Multibeam Advisory Committee

Looking back on seven years of multibeam echosounder system acceptance and quality assurance testing for the ships of the U.S. Academic Fleet

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FEMME | 2018

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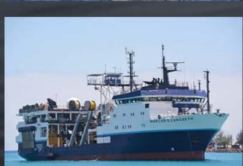
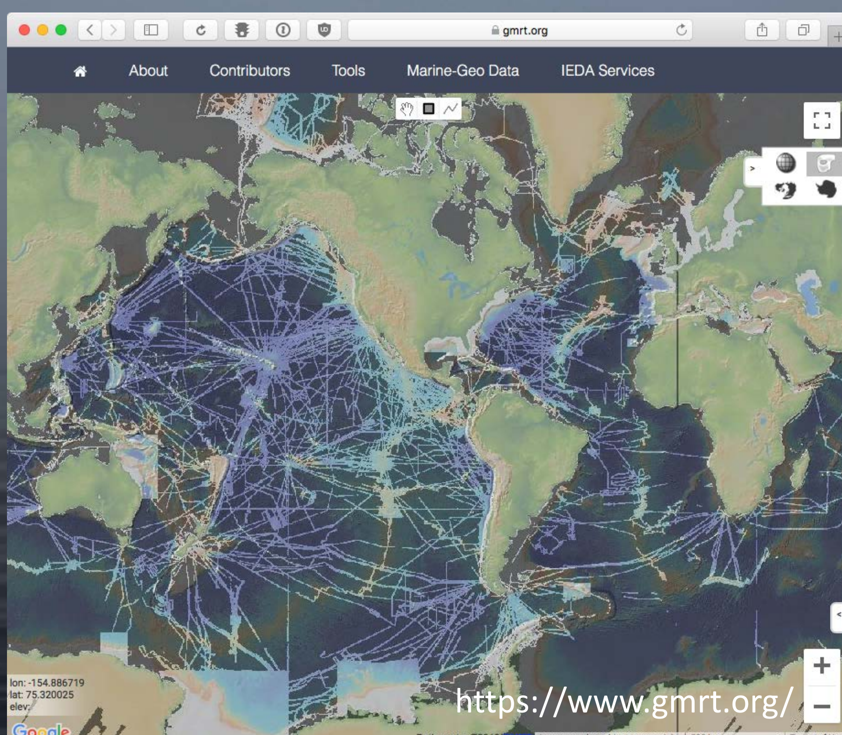
Center for Coastal and Ocean Mapping
Joint Hydrographic Center

Lamont-Doherty Earth Observatory
Columbia University | Earth Institute

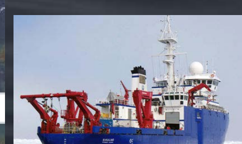
Why ?











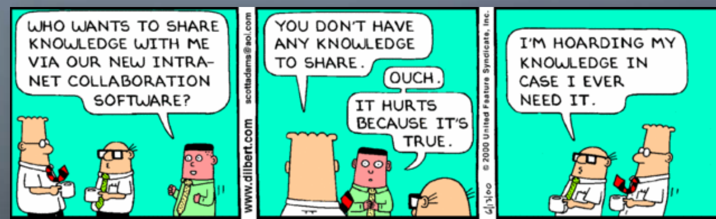
https://www.gmrt.org/

Motivation for the MAC

The MAC is funded to improve multibeam data quality by:

- *Standardizing the tools and approach for system assessment*
- *Documenting and reporting system performance metrics*
- *Provide on-board and remote support*
- *Sharing best practices among ships*

https://mac.unols.org



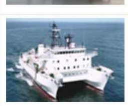
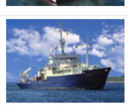
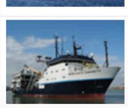
The U.S. Academic Fleet

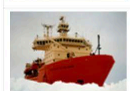
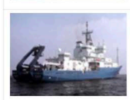
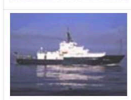
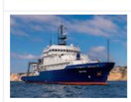
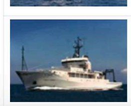
The MAC supports multibeam data quality improvement across NSF-supported vessels:

11 active RVs

1 USCG icebreaker

Total of 14 Kongsberg EM systems (15 after R/V *Roger Revelle* in 2019)

	Atlantis (WHOI)	Kongsberg EM122 (12 kHz, 150°, 1x1° beams)
	Blue Heron (UMN)	Reson SeaBat 8101 (240 kHz, 150°)
	Healy (USCG)	Kongsberg EM122 (12 kHz, 150°)
	Hugh R. Sharp (UDEL)	Reson SeaBat 8101 (240 kHz, 150 °) Reson SeaBat 7101 (240 kHz, 150 °)
	Kilo Moana (UH)	Kongsberg EM122 (12 kHz, 150°) Kongsberg EM710
	Knorr *(retired)* (WHOI)	SeaBeam 2112 (12 kHz, 120°)
	Marcus G. Langseth (LDEO)	Kongsberg EM122 (12 kHz, 150° swath, 1x1° beams)

	Melville *(retired)* (SIO)	Kongsberg EM122 (12 kHz, 150°)
	Nathaniel B. Palmer (USAP)	Kongsberg EM120 (12 kHz, 150°)
	Neil Armstrong (WHOI)	Kongsberg EM122 (12 kHz, 150°, 1x1° beams)
	Roger Revelle (SIO)	Kongsberg EM122 (12 kHz, 150°)
	Sikuliaq (UAF)	Kongsberg EM710 (70 kHz, 140°) Kongsberg EM302 (30 kHz, 140°)
	Sally Ride (SIO)	Kongsberg EM122 (12 kHz) Kongsberg EM712 (40 to 100 kHz)
	Thomas G. Thompson (UW)	Kongsberg EM302 (30 kHz, 150°)

Additional Partners

Additional partners for developing tools and comparing data:

- *NOAA hydrographic and science vessels*
- *Non-UNOLS oceanographic institutes*
- *Private ocean exploration vessels*

