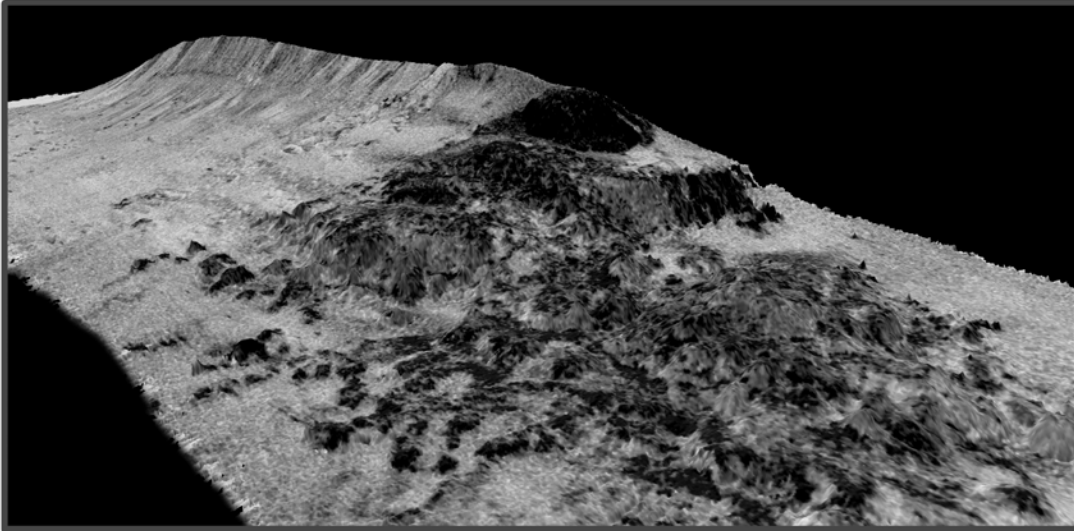


# R/V Falkor Multibeam Echosounder System Review

February 12, 2014



## Report prepared by:

Jonathan D. Beaudoin, Paul D. Johnson and Ashton F. Flinders  
Center for Coastal and Ocean Mapping/Joint Hydrographic Center  
24 Colovos Road  
University of New Hampshire  
Durham, NH

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*Cover image: EM710 acoustic backscatter imagery draped over bathymetry for area south of Diamond Head on the island of O`ahu.*

## Introduction

RV *Falkor* is equipped with Kongsberg Maritime (KM) EM302 and EM710 multibeam echosounders (MBES). Both systems were the subject of an annual system checkup conducted over February 4-7, 2014 in the vicinity of O'ahu, HI (Fig. 1) with the intention of verifying that performance levels of the systems had not degraded during the first two years of mapping operations.

In our experience, multibeam system performance can degrade in terms of:

- **Efficiency (swath coverage):** Transducer degradation and changes in self-noise levels can compromise the maximum range/depth performance. What this means to the end-user is that the system achieves less across-track swath coverage than expected and is thus less efficient as a mapping platform. Monitoring various subsystems, along with assessing coverage abilities, gives an idea of the overall acoustic health of the system as a whole.
- **Bathymetric data quality:** Bathymetric measurement artifacts can result from a number of sources, including faulty configuration of the multibeam and/or ancillary sensors or degradation in performance of the same. Geometric calibration and follow-up accuracy testing is an important set of tests that confirm the quality of the bathymetric data that is acquired.
- **Acoustic imagery quality:** Acoustic imagery, either of the seabed or of water column scatterers, is another data product commonly available from multibeam systems. Acoustic noise levels can degrade the quality of imagery, especially in cases of transient noise events. Other potential sources of artifacts include incorrect sector/swath normalization that can be difficult to correct in post-processing. Imagery products should be examined to identify and correct problems.

To assess RV *Falkor*'s two multibeam systems, the following evaluation procedures were performed during the cruise:

1. Transducer and System Health
2. Noise Evaluation
3. Coverage Evaluation
4. Geometric Calibration
5. Accuracy Evaluation
6. Acoustic Imagery Quality Evaluation

It is the intent of this report to document the outcome of the evaluation procedures and to provide an assessment of the capabilities of both systems with respect to the original baseline assessment conducted during the sea acceptance tests (SAT) performed in May and July of 2012 (Beaudoin et al., 2012) and also to the Year 1 assessment (Beaudoin et al., 2013).

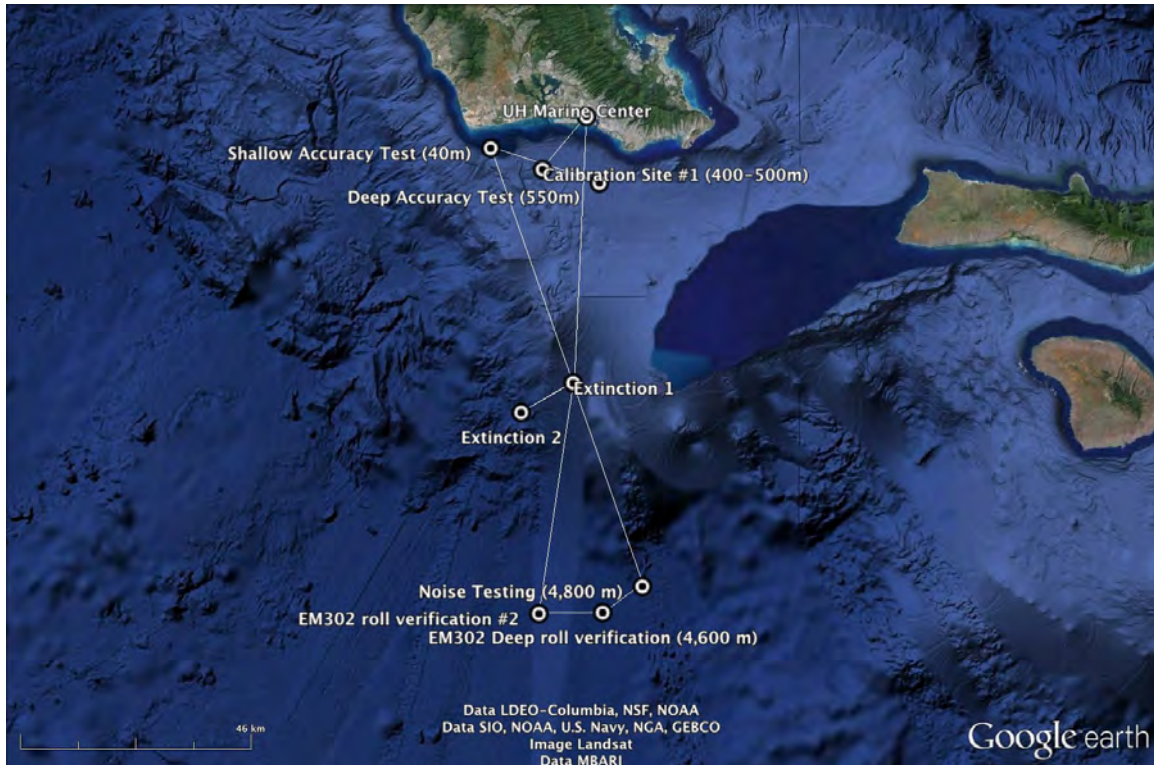


Figure 1. Overview of cruise plan ship track and test site locations.

## System Overview and Ancillary Instrumentation

The EM302 is a 30 kHz MBES capable of full ocean depth mapping though it is most optimally used in depths from 1,500 to 3,000 m. The EM302 system is available in a number of transmit/receiver configurations; the system aboard *Falkor* provides 1°x1° angular resolution, yielding seafloor sounding resolution on the order of 1.7% of oblique range. Though the system is nominally 30 kHz, the full frequency range is 26.5-33.6 kHz.

The EM710 frequency range spans 73-97 kHz; the system aboard *RV Falkor* is capable of 0.5°x1.0° transmit and receiver angular resolution, respectively. The EM710 system is well suited for continental shelf mapping with maximum coverage being achieved at depths typically between 500-1,000 m. Maximum depth performance is typically less than 2,000 m.

Both systems allow for seafloor mapping over a swath of 140°, giving a roll stabilized coverage up to 5.5 multiples of water depth (5.5 x w.d.). The systems are capable of multiple sector transmission, allowing for pitch/yaw motion stabilization and also multi-ping capabilities. The latter functionality doubles the along-track sounding density and permits surveying at higher speeds without loss of data

density. Both systems use the manufacturer's software to configure, monitor and acquire the data, namely Seafloor Information System (SIS), v.3.8.3.

The ancillary components of the two mapping suites aboard RV *Falkor* are listed below:

- SeaPath 320 heading, attitude and positioning sensor
- CNAV positioning correction service
- Seabird 9 Conductivity Temperature Depth (CTD) profiler
- Valeport SV profiler
- Turo XBT
- Valeport miniSVS surface velocimeter
- SBE38 and SBE45 thermosalinograph

All of the above systems were installed in 2011/2012 and were tested extensively in May and July of 2012. All systems were found to be operating correctly and overall results from the 2012 testing indicated that RV *Falkor* multibeam systems were well calibrated and were not noise limited. The initial 2012 tests provide a baseline against which long term monitoring of system performance can be compared to assess system degradation with time.

## Transducer and System Health

A full Built-In Self Test (BIST) diagnostic routine was run dockside on both the EM302 and EM710 with both systems passing all tests prior to sailing. Among other tests, the BIST provides the ability to perform impedance measurements of the RX and TX array. These tests are useful in establishing the health of the transducers, as these components of the mapping system have been known to degrade with time. It is important to note that the BIST impedance measurements do not provide a full characterization of transducer properties as a function of frequency as performed by Ifremer in 2012 (Le Gall and Pacault, 2012), however, they are believed to be good indicators of overall transducer health over their lifetime, especially when conducted on a routine basis.

The EM302 and EM710 receiver impedances and receiver transducer impedances, as measured through the BIST routines, were compared to measurements made during the system acceptance tests in 2012 and 2013 and were found to be within the nominal acceptable range expected by the manufacturer (Fig. 2 and 3 for EM302 and Fig. 4 and 5 for EM710). The BIST output lists two sets of impedance measurements for the EM302 and the EM710, the first set being referred to as the receiver impedance and the second set being the transducer impedance. In this report, we will refer to the first as the receiver channel impedance and the second as the receiver transducer impedance.

EM302 impedances, for both receiver channels and receiver transducers were consistent with previous BIST output dating back to 2012-03-14. The same can be said of the EM710 receiver channel impedances, however, there are inconsistencies between the 2012 and 2013 results for the transducer impedances (Fig. 5) though the 2013 and 2014 results are in general. In all three cases, the values reported are within the allowed range specified in the BIST test and the test thus passes these values, refer to Beaudoin et al. (2013) for more discussion on the 2012/2013 inconsistency.

The transmitter channel impedance tests (not to be confused with receiver transducer impedances tests discussed above) passed for both systems in the general BIST routines available through the graphical user interface in SIS for both the EM710 and the EM302. Transmitter module impedance values were obtained through telnet BIST routines with positive results except for the same failed EM710 transmitter element identified in the 2012 Ifremer transducer report (Fig. 6-7).

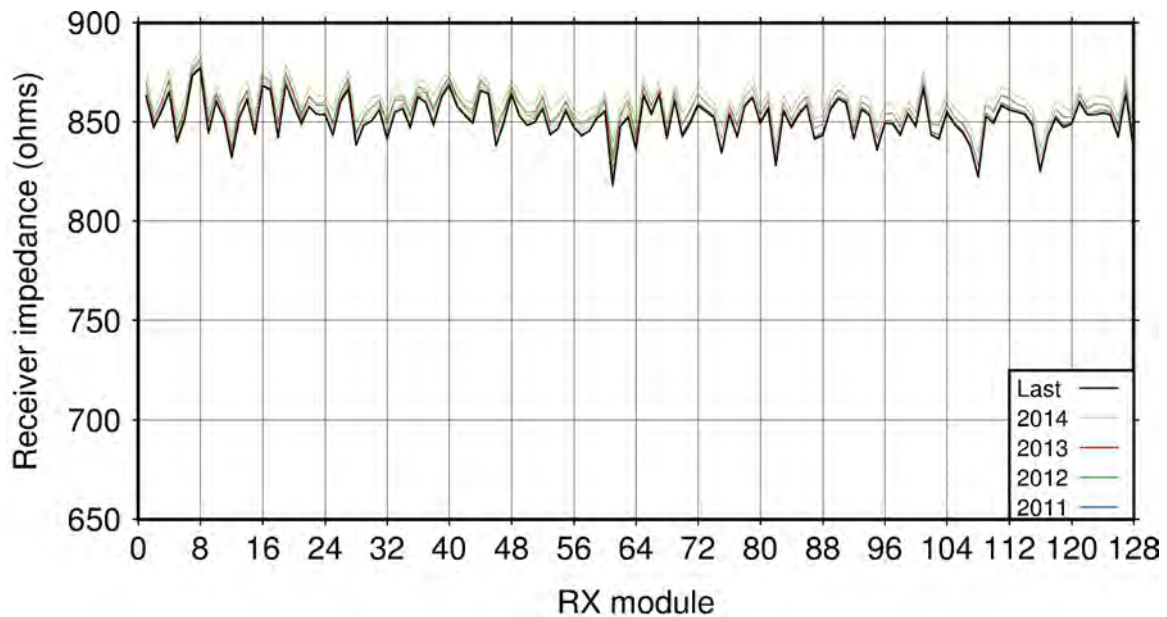


Figure 2. EM302 receiver impedance measurements. Historic measurements are coloured and current measurements from this evaluation in grey/black.

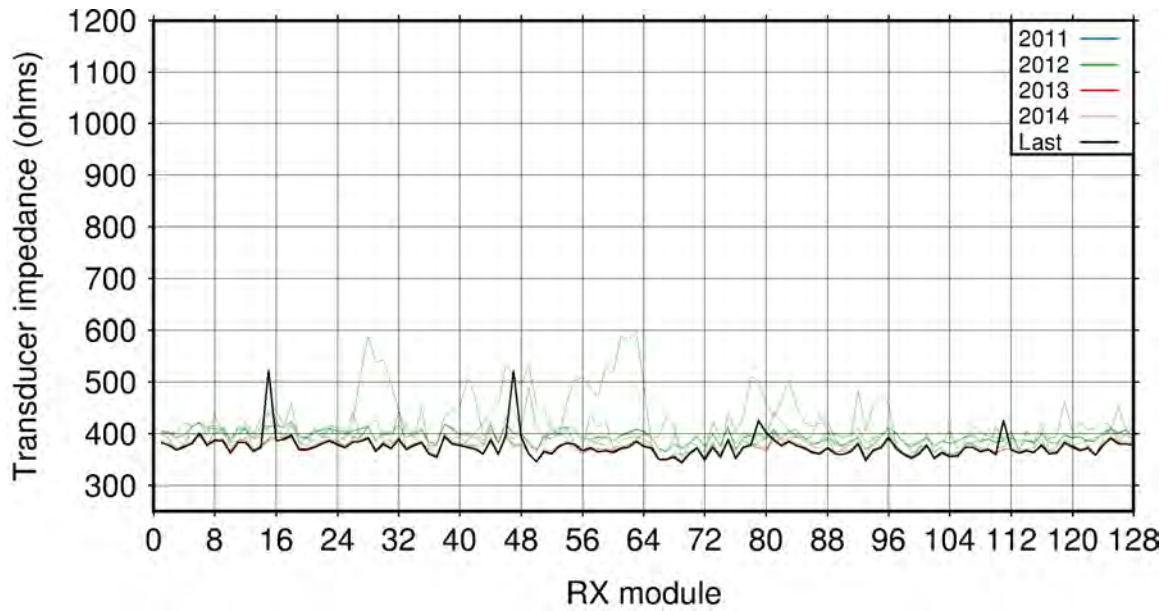


Figure 3. EM302 receiver transducer impedance measurements. Historic measurements are coloured and current measurements from this evaluation are in grey/black. RX modules 15 and 47 are reporting higher levels than observed in 2013 but are still within manufactured defined acceptable limits.

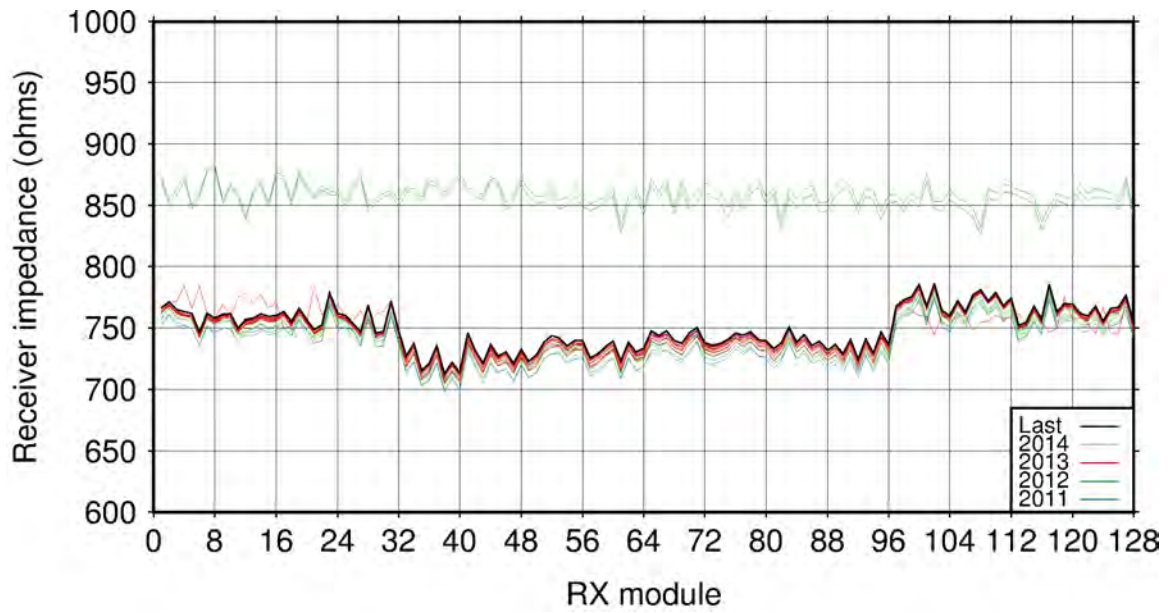


Figure 4. EM710 receiver impedance measurements. Historic measurements are coloured and current measurements from this evaluation are in grey/black.

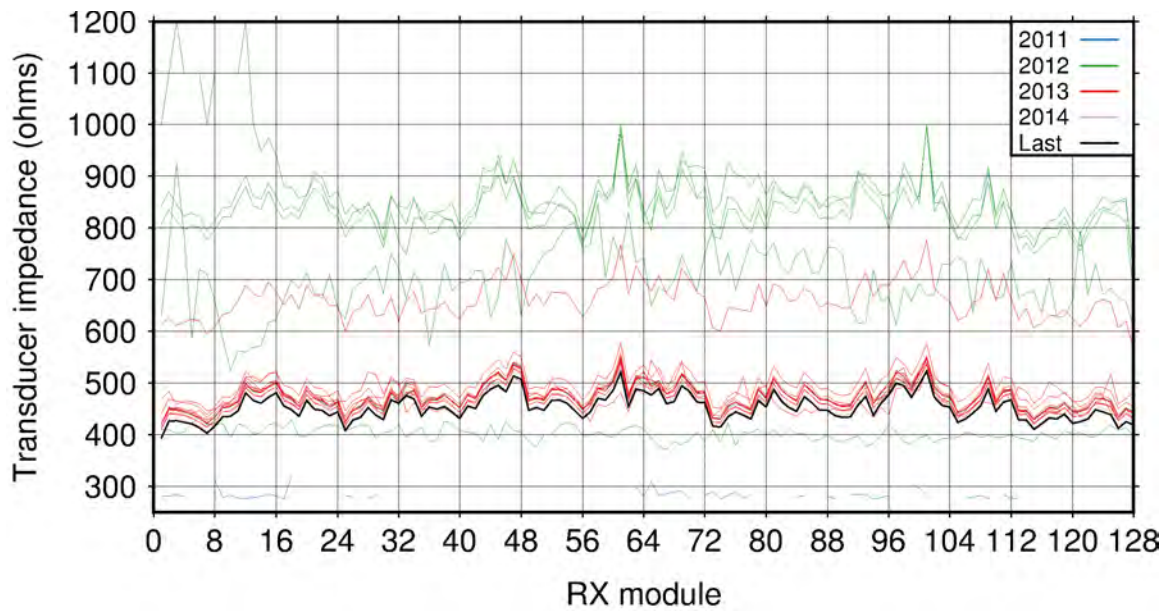


Figure 5. EM710 receiver transducer impedance measurements. Historic measurements are coloured and current measurements from this evaluation are in grey/black. The values greater than 700 ohms are from tests acquired during the 2012 acceptance and sea trials in the North Atlantic. The values in middle group (~400-500 ohms) are from the 2013 tests done in the Bahamas and the 2014 tests done off O’ahu. The low values (~300 ohms) were acquired on 2011-06-12, presumably during early factory testing.

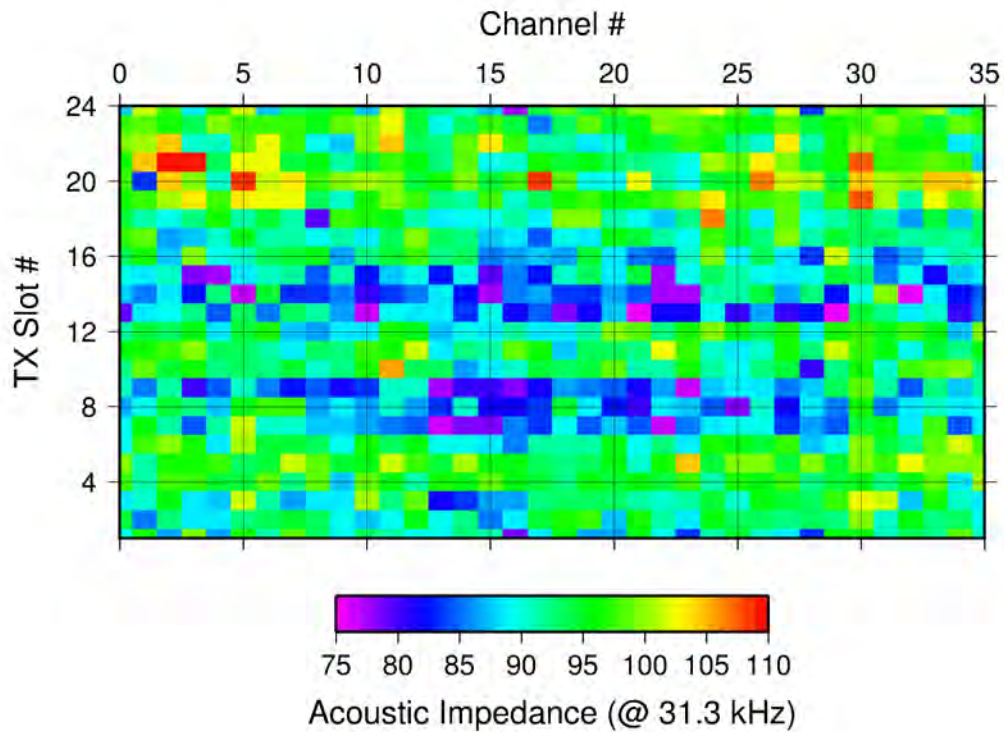


Figure 6. EM302 transmitter acoustic impedances.

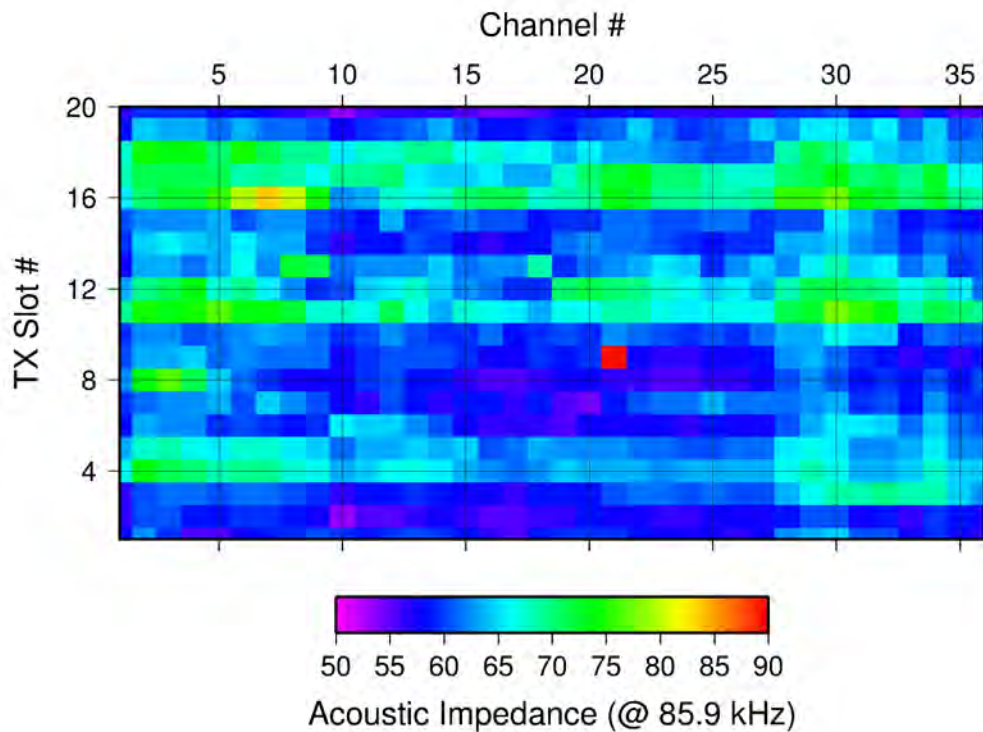


Figure 7. EM710 transmitter acoustic impedances.

## Noise Levels

A potentially major limiting factor in multibeam coverage performance is the effect of self-noise, either mechanical or electrical, on the system’s ability to detect and track the acoustic signal reflected from the seafloor. Comprehensive acoustic testing is possible for problematic installations (Gates and Yearta, 2012), however as RV *Falkor* was initially assessed as a quiet platform (Le Gall et al., 2012), a minimal set of acoustic test routines can be performed through the BIST noise testing routines to determine if significant changes have occurred in terms of ship self-noise levels.

A short series of noise tests for both systems, as a function of vessel speed, were conducted in 4,800 m of water on a course of 340° (Fig. 1). Sea conditions throughout the noise test were:

- Wind: 6 kts at 164°T, 180° relative to ship’s head
- Sea state: Beaufort 2-3 from 164°T, ~180° relative to ship’s head

All acoustic instrumentation, including bridge echosounders, was secured as was all deck work. Power plant configuration was set to “Science Mode”:

*“In this mode, the engine RPM and propeller pitch are firstly tuned at their minimum values (respectively 85 RPM and 5% pitch). Secondly, the propeller pitch raises (to the maximum value of 85%) to increase the vessel speed. And when the propeller pitch has reached 85%, the engine RPM is boosted to more increase the vessel speed.” (Le Gall et al., 2012)*

The receiver broadband noise level was measured using the BIST functionality with twenty tests being conducted at each speed level. The output from a single BIST noise test consists of the broadband noise level, as measured across the typical reception bandwidth spectrum, as a function of each receiver channel across the receiver array, reported as dB ref.  $1\mu\text{Pa}/\sqrt{\text{Hz}}$  (example, EM302; Fig. 8).

Note that Ifremer noise measurement protocols (Beaudoin et al., 2012) differed slightly in the number of tests taken at each speed (they took three) and that the mean results computed from each triplet of tests is computed as a linear mean without any mention of the underlying distribution or whether or not outlier measurements were excluded from their analysis. The tests conducted in these trials and in the 2013 trials (Beaudoin et al., 2013) involved more tests per speed (we took twenty) and several summary statistics are presented to ease comparisons between tests by different parties (e.g. Ifremer, Gates Acoustic Services, etc.). These comments are not made to point out deficiencies in the methods used by other parties, it is our intent simply to highlight that different parties approach the problem of noise evaluation in different manners and this must be appreciated if one is to compare results from differing methods.

The distribution of the data points in the EM302 noise test at 12 kts (Fig. 8) is shown in Fig. 9 along with the median, geometric mean and linear mean. The geometric mean is the mean of the dB values in their natural logarithmic units, i.e. an arithmetic mean of the dB values. The linear mean is the mean of the noise levels in linear intensity units and then expressed in db. Refer to Appendices A and B for equivalent plots for both sensors at all speeds investigated in this work.

The complete noise measurement data set (noise as a function of vessel speed) is plotted as a 2D color image for both the EM302 and EM710 in Fig. 10 and Fig. 11, respectively. This allows for examination of all data points and for a better appreciation of the likelihood and nature of transient noise events such as the event observed in test 20 for the EM302 (Fig. 10).

The series of speed tests allow for construction of platform noise level versus ship speed for both the EM302 and EM710 (Fig. 12 and Fig. 13). In these figures, the data points from all receiver modules and for all tests at a given speed are plotted as black dots, along with the summary statistics across the speed range, indicating the mean (linear and geometric) and the median values for each speed. EM710 noise level characteristics with speed were consistent with those observed in previous

trials performed by Ifremer (Le Gall et al., 2012) in that the EM710 noise level is independent of speed and is instead controlled by electronic self-noise on the order of 38 dB in “Science Mode”.

The EM302 noise tests indicate higher noise levels relative to previous examination where the noise level increased only slightly from 41 dB to 43 dB from speeds of 6 to 12 knots in “Science Mode”. The 2014 evaluation indicates that noise levels are still low at lower speed but then increase much more dramatically at higher speeds relative to previous assessments, particularly on the consistently noisier modules (e.g. 15-18). Mean noise levels now reach 50 dB at 12 kts, an increase of roughly 7-8 dB relative to the assessment in 2013, which is roughly a 6-fold increase. A noise level of 50 dB is still reasonable; for comparison, the noise level specification used by the Naval Oceanographic Office (NAVO) is 49 dB. Of course, it is better to be quieter if possible and since *Falkor* has previously tested as a quiet vessel, it would be prudent to investigate the source of this increased noise level.

Follow up testing for the EM302 in “Constant Speed” mode (RPM fixed at 144) allowed for isolation of variable pitch propeller effects, results indicate that the noise levels increase linearly with propeller pitch up to 70% pitch (Fig. 14). Further testing was done in “Constant Speed” mode with a propeller pitch of 80% to determine if the increased noise level was associated with one of the two propellers. Median noise levels at 80% pitch were 52 dB with both engines operational and clutched in, this dropped to 50 dB with the starboard engine only and to 48 dB with the port engine only (Table 1). Noise levels were identical in with both engine configuration whether the engine was declutched or secured, i.e. the noise level of a secured engine was the same as the noise level of the same engine running but declutched.

**Table 1. Median NL variation with machinery lineup, “Constant Speed” mode with pitch of 80%.**

<b>Machinery Lineup</b>	<b>Median NL (dB re 1μPa/√Hz)</b>
Both engines engaged	52 dB
Port only	48 dB
Starboard only	50 dB

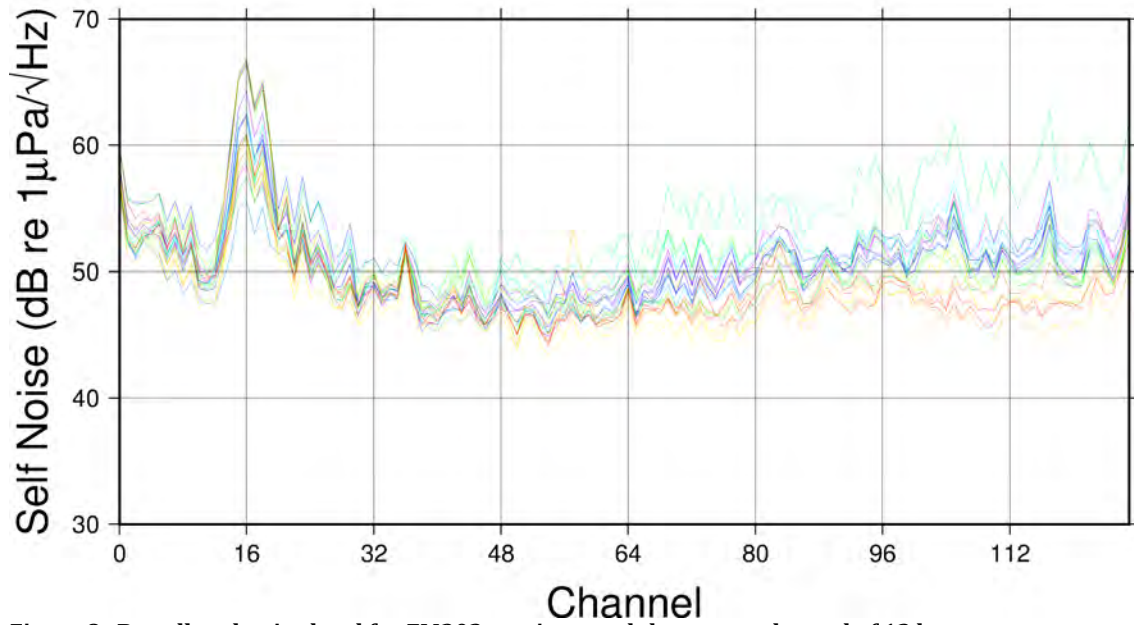


Figure 8. Broadband noise level for EM302 receiver modules at vessel speed of 12 knots.

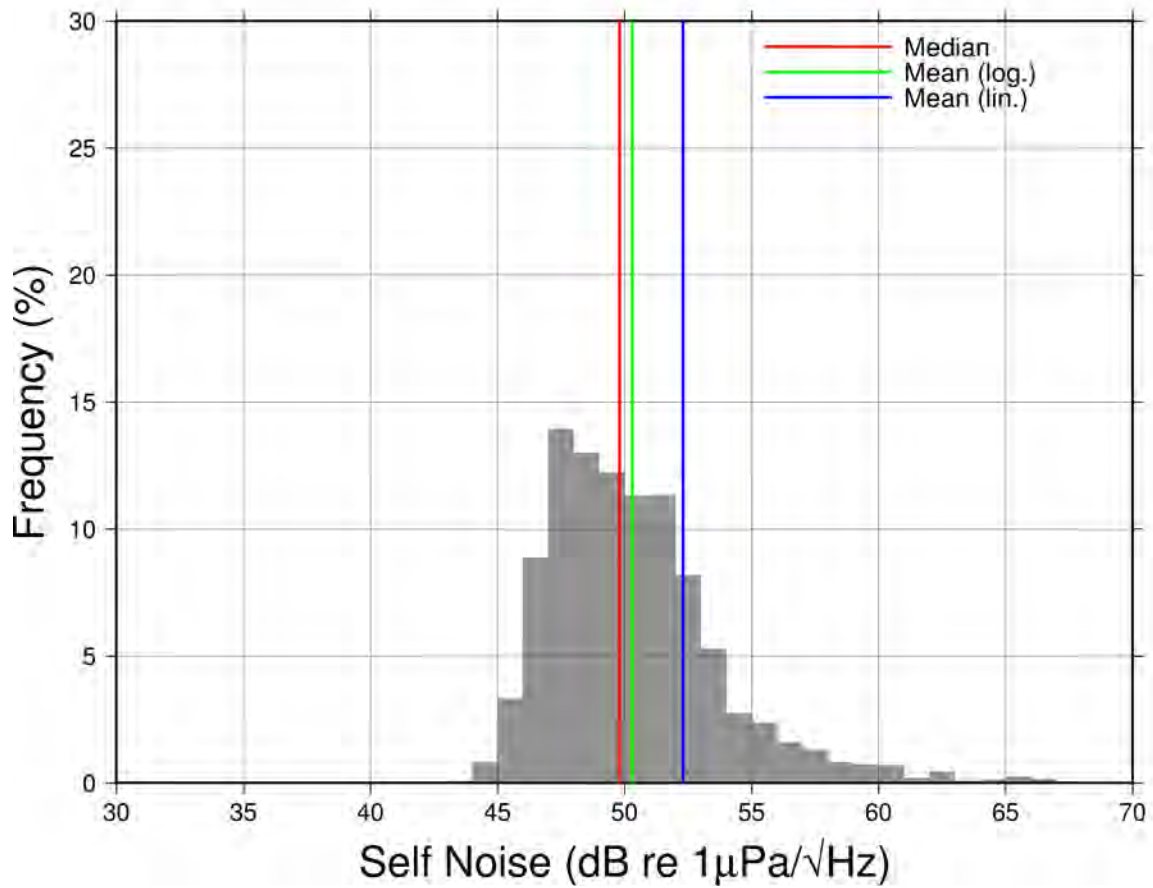


Figure 9. Distribution of noise level measurements for EM302 at 12 knots.

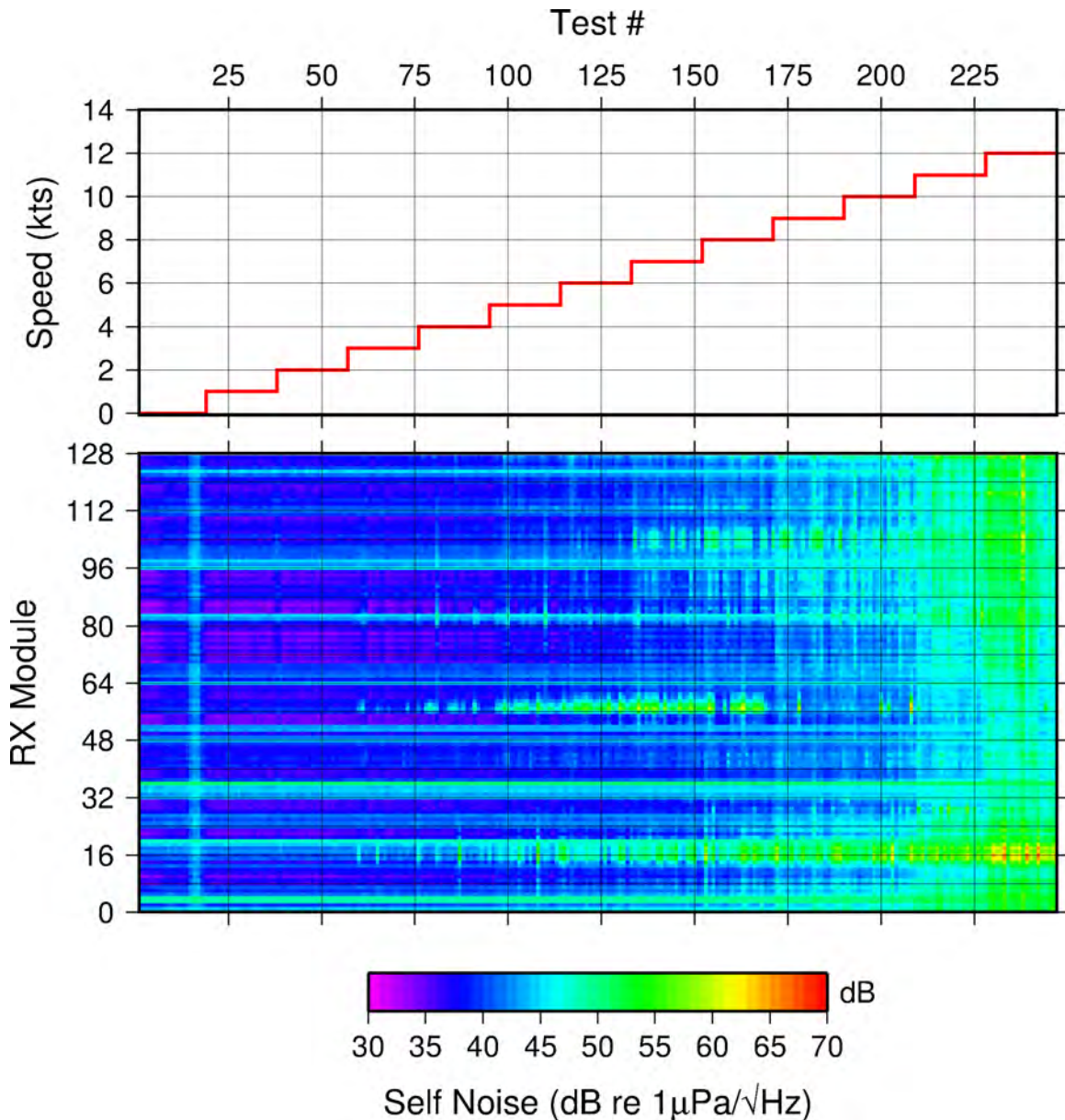


Figure 10. EM302 broadband noise level results for all receiver modules over the course of the entire noise test. Some modules (e.g. 15-18) exhibit systematically increased noise levels (~10 dB) relative to the lowest levels observed on any given test. This is inconsistent with previous results observed in 2012 noise trials based on discussion with T. Gates and could be indicative of a slight change in the noise characteristics of the EM302 that should be monitored.

