environment, as well as the effects of hull cleaning in the yard and possible complications from recent changes in machinery noise

The significant increase in EM122 noise levels at speeds of 10-12 kts seen in 2021 appears to have been ameliorated through the May 2022 tests, but then returned in the October 2022 test and worsened in March 2023; the root causes are not clear, though the high noise levels later in the season may stem from biofouling and associated flow noise (that may be reduced by cleaning)

In some cases (particularly during the 2022 pre-shipyard tests), waves impacting the hull generated broadband noise seen as vertical stripes across all elements, illustrating the effects of sea state on the mapping system noise environment

The EM122 generally shows much higher perceived RX noise levels compared to the EM710 across the 2020-23 tests; this is likely due to relatively low-frequency machinery noise that is more in-band for the EM122 (12-kHz) and suppressed for the EM710 (70-100 kHz)
2020 pre- and post-shipyard data are shown for reference; the 2021-23 results are included on the next slides for comparison. At all speeds and across all test data, high noise levels on the edges of the array (top and bottom edges of image) indicate local impacts of flow and machinery noise arriving through the hull. The vertical stripes are likely caused by swell impacting the hull during the RX noise test cycle; these illustrate the broadband noise perceived due to sea state but do not represent typical machinery or flow noise. The general reduction from pre- to post-shipyard noise levels shown at left indicate the benefits of hull cleaning and reduced flow noise.
A significant increase in noise levels across the array at all speeds in October 2022 and March 2023.

A diver inspection in late April 2023 revealed significant biofouling that is likely the primary driver of the very high noise levels at speed.

However, the biofouling does not explain the elevated noise levels at low speed; these are typically related to machinery noise.
RX Noise BIST Assessment

2022 Pre-shipyard

RX Noise vs. Speed
EM122 (S/N 109)
Date: 2022-03-24
Freq: 12 kHz

RX Noise (dB re 1 µPa/√Hz)

2022 Post-shipyard

RX Noise vs. Speed
EM122 (S/N 109)
Date: 2022-05-22
Freq: 12 kHz

RX Noise (dB re 1 µPa/√Hz)

2023 March 22

RX Noise vs. Speed
EM122 (S/N 109)
Date: 2023-03-22
Freq: 12 kHz

RX Noise (dB re 1 µPa/√Hz)
Diver inspection showing biofouling on/near arrays (April 2023)
Generators 1, 2, and 3 were online during the 2023 noise vs. speed testing (0-120 RPM).

Additional testing was performed with a variety of generator lineups to try to identify any changes with machinery while operating at the maximum 120 RPM prop shaft speed.

Seawater pumps SVP flow-through pump were secured during this round of testing.

Additional testing at 0 and 120 RPM shown here on April 1, 2023, indicates a slight reduction in noise levels at 0 RPM compared to March 22; this may suggest a different sources of machinery noise (i.e., pumps) during the March noise vs. speed testing.

There were no significant differences in EM122 RX noise levels between machinery lineups at the 120 RPM load (next slide).
RX Noise BIST Assessment

EM122 Noise Levels at 120 RPM
2020 pre- and post-shipyard data are shown for reference; the 2021-23 results are included on the next slides for comparison.

The vertical stripes are likely caused by swell impacting the hull during the RX noise test cycle; these illustrate the broadband noise perceived due to sea state but do not represent typical machinery or flow noise.

Horizontal stripes are noise persisting across all tests; based on spacing, these may be related to the clustered high-Z values shown for Board 2 in the EM710 RX Channels impedance test plots.
2022 results (included here for reference) show generally low noise levels and negligible changes with speed.

*Note that post-shipyard EM710 tests at shaft speeds <60 RPM included BIST errors and are not presented here.*

The vertical stripes shown in the pre-shipyard data are likely caused by swell impacting the hull during the RX noise test cycle; these are not present in the post-shipyard data collected in calm seas, illustrating the broadband noise perceived due to sea state.

Noise levels were observed to increase with speed in 2021 (next slide) but not in 2022; this trend returned in 2023 data, starting at lower speeds (compared to 2021) and suggesting a more severe impact from biofouling on the hull and arrays.
RX Noise BIST Assessment

2022 Pre-shipyard

RX Noise vs. Speed
EM710 (S/N 219)
Date: 2022-03-25
Freq: 70-100 kHz

2022 Post-shipyard

RX Noise vs. Speed
EM710 (S/N 219)
Date: 2022-05-22
Freq: 70-100 kHz

EM710 Noise Level vs. Speed

2023 March 22

RX Noise vs. Speed
EM710 (S/N 219)
Date: 2023-03-22
Freq: 70-100 kHz

RX Module (Index starts at 0)

RX Noise (dB re 1 μPa/√Hz)
Generators 1, 2, and 3 were online during the 2023 noise vs. speed testing (0-120 RPM)

Additional testing was performed with a variety of generator lineups to try to identify any changes with machinery while operating at the maximum 120 RPM prop shaft speed

Seawater pumps SVP flow-through pump were secured during this round of testing

There were no significant differences in EM122 RX noise levels between machinery lineups at the 120 RPM load (next slide)