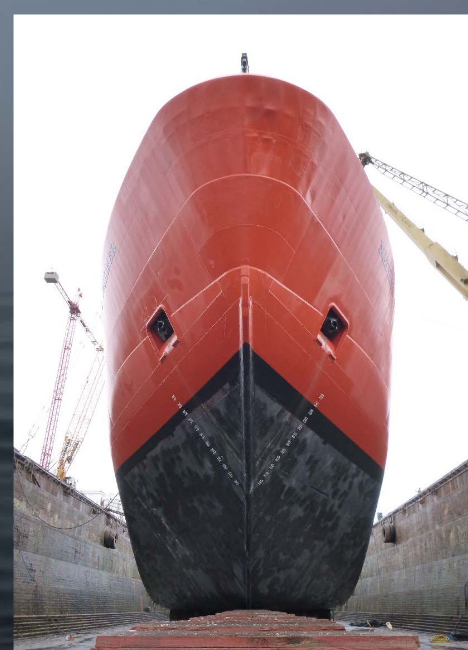
MAC Approaches

The MAC is involved throughout the multibeam life cycle:

Sea Acceptance Testing (SAT)
establishing baseline performance of new installations (11)

Quality Assurance Testing (QAT)
assessing performance of existing installations, especially before/after shipyard periods (20)

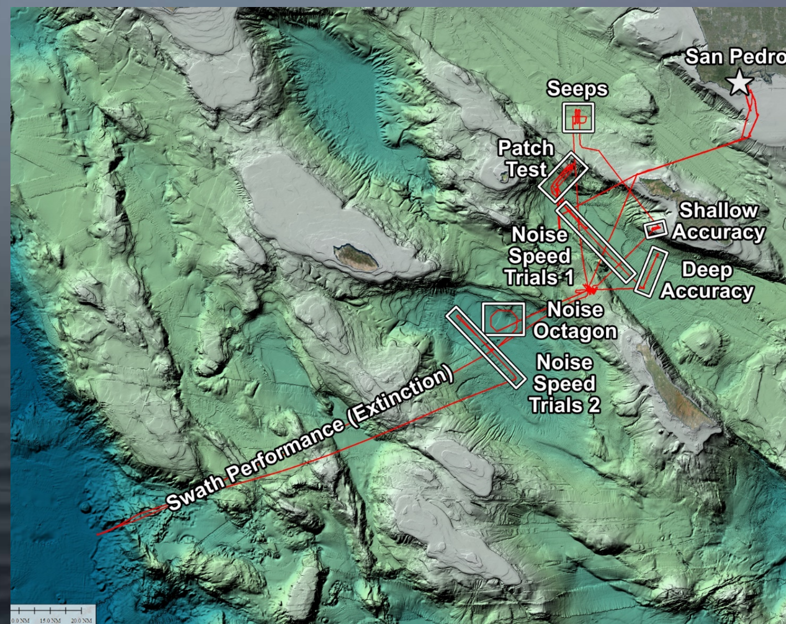
Acoustic Noise Testing (ANT)
characterizing vessel noise and troubleshooting acoustic interference (MAC & Gates Acoustics) (9)



MAC Approaches

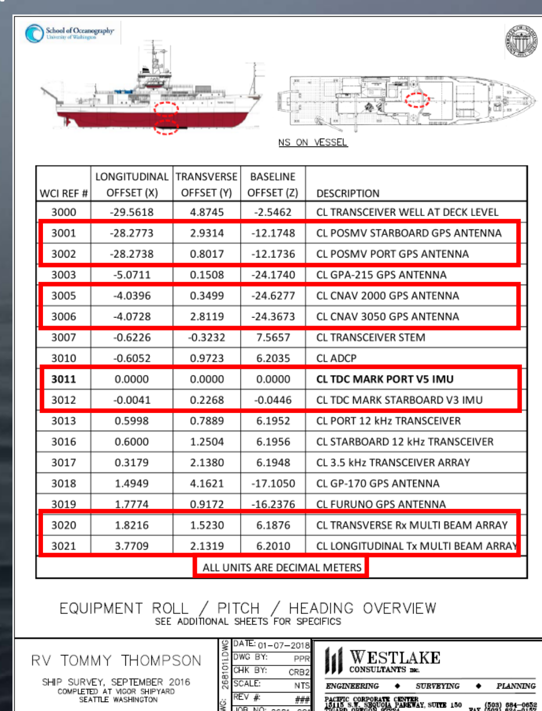
SAT and QAT procedures include:

1. Geometry review
2. Configuration review
3. Calibration (patch test)
4. Swath accuracy
5. Swath coverage (extinction)
6. RX noise testing
7. Impedance testing
8. Documentation and back-up



1. Geometry Review: MAC Approach

- The vessel survey is the foundation for correct sensor integration and high data quality
- MAC reviews survey report and advises operator on translation / interpretation for:
  1. mapping system origin
  2. motion sensor and antenna offsets
  3. transducer array offsets
  4. waterline



NS ON VESSEL

WCI REF #	LONGITUDINAL OFFSET (X)	TRANSVERSE OFFSET (Y)	BASELINE OFFSET (Z)	DESCRIPTION
3000	-29.5618	4.8745	-2.5462	CL TRANSCEIVER WELL AT DECK LEVEL
3001	-28.2773	2.9314	-12.1748	CL POSMV STARBOARD GPS ANTENNA
3002	-28.2738	0.8017	-12.1736	CL POSMV PORT GPS ANTENNA
3003	-5.0711	0.1508	-24.1740	CL GPA-215 GPS ANTENNA
3005	-4.0396	0.3499	-24.6277	CL CNAV 2000 GPS ANTENNA
3006	-4.0728	2.8119	-24.3673	CL CNAV 3050 GPS ANTENNA
3007	-0.6226	-0.3232	7.5657	CL TRANSCEIVER STEM
3010	-0.6052	0.9723	6.2035	CL ADCP
3011	0.0000	0.0000	0.0000	**CL TDC MARK PORT V5 IMU**
3012	-0.0041	0.2268	-0.0446	CL TDC MARK STARBOARD V3 IMU
3013	0.5998	0.7889	6.1952	CL PORT 12 kHz TRANSCEIVER
3016	0.6000	1.2504	6.1956	CL STARBOARD 12 kHz TRANSCEIVER
3017	0.3179	2.1380	6.1948	CL 3.5 kHz TRANSCEIVER ARRAY
3018	1.4949	4.1621	-17.1050	CL GP-170 GPS ANTENNA
3019	1.7774	0.9172	-16.2376	CL FURUNO GPS ANTENNA
3020	1.8216	1.5230	6.1876	CL TRANSVERSE Rx MULTI BEAM ARRAY
3021	3.7709	2.1319	6.2010	CL LONGITUDINAL Tx MULTI BEAM ARRAY