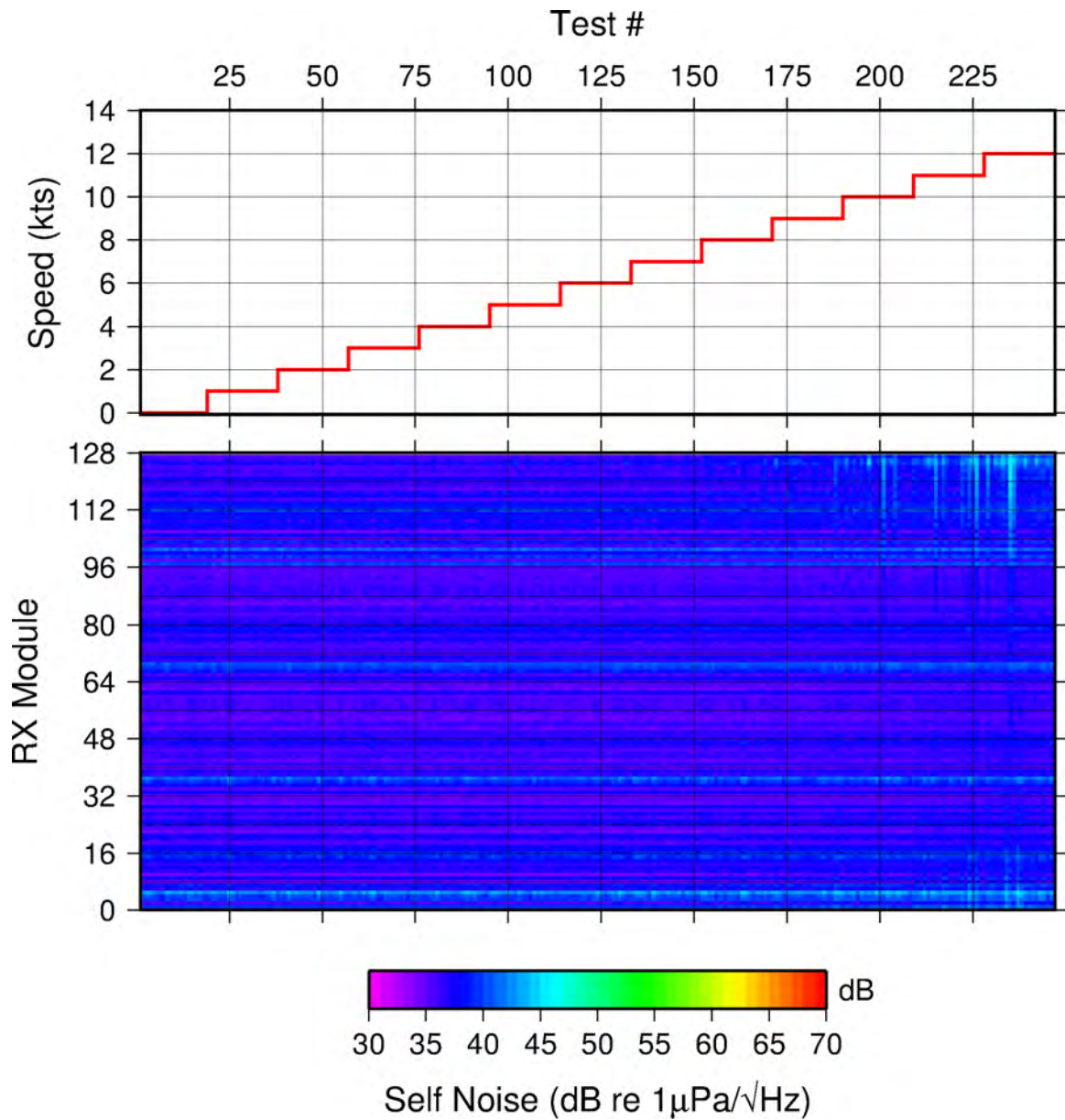


Figure 11. EM710 broadband noise level results for all receiver modules over the course of the entire noise test.

# RV Falkor EM302 Self Noise vs Speed

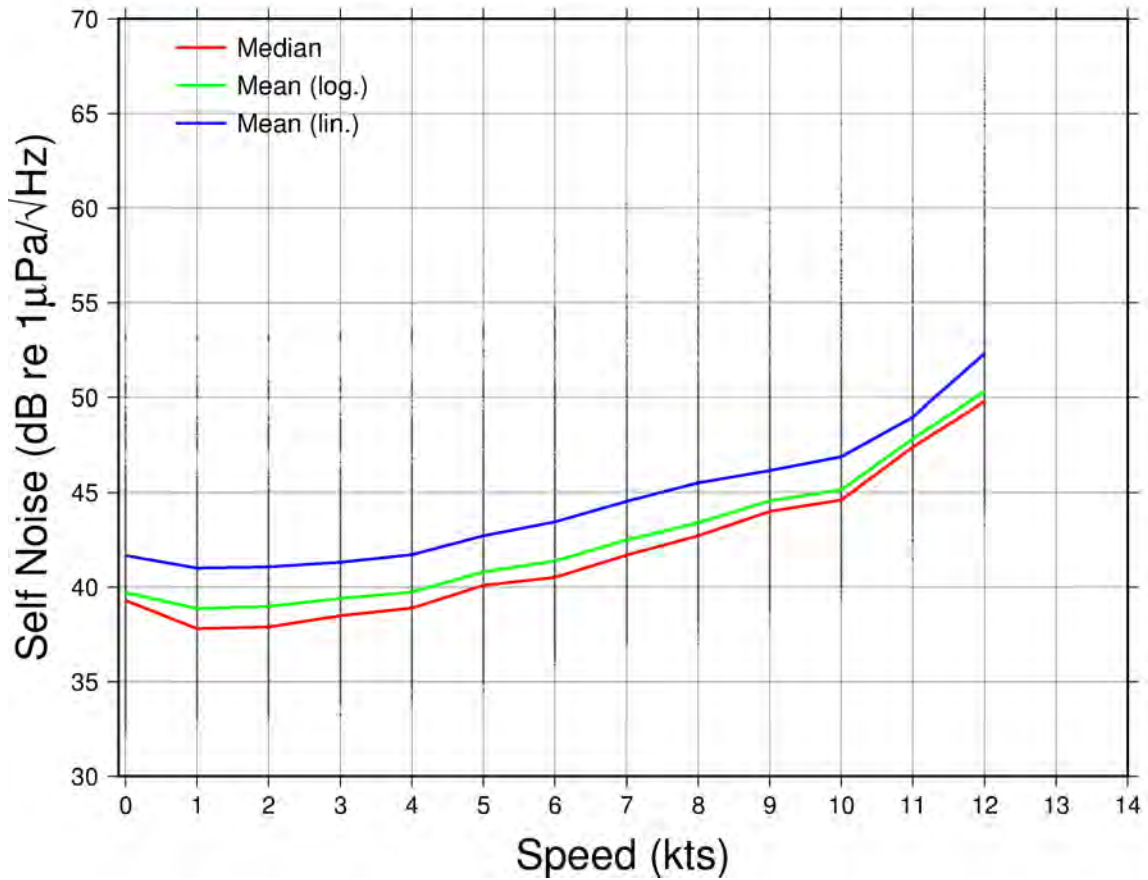


Figure 12. EM302 broadband noise level versus speed. Noise levels have increased relative to previous evaluations for speeds greater than 4 kts.

# RV Falkor EM710 Self Noise vs Speed

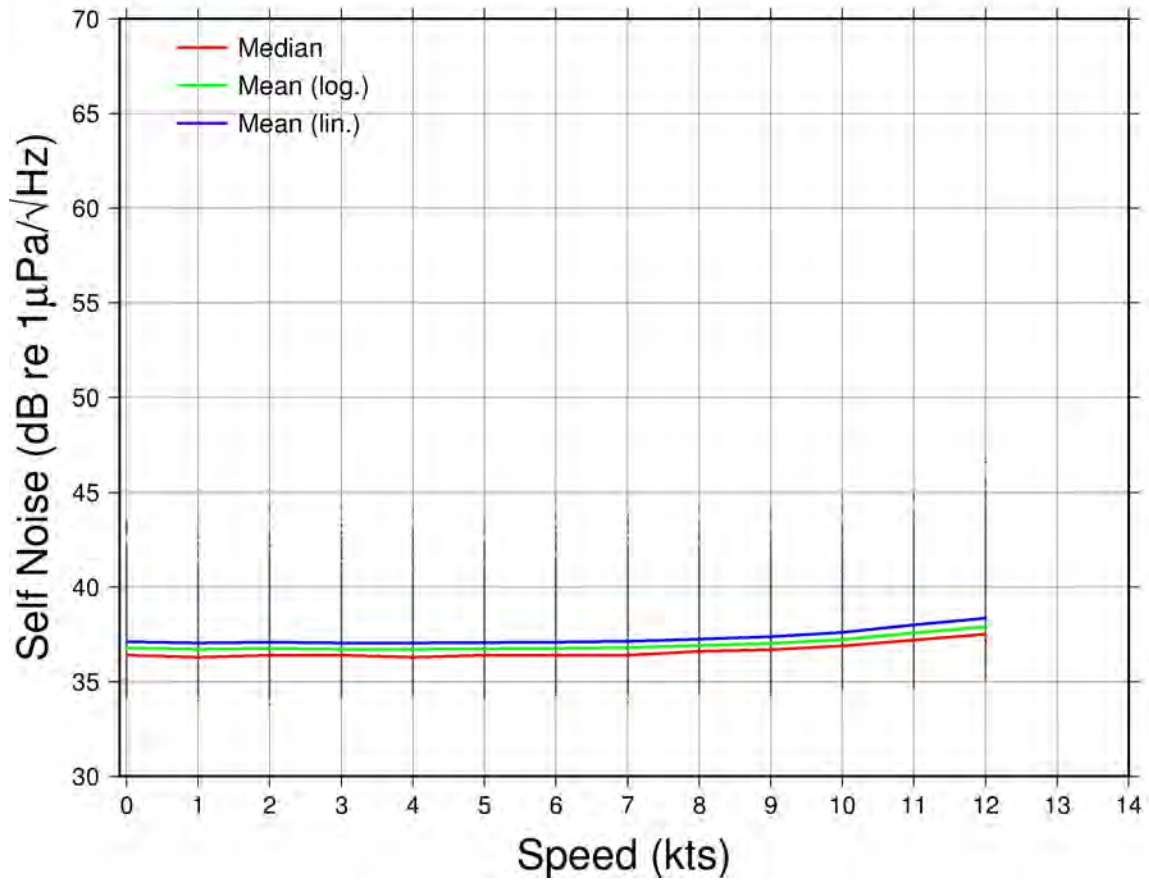


Figure 13. EM710 broadband noise level versus speed. Performance is consistent with previous evaluations in 2013.

# RV Falkor EM302 Self Noise vs Pitch

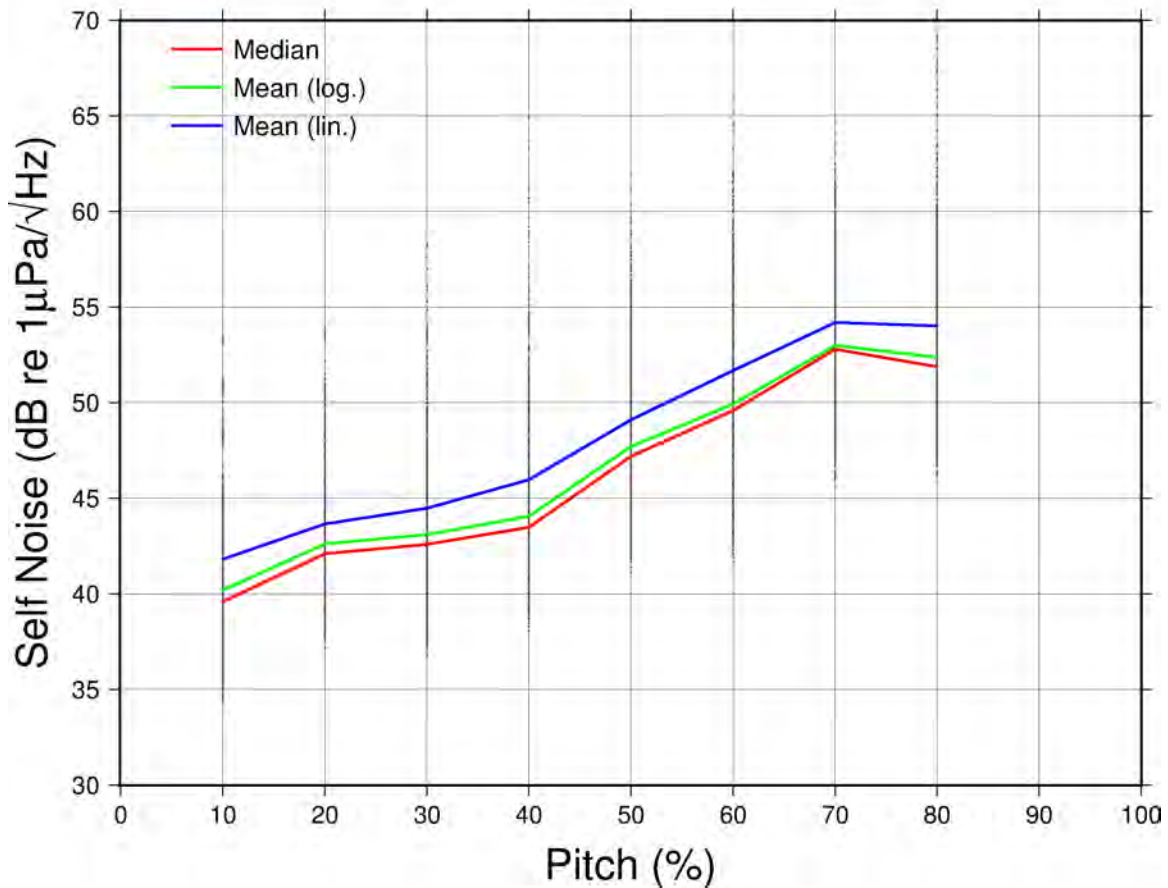


Figure 14. EM302 mean NL as a function of propeller pitch with shaft RPM held constant at 144 RPM. The ship was running in “Constant Speed” mode.

## Coverage Evaluation

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 achievable coverage and to compare 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.

Following the methods used in the 2012 and 2013 sea trials (Beaudoin et al., 2012; Beaudoin et al., 2013), system swath coverage was evaluated over a set of test lines running perpendicular to depth contours down to deep ocean depths (~3,500 m) west of Penguin Bank (Fig. 1). Additional data were acquired during transits to the south during mammal protection mode testing operations. Both the EM710 and EM302 were run with the depth mode set to automatic where the systems chooses the depth mode automatically based on water depth.

For the EM710, coverage was similar to that achieved during previous trials with the system maintaining maximum angular swath coverage to depths of ~500 m (Fig. 15). The EM302 held maximum swath to ~1,500 m (Fig. 16), however its maximum coverage at great depth was reduced by ~25% compared to what was achievable during the 2013 trials in the Bahamas. Oceanographic, sea state and seafloor backscattering strength conditions were similar between the two trials. The impedance measurements do not indicate any degradation to the sonar hardware itself and the reduction in achievable coverage is likely due to the increased noise levels affecting the EM302.

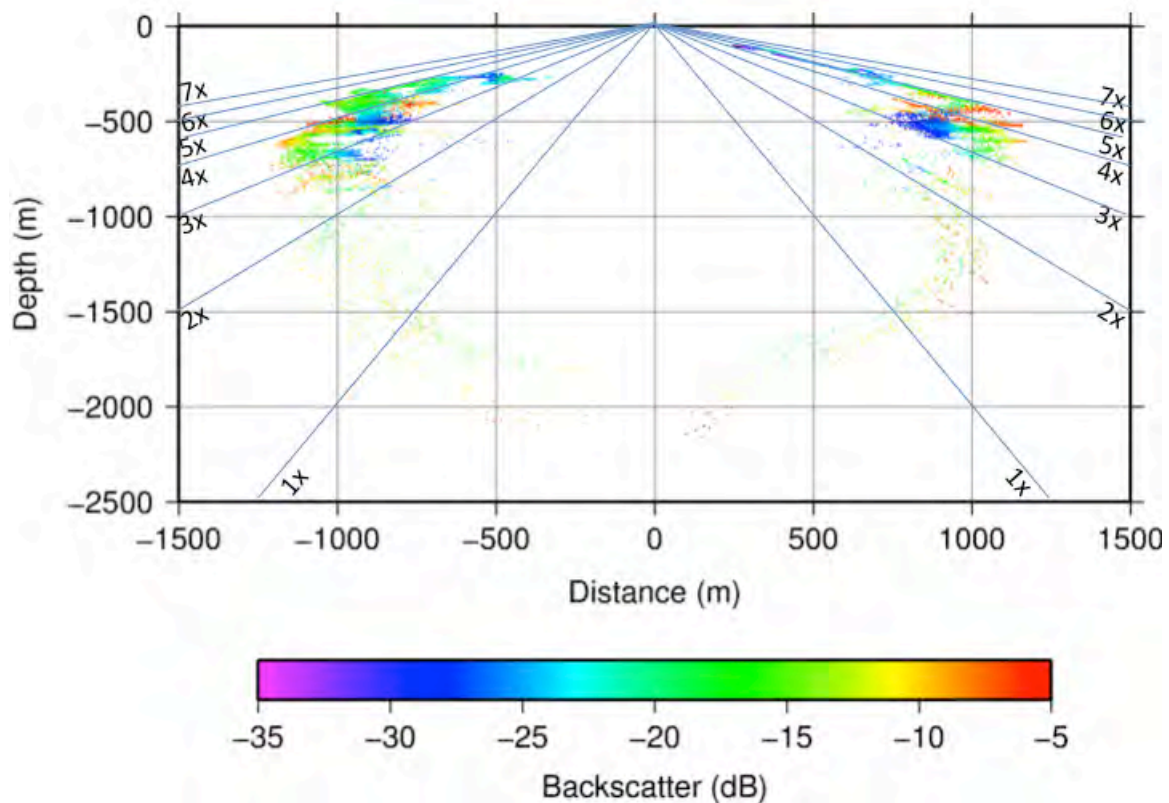


Figure 15. EM710 coverage evaluation.

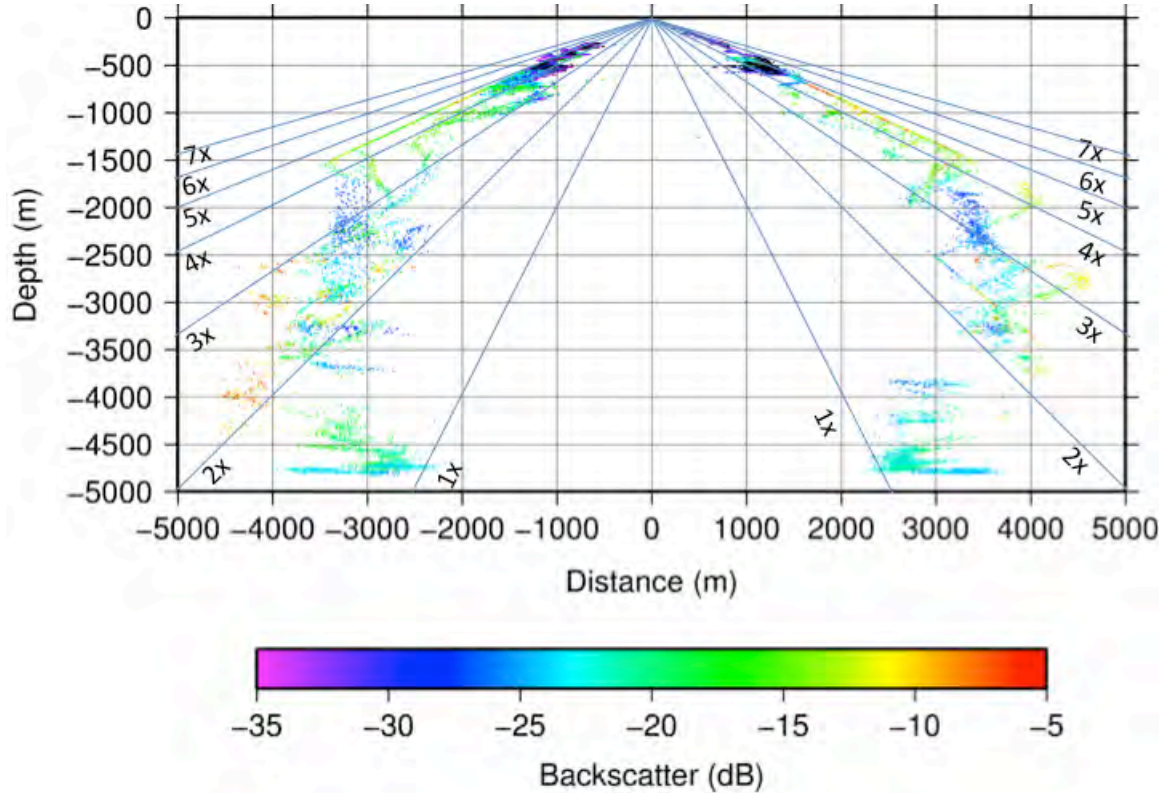


Figure 16. EM302 coverage evaluation. Deepest depths encountered were approximately 4,800 m in which the system achieved 1.5x w.d. coverage for a total swath width of nearly 7 km. Similar testing in the 2013 evaluation saw the system achieving nearly 9 km of swath coverage in the same water depth with similar backscatter levels. This drop in achievable coverage could be explained by the higher noise levels relative to the levels measured in 2013.

## Sensor Geometry Verification and Calibration

System calibration was done over a 550 m deep site just south of O`ahu (Fig. 1) with both systems being calibrated simultaneously. Prior to calibration procedures, the linear and angular offsets of all seabed mapping system components (EM710, EM302, SeaPath 320) were compared to the previously documented settings to verify the configuration of the MRU and multibeam echosounder systems. It was found that the linear offsets agreed with the original survey measurements, however, it was found that the angular offsets of both the multibeam systems and the MRU (as configured in SIS) had reverted to the 2012 values instead of the values established during the 2013 calibration activities (Beaudoin et al., 2013). The MRU angular offsets, as configured in the Seapath, were unchanged and correct.

The EM302 and EM710 systems were configured with the angular offsets from the original survey report to provide a fresh baseline for the calibration. A sign correction was applied to address an error in the 2013 calibration for the EM710 receiver pitch and roll angles. The mount angles of the MRU, as configured in SIS, were set to zero. The mount angles for the MRU, as configured in the SeaPath software, were not modified and match those established in the original survey document.

A standard “patch test” procedure was used to determine the residual angular misalignment angles between the MRU and the EM710/EM302 arrays. Calibration lines were run with both systems operating simultaneously while fully synchronized with the EM302 as the master. Offsets were determined one at a time and were immediately evaluated and applied in SIS. This was immediately followed by a repeat of the calibration lines to confirm correct application of the offset from the first pass prior to moving to the next offset solution. Patch test results were consistent with findings from previous years, indicating that the installation has remained unchanged over a 2 year time period.

Residual angular offsets were nearly negligible (generally  $<0.05^\circ$  for roll, pitch and heading). Following the procedure from 2012, these were applied to the MRU angular offset fields in SIS. Final system installation results are summarized in Table 2 below, items in **bold** differ from the previous system installation geometry summarized in Beaudoin et al. (2013). Contrary to previous calibrations, the heading offset was applied to the MRU and not in the stand-alone heading field, the default location for SIS to apply it, as we felt that this was more intuitive since there is no additional standalone heading sensor.

**Table 2. Summary of Installation Geometry as configured in SIS.**

<b>Parameter</b>	<b>EM710</b>	<b>EM302</b>
Transmitter X	18.84 m	18.89 m
Transmitter Y	-2.12 m	-1.32 m
Transmitter Z	6.09 m	6.09 m
Transmitter roll	0.10°	0.02°
Transmitter pitch	0.30°	0.26°
Transmitter heading	359.69°	359.85°
Receiver X	17.45 m	16.94 m
Receiver Y	-2.28 m	-1.61 m
Receiver Z	6.10 m	6.11 m
Receiver roll	<b>-0.04°</b>	0.07°
Receiver pitch	<b>-0.44°</b>	0.54°
Receiver heading	179.90°	359.82°
MRU X	0.00 m	0.00 m
MRU Y	0.00 m	0.00 m

MRU Z	0.00 m	0.00 m
MRU roll	<b>0.03°</b>	0.03°
MRU pitch	<b>-0.03°</b>	0.00°
MRU heading	<b>0.00°</b>	<b>-0.06°</b>
Stand-alone heading	0.00°	0.00°
Waterline Z	0.57 m	0.57 m
Positioning time latency	0.00 sec	0.00 sec

## Accuracy Evaluation

Accuracy testing was conducted over two areas (Fig. 1), with average depths of 40 m and 550 m for the northern and southern sites, respectively. For both sites, reference surfaces were constructed over a flat seafloor by running 7 survey lines of 10 w.d. length, with 1 w.d. spacing. Vessel speed was limited to 6 knots in both cases. Prior to acquisition of the reference survey lines, an CTD profile was acquired and uploaded to the echosounders after processing with the SVP Editor software (discussed below).

Both reference surface surveys ran with both echosounders running in a synchronized manner with the EM302 as the master. The EM710 and EM302 systems were run with the following configuration for the shallow site:

- VERY SHALLOW mode (EM710) and SHALLOW mode (EM302)
- Dynamic dual swath
- Pitch and Yaw stabilization enabled
- Angular sector limited to +/-60°

For the deep site, the main line settings for the two systems were the same as above except that the depth mode was MEDIUM for both systems.

All soundings were corrected for tide using a global tidal model described in Florent et al. (2006). The reference surfaces were constructed using an inverse distance weighting gridding scheme with grid resolutions of ~1% of water depth. Soundings contributed to the gridded solutions with a 1° beam footprint radius of influence and beam weighting scheme that provided more weight to soundings in the nadir region with beam weighting decaying linearly with beam number from nadir (loosely equivalent to a beam angle weighting scheme).

Cross lines, run orthogonally to the main lines, were acquired with soundings from the cross lines being compared to the reference surfaces constructed from the main

lines. Note that time constraints did not allow for testing of EM710 MEDIUM mode or of a thorough examination of dual-swath/single-swath modes in those modes that support dual-swath. The EM302 cross lines were compared to the EM302 reference surface at the shallow site and the EM710 cross lines were compared to the EM710 reference surface. In all cases, bathymetric slopes were computed from the reference surface and used as a mask to exclude areas of significant topography ( $>5^\circ$ ) from the crossline analysis.

Example results are shown for EM710 DEEP mode (dual swath) in Fig. 17 with a scatter plot of the depth differences between a cross line and a reference surface as a function of beam angle. The mean depth bias is computed in  $1^\circ$  angular bins across the swath and is shown as the solid lines, these being color coded by sector and by swath number in the dual swath geometry (blue-red is swath #1 of 2, magenta-cyan is swath #2 of 2). The dashed lines, using the same color-coding, indicate the standard deviation in each  $1^\circ$  angular bin; these are also plotted as a function of beam angle in Fig. 18. Similar plots are presented in Appendix C and D for the various sounder modes investigated during the accuracy tests.

Referring to the accuracy plots in Appendices C and D, both systems show beam depth biases less than 0.05% w.d. across the majority of their achievable swaths with small residual refraction-like artifacts in the outer portions of the swath.

Standard deviations about the mean bias are typically within  $\pm 0.15\%$  to  $0.25\%$  w.d ( $1-\sigma$ ) across the majority of the swath with higher uncertainties at the limits of the swath as expected. Noisy soundings do occur in the usual cases: a deeper mode is used than what is recommended for a particular water depth, etc. As expected, the EM302 performed quite poorly in the shallow area (40 m water depth) with a systematic refraction-like bias across the swath and markedly increased bottom detection noise. The EM710 evaluations suffered from running the systems simultaneously in the shallow area, a repeat run with EM710 only in VERY SHALLOW mode indicated improved performance levels, typical of what would be expected.

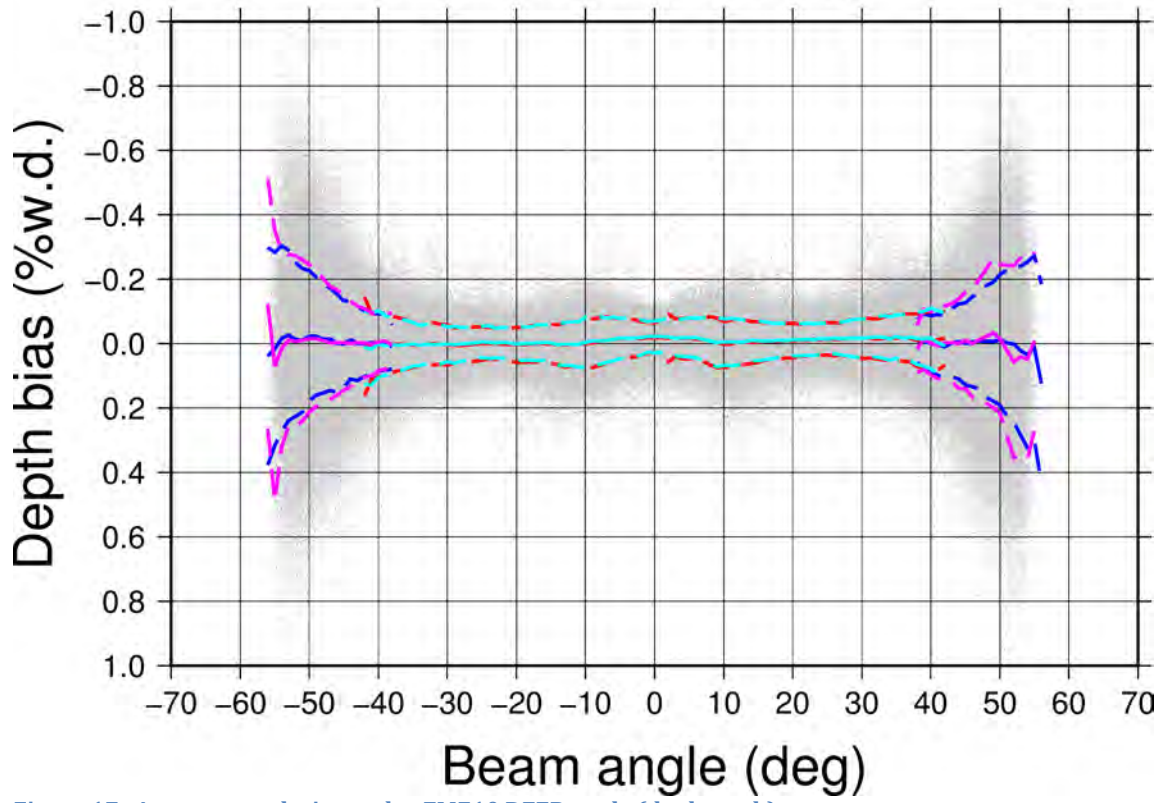


Figure 17. Accuracy analysis results, EM710 DEEP mode (dual swath).

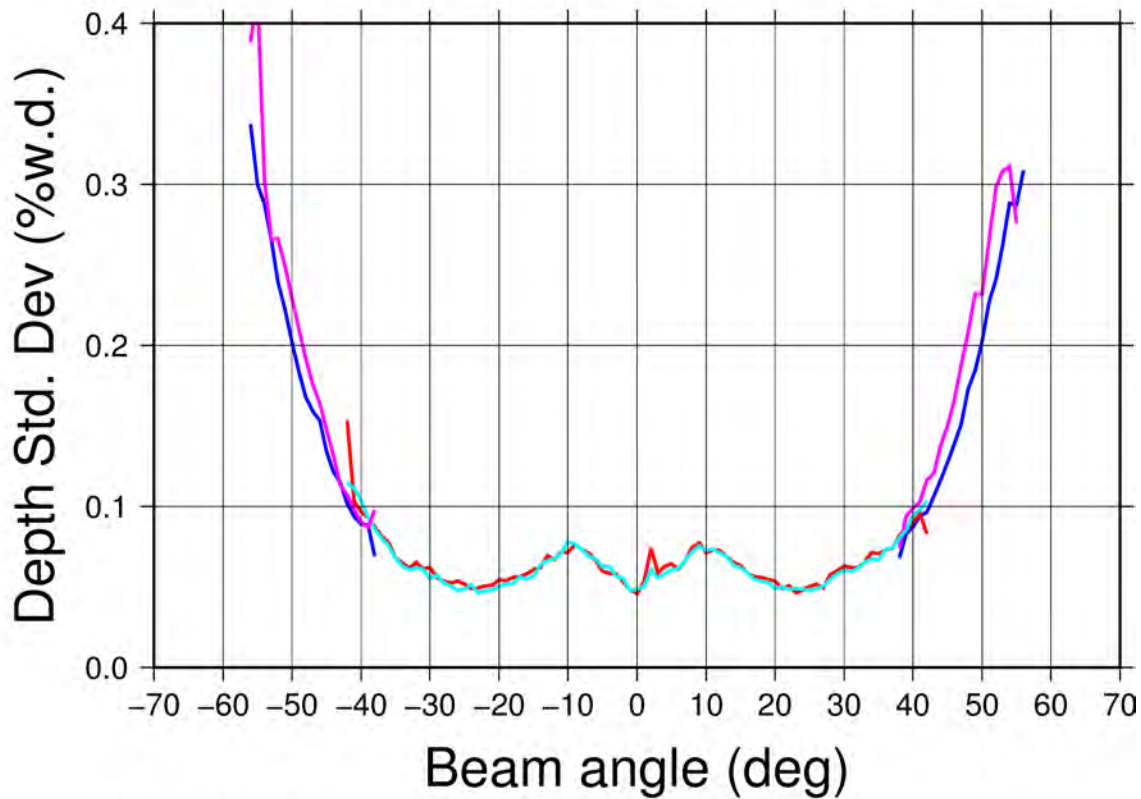


Figure 18. Accuracy analysis results, EM710 DEEP mode (dual swath).

## Mammal Protection Mode

At the specific request of SOI, the Mammal Protection Mode features of the EM302 and EM710 systems were tested to confirm that they functioned as expected.

The EM710 and EM302 provide a Mammal Protection Mode that offers sonar functionality to reduce the impact of high source levels on marine mammals:

1. **Reduction of source level by -10 dB or -20 dB.** Upon selection, this is effective immediately and the output power of the sonar is reduced accordingly.
2. **“Soft Startup”.** At start up time, the sonar’s output source level is reduced and is increased gradually to full power over a user-defined period of time (maximum of 15 minutes).

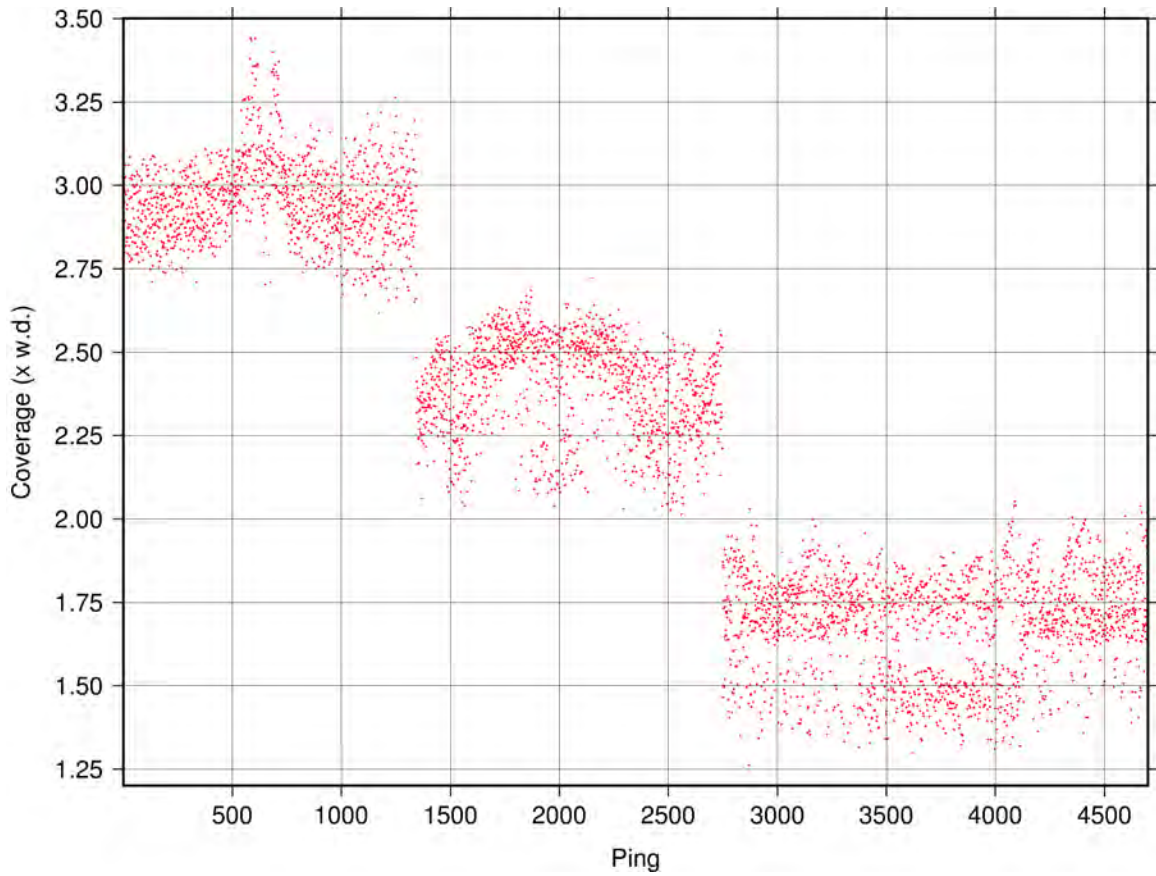
Mode (1) appears to work as expected for both systems. This was tested by operating each system in a water depth in which the outer sector was attenuation limited (i.e. the system could not track the seafloor out to the edge of the full ensonification sector due to signal attenuation) and then reducing the source level by -10 dB and then -20 dB, all the while monitoring the coverage achieved by the

system. It should be noted that this is an indirect method of confirming that the source level is reduced and that it does not confirm that the source level is indeed reduced by the prescribed amount. Refer to Figs. 19-20 for plots of coverage reduction with the different operating modes. Acoustic modeling could be used to confirm that the reduction in coverage is consistent with the lower source level, this would then verify that the source level does indeed drop by the intended amount.

Mode (2), the “Soft Startup”, appears to function as intended with the EM302. The EM710, however, was found to behave in a manner inconsistent with our expectations, in that it would provide a reduced ramp up time relative to what was requested by the operator, e.g. after requesting a 15 min start up time, the system would ramp up by only 4 min. This issue was raised with the manufacturer (see email correspondence in Appendix E) who undertook their own testing of the feature on another system. It was found that there is an error in the EM710’s implementation of the “Soft Startup” functionality and the manufacturer suggested a software upgrade, however, they also provided a workaround solution to work with the currently installed version of SIS. This workaround procedure, detailed below, was verified during our testing.

1. Configure the system with the desired “Soft Startup” time interval in the Runtime Parameters window of SIS.
2. Allow the system to ping once with a reduced source level of -20 dB.
3. Secure pinging, wait 15 minutes (or period of time defined as soft-start ramp time).
4. After the 15 minute wait period (or soft-start ramp time), begin pinging and the correct time ramp will be used.