ALL UNITS ARE DECIMAL METERS

EQUIPMENT ROLL / PITCH / HEADING OVERVIEW
SEE ADDITIONAL SHEETS FOR SPECIFICS

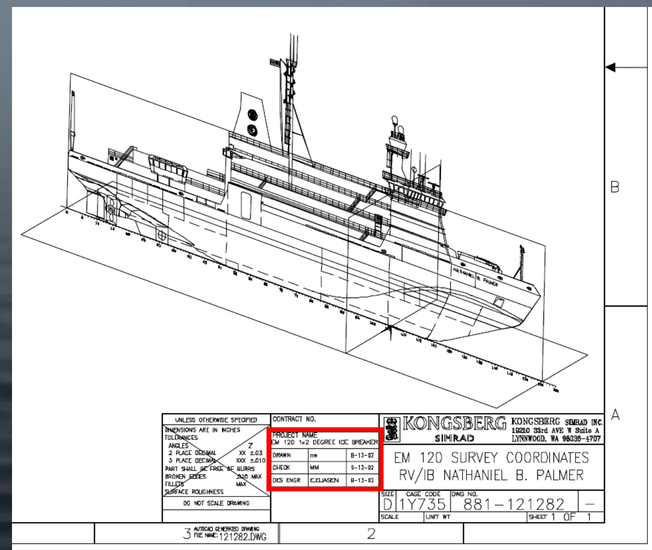
RV TOMMY THOMPSON
SHIP SURVEY, SEPTEMBER 2016
COMPLETED AT VIGOR SHIPYARD
SEATTLE WASHINGTON

DATE: 01-07-2018
DWG BY: PPR
CHK BY: CRB2
SCALE: NTS

WESTLAKE CONSULTANTS INC.
ENGINEERING ◆ SURVEYING ◆ PLANNING

1. Geometry Review: Lessons from the Fleet

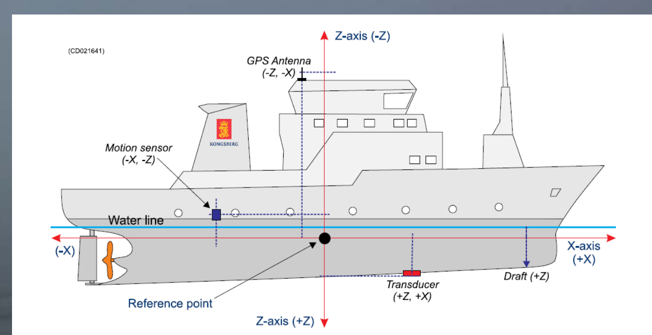
- Survey reports are referenced for decades by operators, shipyards, and other surveyors
- Wide range of vessel survey report quality
- The cost of a high-quality survey is trivial compared to the costs of:
  1. lost sea days
  2. incorrect calibration results
  3. poor data quality
  4. difficulty reestablishing the vessel frame

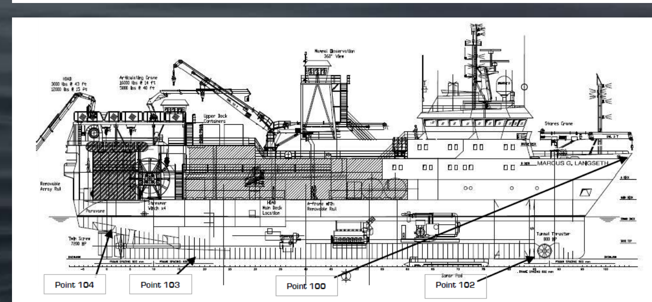


Original survey (2002) used in survey for upgrade (2015)

1. Geometry Review: Lessons from the Fleet

- Survey results are typically correct, but often reported in unclear or inconsistent formats
- May need to 'sanity check' the survey
- Operators must demand clarity in reporting:
  1. Origin of survey
  2. Axes, units, and sign conventions (KM)
  3. Images of all survey points
  4. Internal review before publishing
  5. Delivery with time for client review





Westlake survey of MGL

2. Configuration Review: MAC Approach

- Advise operator on unified mapping sensor reference frame; this is typically aligned with vessel frame, but not always coincident
- Ensure multiple reviewers independently agree on offsets for each sensor in unified frame
- Clarify with surveyor and/or manufacturer (e.g., antenna phase center height)
- Talk to the ship techs about what has changed!

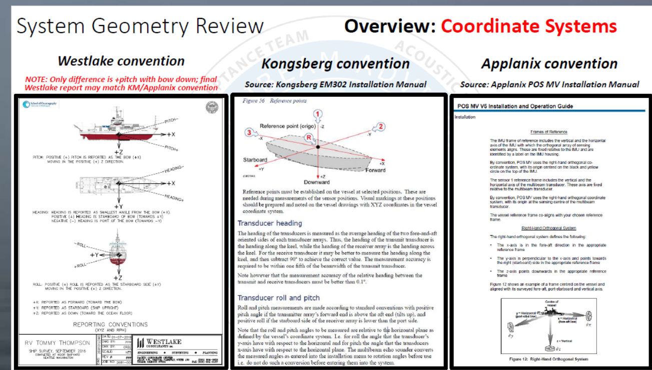


Table 3. Antenna and MRU offsets recorded in the Seapath configuration after system geometry review during HE17TA. Pre-HE17TA values are shown in parentheses, if changed during review and calibration. Seapath GNSS antennas are installed at the locations listed in the survey reports as 'IMU Choke Ring' in 2010 and 'POS MV' in 2014. The Master Reference Plate (MRP) is the origin of the vessel, SIS, Seapath, and POS MV reference frames. Position and attitude data fed to SIS are valid at the origin. NOTE: the Seapath is considered the 'primary' motion system (Seapath data are received by the EM122 on COM3, typically used for the 'secondary' system, due to the order of installation of these systems). It is noted also that MRU installation angle modifications on the order of 0.001° are likely due to rounding differences in converting from DMS format, and do not appreciably affect the data.