Real-time monitoring of both aspects of Mammal Protection Mode functionality can be seen in the Numerical Display in SIS as shown in Fig. 21. For post-cruise verification of Mammal Protection Mode, it should be noted that the source level reduction level is recorded in the **Transmit Power** field of the **Runtime parameters** datagram in the raw sonar data files (.all files) (Kongsberg, 2013). This was verified to be true for both modes (1) and (2).



**Figure 19. Reduction of swath coverage resulting from enabling EM710 mammal protection mode in 500 m water depth. Pings 0-1400 have no protection enabled, pings 1400-2750 have a source level reduction of -10 dB and pings 2750-4700 have a source level reduction of -20 dB.**

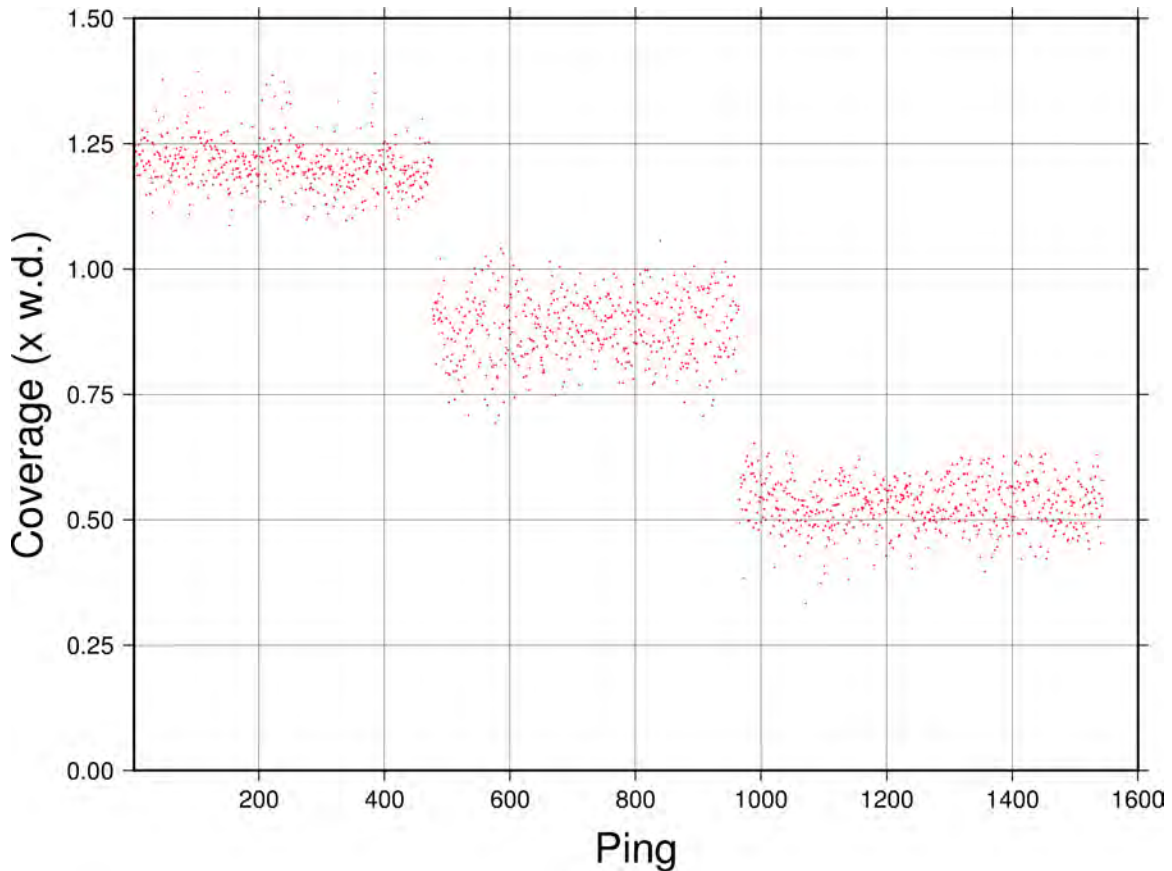


Figure 20. Reduction of swath coverage resulting from enabling EM302 mammal protection mode in 4,700 m water depth. Pings 0-450 have no protection enabled, pings 450-950 have a source level reduction of -10 dB and pings 950-1550 have a source level reduction of -20 dB.

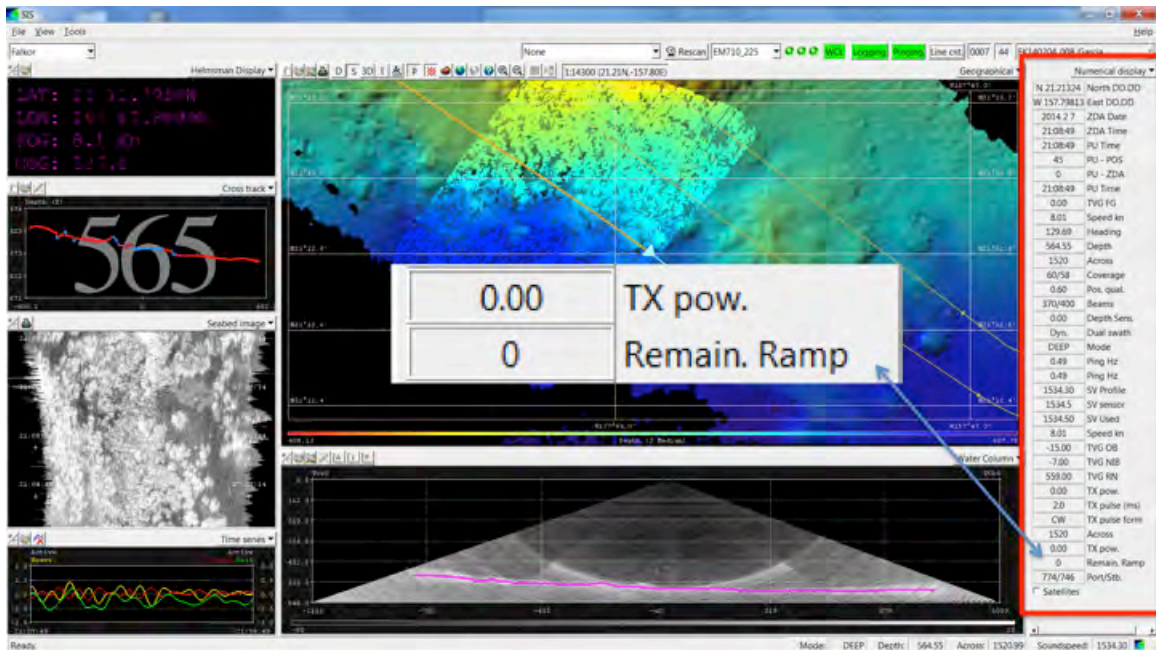


Figure 21. Screen grab of SIS showing the numerical display tab where the Mammal Protection Mode parameters can be monitored. The "TX pow." field will show -20 or -10 when the source level is reduced.

The “Remain. Ramp” field will countdown the number of minutes until full transmit power is achieved. Note that the SIS manual indicates that this field will countdown in seconds but this was not found to be the case.

## Acoustic Imagery Quality

The multibeam systems were exercised through several depth modes during the accuracy trials. Acoustic imagery products were prepared for each mode and are included in Appendix E. Sample seabed imagery for the EM710 in VERY SHALLOW mode and EM302 in DEEP mode is shown in Fig. 22 and 23, respectively. The seabed imagery appears to remain well balanced between the swaths of the dual swath geometry for both systems. Sector balancing of the EM302 is satisfactory with some exceptions that appear to be aggravated when running with yaw stabilization enabled. The same can generally be said of the EM710, which does not support sector level balancing (but does with the currently available release of the SIS software and EM710 firmware). These residual sectors offsets are easily filtered in most commercial software applications.

Water column imagery is satisfactory with only occasional artifacts due to transient noise events and slight interference between the EM302 and EM710. Note that this interference does not seriously affect the bottom tracking abilities of either system when run in a synchronized configuration (but it has been shown to increase noise levels slightly) but it may prove undesirable for water column mapping missions.

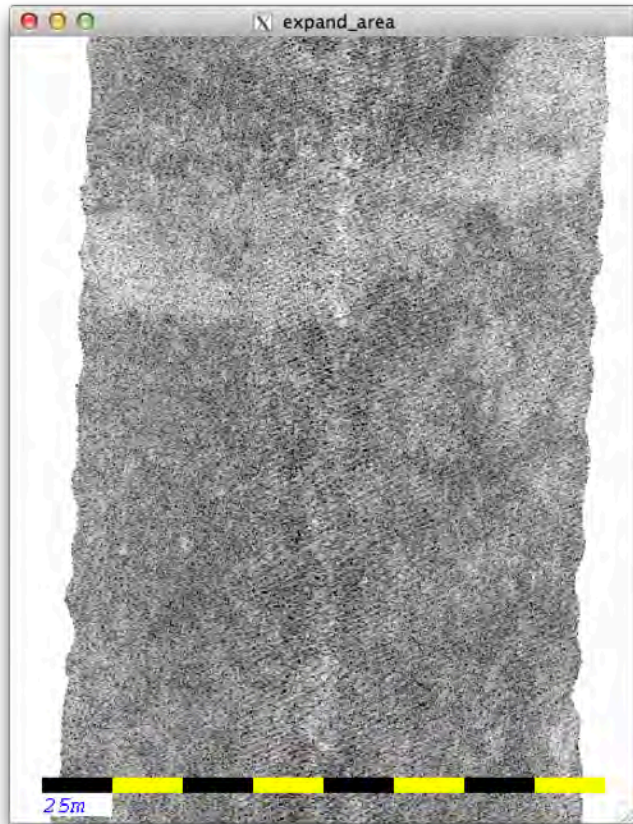


Figure 22. EM710 VERY SHALLOW seafloor imagery.

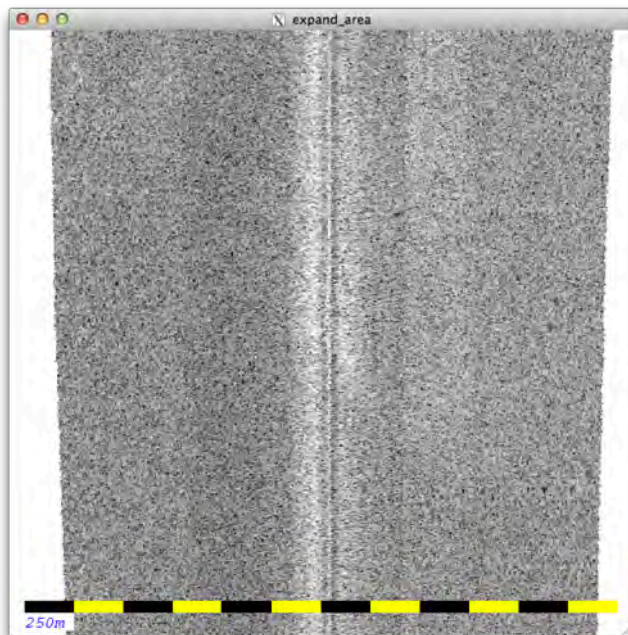


Figure 23. EM302 DEEP (CW only) seafloor imagery.

## Software Installation

### SVP Editor

SVP Editor is an application that provides pre-processing tools to help bridge the gap between sound speed profiling instrumentation and multibeam echosounder acquisition systems. This software was developed and is maintained by the Multibeam Advisory Committee (MAC) under NSF grant 1150574 (Beaudoin, 2013). The software is freely available online at <http://mac.unols.org>. Version 1.0.2 of the software was installed in 2012 on the CTD processing machine, version 1.04 was installed during the 2013 ship visit. The most recent version (1.0.5) was installed during the 2014 ship visit with training in new functionality provided to one of the MTs. The new version of the software was used throughout the trials described in this report and appears to be functioning correctly with data from the CTD, Velocimeter and XBT systems all being successfully tested. It was found that the XBT, Velocimeter and CTD systems provide consistent results within their stated uncertainty levels.

During the inter-sensor comparison, it was noted that the salinity values calculated from the Valeport sensor was very noisy on the order of +/- 1 psu (note that the Valeport sensor measures sound speed and temperature and that SVP Editor uses these to calculate a salinity estimate). Upon further investigation it was found that the difference in sensor response time is likely causing salinity spiking in the calculation of salinity with data samples where the rate of change of sound speed and temperature are pronounced. This phenomenon is well known with CTD systems and there is sensor alignment functionality in the Seabird SBE Data Processing software to account for this for Seabird CTD systems. Similar sensor alignment functionality could be implemented in SVP Editor, however, we feel that is a low priority. This is due to the fact that the salinity values are only used to estimate the attenuation (for seabed imagery compensation) and the noise tends to cancel out over the profile due to the nature of the spiking artifacts where a positive spike is associated with a negative spike. If high quality backscatter corrections are desired, it is advised to use the Seabird CTD sensor.

## Principal Findings & Recommendations

### Follow-Up of 2013 Recommendations

Recommendations from the 2013 final report on the multibeam status are repeated below along with follow up discussion as appropriate in bold text.

1. An upgrade to a more recent version of SIS is recommended for the next visit. This would ideally entail a visit from a Kongsberg technician to perform the upgrade and also would be timed to occur during a 2014 system check up visit from UNH/CCOM. **At the time of cruise planning, we did not feel that an upgrade to SIS 3.9 was advisable due to instabilities we have witnessed with SIS 3.9.1 on a previous cruise on another ship.**
2. MTs should familiarize themselves with new features of SVP Editor v.1.0.4. Currently, only one of them has been shown the new features. **MTs appear to be familiar with SVP Editor functionality.**
3. BIST tests should be routinely conducted (at least monthly). Meta data should be noted at the time of the BIST if noise measurements are to be of any use, e.g. ship speed, sea state/direction, wind speed/direction, water depth, other acoustic equipment in operation at time of test. A file naming convention should be established and followed. BIST output files should automatically be backed up along with other multibeam data. **This has not been done. The noise issues associated with the EM302 could have been discovered much earlier or diagnosed more quickly had a time series of BIST measurements been taken.**
4. An investigation into whether or not the second Seapath MRU could be used as a backup for the multibeams, without compromising its primary purpose, should be done. A patch test should be conducted if this is possible such that the angular offsets are known for this system in the event that it must be used for the multibeam systems. **This has not been done. Time should be allocated to examine this possibility during upcoming ship visits.**

### Recommendations from 2014 System Review

1. At the start of the cruise we found that the system parameters had been restored to values determined during the initial 2012 sea trials. To avoid potential misconfiguration of the systems, **we recommend that the following procedure be followed every time the systems are used for mapping purposes:**
  - EM302
    - In SIS, access the file menu and choose “Import PU parameters...”
    - Navigate to D:\sisdata\common\pu\_param
    - Select “20140206\_SafeStart\_EM302.txt”
    - When prompted whether to change the serial number, choose “No”
  - EM710
    - In SIS, access the file menu and choose “Import PU parameters...”
    - Navigate to E:\sisdata\common\pu\_param
    - Select “20140206\_SafeStart\_EM710.txt”

- When prompted whether to change the serial number, choose “No”
- 2. Disk defragmentation was scheduled for both EM302 and EM710 to run automatically once a week, which is imprudent to run on active acquisition machines. We disabled the scheduled activity. Defragmentation can be run manually when the machines are not actively involved with acquisition. **We recommend that other acquisition systems be checked to ensure that the automatic defragmentation is not enabled.**
- 3. The SeaPath was configured to deliver AttVel datagrams to the EM302 at a rate of 1 Hz (interval of 1.0s). This is insufficient and has been increased to 100 Hz (interval of 0.01s). A backup of the SeaPath configuration file with this change was made. **We recommend that this configuration file be stored on a computer other than the Seapath HMI.**
- 4. We removed the majority of old survey data sets, including bathymetry raw data files, grid files and SVP files. We also purged old surveys from the SIS database to improve SIS responsiveness. Once removed, the disks were defragmented to improve I/O performance. **In the upcoming field season, we recommend that completed surveys be removed from the SIS database via the “Remove survey from database” option in the SIS File menu.**
- 5. BIST tests are not being run at all, let alone on a routine basis, as we have been advising since 2012. These are important diagnostic files and help to identify problems early and allow for the long term tracking of system health. **We strongly recommend that BISTs be run on at least a monthly basis throughout the year using the following procedure:**
  - a. Power on TRU and start SIS.
  - b. Access the BIST testing suite through the installation parameters.
  - c. Run all the BIST tests.
  - d. If in water depths greater than 1,000 m:
    - i. Secure deck work (e.g. needle gun) and non-essential machinery (e.g. winches).
    - ii. Note sea state, ship course, direction and intensity of seas and wind. If possible, alter course such that seas are arriving on the stern.
    - iii. Note vessel speed, propulsion line-up (Science, Constant Speed, etc.) and shaft RPM and propeller pitch.
    - iv. Run an additional 10 RX Noise Level tests (note: not the RX Noise Spectrum test).
  - e. Save the BIST output file in a centralized location using a naming convention such as:
    - i. YYYYMMDD\_HHMMSS\_EM302\_BIST.txt
    - ii. YYYYMMDD\_HHMMSS\_EM710\_BIST.txt
- 6. The EM302 is noisier relative to previous evaluations. We do not feel that this is indicative of system degradation since transmitter and receiver channel/transducer impedances are largely unchanged. The noise levels are associated with increased speed through the water and can be due to either

increased flow noise and/or the propulsion system. Noise levels are ~3dB higher at 8 kts and ~8dB higher at 12 kts. This is not a catastrophic increase in noise levels but it will impact the efficiency of the system during the upcoming mapping cruise. This could be related to propeller pitch, flow noise or noise from the main engines, however, the last is doubtful since we tested in constant speed mode (with a fixed shaft RPM) and the noise continued to increase with speed (which was altered through propeller pitch). While adrift, the system noise level was the same as last year so we do not expect that this could be due machinery noise from systems not related to propulsion (e.g. generators). The increased noise levels will impact sensor efficiency either through decreased coverage at higher speeds or increased mission time due to slowing the vessel to avoid noise issues. At full ocean depth (>4,000 m), we would expect to see the achievable coverage to be compromised on the order of 10-30% depending on ship speed (this is based on the results of the mammal protection mode testing where the source level was reduced by 10 dB, which would roughly have the same effect as increasing the noise level by 10 dB). **We recommend that further noise testing be done to identify the source of the noise. A diver inspection may be warranted while the ship is in port to assess the state of the propellers and marine growth on the hull. Consultation with an acoustic noise specialist such as Tim Gates would be prudent before undertaking any noise testing or diver evaluations as he could suggest the most prudent course of action.**

## Summary & Conclusion

The transducer impedances are similar to baseline measurements in 2012 and with those taken in 2013. Transducer conditions, based on these tests, are acceptable and there is no sign of degradation of the transducer arrays.

Noise levels for the EM710 remain unchanged and very low. Noise levels for the EM302 have increased at higher speeds though they remain low when the ship is stationary in the water, suggesting that the increase is associated with flow noise and/or the propulsion system.

The systems were successfully calibrated with a second confirmation calibration indicating that the results are acceptable. Angular offsets are small and very similar to those found in previous evaluations. The systems have been updated with the new calibration results.

Both multibeam systems provide bathymetric measurements that are in agreement with the expected performances of the systems and that are consistent with previous examinations. There is no evidence of degradation of ancillary sensor performance since the previous accuracy tests.

Seabed imagery quality is good and is generally artifact free. There are residual inter-sector imbalances with the EM302 despite the signal balancing routines undertaken in 2012. The EM710 has slight signal imbalances, however, it is not currently possible to correct for this using the same mechanism that is used for the EM302 (though this would be possible in the latest release of SIS). In both cases, the residual offsets are easily corrected in commercial processing software.

At SOI request, verification testing of the Mammal Protection Mode functionality was undertaken. The source level reduction features are confirmed to work as expected. The “Soft Startup” works as expected with the EM302 but a software error affects the EM710 and a workaround procedure to ensure the correction functionality of the EM710 soft start must be followed. The workaround procedure is not particularly onerous and can be addressed through an upgrade to SIS and the firmware for the EM710.

As a whole, the two multibeam systems are in satisfactory working condition and we do not anticipate any problems with either system for the 2014 mapping season with the caveat that the increased noise levels will reduce the coverage efficiency of the EM302 sensor in deeper water.

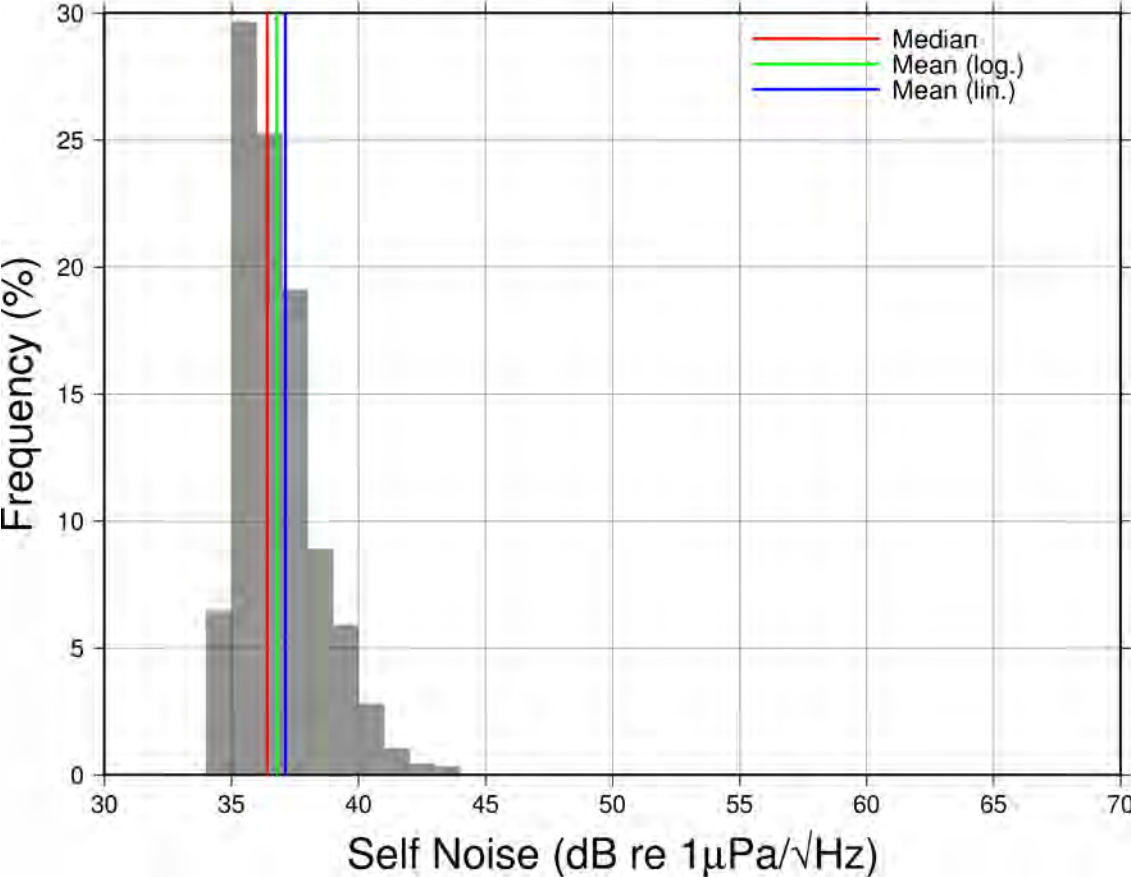
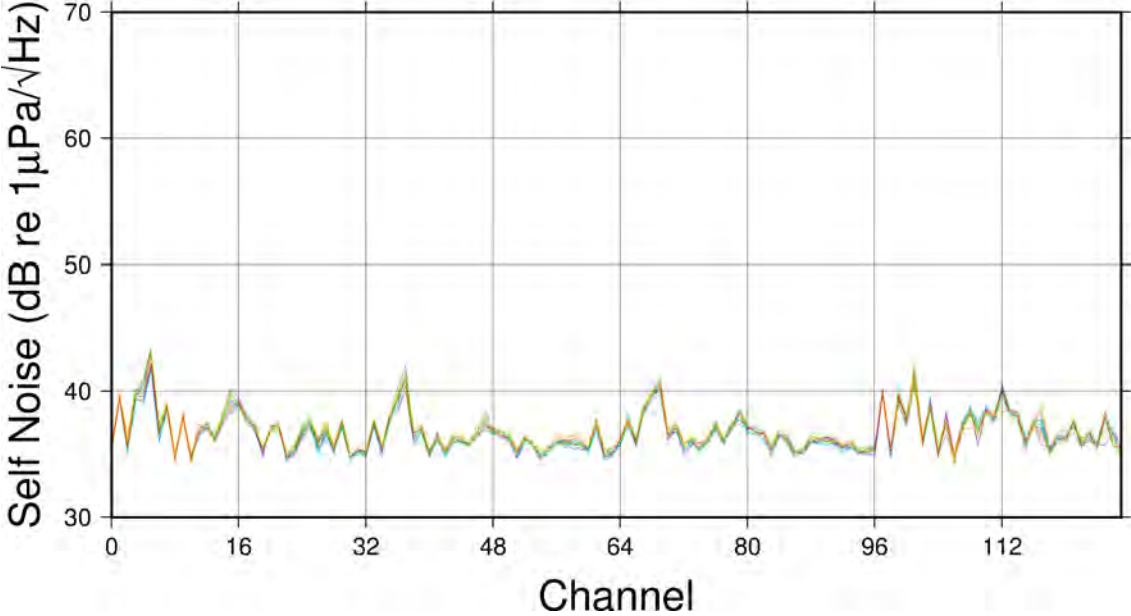
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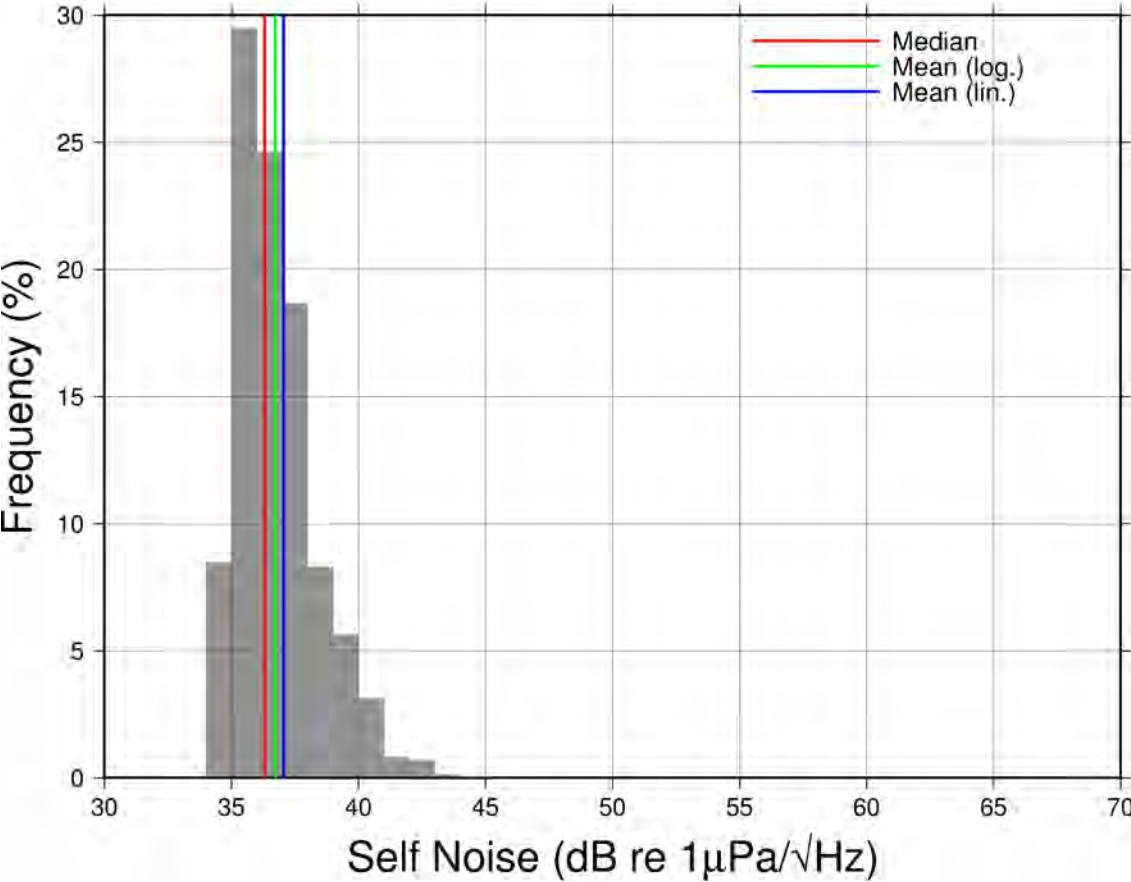
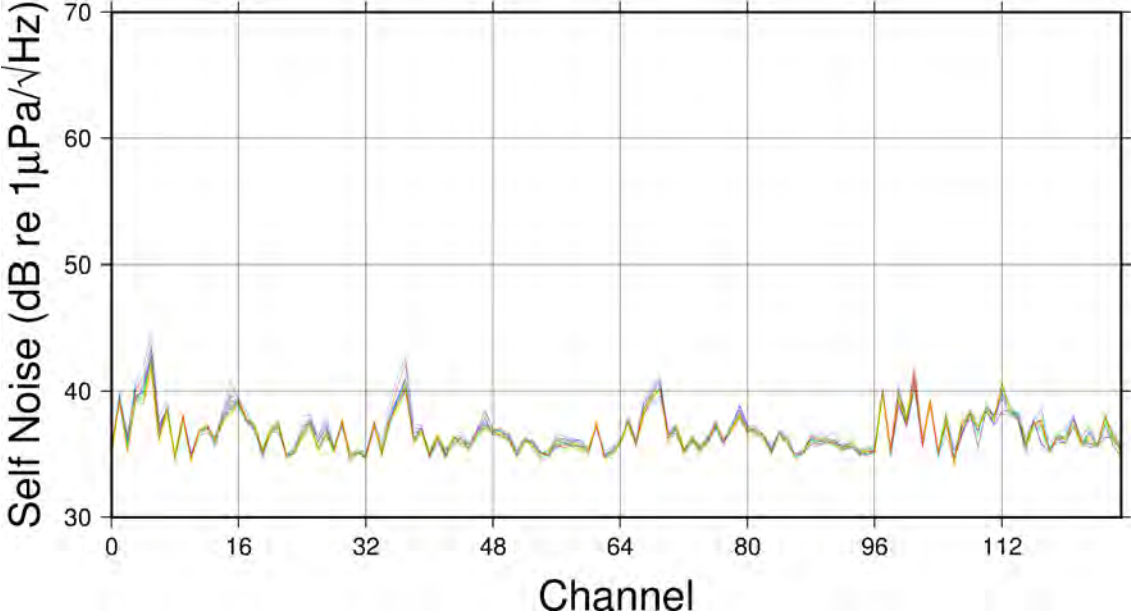
## **Appendix A – EM710 Noise Measurements**

All figures in this section show self-noise levels for the EM710 as measured using the receiver hydrophones. The upper plots show the output as a function of receiver module. The lower plots show the distribution of the same data along with the median, geometric mean and linear mean. The geometric mean is the mean of the dB values. The linear mean is the mean of the noise levels in linear intensity units and then transformed back to dB.

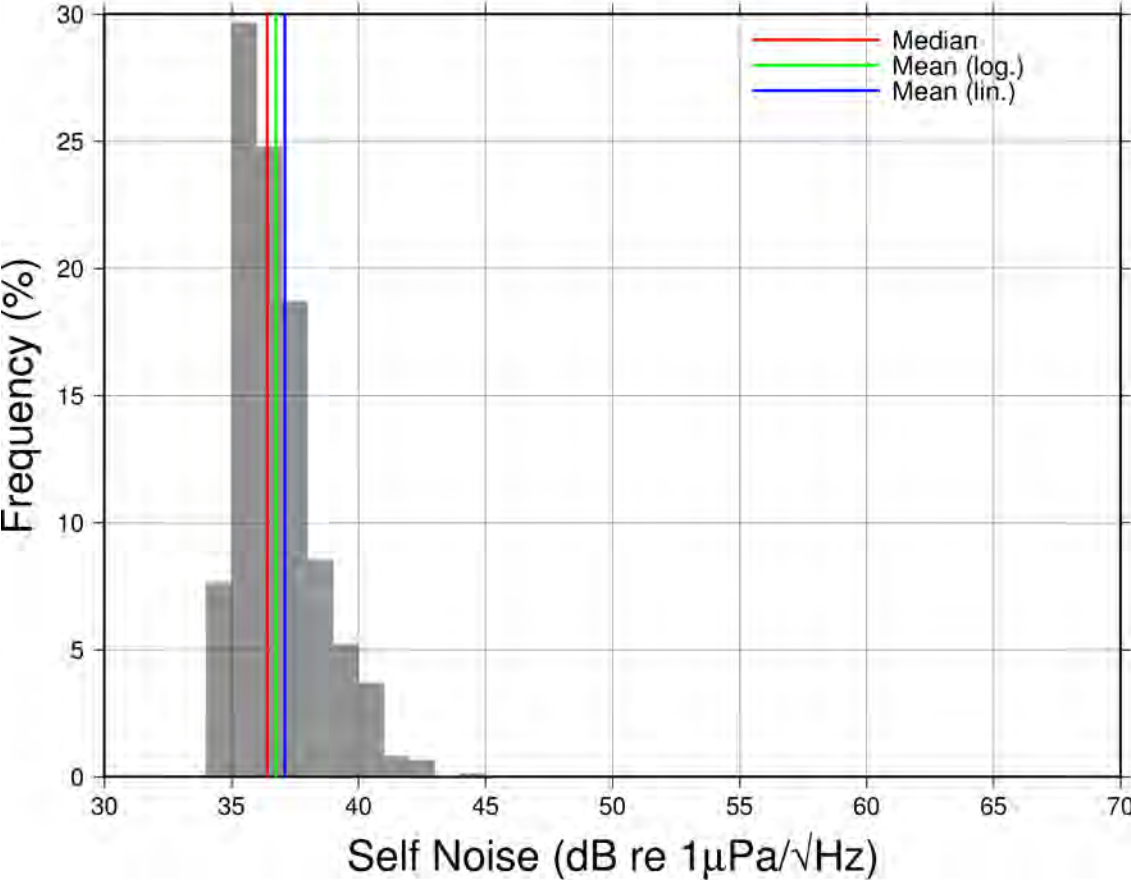
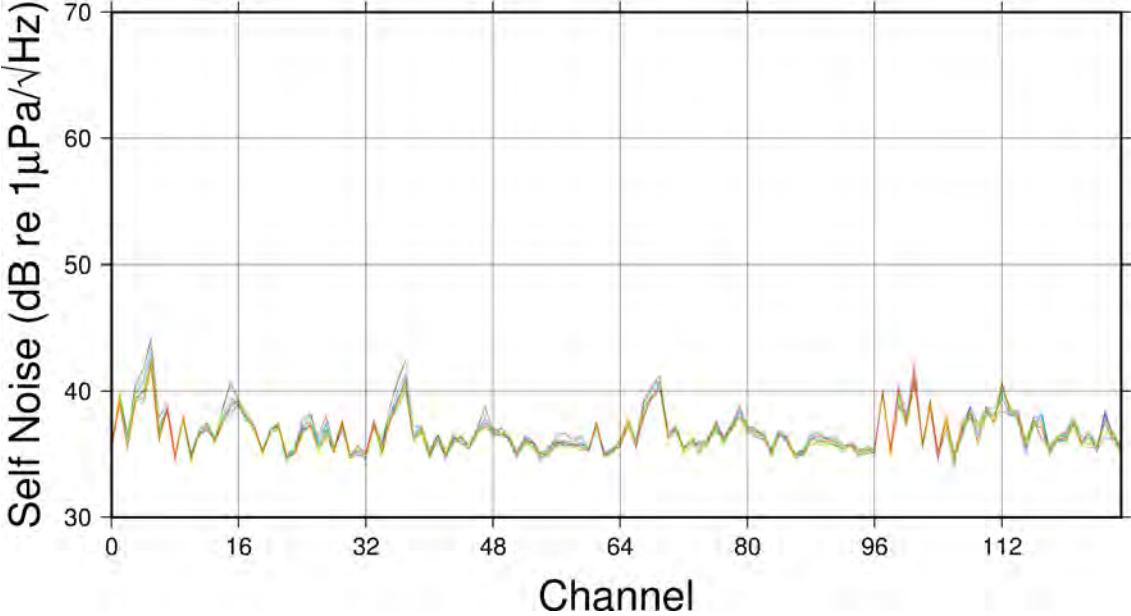
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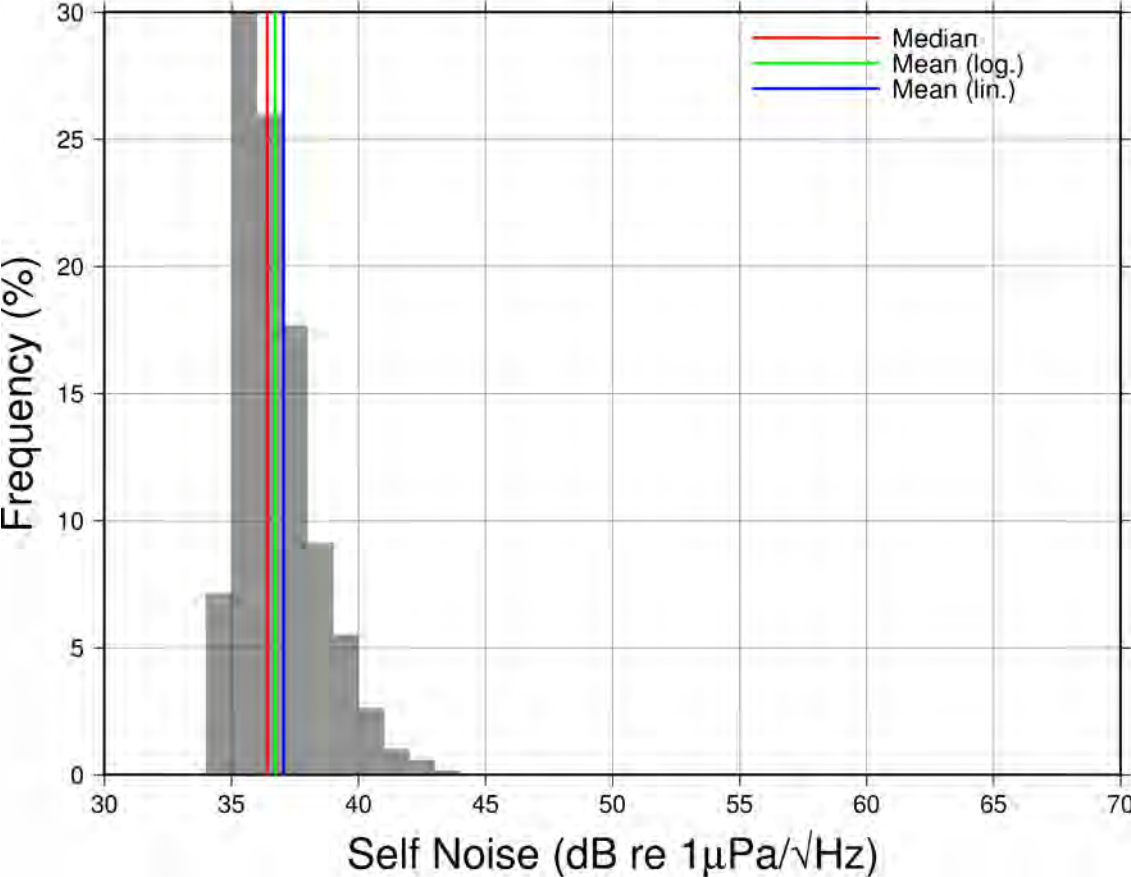
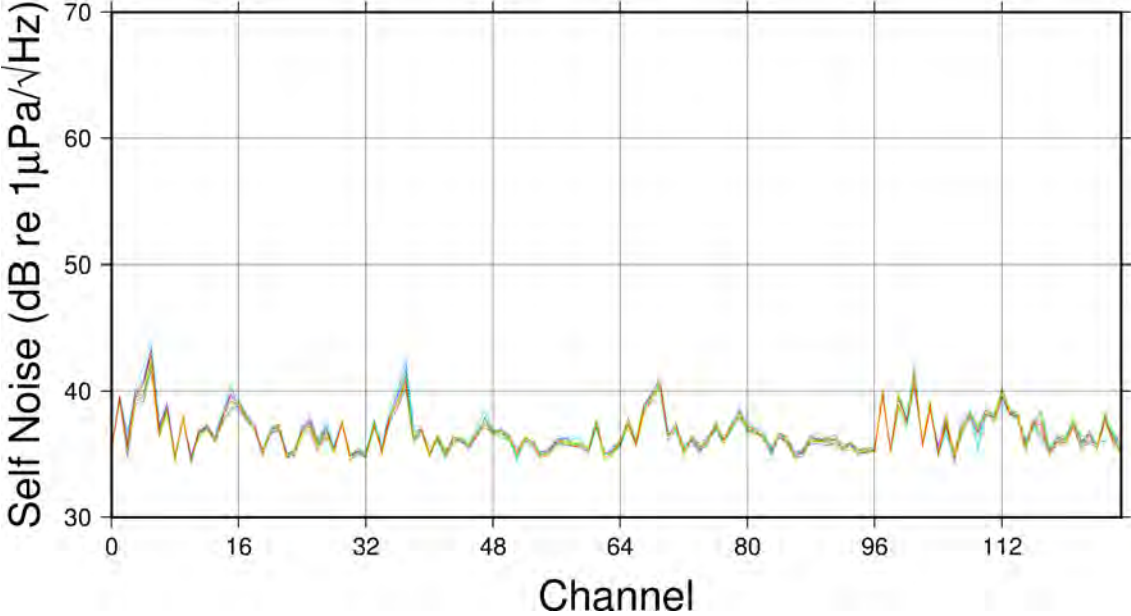
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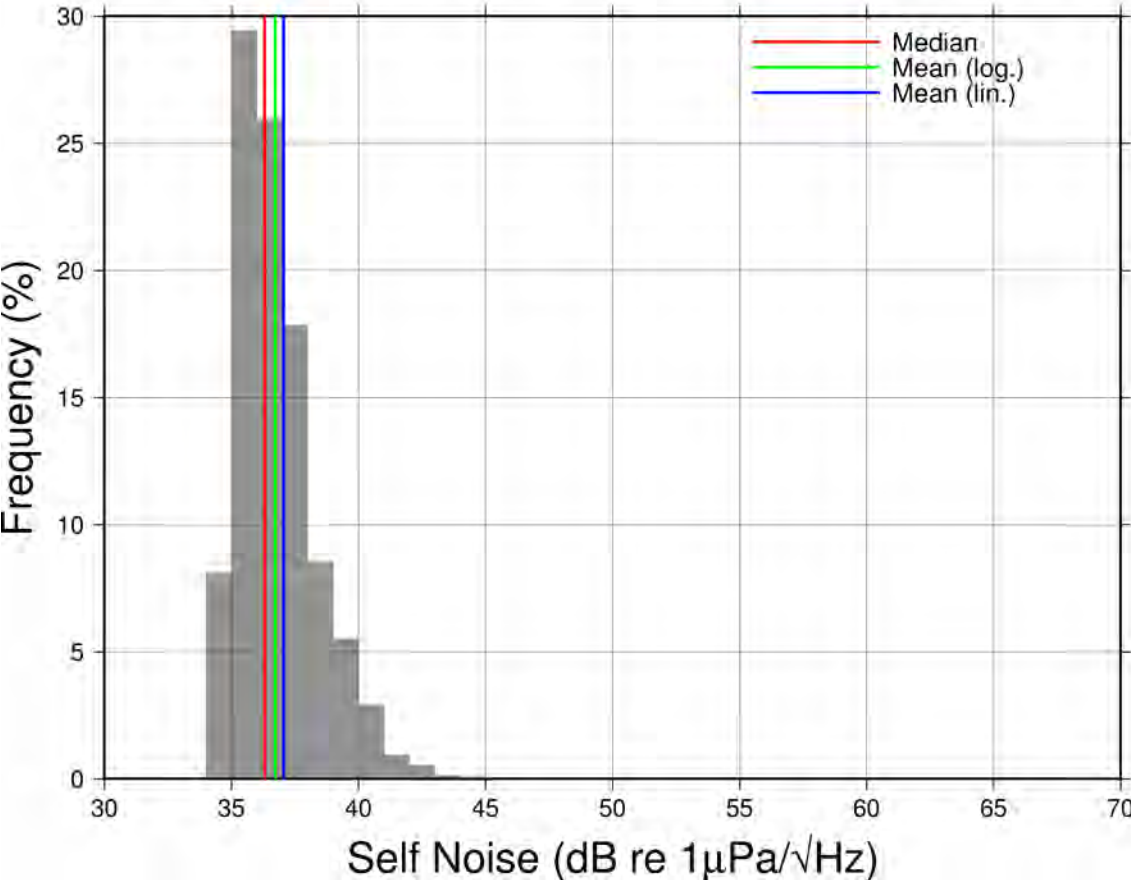
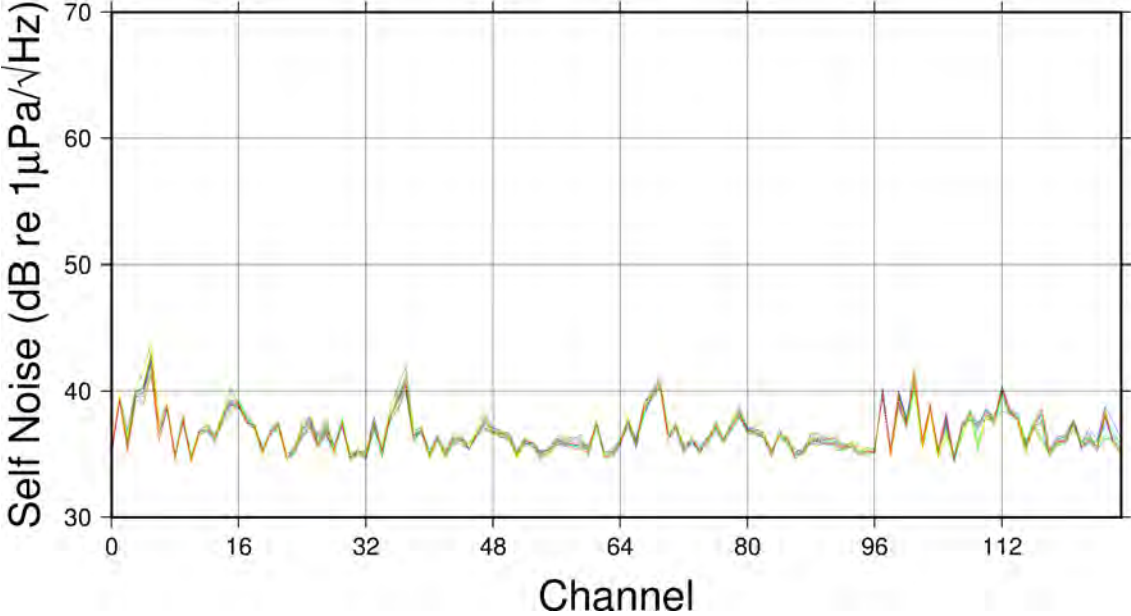
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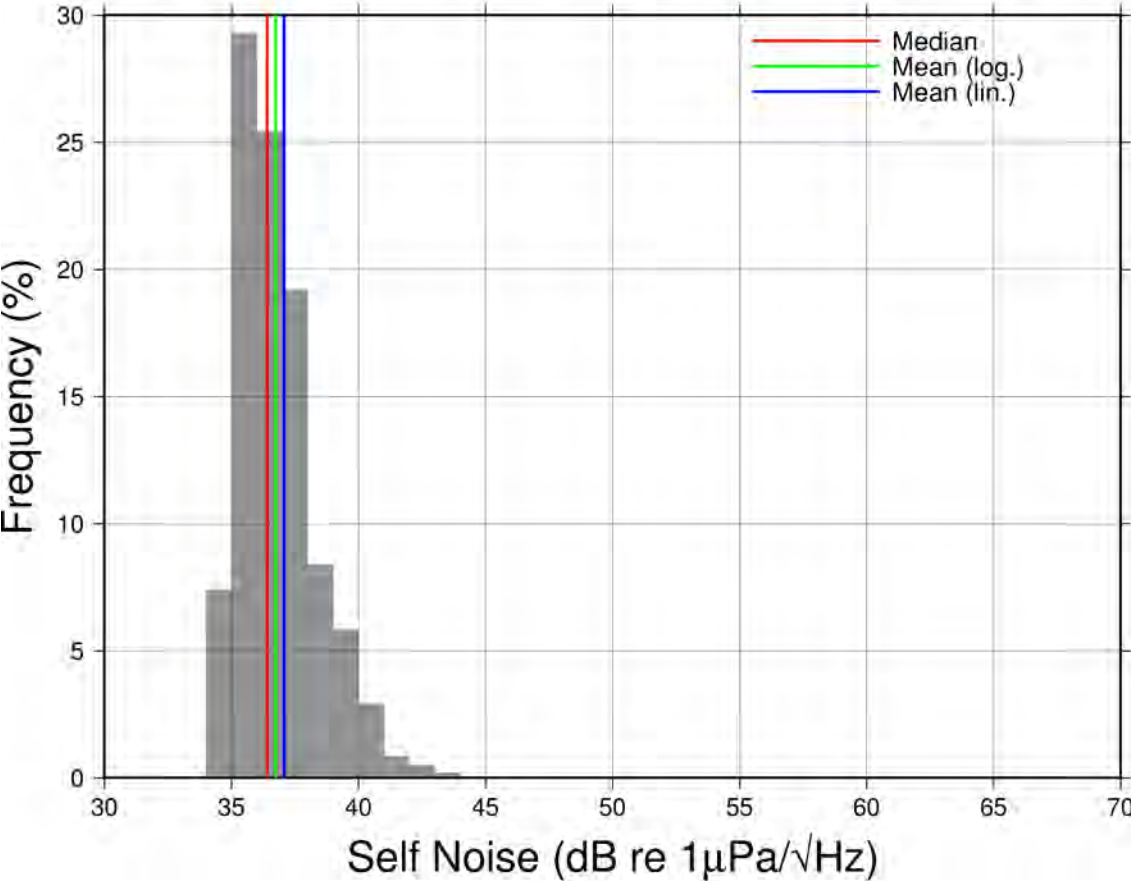
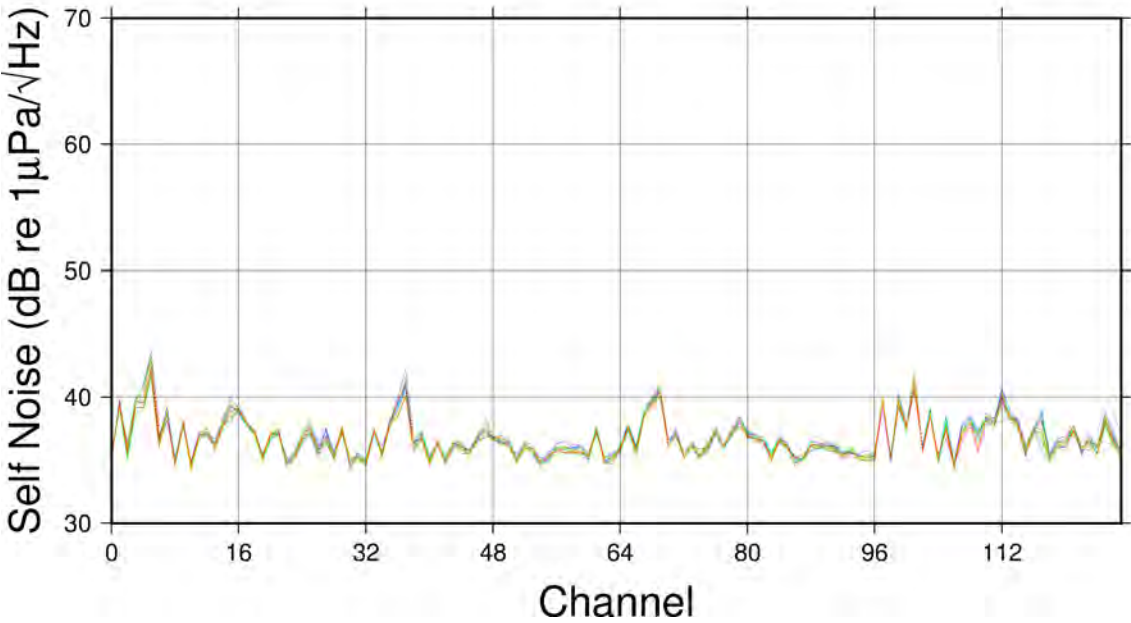
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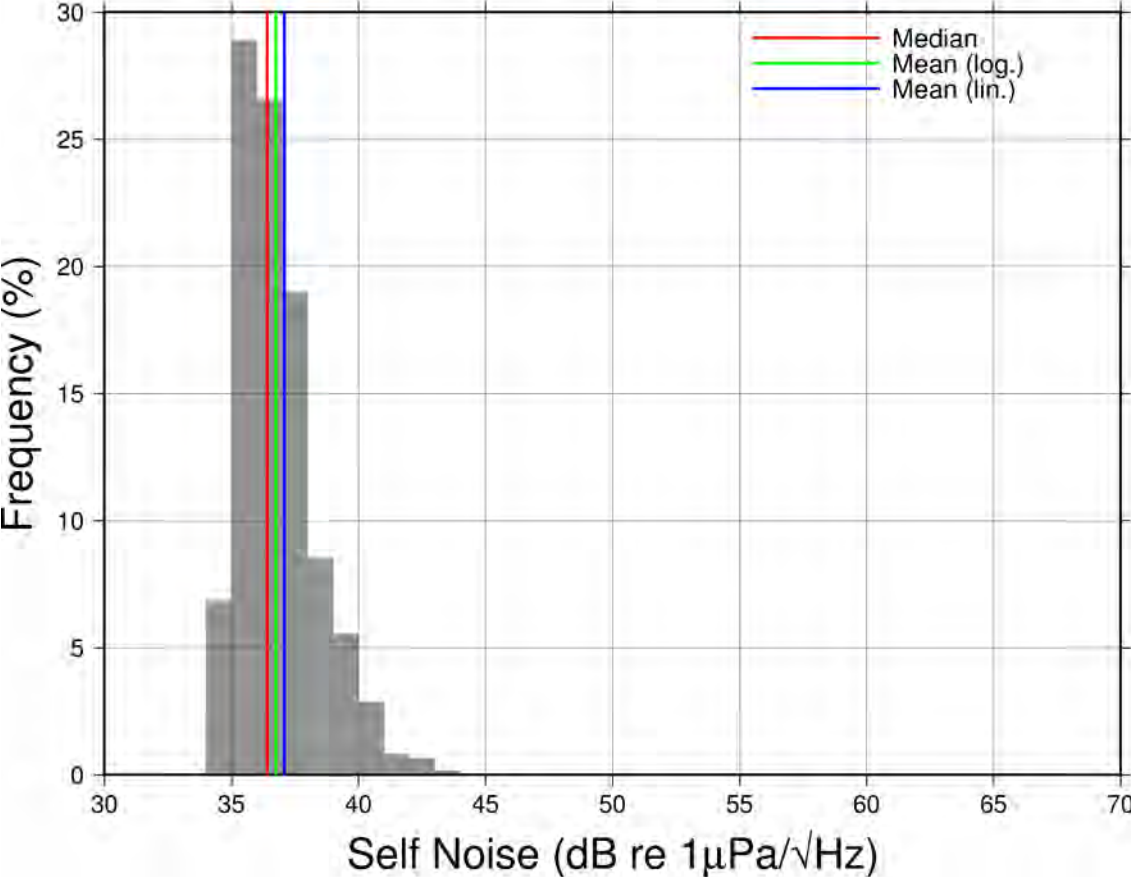
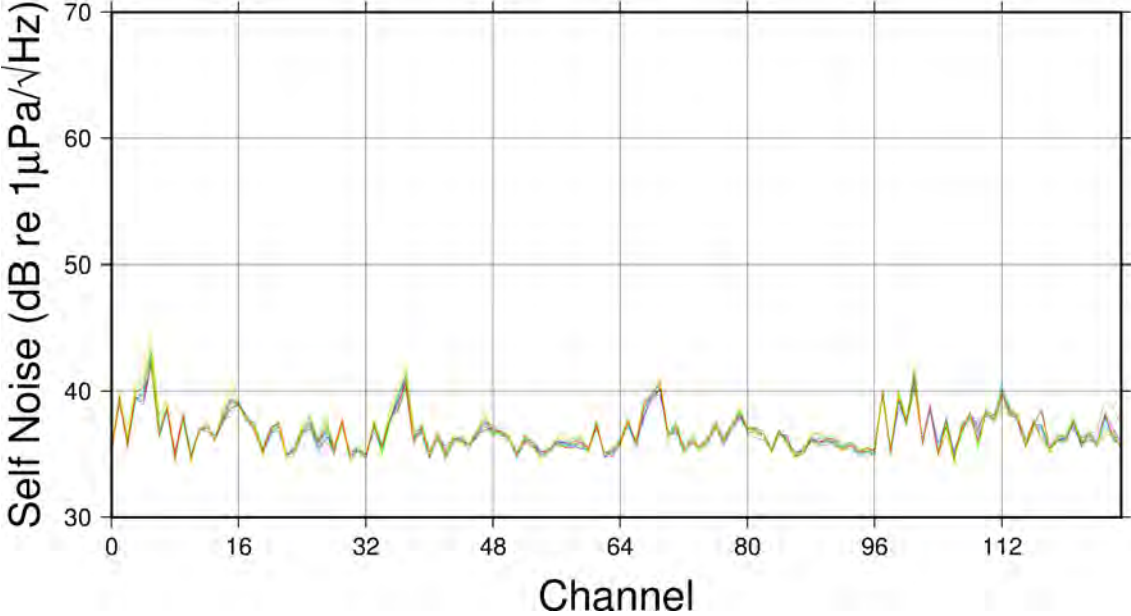
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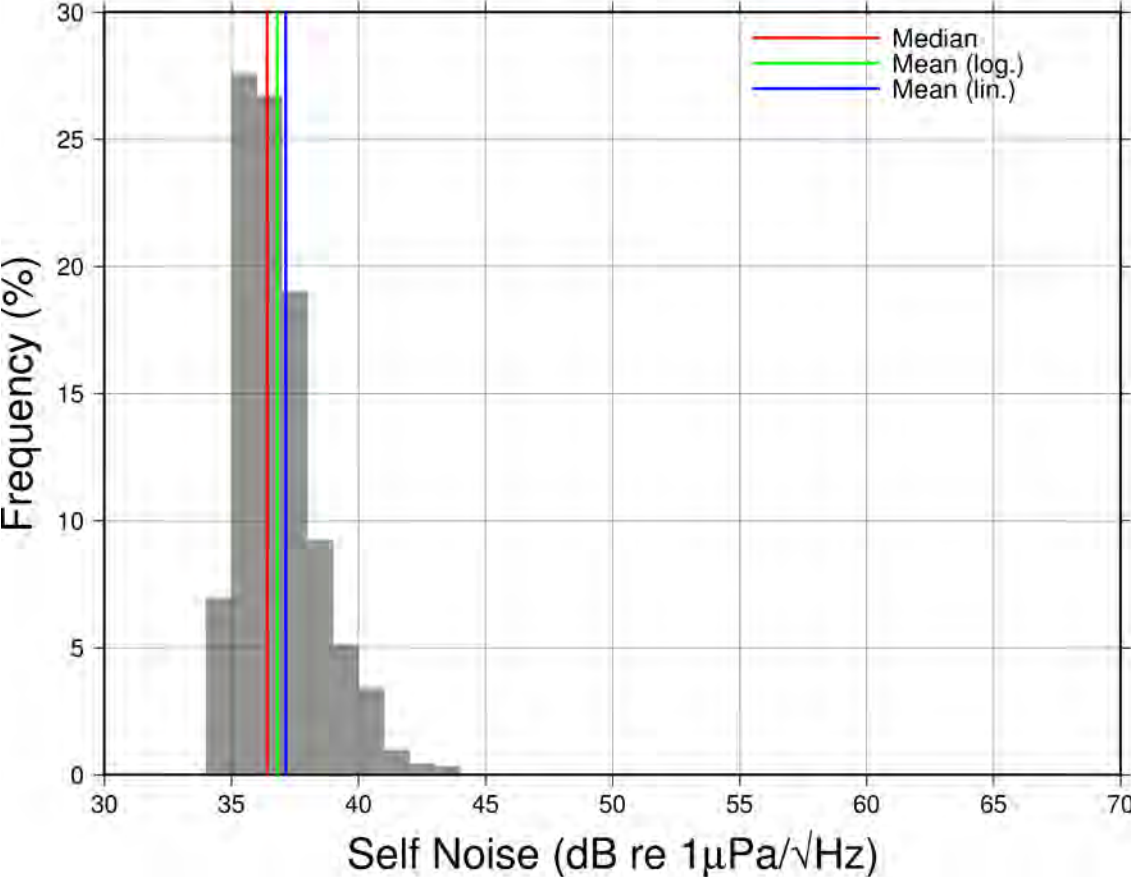
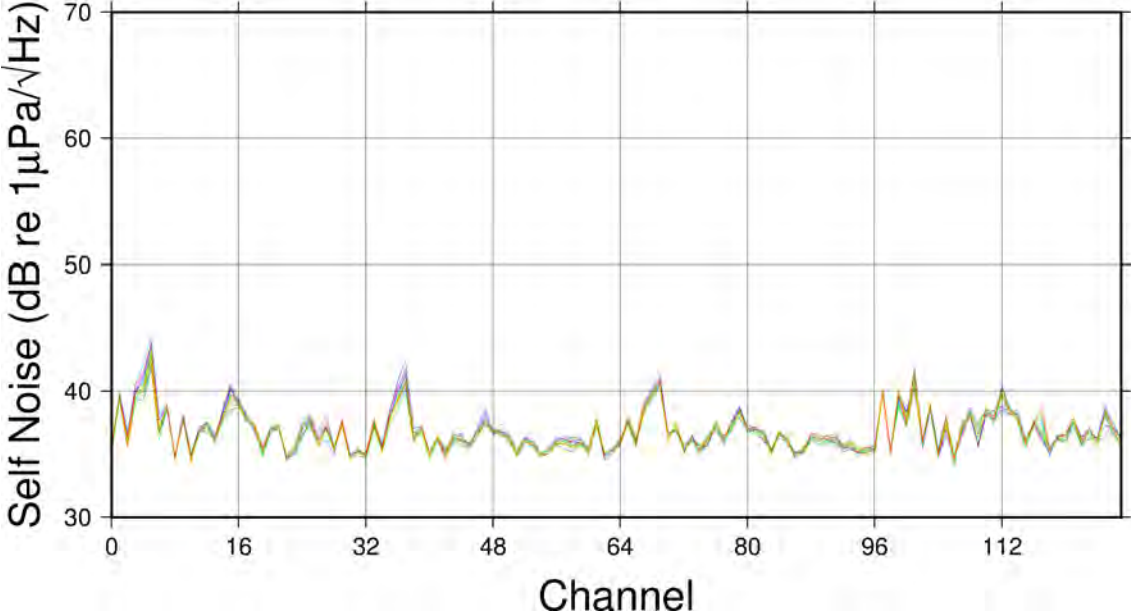
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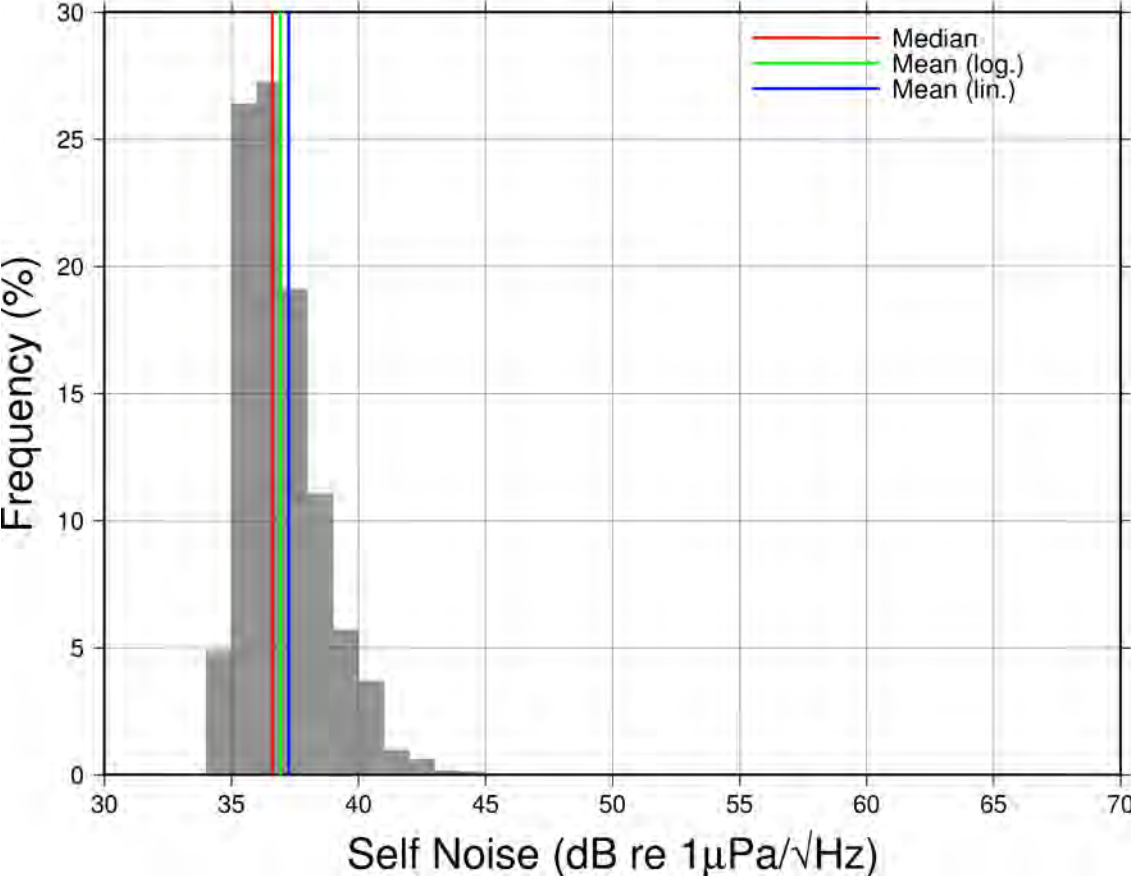
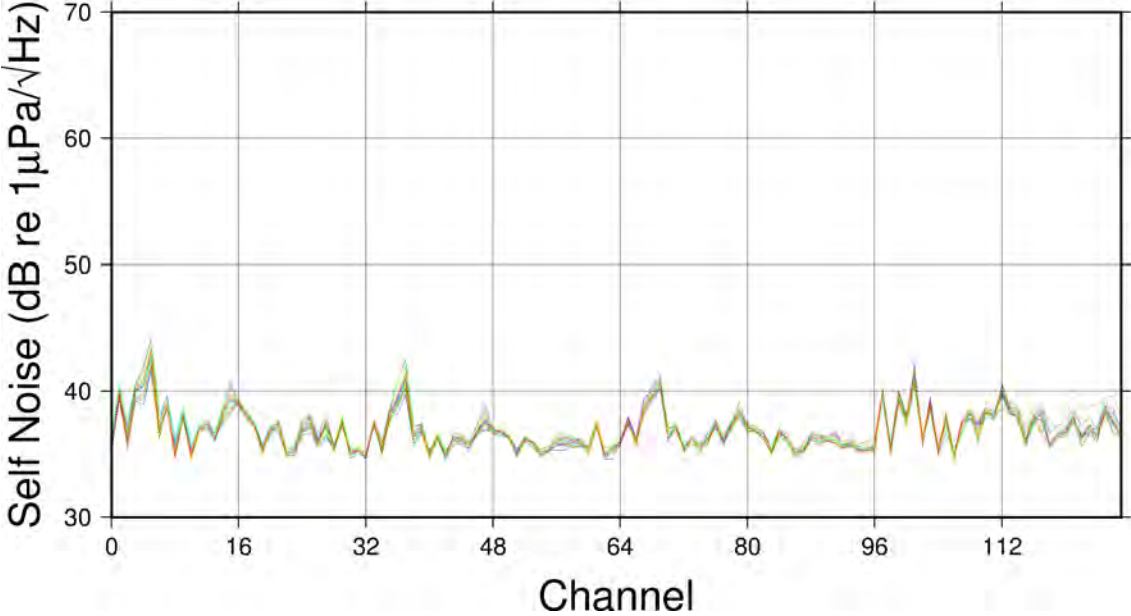
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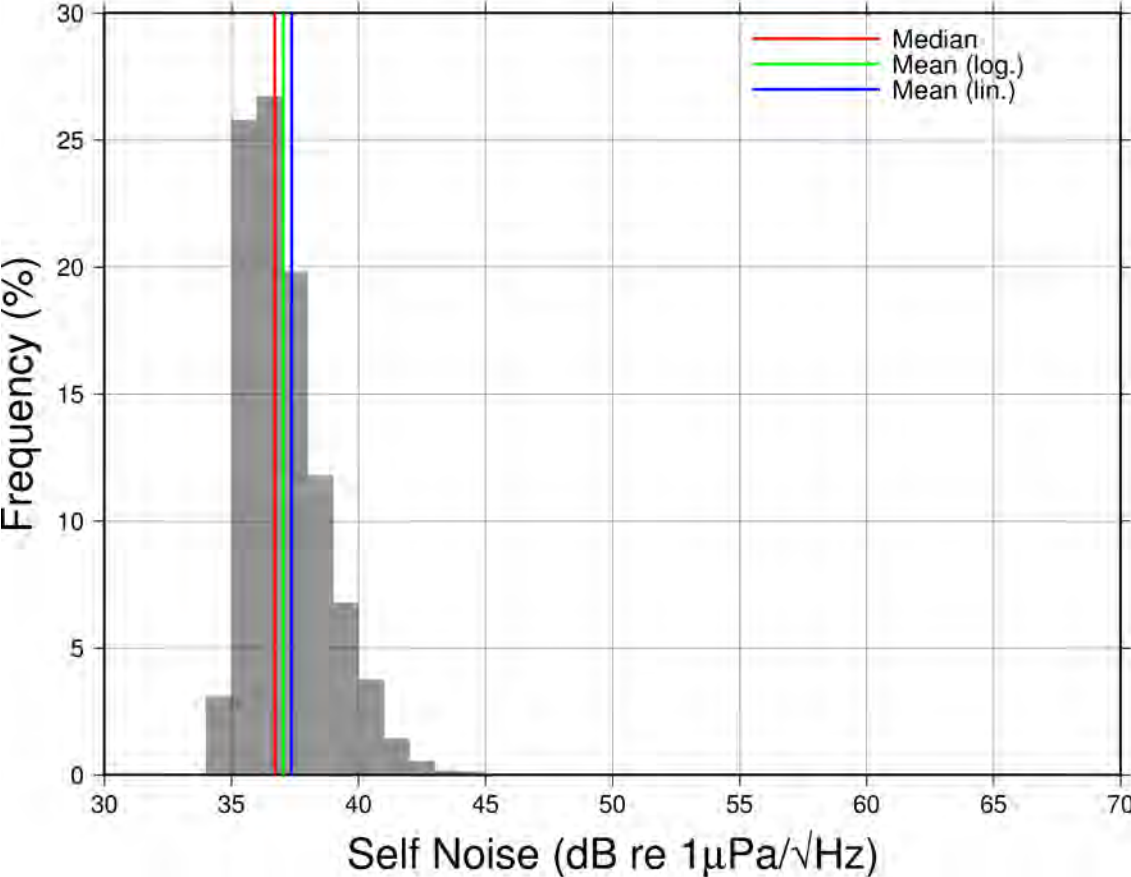
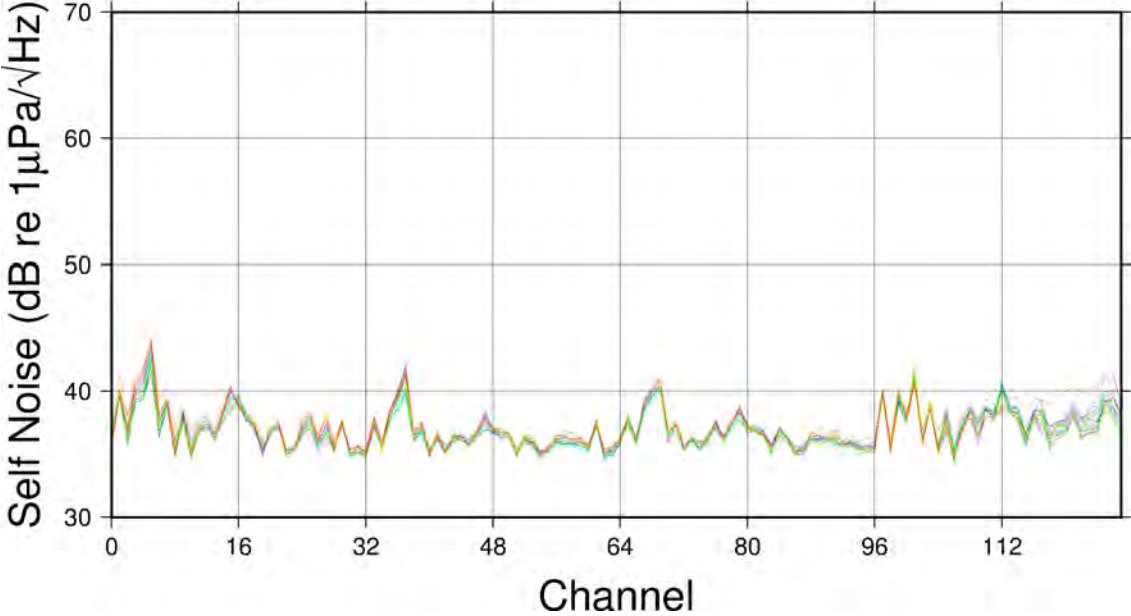
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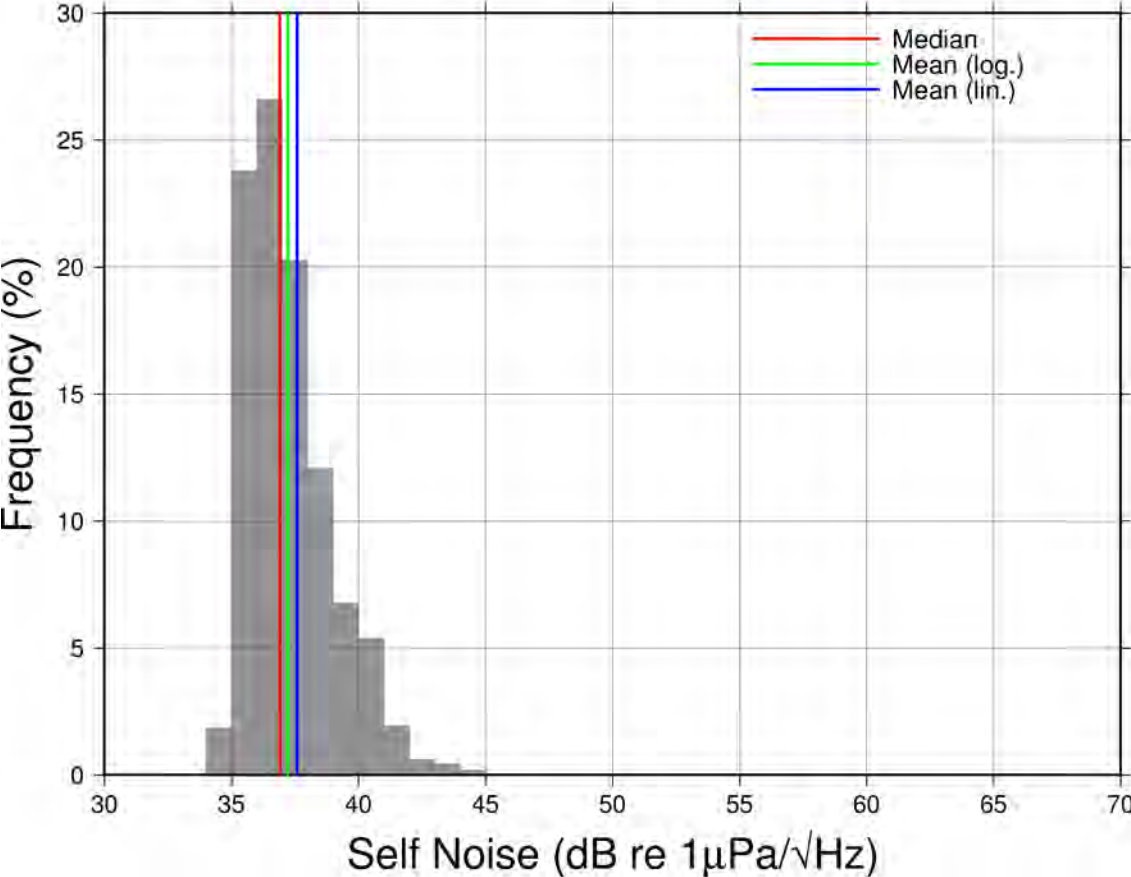
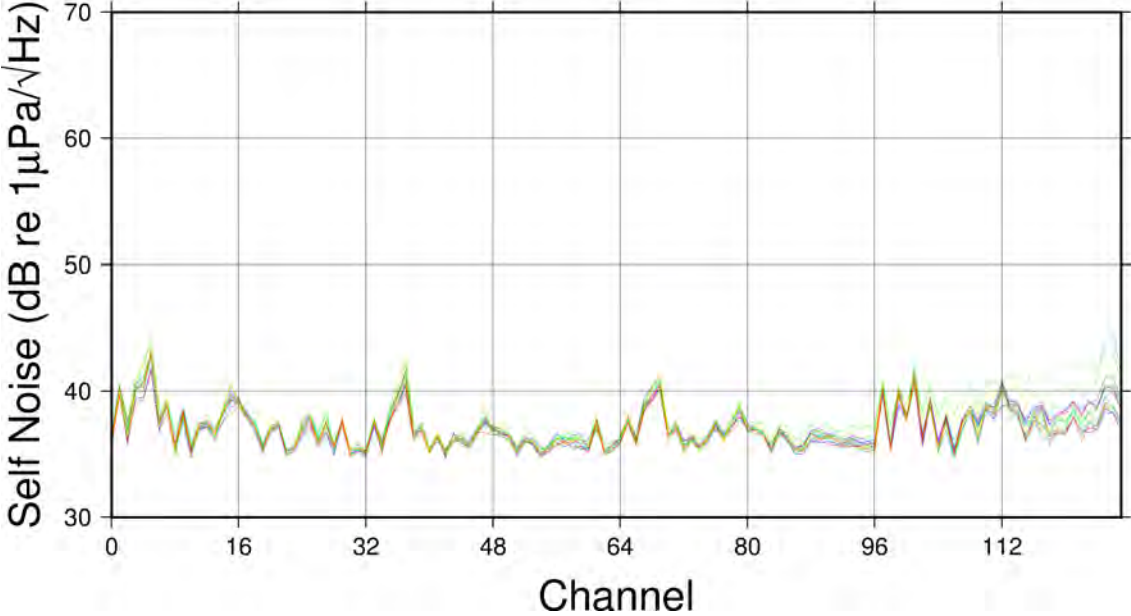
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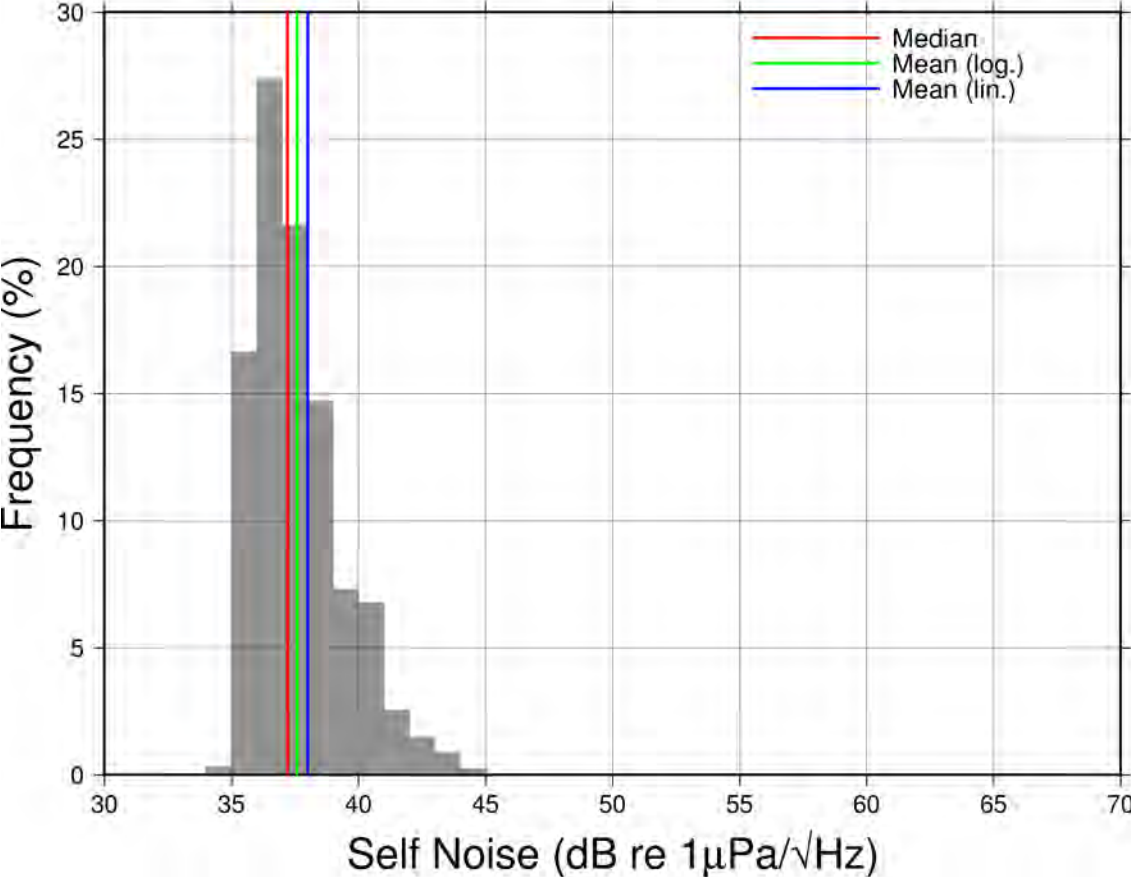
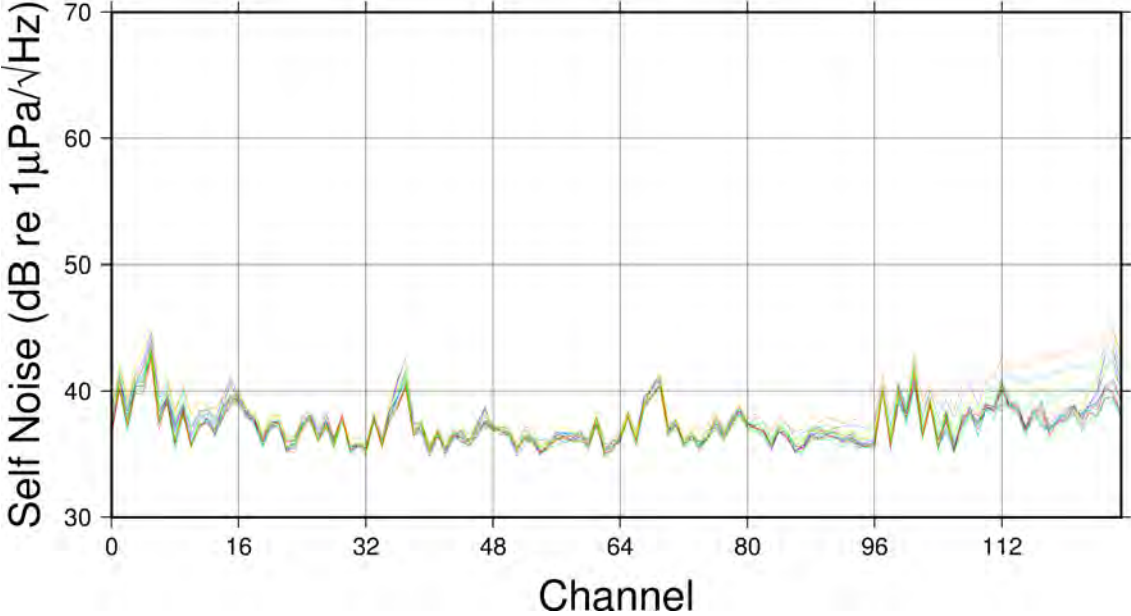
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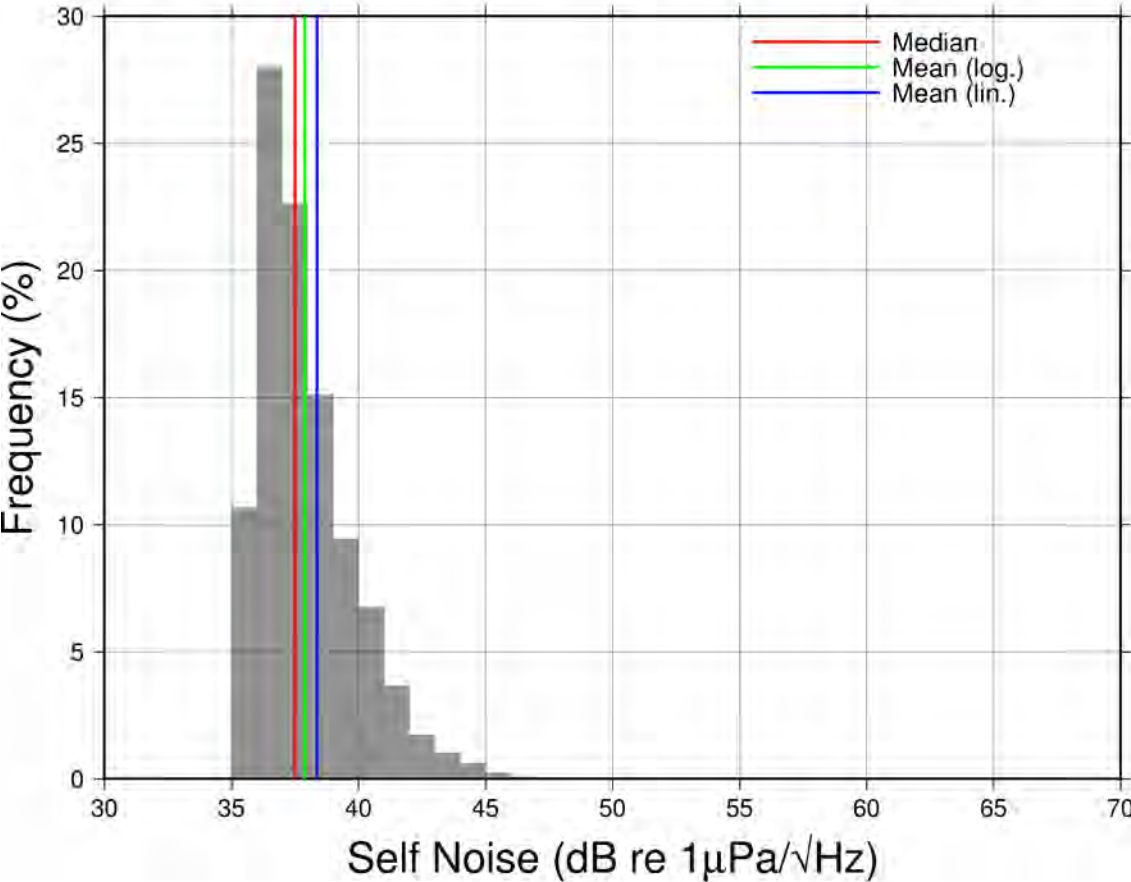
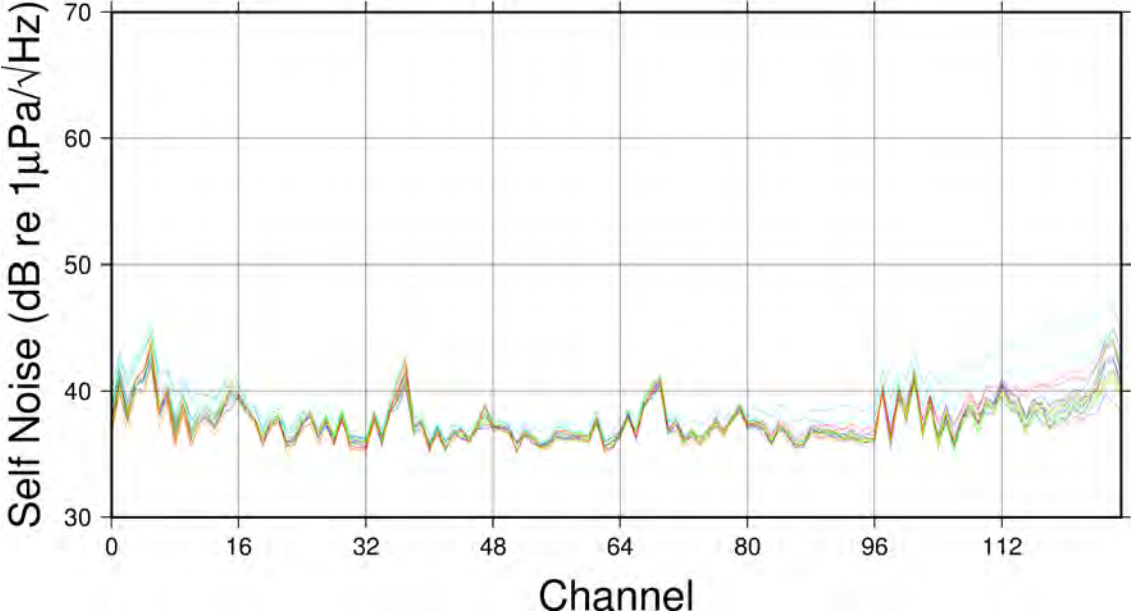
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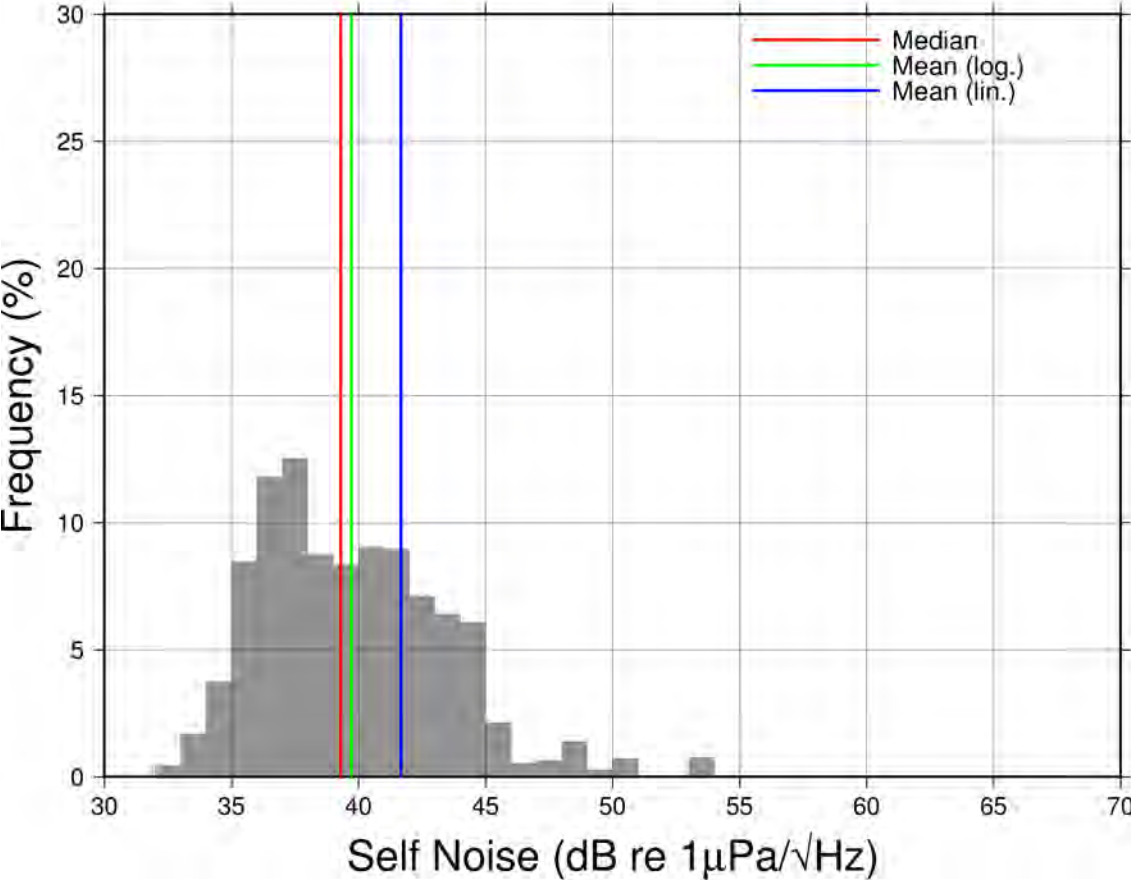
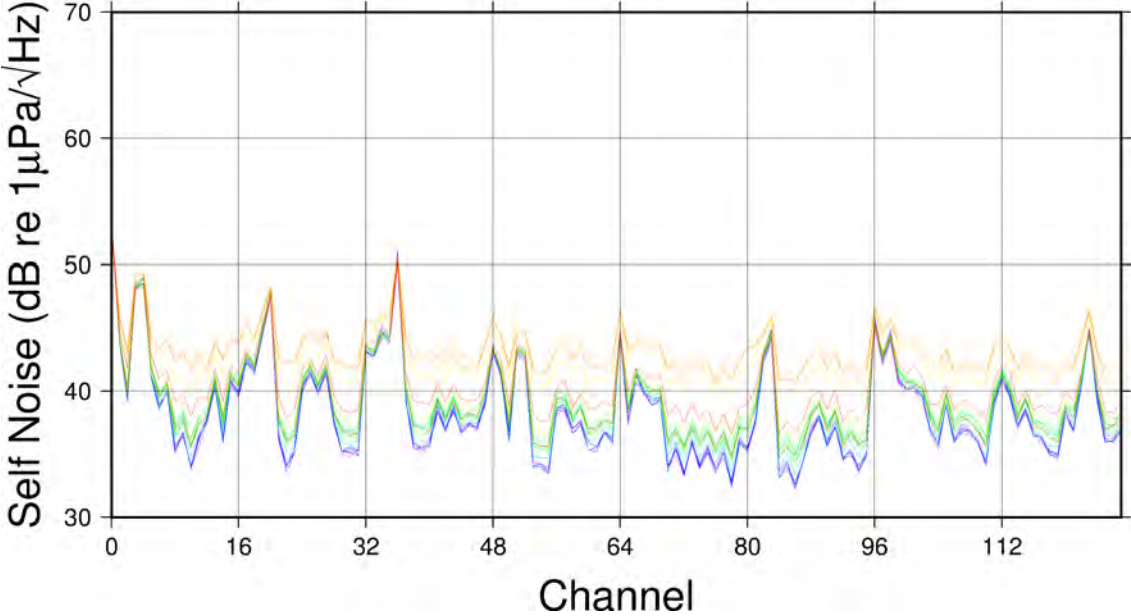
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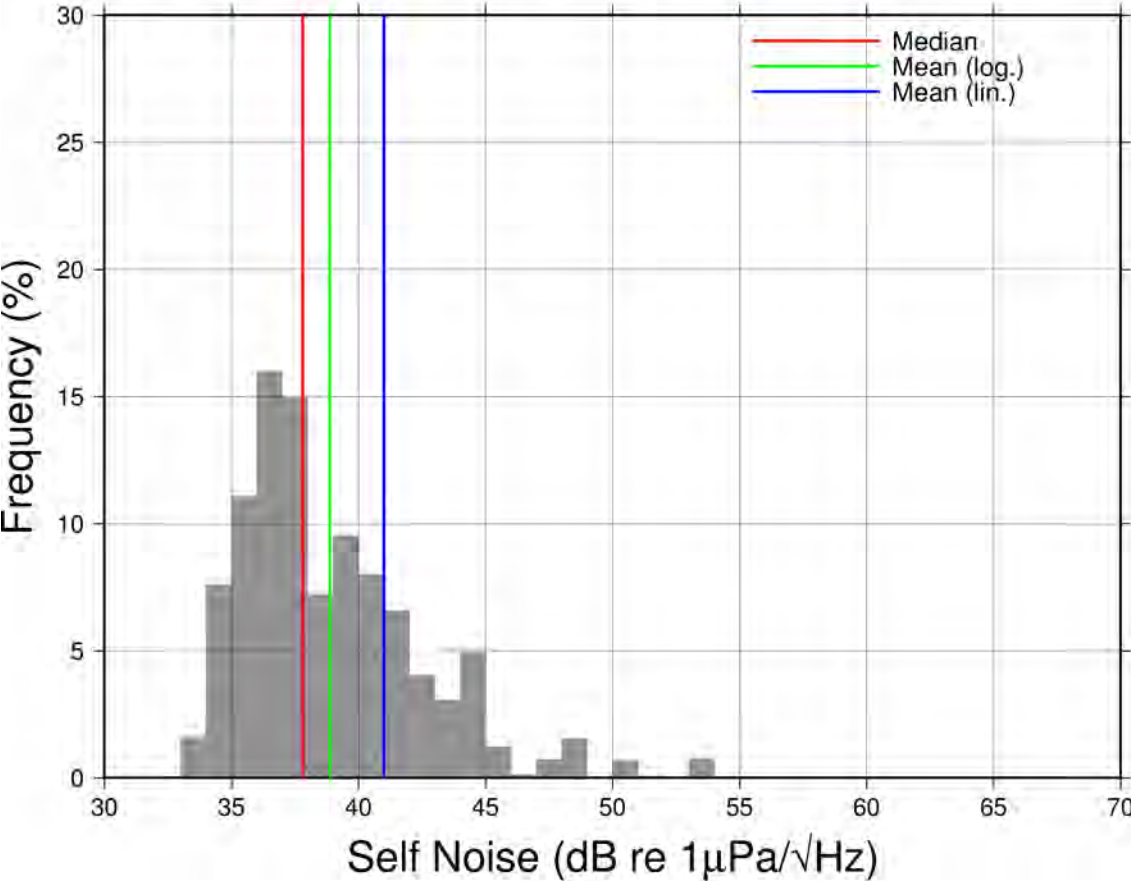
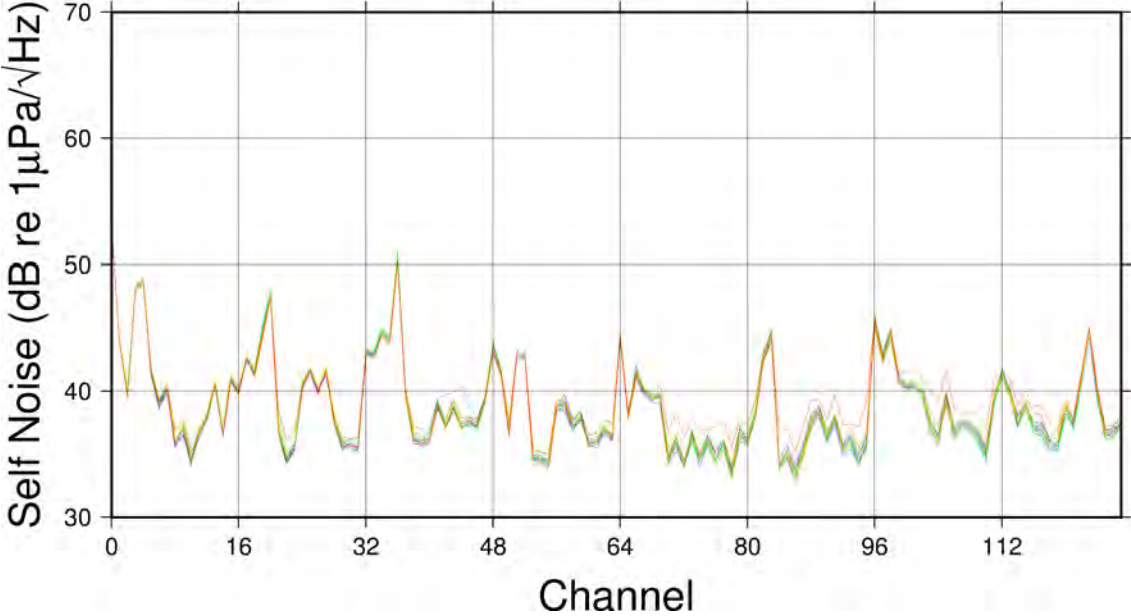
## Appendix B – EM302 Noise Measurements