Seapath Origin at MRP	X	Y	Z	Roll	Pitch	Yaw
	BOW +	STBD +	DOWN +	PORT UP +	BOW UP +	COMPASS +
GNSS Ant. 1 (Port)	-52.557	-2.209	-22.100			
GNSS Ant. 2 (Stbd)	-52.576	2.291 (2.288)	-22.107 (-22.113)			
MRU	-2.047	-0.296	-0.603	-179.739 (-179.742)	-0.146 (-0.151)	1.206

2. Configuration Review: Lessons from the Fleet

- A physical marker for the origin (e.g., granite block or MRU target) is technically unnecessary but extremely valuable for discussions of reference frames and offsets
- Incorrect settings sneak in and persist for years, even on carefully monitored installations
- As operators and scientists come and go, clear documentation of the most recent correct configuration is critical

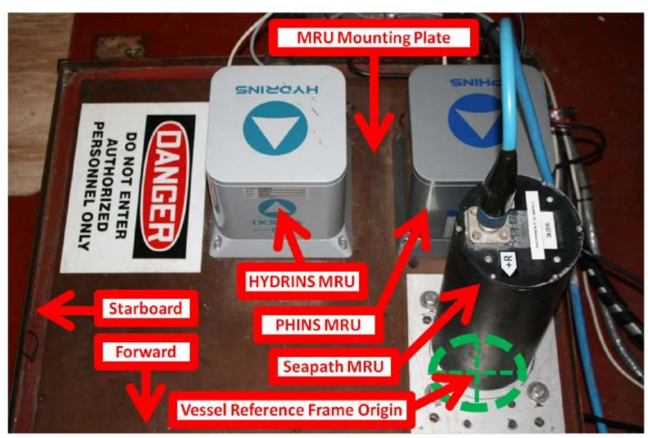
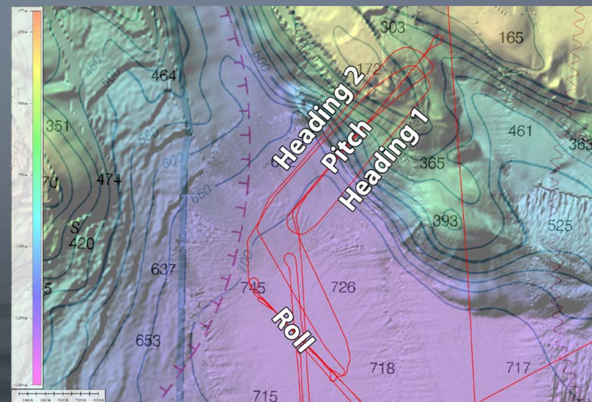


Figure 9. MRU mounting plate (viewed looking astern).

3. Calibration: MAC Approach

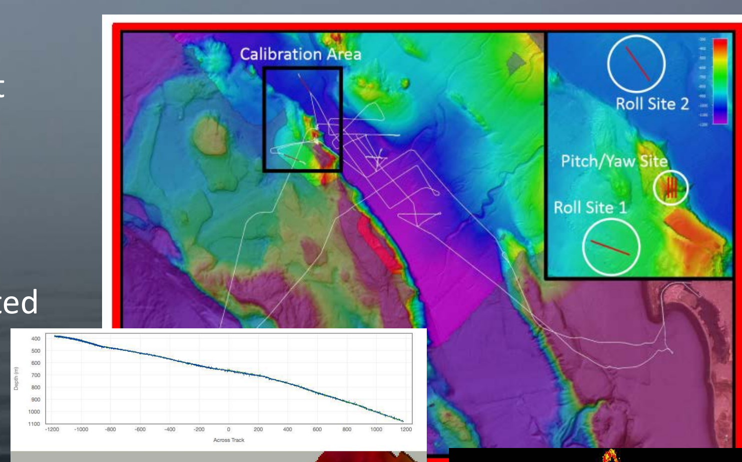
- Provide calibration lines, runtime parameters, and time estimates
- On-board or **remote** support for data acquisition, analysis, and final configuration
- Residual pitch, roll, and heading are attributed to the motion sensor and applied in SIS

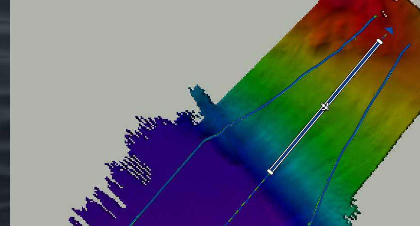


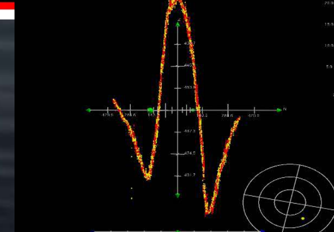
Line Acquistion Information																			
Test	Pre-test settings	Transit to Cal	Pitch Verification Pass 1	Turn	Pitch Verification Pass 2	Transit A to C	XBT	Roll Verification Pass 1	Turn D to D	Roll Verification Pass 2	Transit C to H	XBT	Yaw Verification Pass 1	Transit G to F	Yaw Verification Pass 1	Transit G to A	Est. Transit to Cal Hours	Est. Cal. Hrs	Est. Verif. Hrs
XBT Prior to Line			No		No			Yes		No			No		No				
SIS Line Name			55	56	57			60		62			65		69				
Start Point (see figure)			**A**		**B**			**C**		**D**			**H**		**F**				
End Point (see figure)			**B**		**A**			**D**		**C**			**G**		**E**				
Speed (kts)		10	6	6	6	10		6	6	6	10		6	10	6	10			
Distance (nm)		200	4.3		4.3	6		3.8		3.8	6.5		4.3	4.6	4.3	3.5			
Course Over Ground			210		30			225		45			210		210				
Time (est. minutes)		1200	43	15	43	36	15	38	15	38	39	15	43	28	43	21	20	7.2	7.2
Pre-test MRU Angle (SIS, AS-RUN)			0.00					0.00					0.00						
EM302 Result - 1st Pass			-0.18					0.01					-0.05						
EM302 Result - Verification			-0.02					0					0.05						
EM302 Results - Final			-0.2					0.01					0						

3. Calibration: Lessons from the Fleet

- Planning windows for calibrations vary widely (usually months, sometimes just minutes)
- Overcoming ‘it is just for science’
- Calibrations can be planned and executed opportunistically
- Have more than one person evaluate the data.