All figures in this section show self-noise levels for the EM302 as measured using the receiver hydrophones. The upper plots show the output as a function of receiver module. The lower plots show the distribution of the same data along with the median, geometric mean and linear mean. The geometric mean is the mean of the dB values. The linear mean is the mean of the noise levels in linear intensity units and then transformed back to dB.

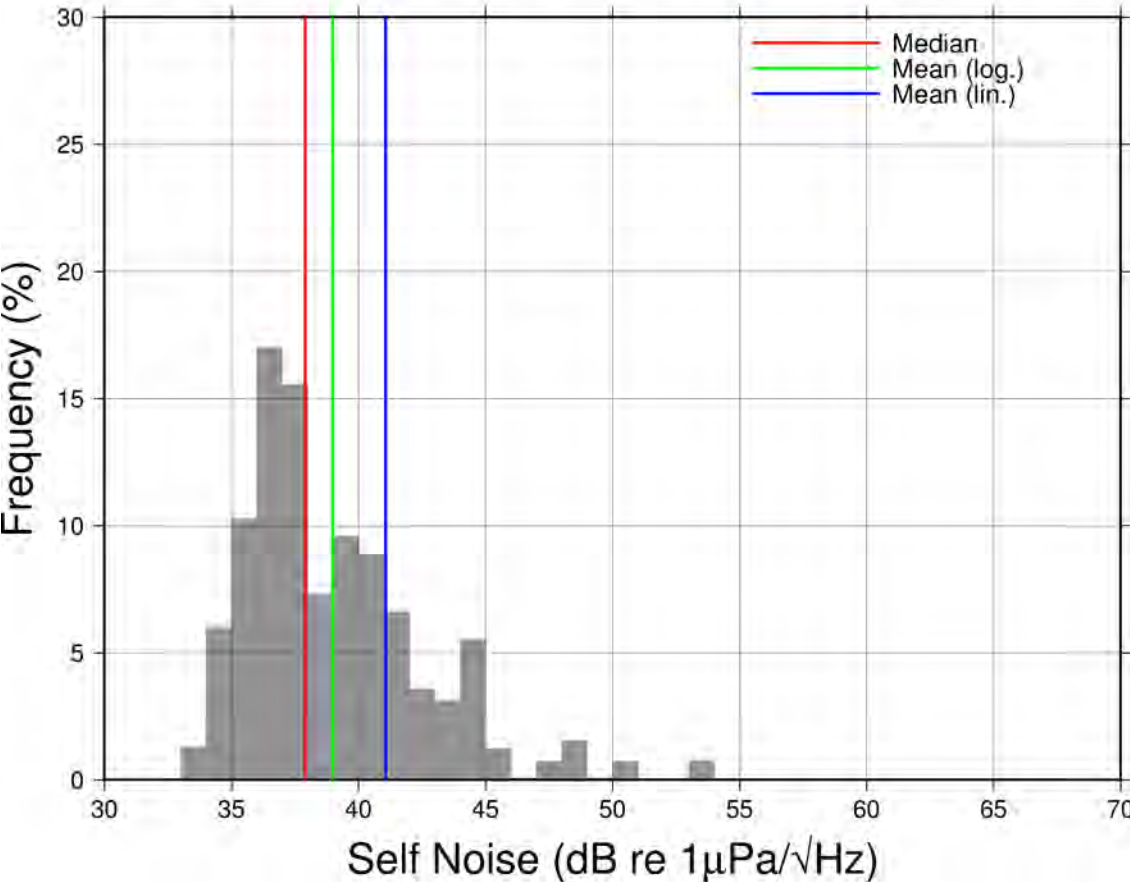
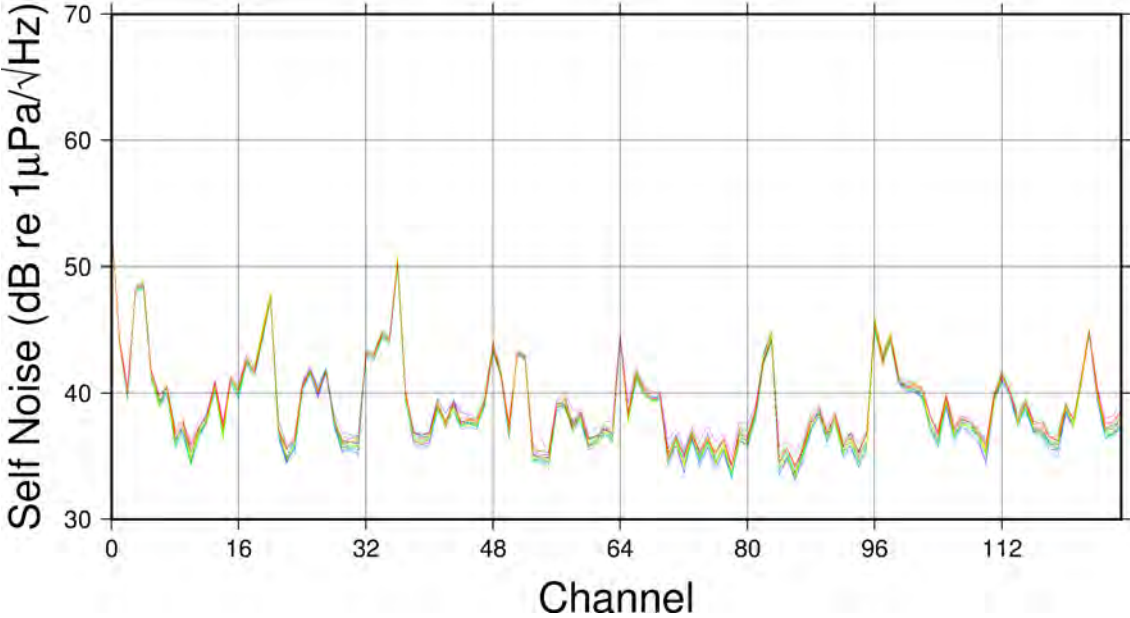
# RV Falkor EM302 Self Noise -- 00 kts



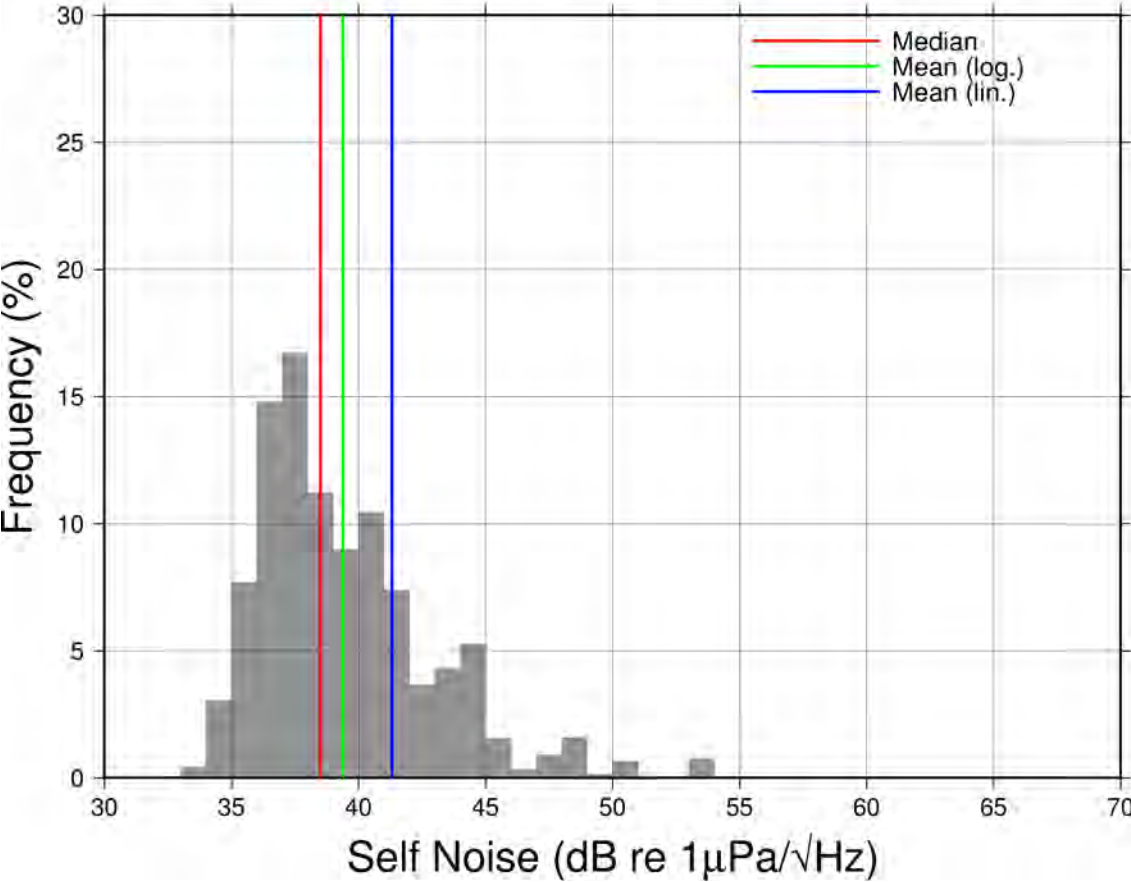
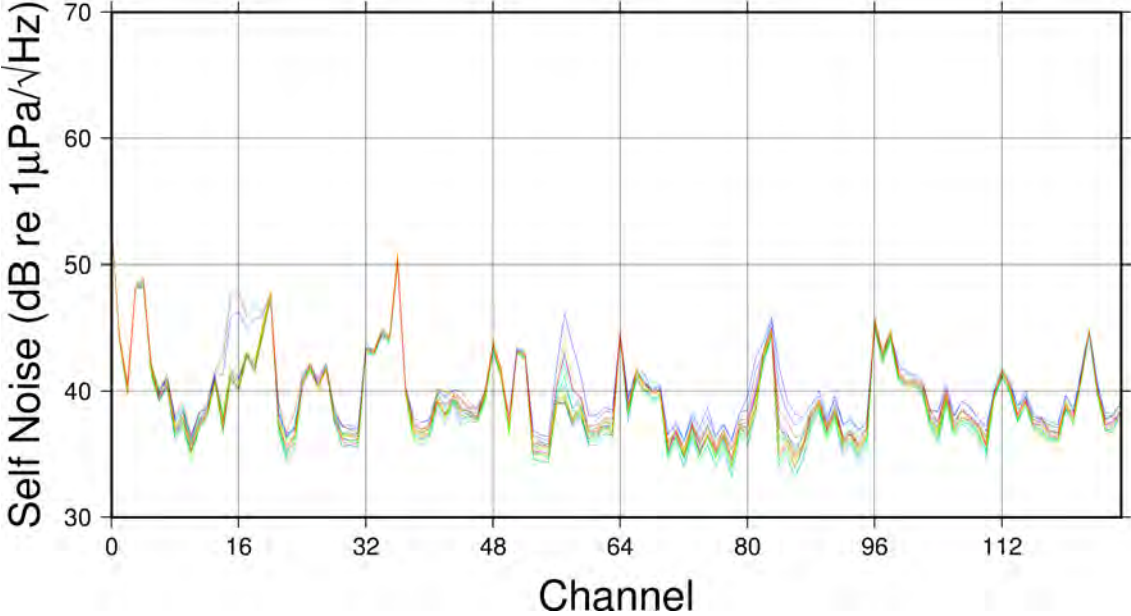
# RV Falkor EM302 Self Noise -- 01 kts



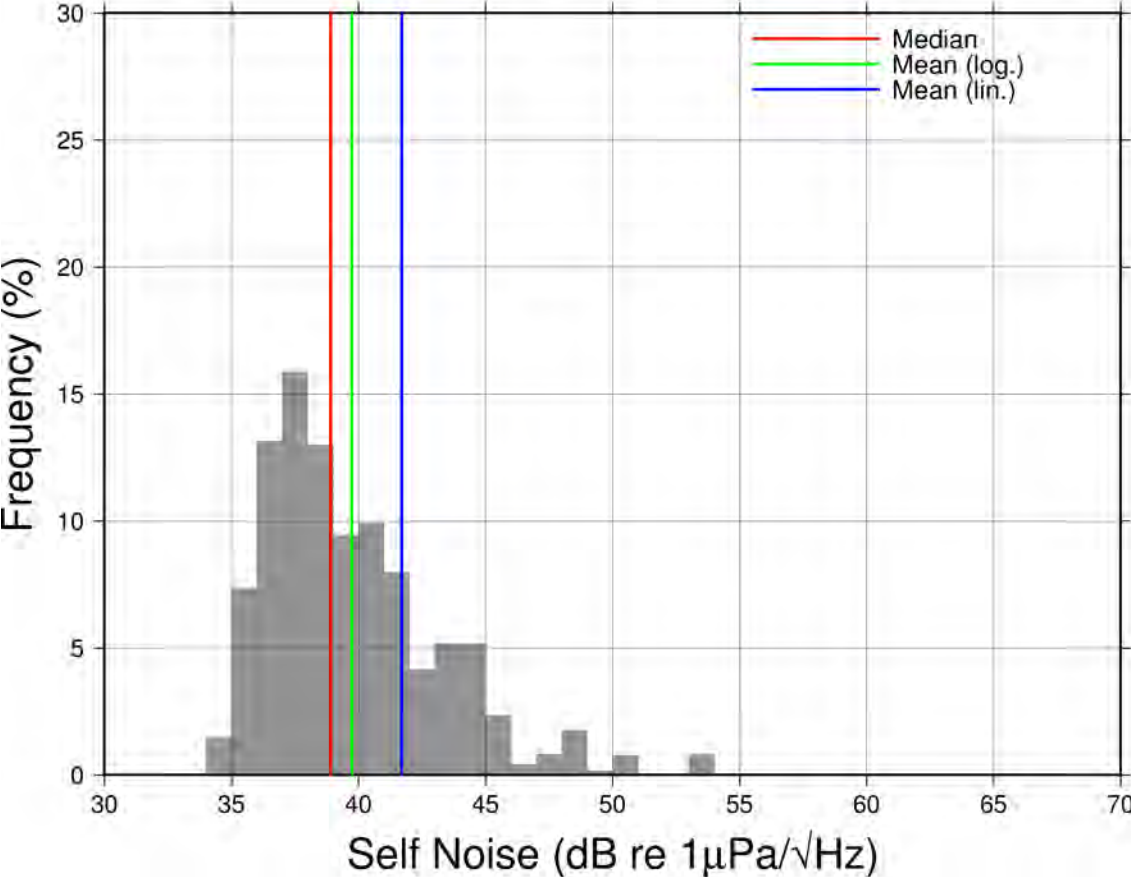
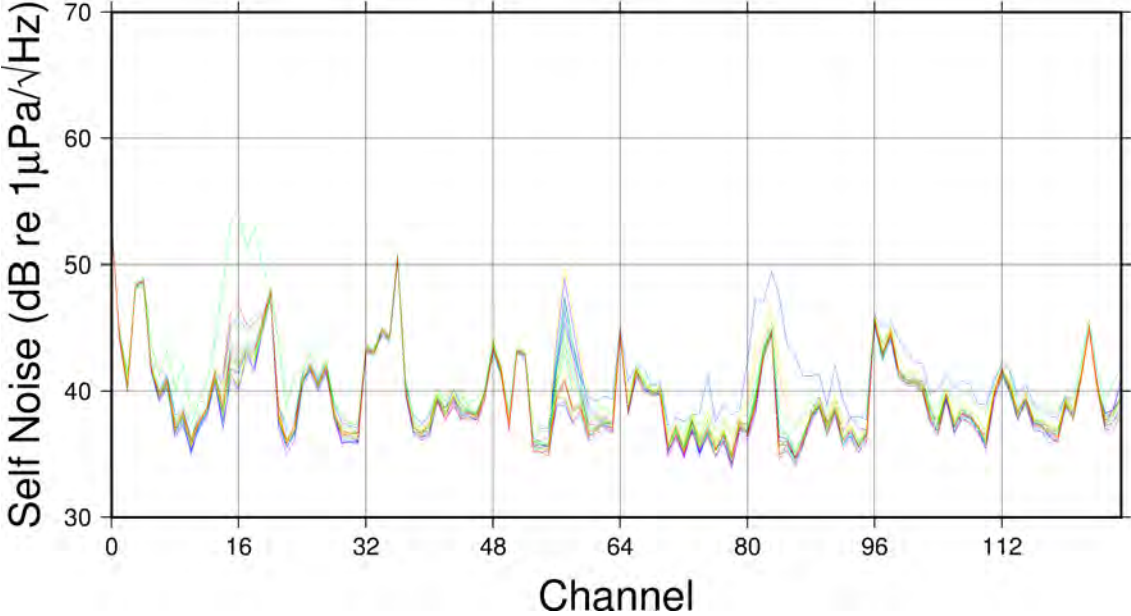
# RV Falkor EM302 Self Noise -- 02 kts



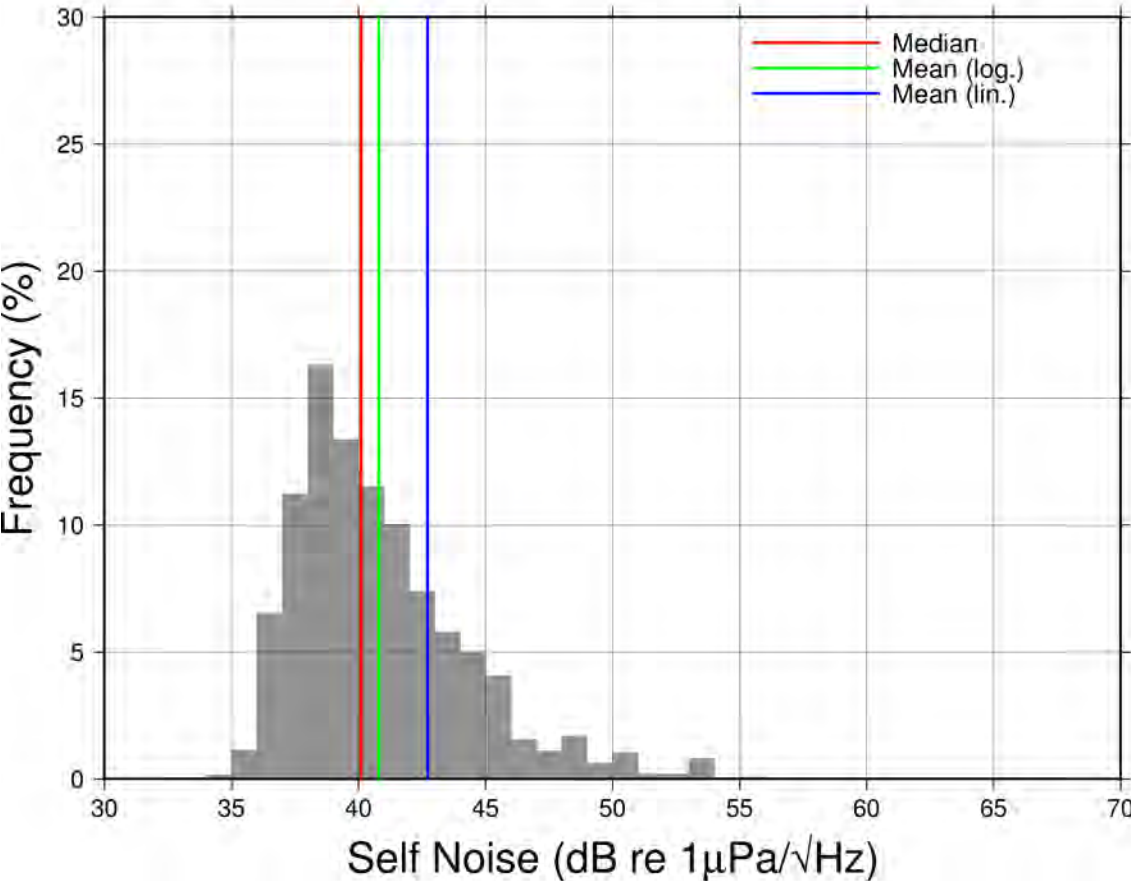
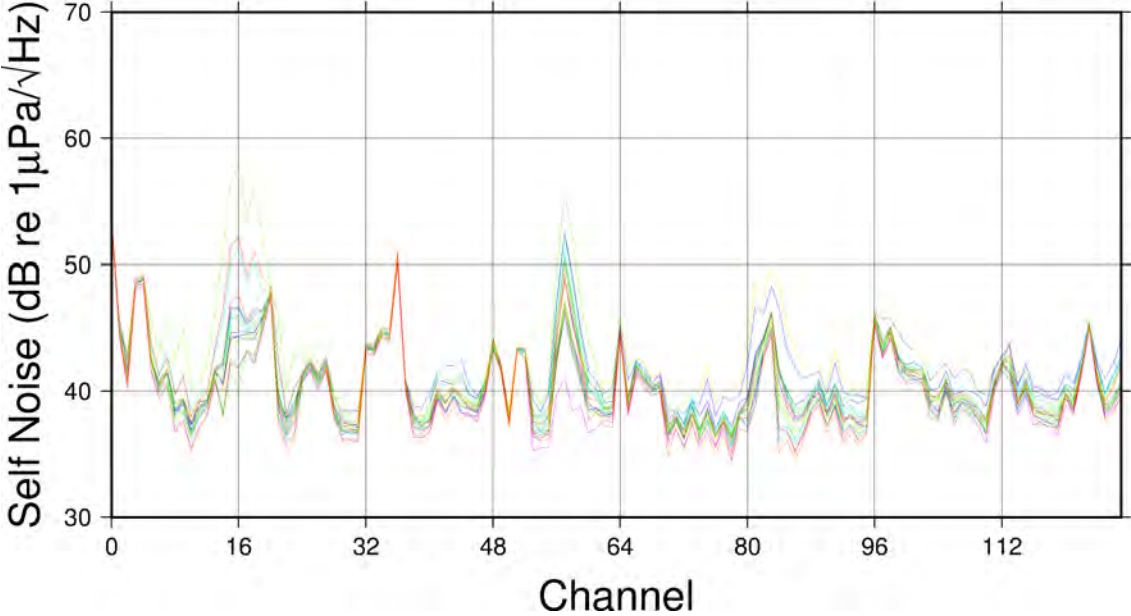
# RV Falkor EM302 Self Noise -- 03 kts



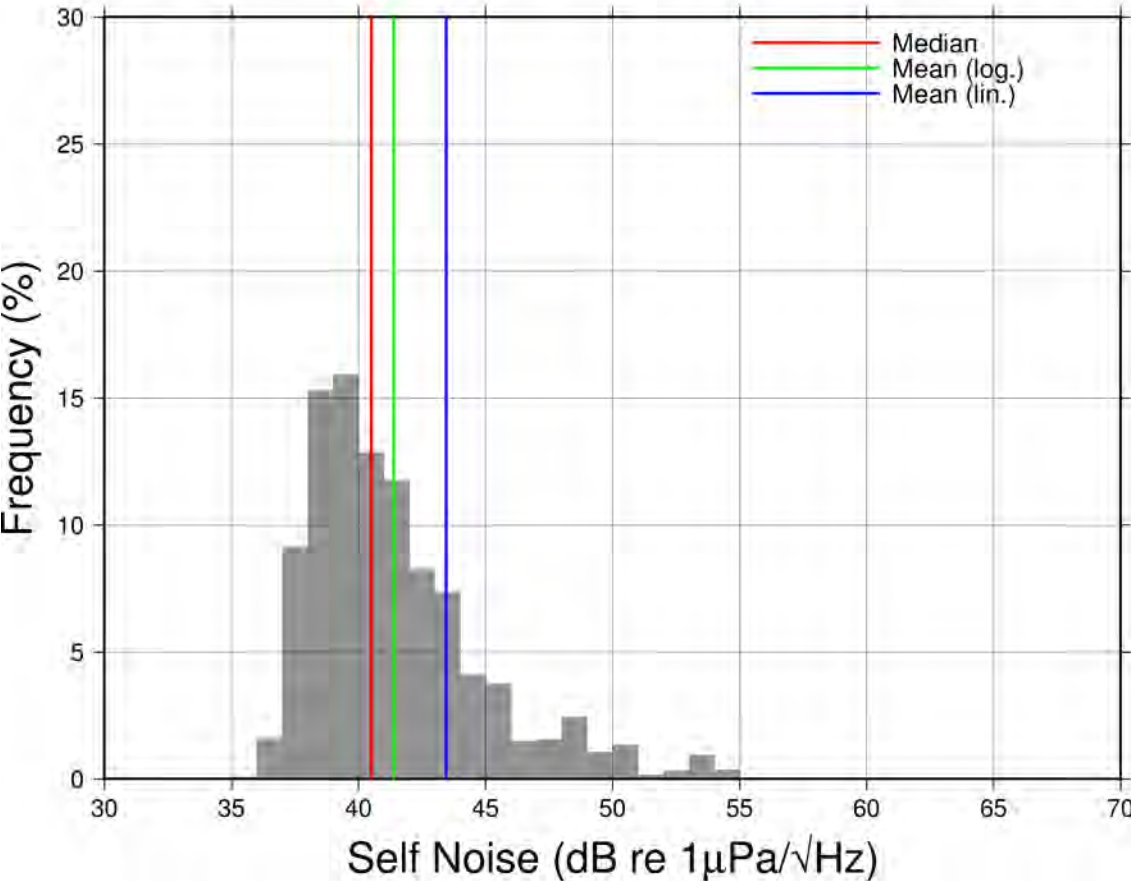
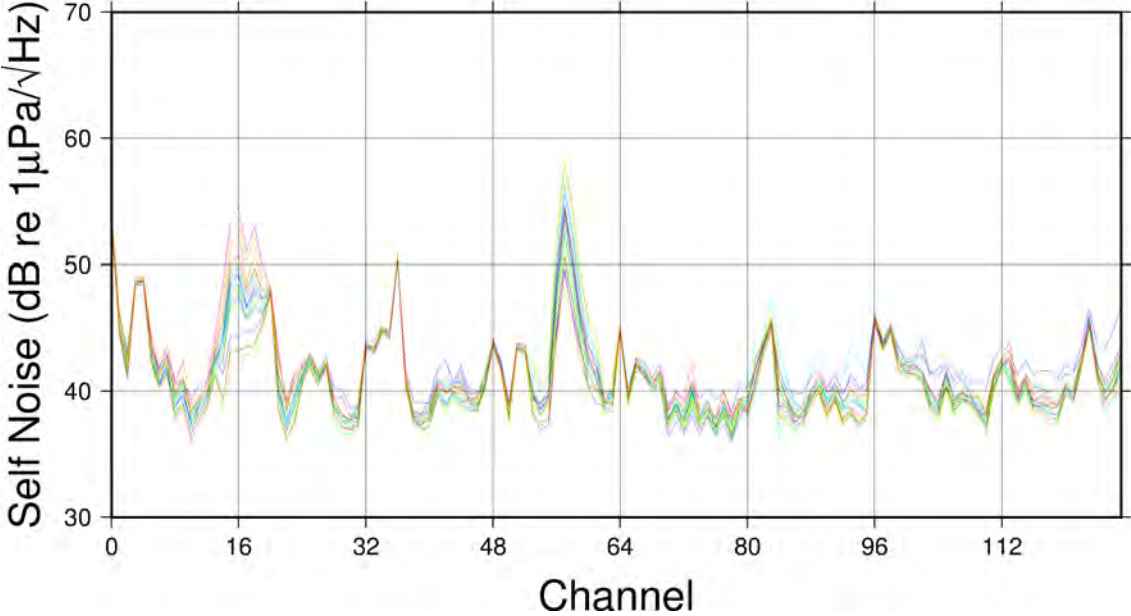
# RV Falkor EM302 Self Noise -- 04 kts



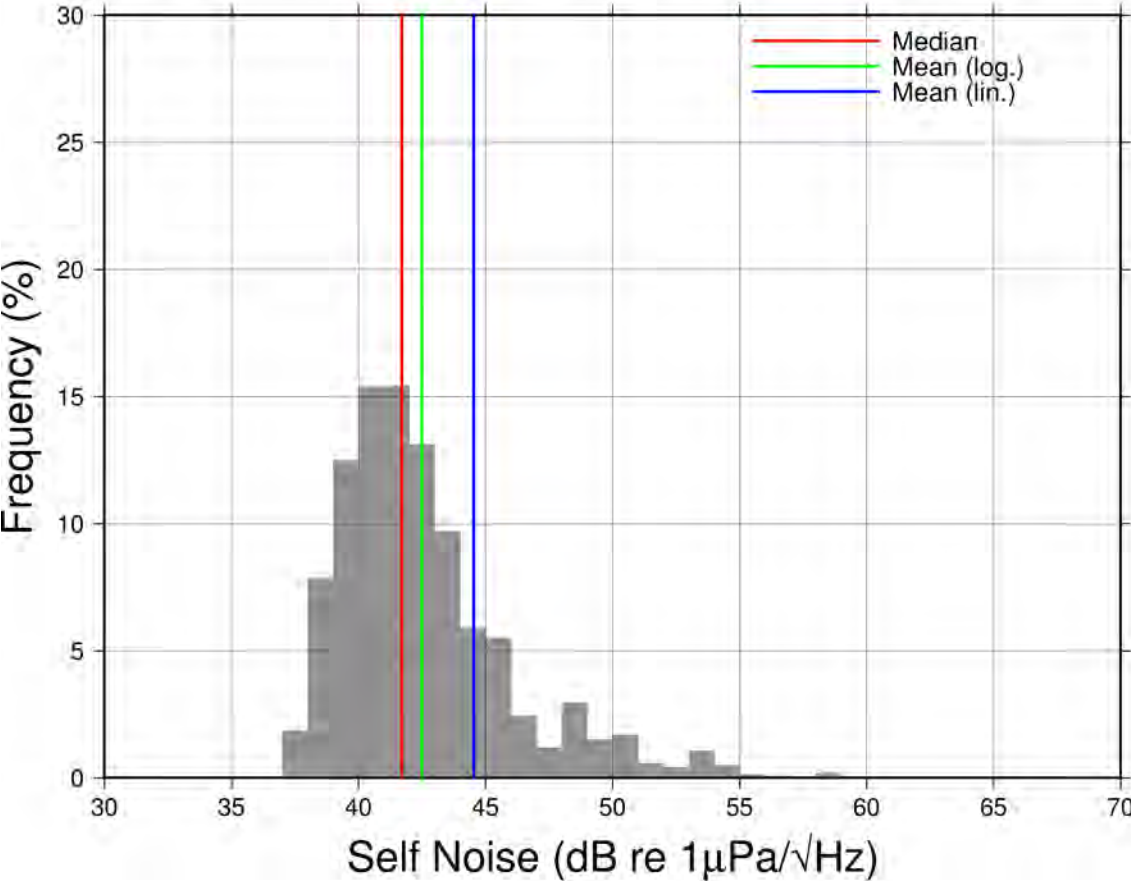
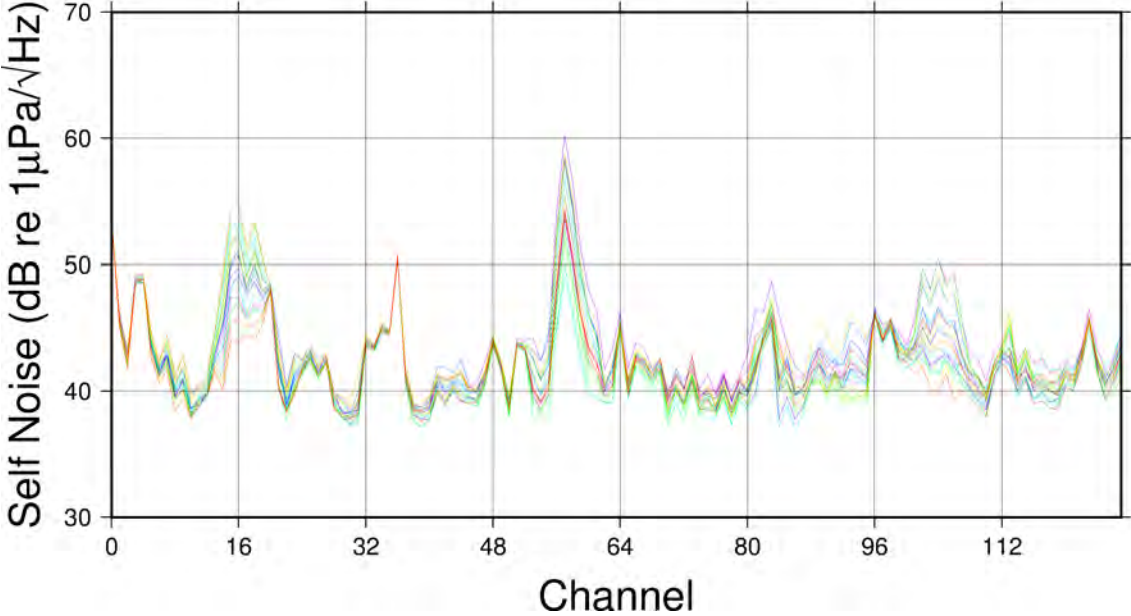
# RV Falkor EM302 Self Noise -- 05 kts



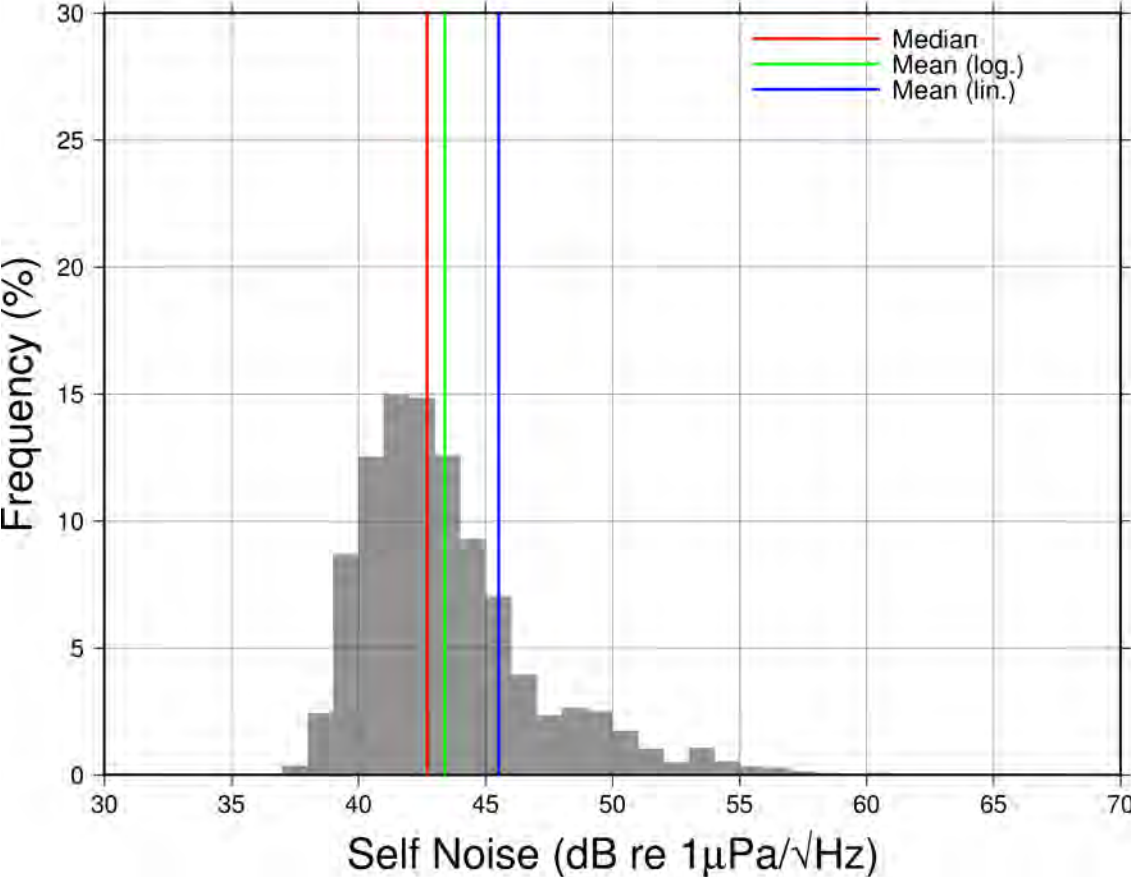
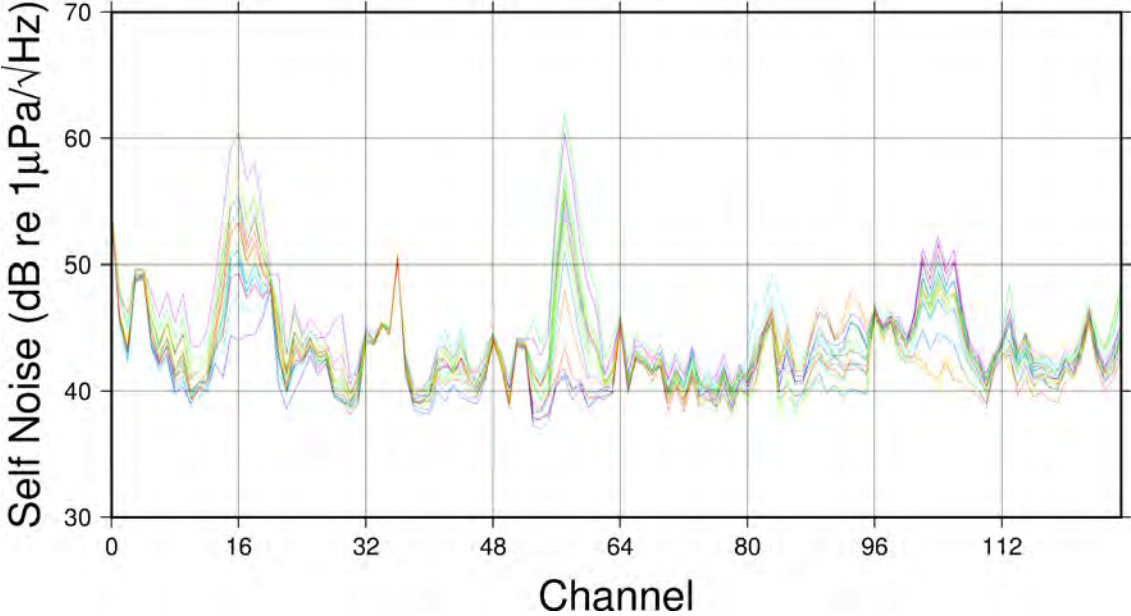
# RV Falkor EM302 Self Noise -- 06 kts



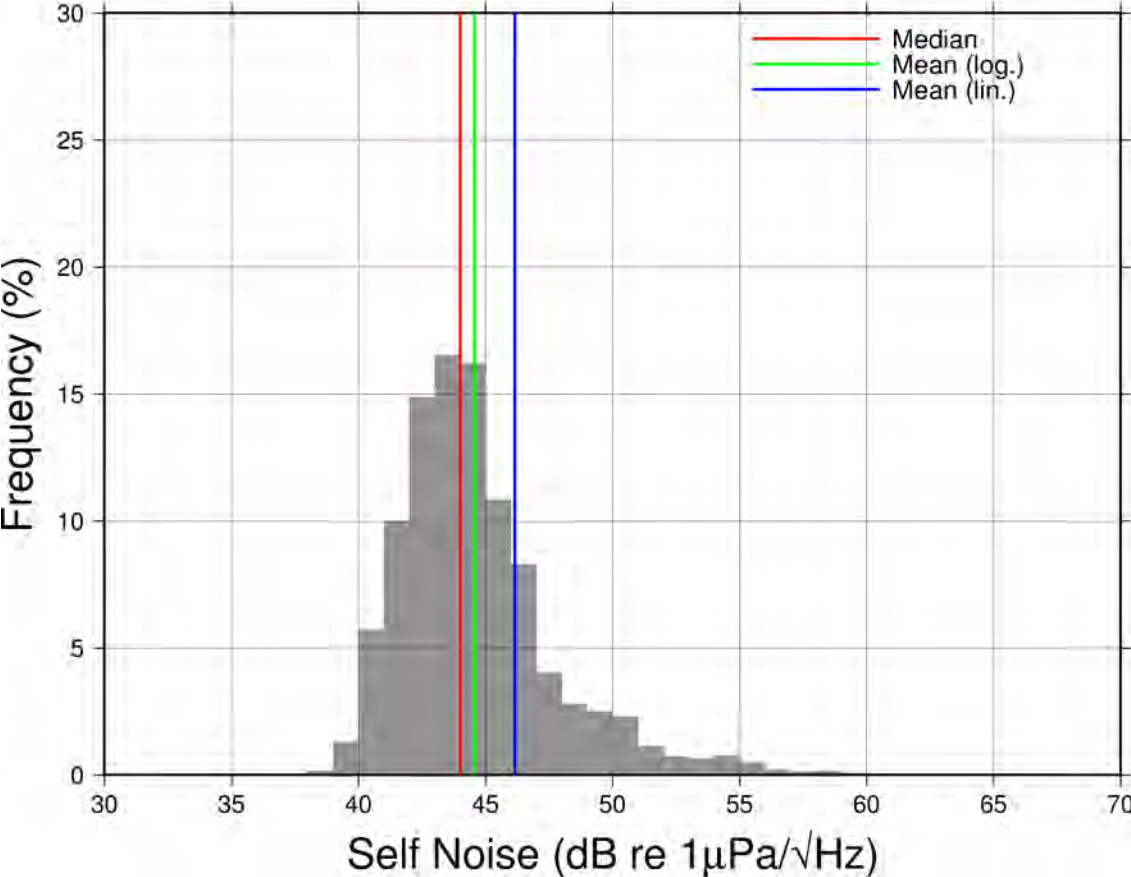
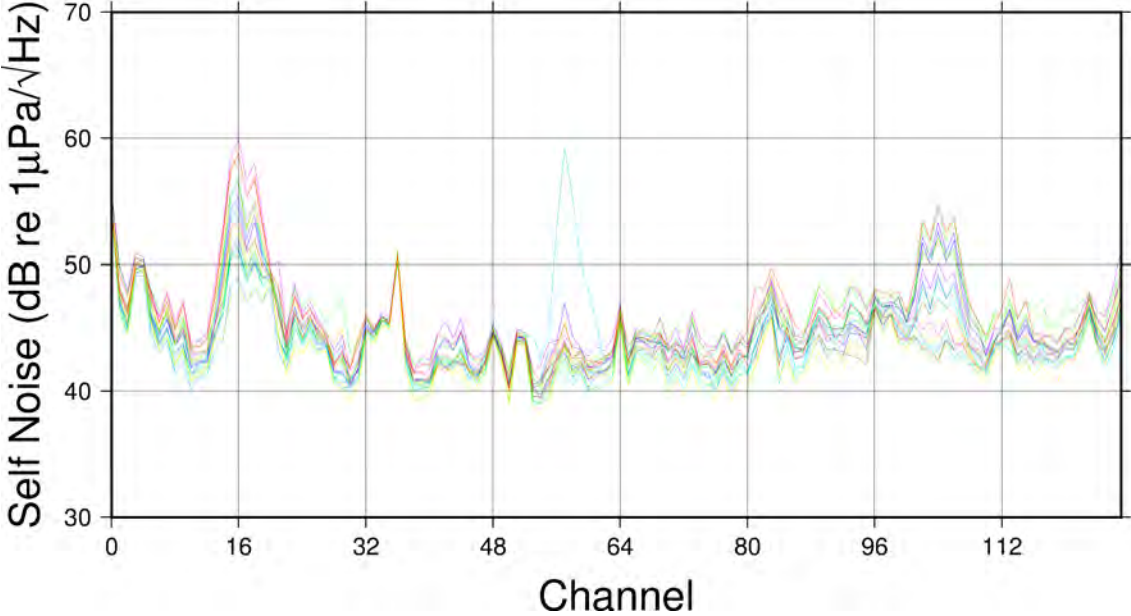
# RV Falkor EM302 Self Noise -- 07 kts



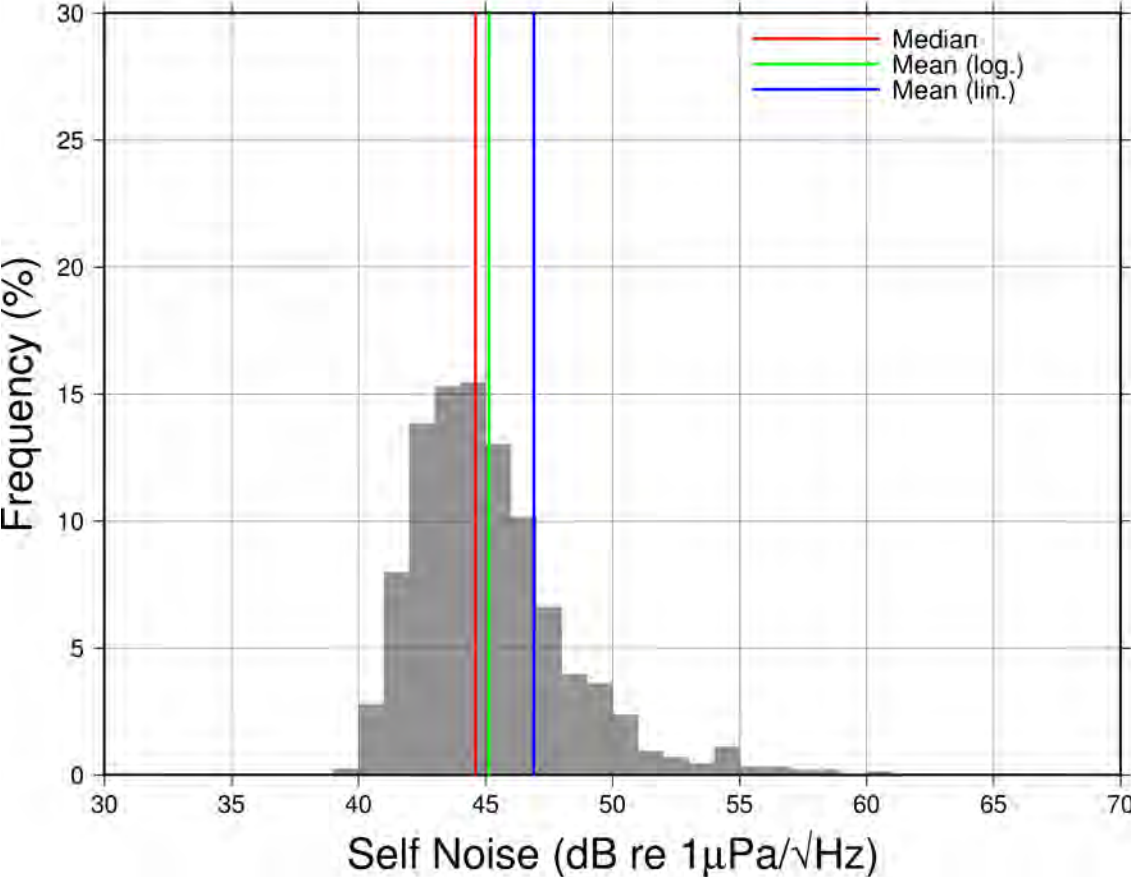
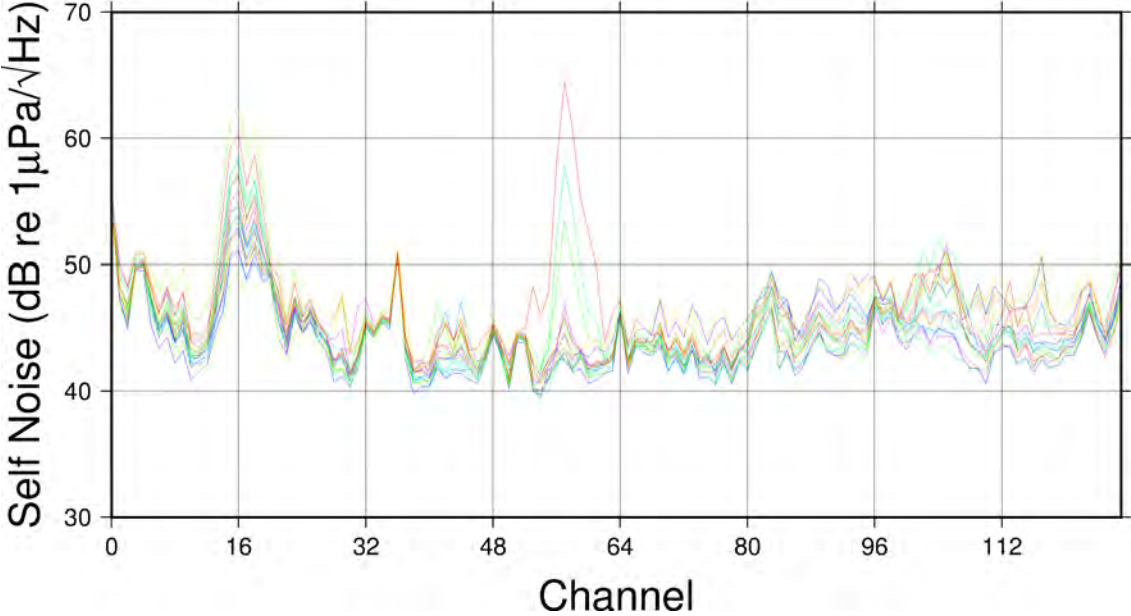
# RV Falkor EM302 Self Noise -- 08 kts



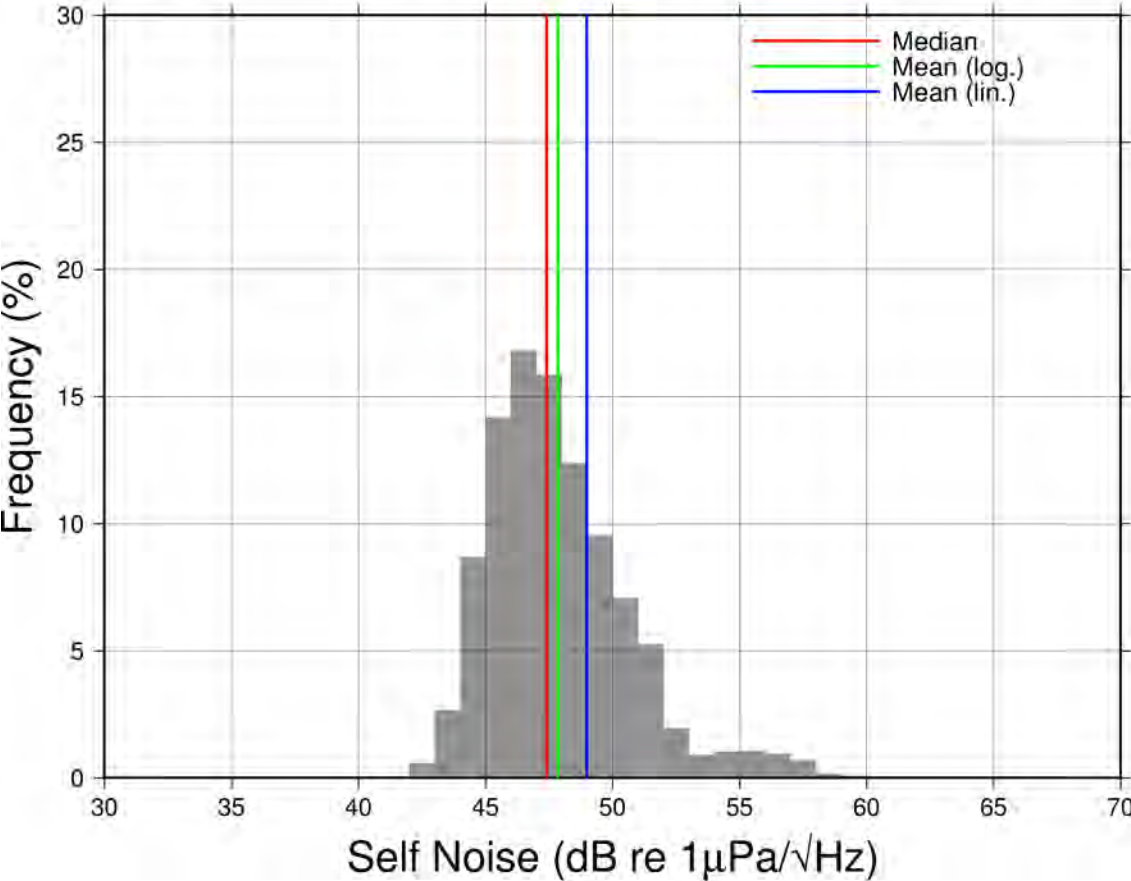
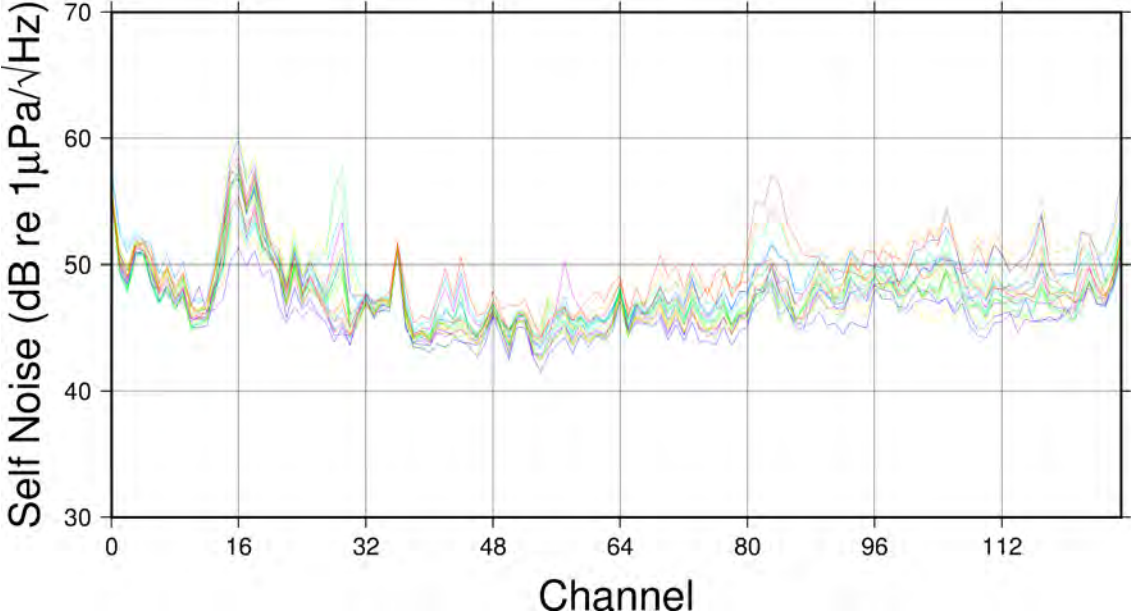
# RV Falkor EM302 Self Noise -- 09 kts



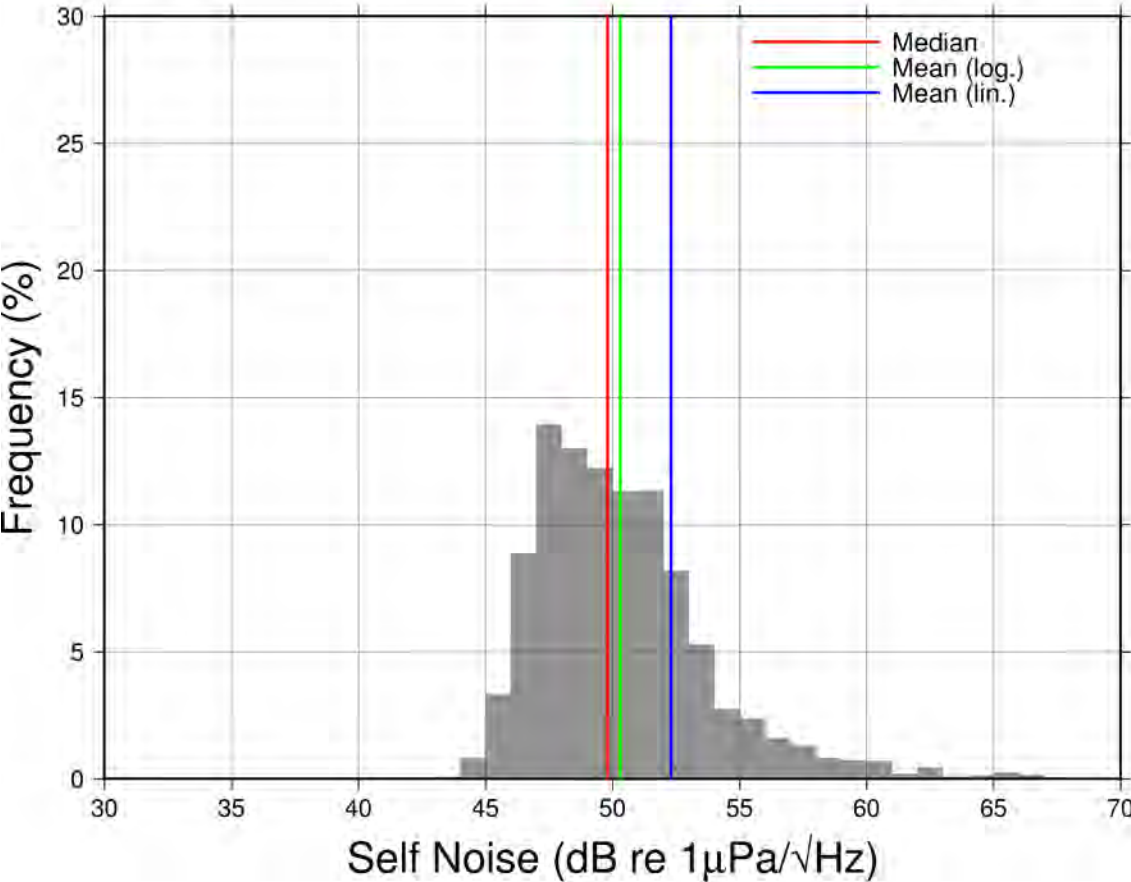
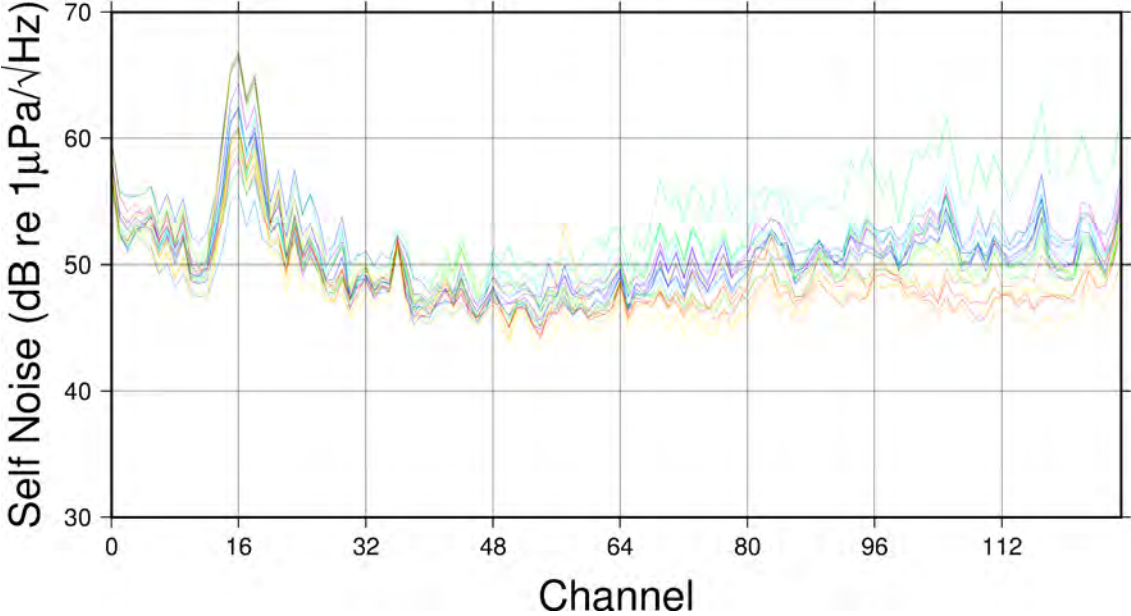
# RV Falkor EM302 Self Noise -- 10 kts