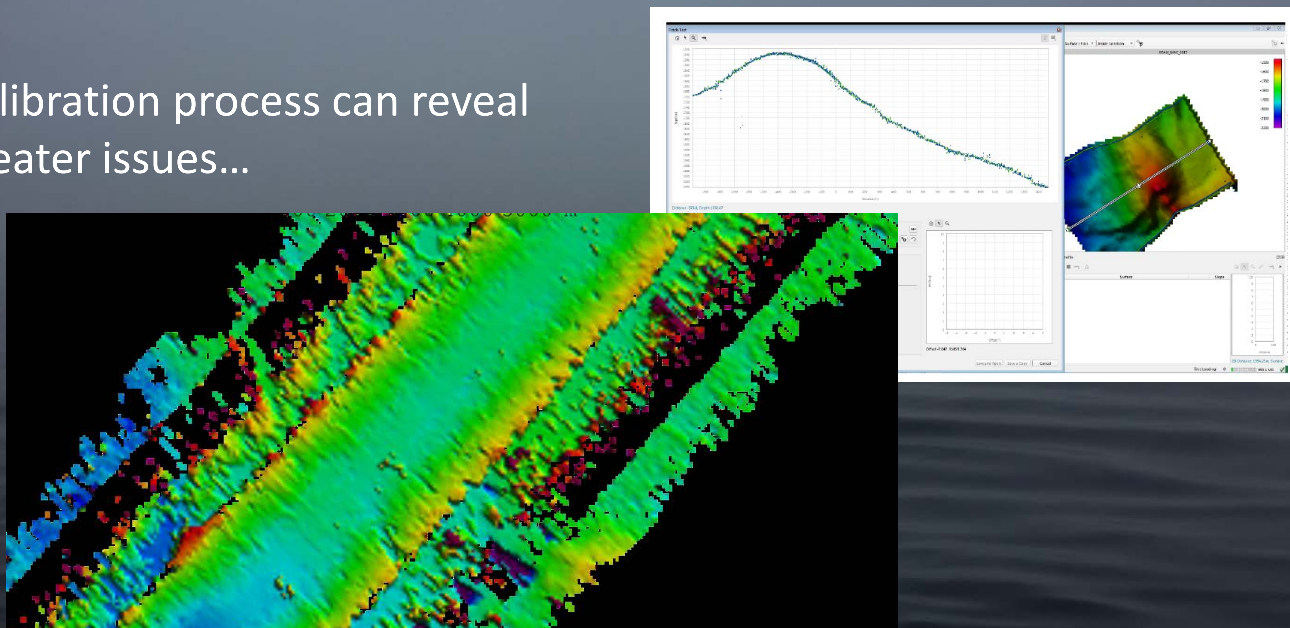






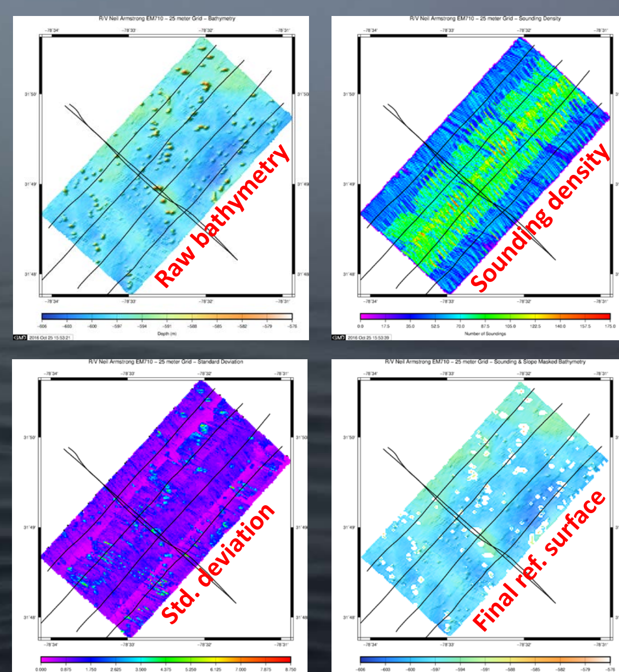
3. Calibration: Lessons from the Fleet

- Calibration process can reveal greater issues…



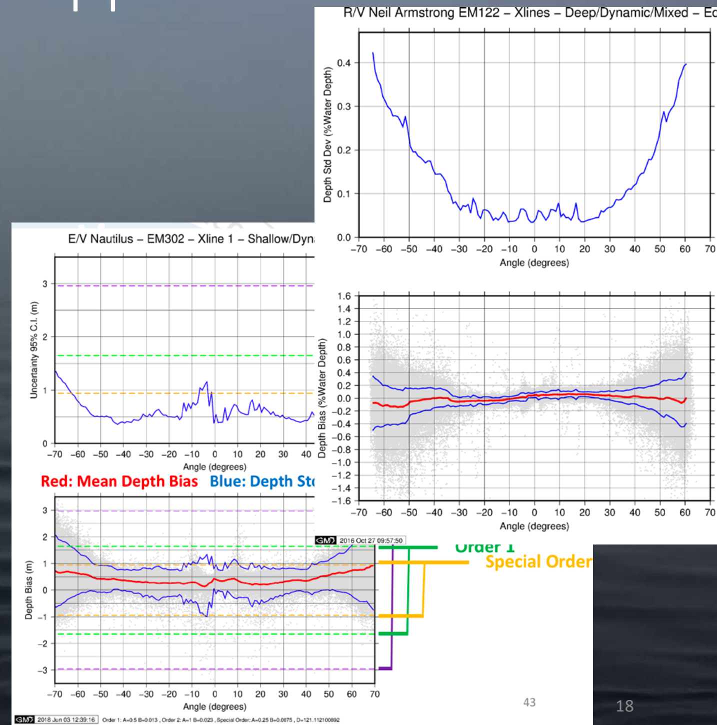
4. Swath Accuracy: MAC Approach

- Ensure all other acoustic systems are **secured**
- Collect a high-density reference surface over flat terrain in depths suitable for frequency
- Mask grid cells with low sounding density, high standard deviation, and/or high slopes
- Collect crosslines in 'typical' survey mode for that site



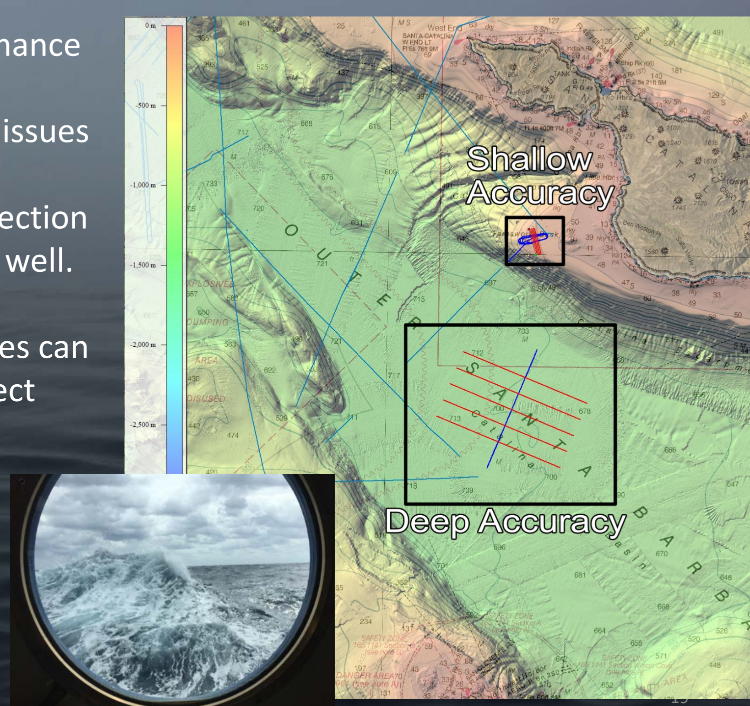
4. Swath Accuracy: MAC Approach

- Calculate differences between soundings and corresponding reference surface cells
- Group differences by beam angle, plot mean and std. dev. of differences across swath
- Repeat reference surface and crosslines in shallower and deeper sites as time allows