# RV Falkor EM302 Self Noise -- 11 kts



# RV Falkor EM302 Self Noise -- 12 kts

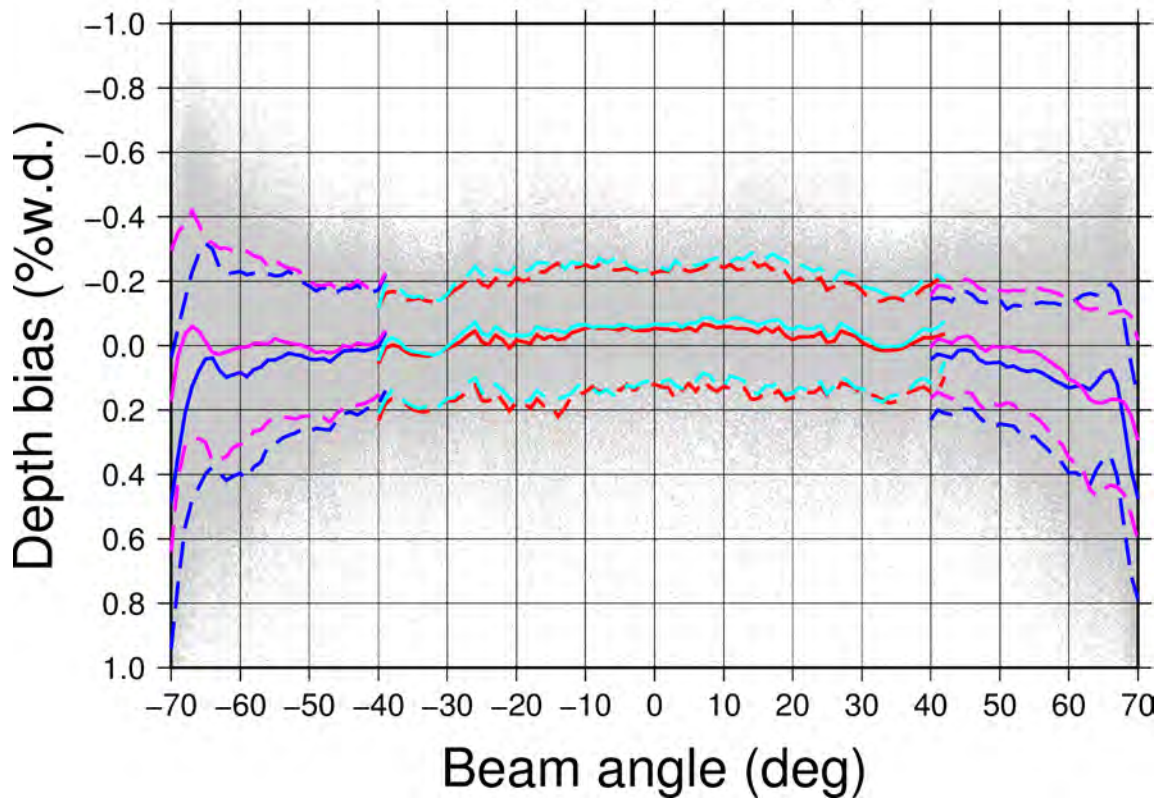
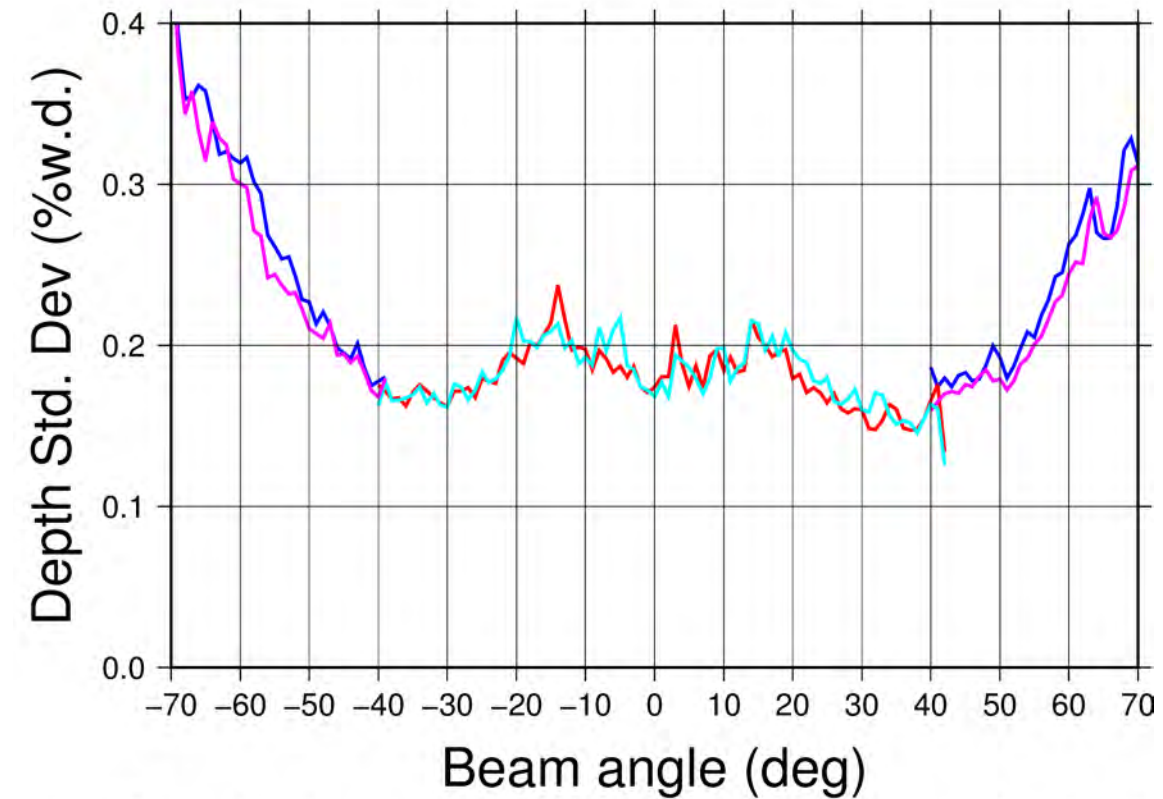


## Appendix C – EM710 Accuracy Testing

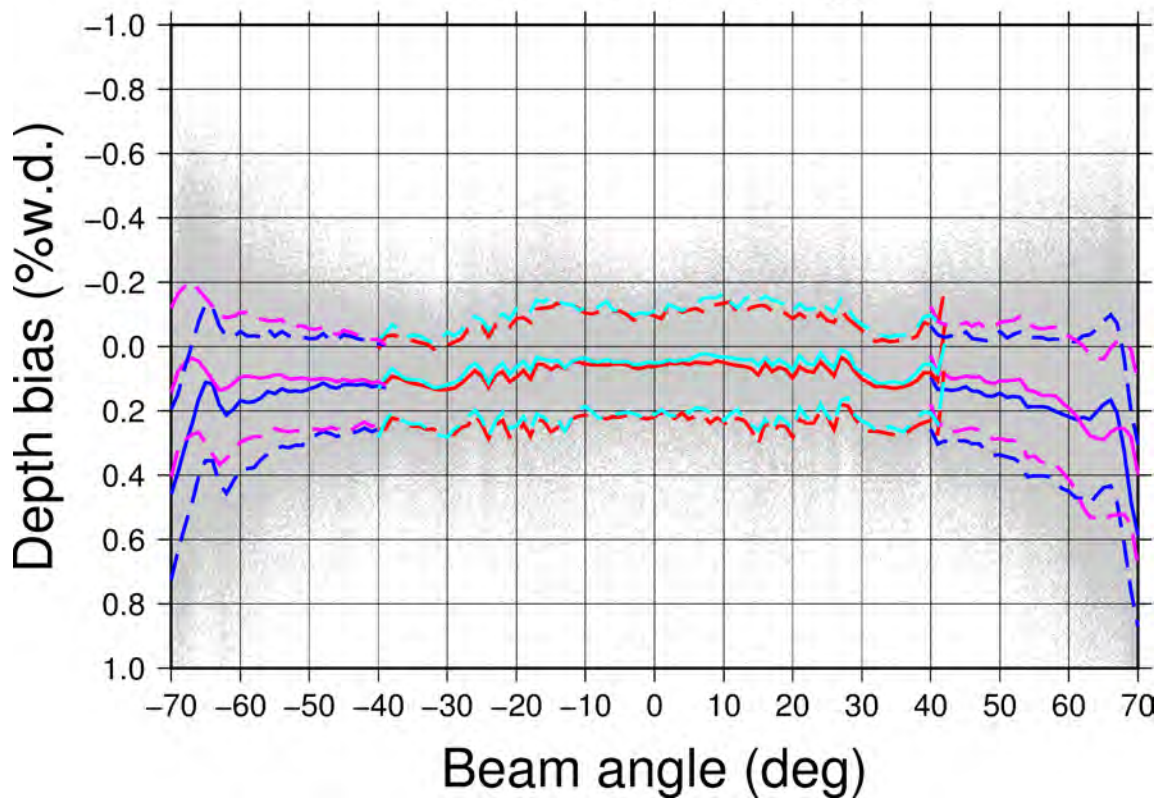
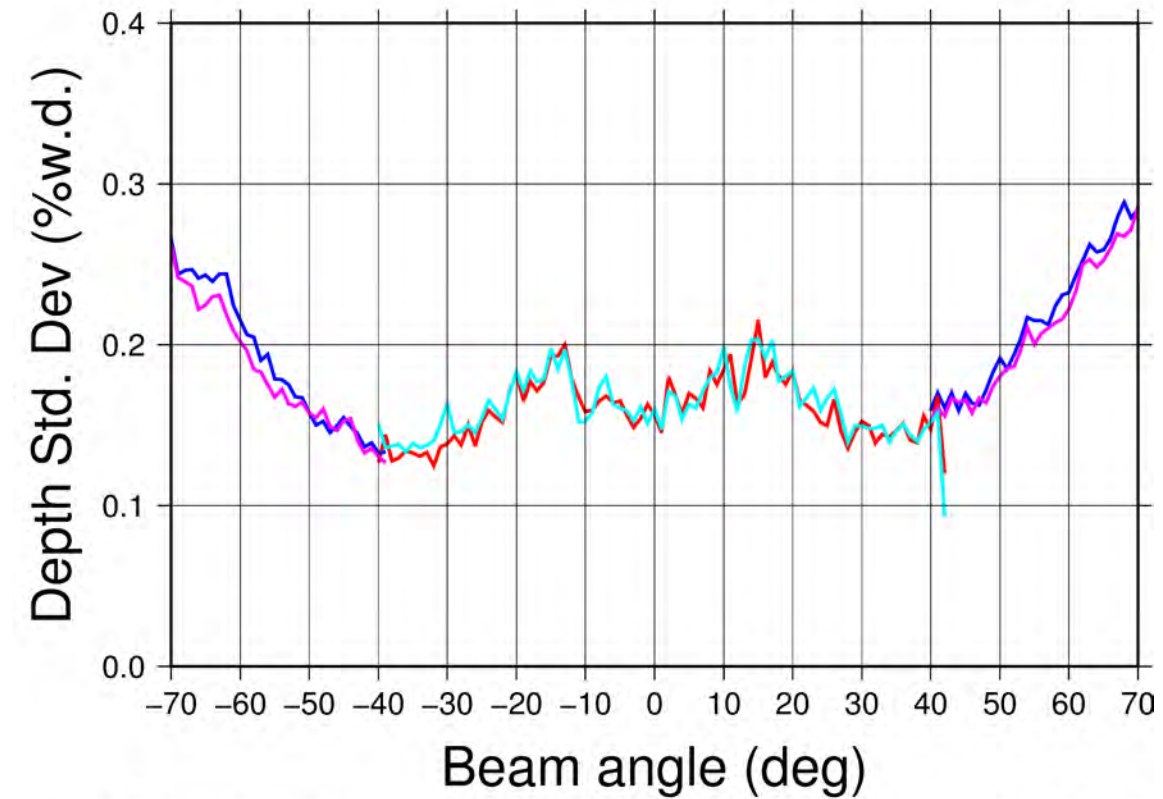
All figures in this section show a scatter plot of depth differences between cross line soundings and a reference surface in the lower half of the figure. The mean and standard deviation is computed in 1° bins across the swath with the mean plotted as a solid line and the standard deviation ( $1-\sigma$ ) plotted as dashed lines. Color-coding corresponds to the transmission sectors, alternating in red-blue or magenta-cyan across the swath. Red-blue indicates data from the first swath of the dual-swath geometry and magenta-cyan is for the second swath of the dual-swath geometry. The upper half of each plot shows the standard deviations (the dashed-lines in the lower plot).

The VERY SHALLOW mode investigation was initially done with the EM302 pinging simultaneously and bottom detection noise levels suffered due to this. A second pass was done with the EM302 secured and bottom detection noise levels for the EM710 dropped to normal levels. These two tests are referred to as VERY SHALLOW and VERY SHALLOW2 for the runs with and without EM302, respectively.

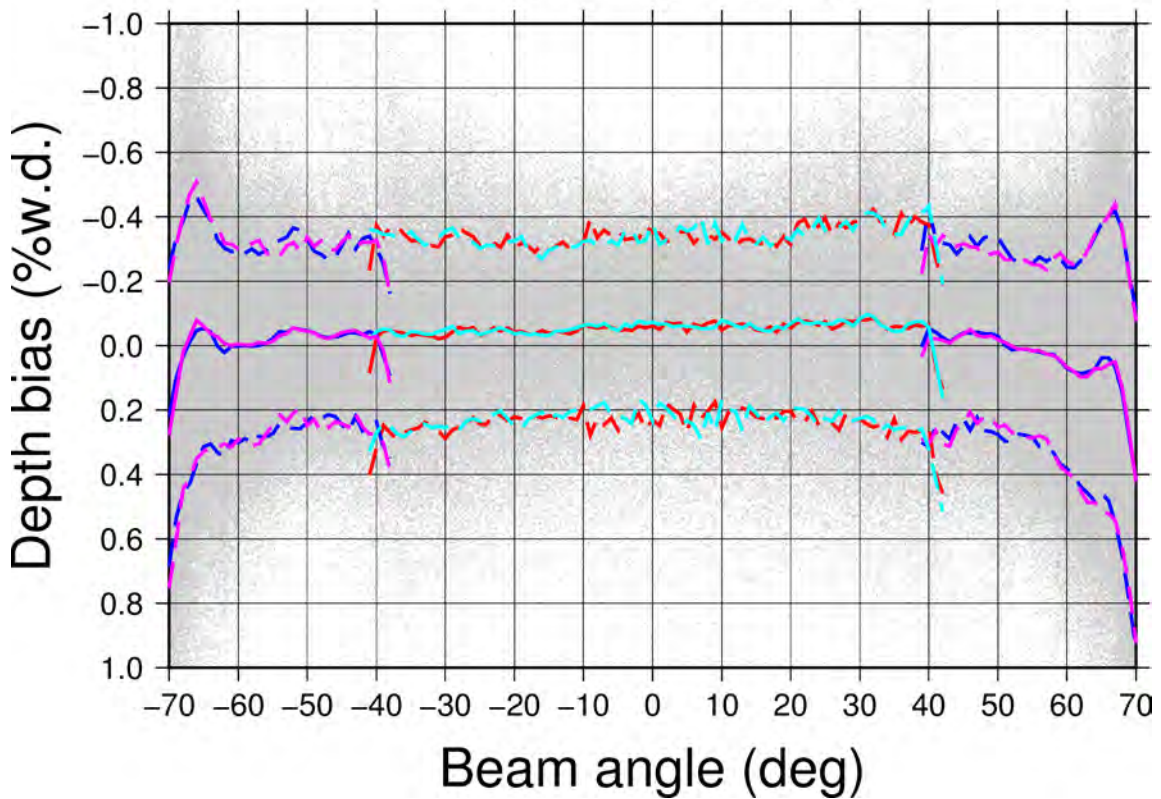
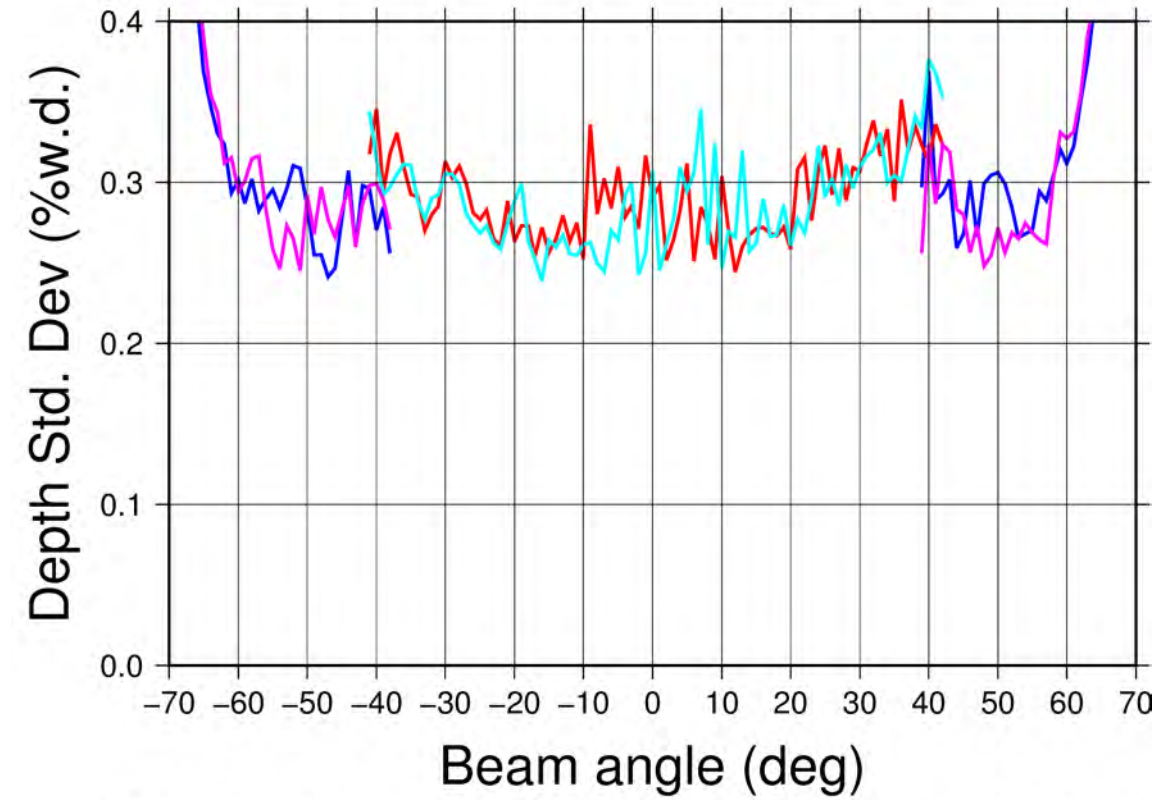
# EM710 VERY SHALLOW



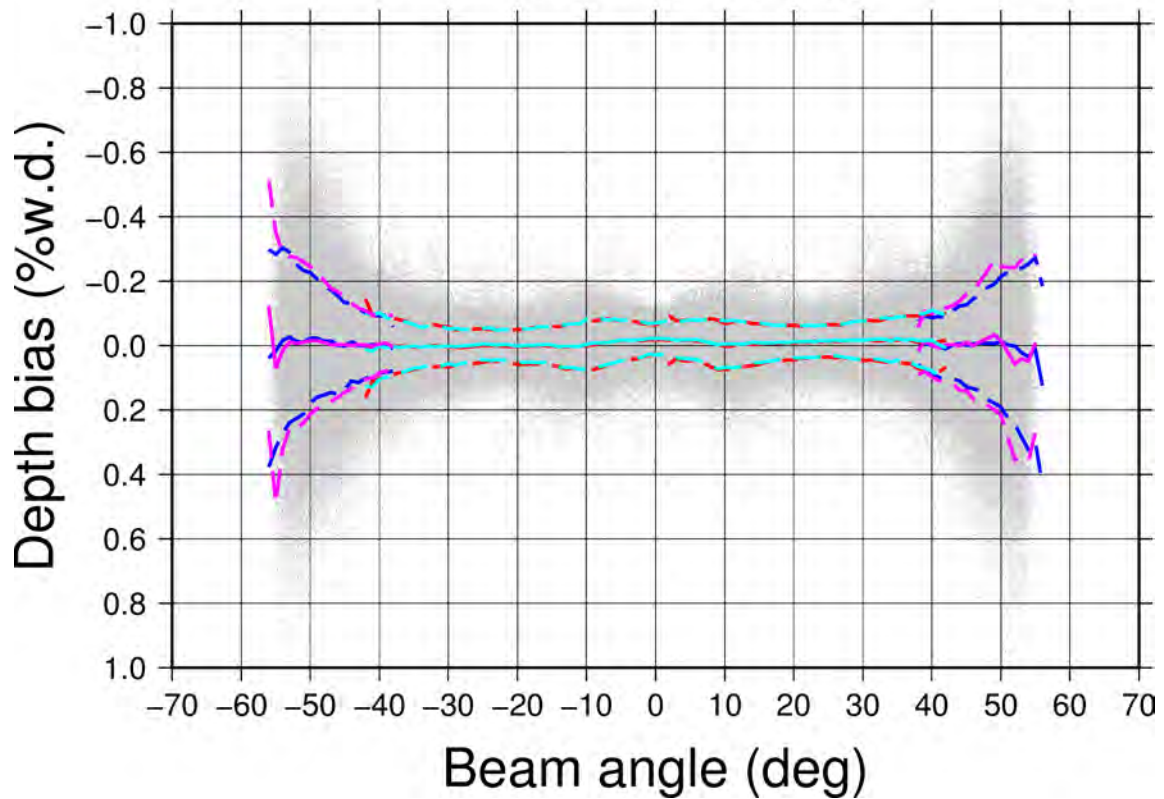
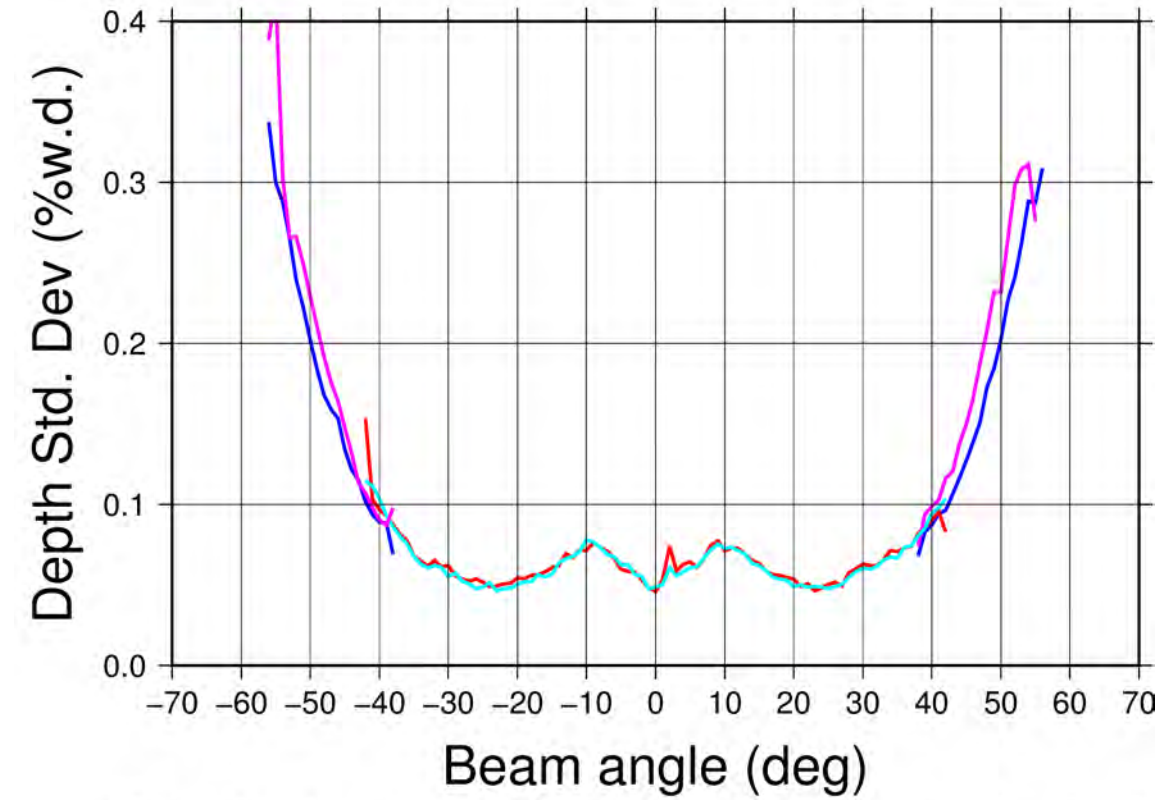
# EM710 VERY SHALLOW2



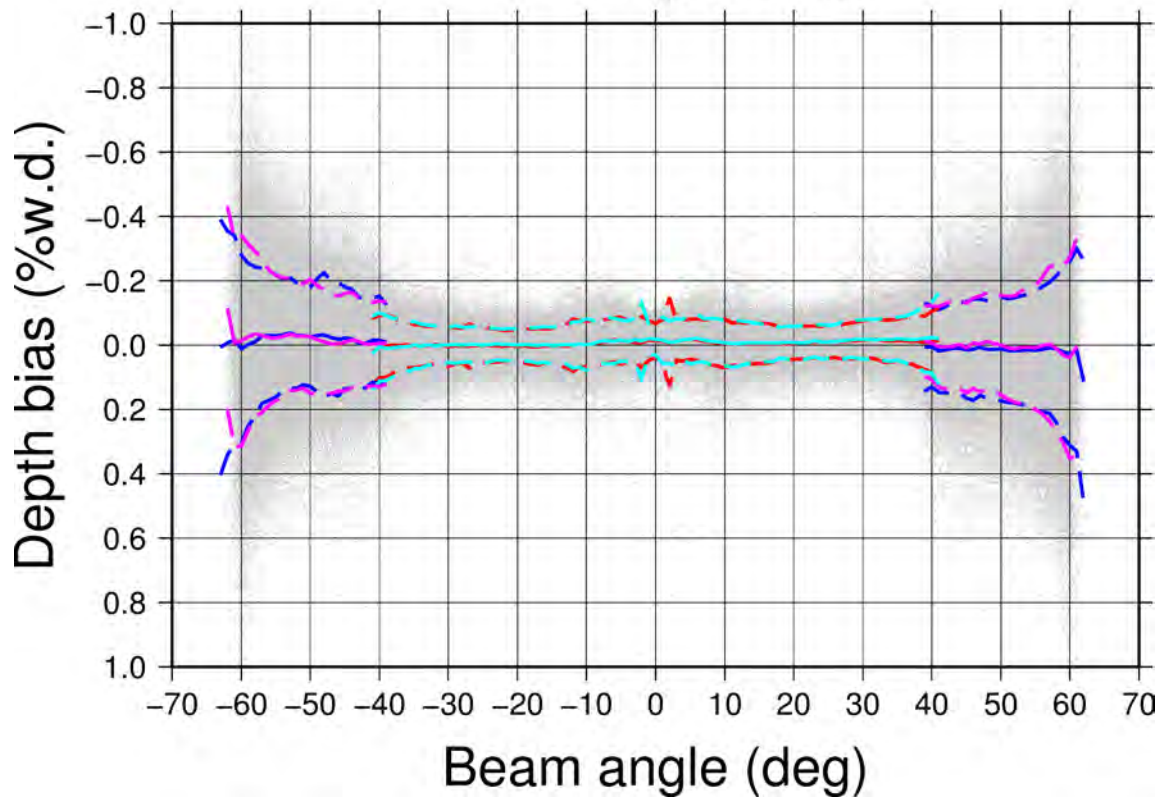
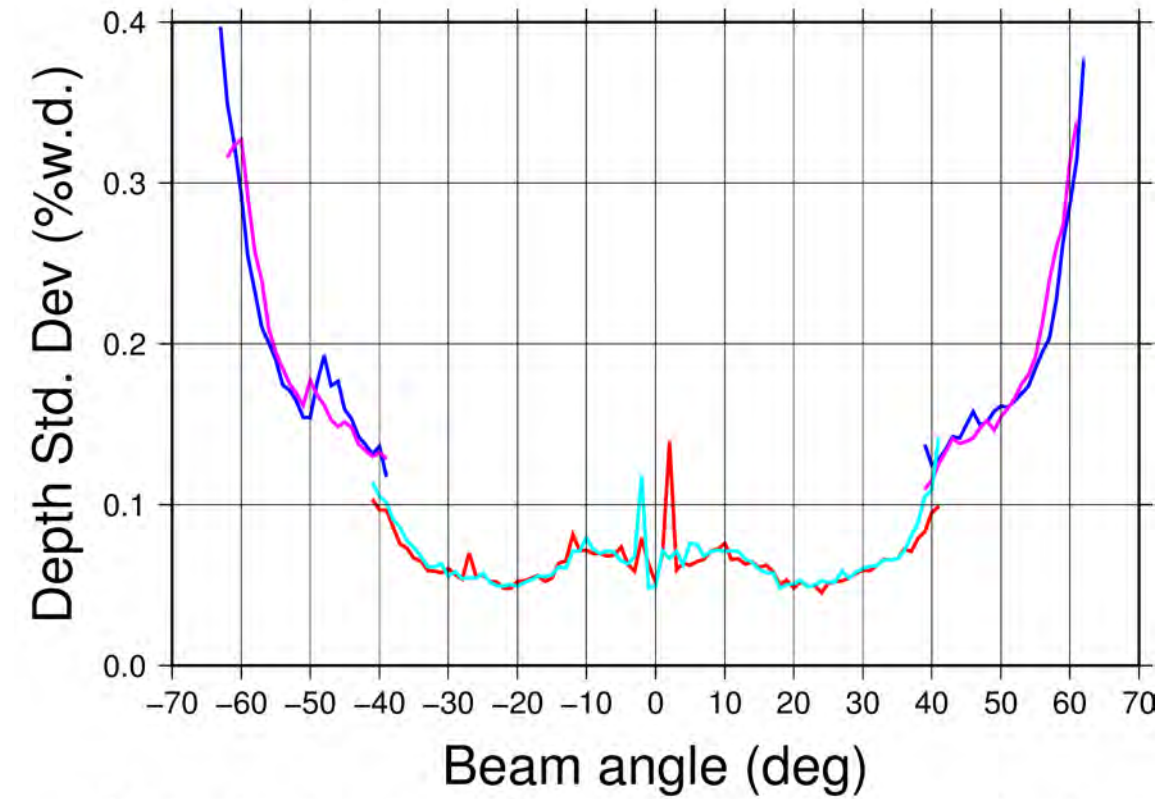
# EM710 SHALLOW



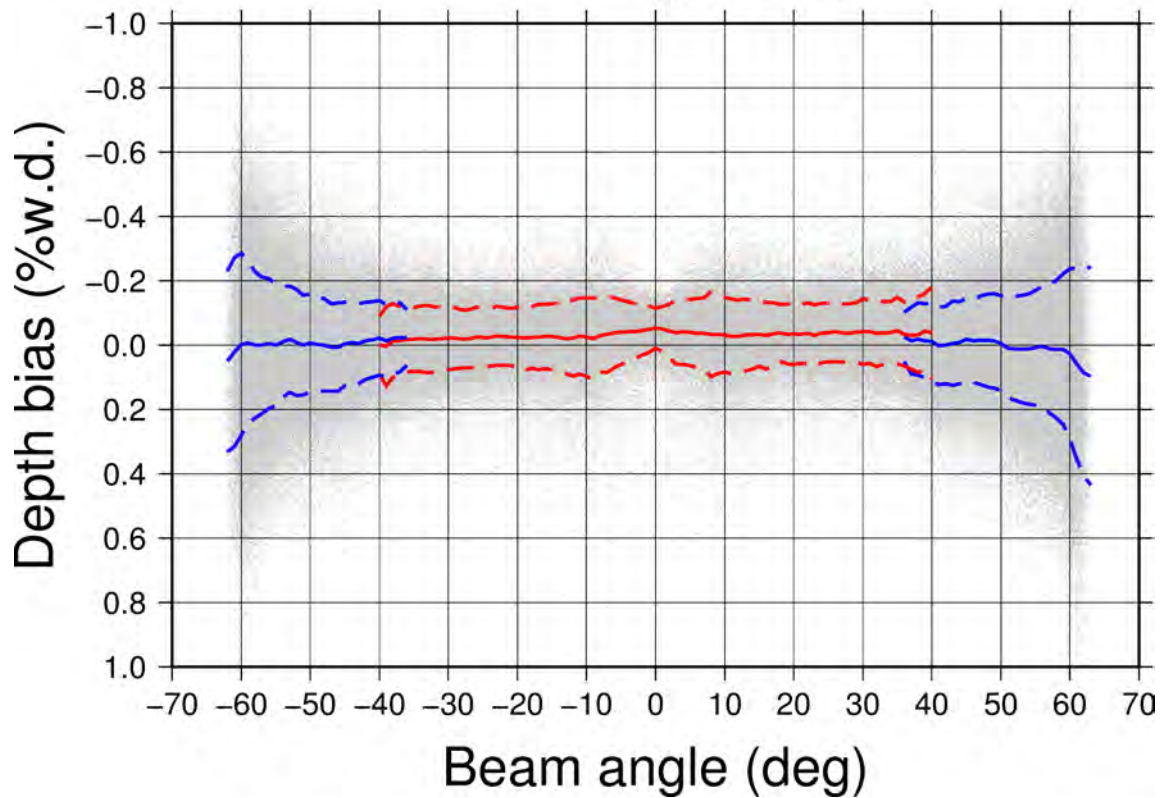
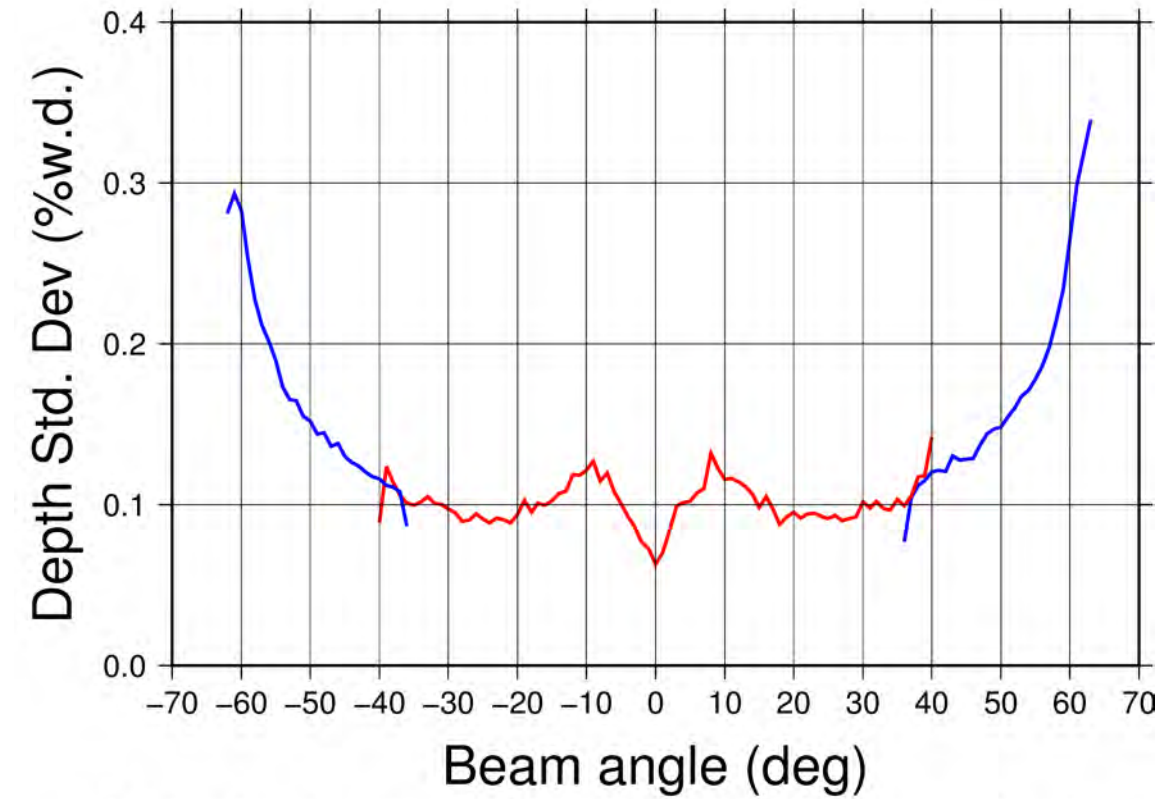
# EM710 DEEP CW DUAL



# EM710 DEEP FM DUAL



# EM710 VERY DEEP

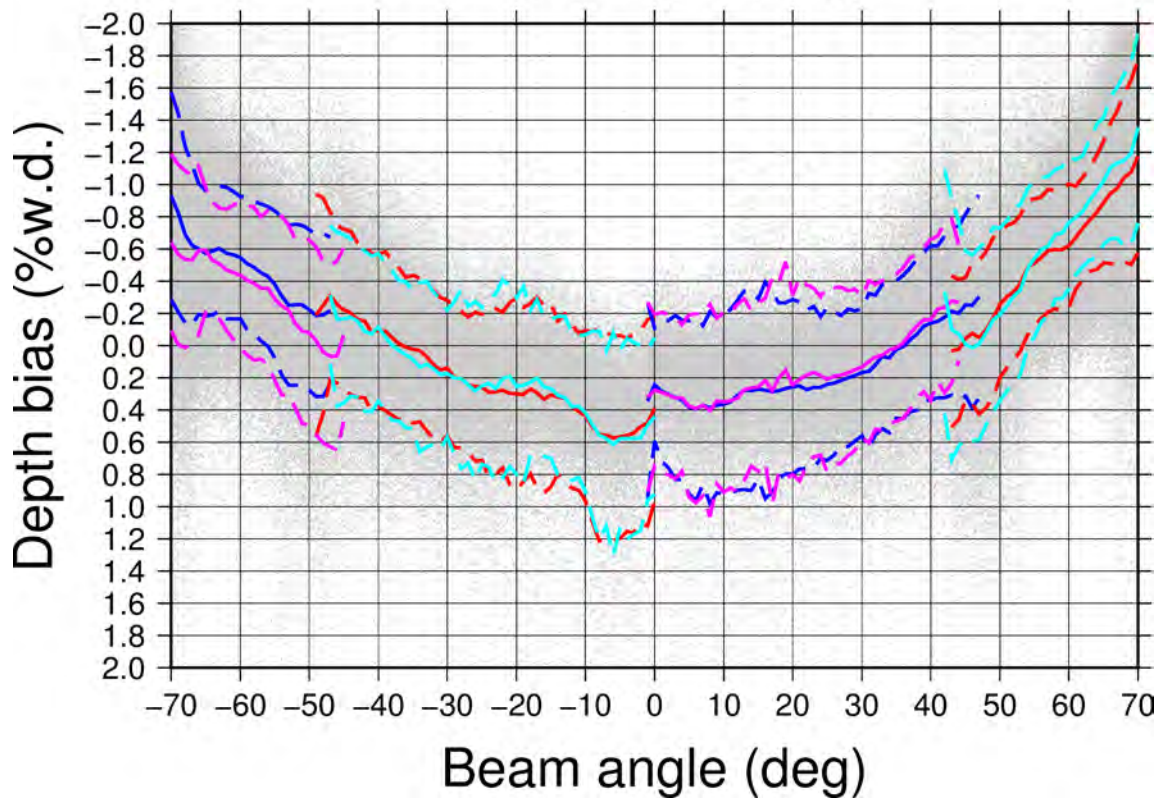
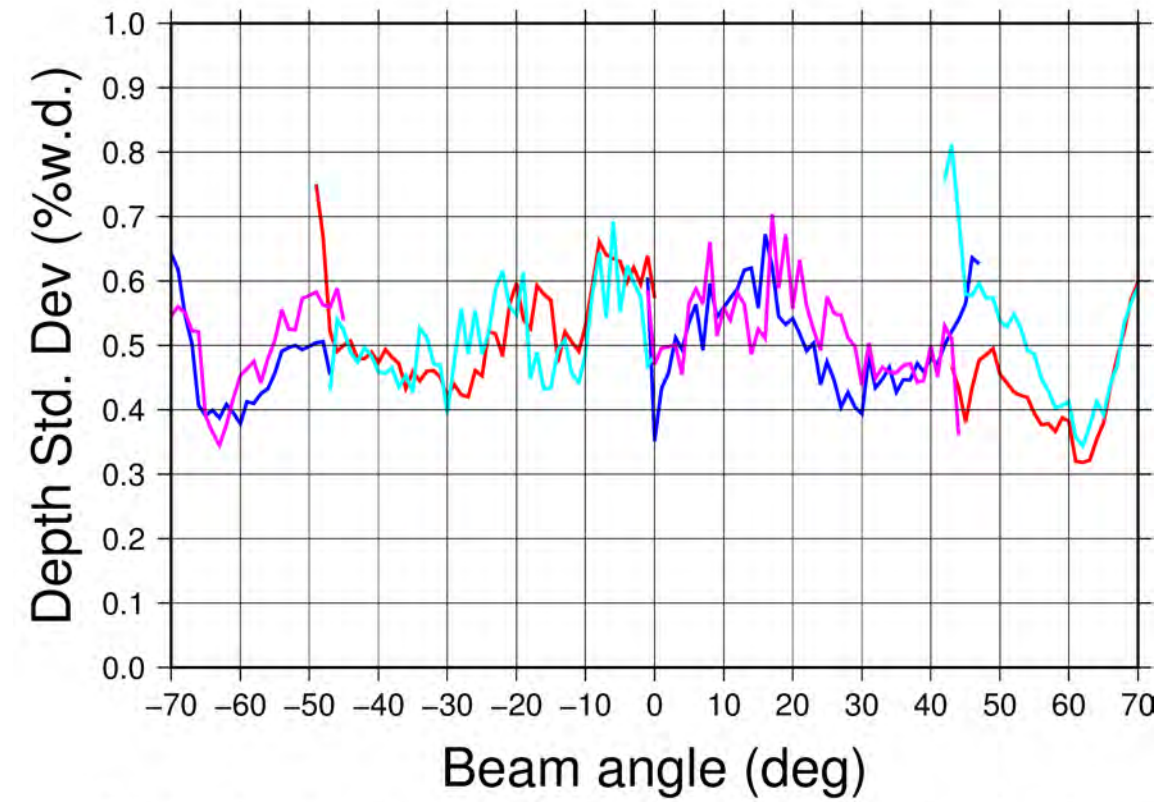


## Appendix D – EM302 Accuracy Testing

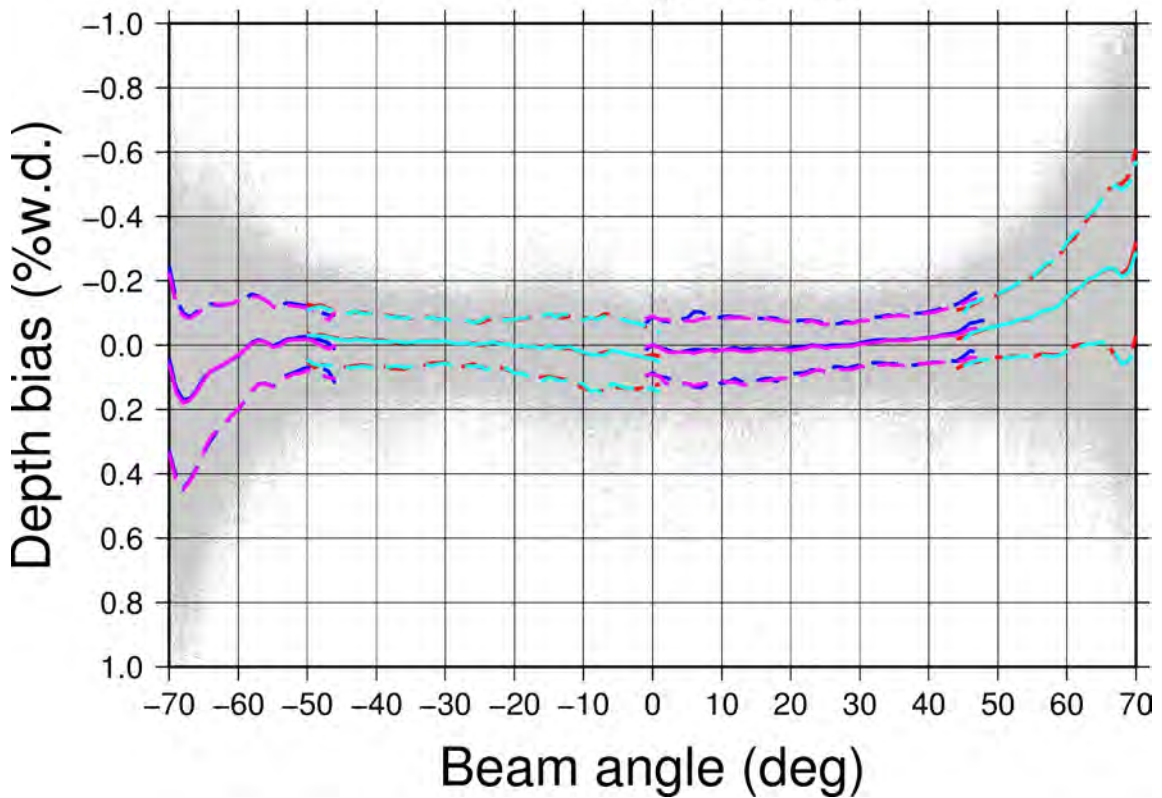
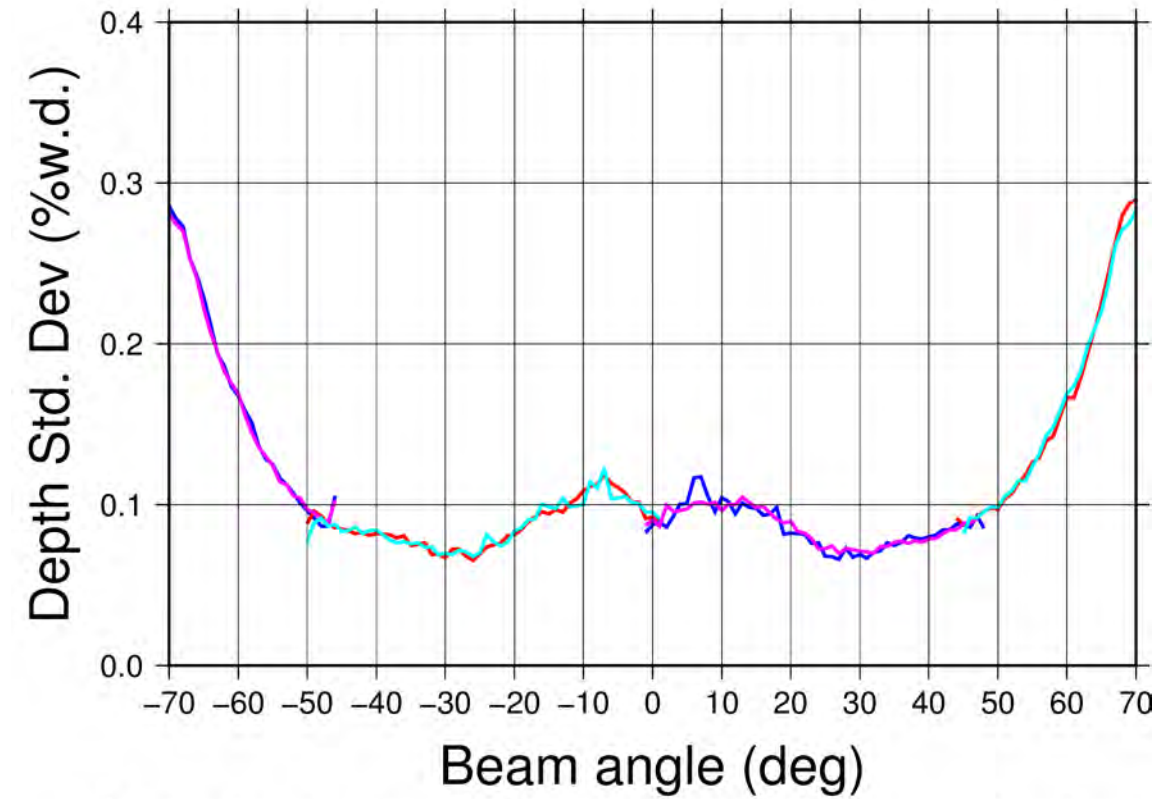
All figures in this section show a scatter plot of depth differences between cross line soundings and a reference surface in the lower half of the figure. The mean and standard deviation is computed in 1° bins across the swath with the mean plotted as a solid line and the standard deviation ( $1-\sigma$ ) plotted as dashed lines. Color-coding corresponds to the transmission sectors, alternating in red-blue or magenta-cyan across the swath. Red-blue indicates data from the first swath of the dual-swath geometry and magenta-cyan is for the second swath of the dual-swath geometry. The upper half of each plot shows the standard deviations (the dashed-lines in the lower plot).

The testing done in SHALLOW mode suffer from increased bottom detection noise due to interference with the EM710, which was running at the same time.

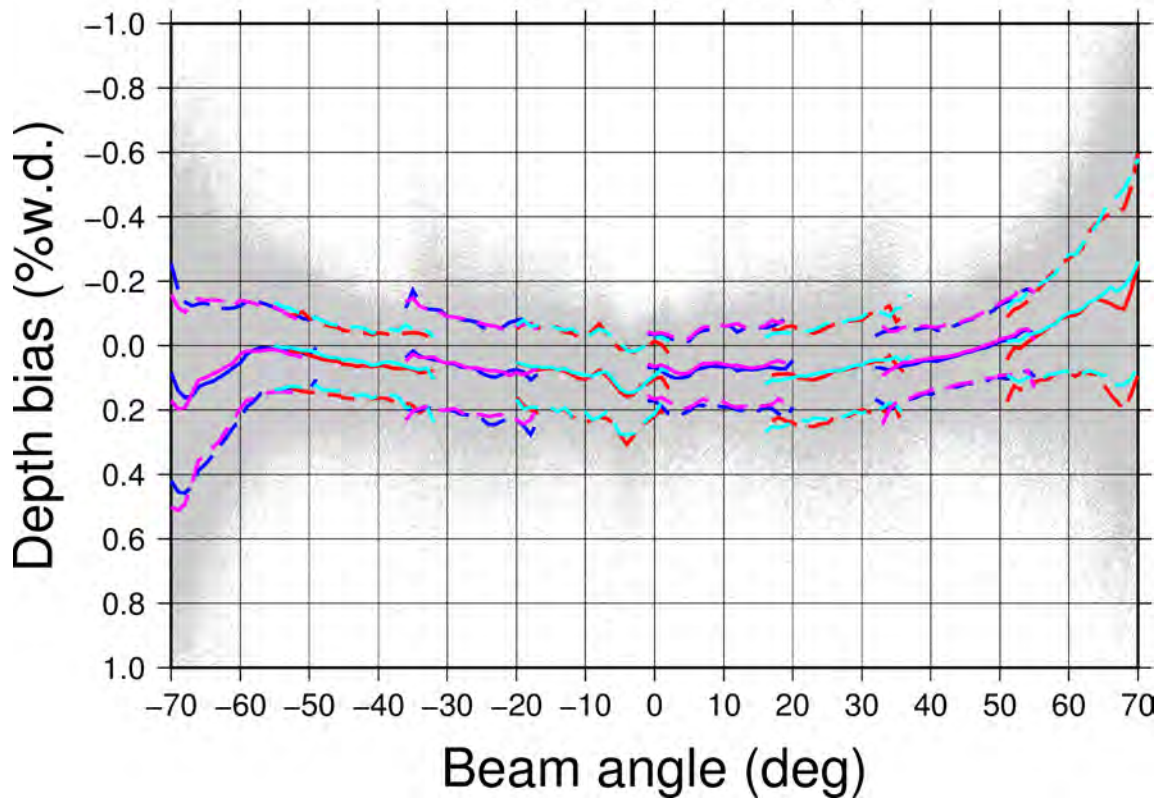
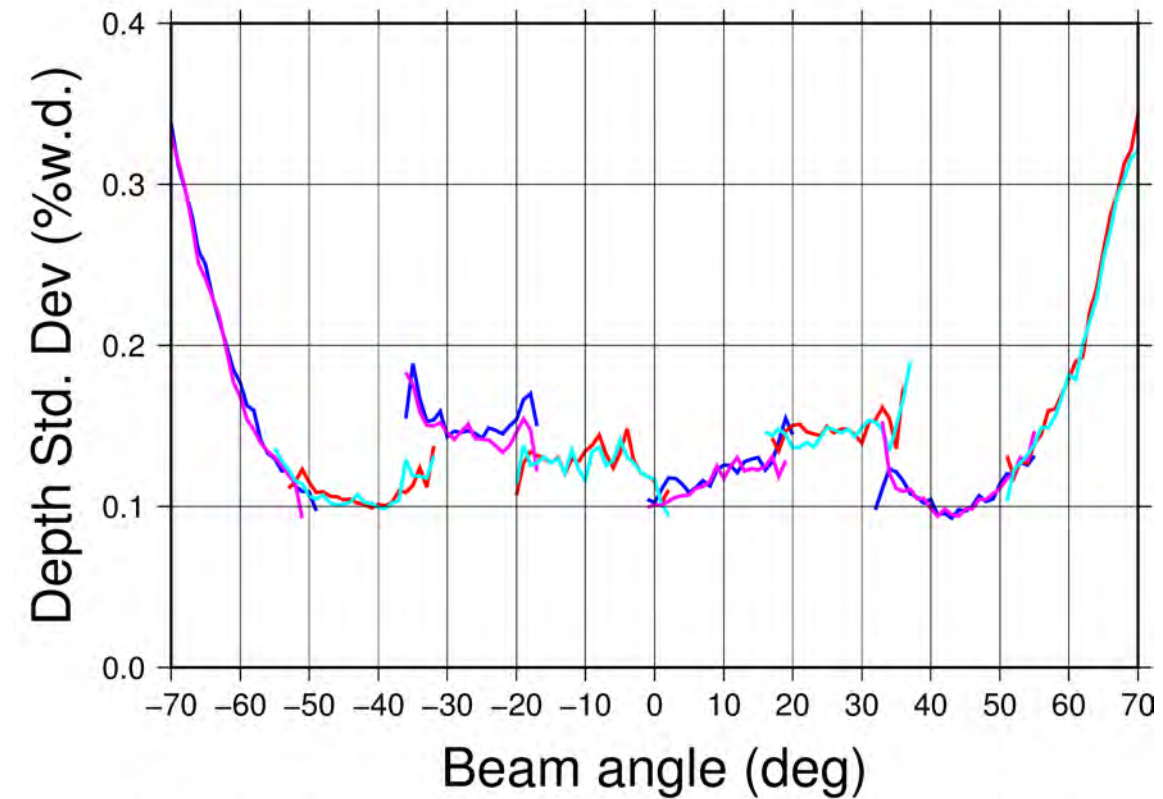
# EM302 SHALLOW



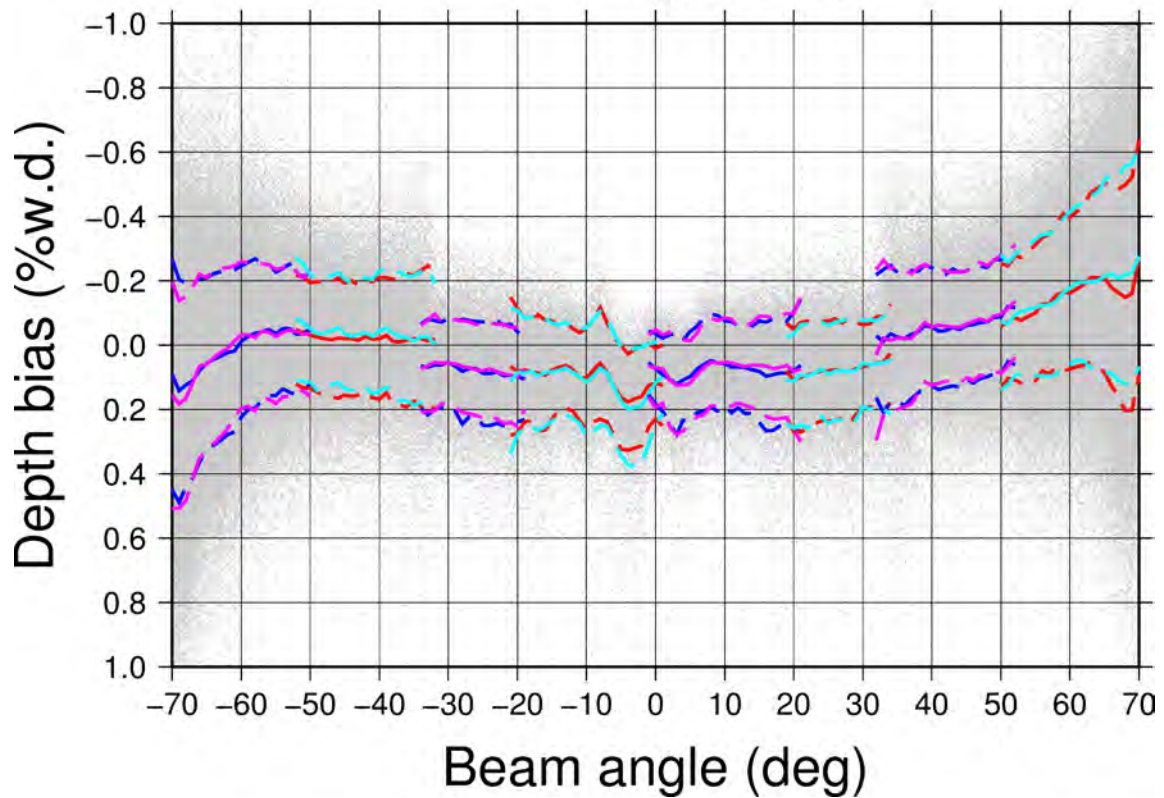
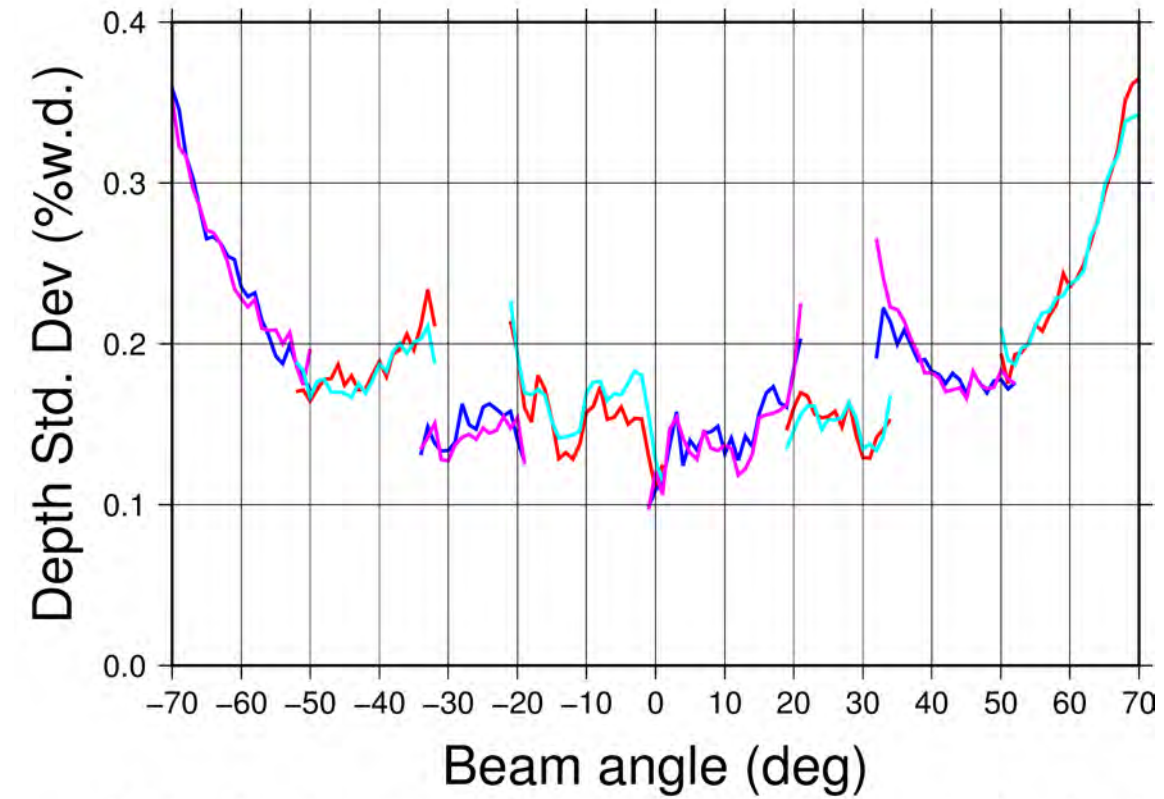
# EM302 MEDIUM



# EM302 DEEP CW DUAL



# EM302 DEEP FM DUAL



## Appendix E – Mammal Protection Mode Correspondence

NOSTP\_Hyd\_Support  
[km.hydrographic.support@kongsberg.com]

Actions

To:

Jonathan Beaudoin; Mark.Amend@km.kongsberg.com

Cc:

aaron.berry@km.kongsberg.com; Johnson, Paul [pjohnson@ccom.unh.edu]; ned.eliasen@km.kongsberg.com; NOSTP\_Hyd\_Support [km.hydrographic.support@kongsberg.com]

Friday, February 07, 2014 10:09 AM

Hi

How the mammal protection should work

If set before first ping it should use the value set. (ex 15 min)

When you have been pinging turn of pinging and on again, it will not do another 15min but use the time it has been turned off for the new ramp.

So if you have been pinging turned off for 5 min and then on again it will only ramp up for 5 min, if it has been off for 30 min it will use 15 min.

We have done some testing here and as far as we can see the EM302 is working as intended, while the EM710 is not. The initial ramp time is calculated wrong the first time.

So a workaround with the system as it is, is to ping once, turn off pinging for 15min (or the length of the ramp time you like to use) then start pinging again.

Optionally install latest sw available on web and on EM710 ftp the attached out file to the root catalogue of the TRU

With Regards

Torgrim Eldevik

Engineer Service

Main Switch Board:

Direct Office Phone: +4733023989

Global 24 Hours Service: +47 33 03 24 07

E-mail: km.hydrographic.support@kongsberg.com

[Kongsberg Maritime](#)

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If received in error, please delete it immediately from your system and notify the sender promptly.

----- Original Message -----

From: beaudoin@qps.nl

Received: 06/02/2014 01:10  
To: Mark.Amend@km.kongsberg.com  
Cc: aaron.berry@km.kongsberg.com; Johnson, Paul;  
ned.eliasen@km.kongsberg.com; NOSTP\_Hyd\_Support  
Subject: RE: EM710/EM302 mammal protection mode

Yes, avoiding the cold indeed we are!

We're seeing bizarre behaviour in both the EM710 and EM302. We've tried a few methods:

- 1) with system pinging, engage "soft start"
- 2) with pinging secured, engage "soft start" and engage pinging.
- 3) enable "soft start" and restart SIS and begin pinging
- 4) enable "soft start", restart TRU and SIS and begin pinging.

In all cases, the EM710 would report the "remaining ramp" time of 4 minutes instead of the 15 minutes we asked for. With the EM302, it would give us 15 minutes but then would occasionally jump to a lower number. The manual provides little instruction or detail.

We also have K-Sync running, both systems are sync'd to ping more or less simultaneously with the EM302 as master.

I believe Colleen Peters, one of the Marine Techs aboard, has been in touch with you prior to this about renewing their support contract.

jb

---

From: Mark Amend [Mark.Amend@km.kongsberg.com]  
Sent: Wednesday, February 05, 2014 6:38 PM  
To: Jonathan Beaudoin  
Cc: pjohnson@ccom.unh.edu; Aaron Berry; CRM KM Hydrographic Support; Ned Eliasen  
Subject: Re: EM710/EM302 mammal protection mode

Hi JB-

Avoiding the cold are ye? I see the AIS track darting around near Honolulu..

Cc-ing Aaron and KM Support, as they might be familiar with that mode and how it *should* work. Is this with both the 710 and 302? I looked at the main SIS release notes since then (3.9.2, 4.1.3) and don't see a mention of known issues with mammal protection.

I would think a SIS upgrade might be in order regardless, but our guys haven't kicked around 4.1.3 much yet. I think there are PU updates with that, too.

-Mark

Jonathan Beaudoin ---02/05/2014 01:34:27 PM---Hi Mark, I'm out on RV Falkor doing their yearly multibeam shakedown cruise with Paul. We've been a

From: Jonathan Beaudoin <beaudoin@qps.nl>  
To: Mark Amend [Mark.Amend@km.kongsberg.com] <Mark.Amend@km.kongsberg.com>,  
Cc: "pjohnson@ccom.unh.edu" <pjohnson@ccom.unh.edu>  
Date: 02/05/2014 01:34 PM  
Subject: EM710/EM302 mammal protection mode

---

Hi Mark,

I'm out on RV Falkor doing their yearly multibeam shakedown cruise with Paul. We've been asked to verify that mammal protection mode is working, we're running SIS 3.8.3 out here.

We can verify that dropping the source level -10 dB and -20 dB works for both systems (well, at least it reduces the coverage, our only tangible evidence that it works). Our problem is that "soft startup" seems to be working inconsistently. When we choose this option, and watch the start up countdown timer in the SIS Numerical Display, it seems to jump to a random startup time.

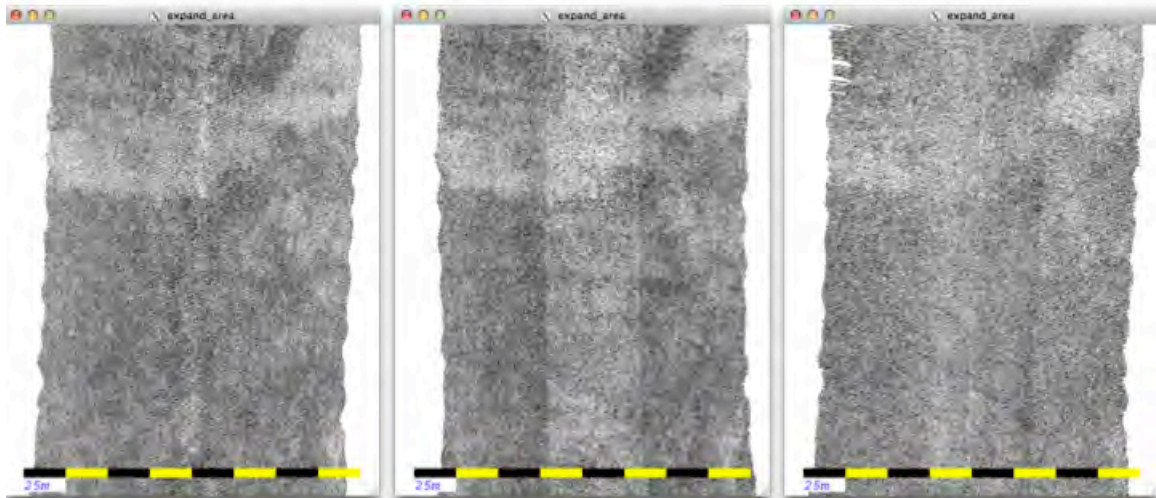
Our question is: are there any known issues with the soft startup option in SIS 3.8.3 that might have been rectified in a later release of SIS? Our clients need to be assured that they can use the soft start option (and that it works as expected) for upcoming, back-to-back 35 day mapping cruises, even if this means a SIS upgrade.

jb

## Appendix F – Bathymetry and Acoustic Imagery Quality

Sample data sets from the crosslines run for the accuracy analysis exercises are shown below in two formats: (1) sun-illuminated bathymetry, this highlights noise and systematic artifacts in the bathymetry, and (2) seafloor imagery data. The sensor and mode in each case are annotated in the imagery. The first set shows the three modes investigated for the EM710 and EM302 at the shallow accuracy test site (EM710 VERY SHALLOW, EM710 SHALLOW and EM302 SHALLOW). The second set of four images shows the modes investigated at the deep accuracy test site (EM710 DEEP CW, EM710 DEEP FM, EM710 VERY DEEP, EM302 DEEP CW, EM302 DEEP FM, EM302 MEDIUM).

**Shallow Accuracy Test Site (40 m water depth)  
Raw Seafloor Imagery**

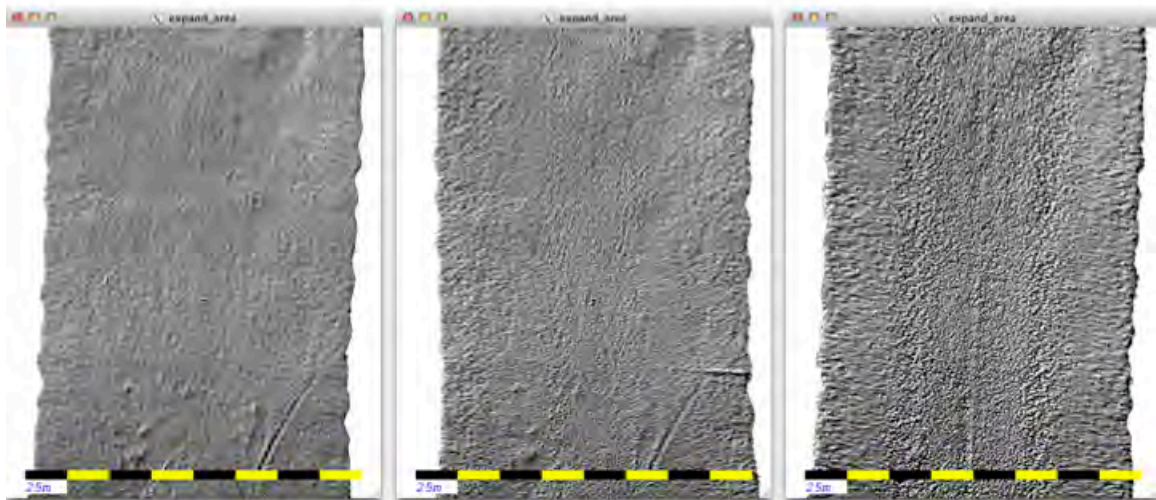


**EM710 VERY SHALLOW**  
Ideal depth range: 0-100 m  
Three sectors, 0.2 ms pulse lengths for all

**EM710 SHALLOW**  
Ideal depth range: 200-300 m  
Three sectors, 0.5 ms pulse lengths for all

**EM302 SHALLOW**  
Ideal depth range: 0-140 m  
Four sectors, 1.1 ms pulse lengths for all

**Shallow Accuracy Test Site (40 m water depth)  
Bathymetry with false sun-illumination**

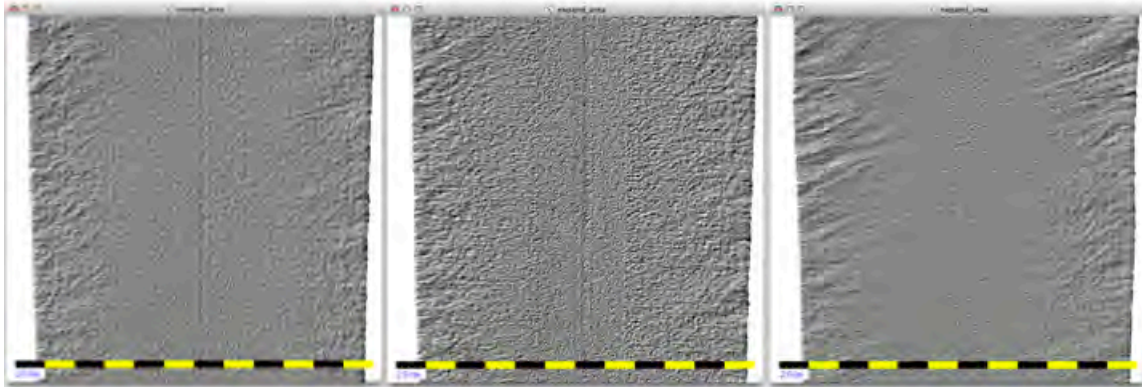


**EM710 VERY SHALLOW**  
Ideal depth range: 0-100 m  
Three sectors, 0.2 ms pulse lengths for all

**EM710 SHALLOW**  
Ideal depth range: 200-300 m  
Three sectors, 0.5 ms pulse lengths for all

**EM302 SHALLOW**  
Ideal depth range: 0-140 m  
Four sectors, 1.1 ms pulse lengths for all

**Deep Accuracy Test Site (550 m water depth)  
Bathymetry with false sun-illumination**

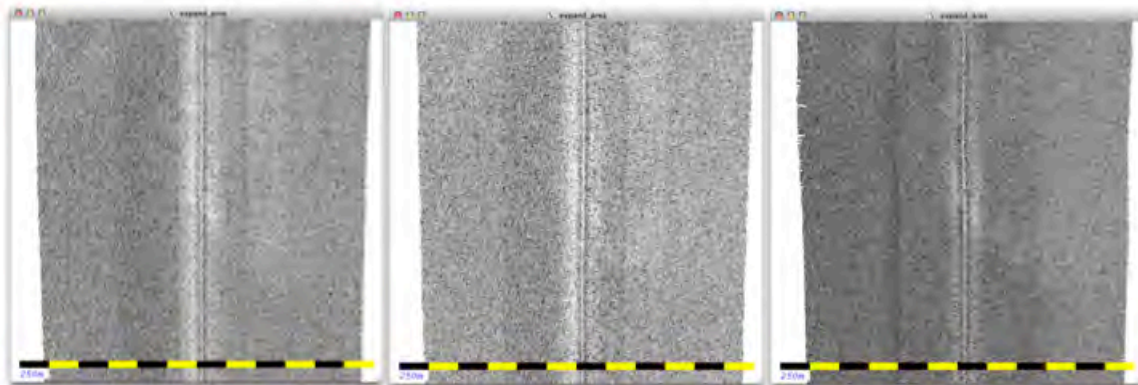


**EM302 DEEP (CW)**  
Ideal depth range: 750-3,300 m  
Eight sectors, 5 ms pulse lengths for all

**EM302 DEEP (FM)**  
Ideal depth range: 750-3,300 m  
Eight sectors, 5 ms pulse lengths for inner 4 CW, 30/50 ms pulse lengths for outer pairs

**EM302 MEDIUM**  
Ideal depth range: 140-750 m  
Four sectors, 2 ms pulse lengths for all

**Deep Accuracy Test Site (550 m water depth)  
Raw Seafloor Imagery**

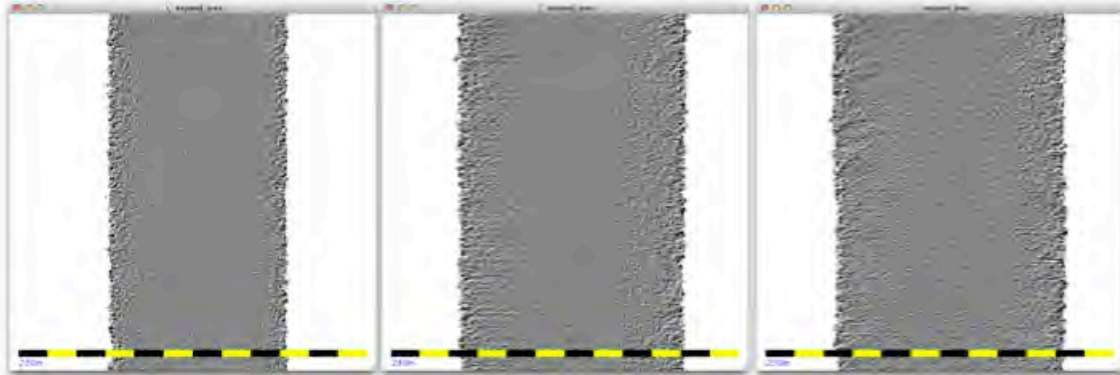


**EM302 DEEP (CW)**  
Ideal depth range: 750-3,300 m  
Eight sectors, 5 ms pulse lengths for all

**EM302 DEEP (FM)**  
Ideal depth range: 750-3,300 m  
Eight sectors, 5 ms pulse lengths for inner 4 CW, 30/50 ms pulse lengths for outer pairs

**EM302 MEDIUM**  
Ideal depth range: 140-750 m  
Four sectors, 2 ms pulse lengths for all

**Deep Accuracy Test Site (550 m water depth)  
Bathymetry with false sun-illumination**

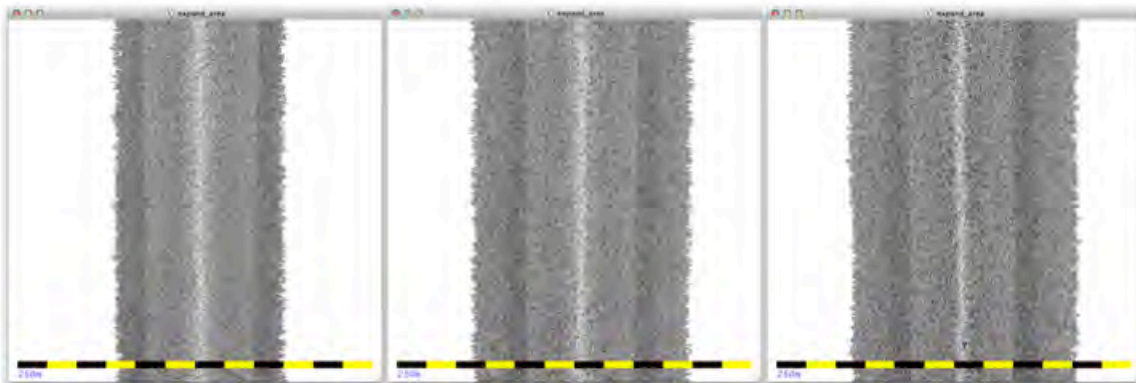


**EM710 DEEP (CW)**  
Ideal depth range: 300-500 m  
Three sectors, 2 ms pulse lengths for all

**EM710 DEEP (FM)**  
Ideal depth range: 300-500 m  
Three sectors, 20 ms pulse for outer sectors, 2 ms for central sector

**EM710 VERY DEEP**  
Ideal depth range: 500-1000 m  
Three sectors, 40 ms pulse for outer sectors, 20 ms for central sector

**Deep Accuracy Test Site (550 m water depth)  
Raw Seafloor Imagery**



**EM710 DEEP (CW)**  
Ideal depth range: 300-500 m  
Three sectors, 2 ms pulse lengths for all

**EM710 DEEP (FM)**  
Ideal depth range: 300-500 m  
Three sectors, 20 ms pulse for outer sectors, 2 ms for central sector

**EM710 VERY DEEP**  
Ideal depth range: 500-1000 m  
Three sectors, 40 ms pulse for outer sectors, 20 ms for central sector