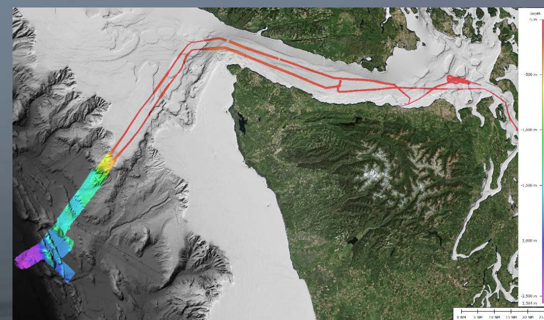
4. Swath Accuracy: Lessons from the Fleet

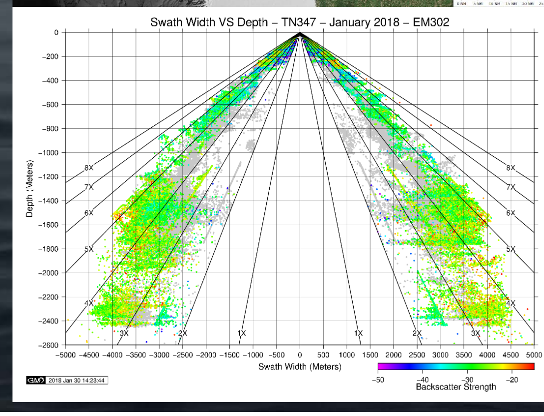
- Useful for detecting changes in performance
- Sea state can overwhelm performance issues
- Problems with refraction and tidal correction can make interpretation challenging as well.
- Documenting and reusing reference sites can save significant time, provide more direct comparison among similar systems



5. Swath Coverage: MAC Approach

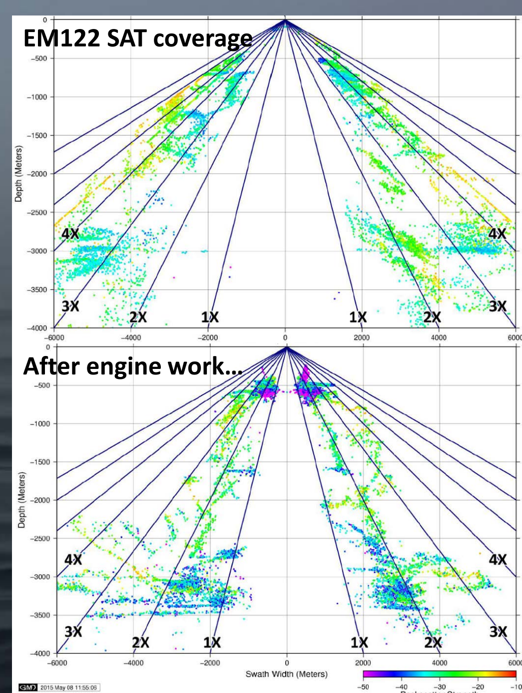
- Collect data over wide range of depths in fully automatic mode with maximum swath limits
- **Ensure all other acoustic systems are secure**
- Hopefully gentle slopes and lines perpendicular to the slopes
- Extract outermost valid soundings and remove those with extremely high / low reflectivity
- Plot soundings vs. depth





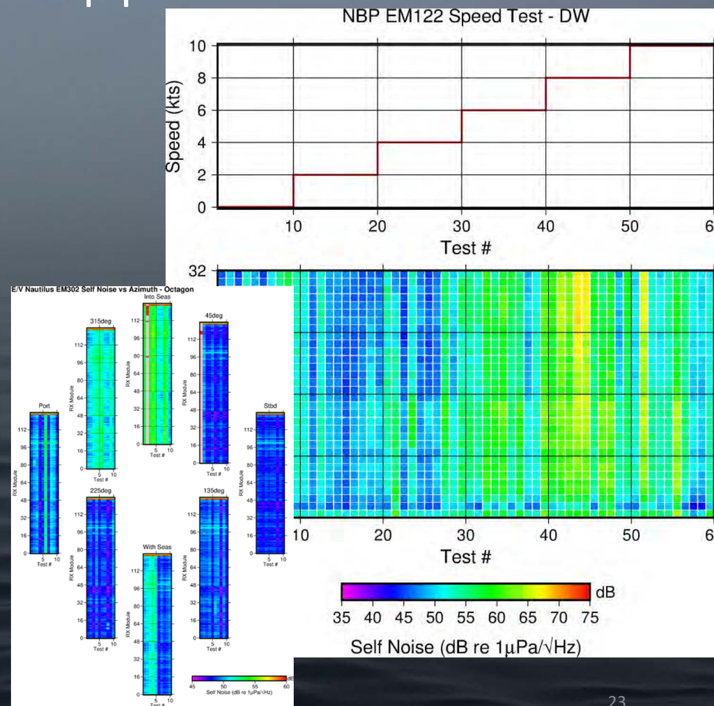
5. Swath Coverage: Lessons from the Fleet

- Coverage testing data can be easily and routinely collected on transits or after a survey
- Calculated following each SAT, QAT, or cruise using either scripts or commercial programs
- Changes from baseline data are easily seen
- Very useful for ship to ship, system to system comparison
- Up-to-date swath coverage plots are extremely useful for survey planning



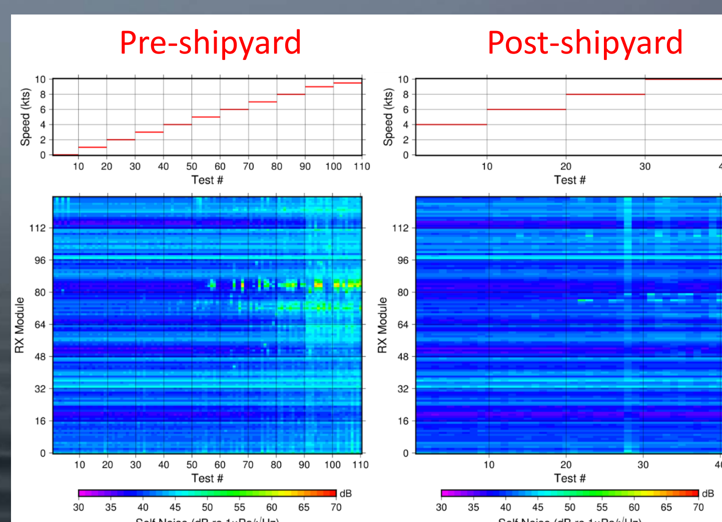
6. RX Noise Testing: MAC Approach

- Collect RX Noise and RX Spectrum BISTs to examine perceived platform noise under various circumstances:
    1. Noise vs. speed / RPM
    2. Noise vs. machinery / engine lineup
    3. Noise vs. heading (rel. prevailing seas)
- Ensure all other echosounders are secure
- Run 10-20 BISTs at each speed / setting / heading, then remove outliers and average

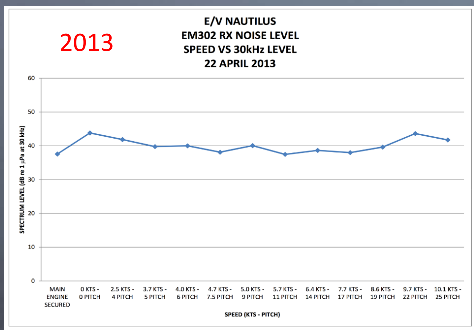


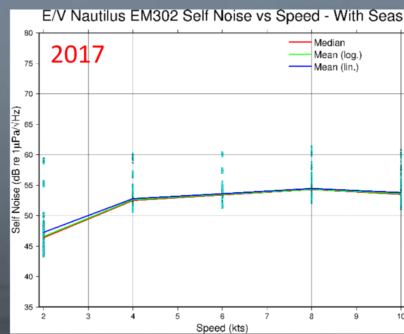
6. RX Noise Testing: Lessons from the Fleet

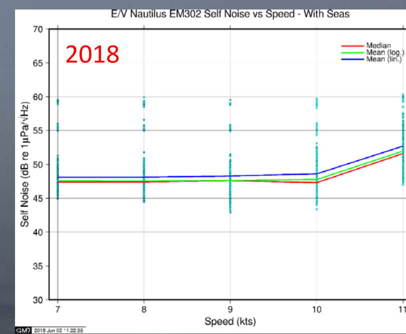
- RX noise data is critical for identifying problems and monitoring changes over time (e.g., improvement after array cleaning)
- Use with swath coverage plots to identify:
    1. noise sources in hardware vs. vessel
    2. optimal speeds, machinery lineups
    3. impacts of sea state and biofouling



6. RX Noise Testing: Lessons from the Fleet



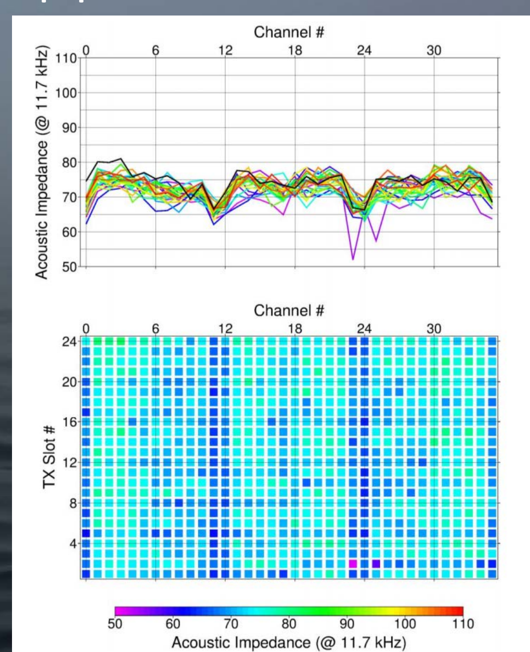




Having baseline data is critical!

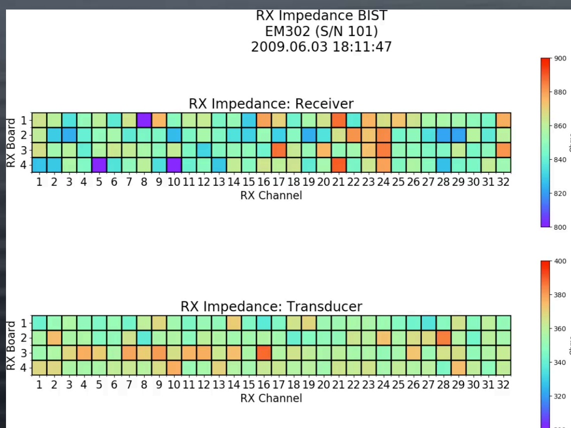
7. Impedance Testing: MAC Approach

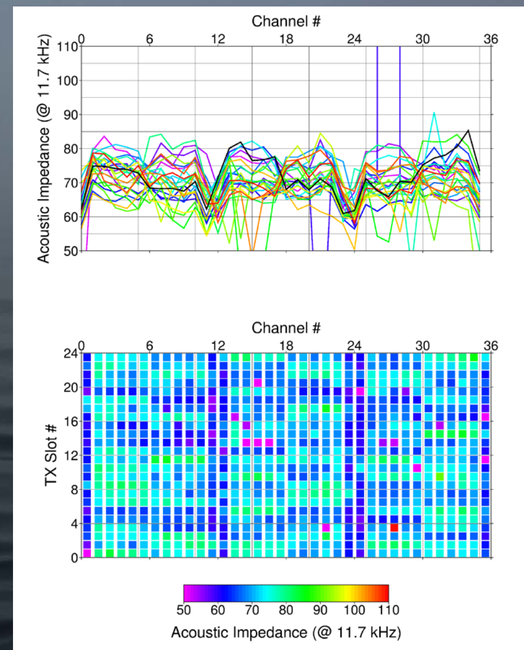
- Collect TX Channels and RX Channels BISTs to monitor:
  1. TX transducer acoustic impedance
  2. RX receiver electrical impedance
  3. RX transducer electrical impedance
- Not a replacement for direct measurements at each element (e.g., KM Cypher tool), but a proxy for hardware health over service life



7. Impedance Testing: Lessons from the Fleet

- In combination with RX noise data, RX & TX impedance critical for troubleshooting symptoms, isolating array degradation
- Annual (or more frequent) evaluation helps owners plan array replacement

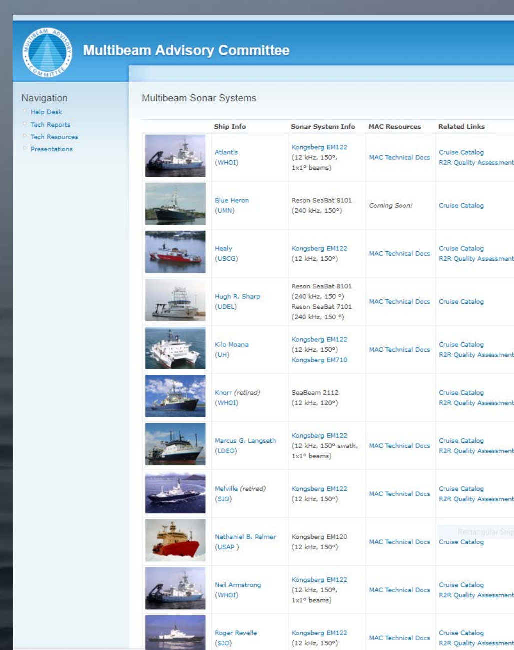




12-kHz TX array after 10 years of icebreaking

8. Documentation: MAC Approach

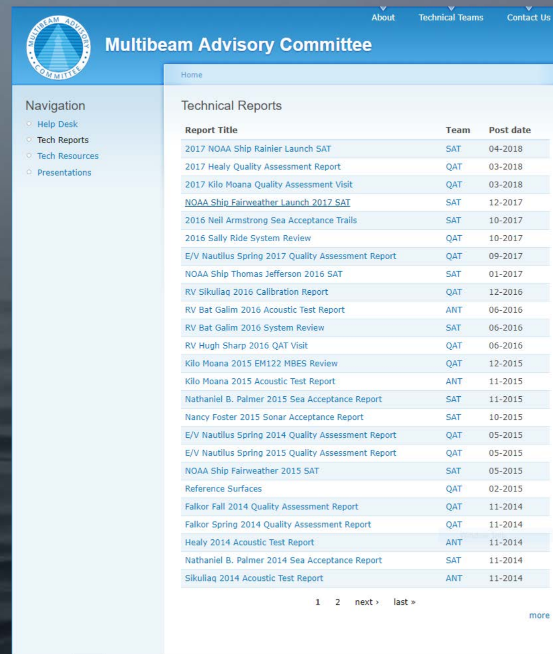
- SAT, QAT, & ANT reports available at http://mac.unols.org
- Full documentation of system geometry and layout
- Screenshots of all post-calibration Installation Parameters, communication settings, and positioning / attitude system configurations
- Backups of PU Parameters and BISTs



http://mac.unols.org

8. Documentation: Lessons from the Fleet

- Fleet-wide reports help operators share best practices and improve data quality over time
- Efficiencies for all in reusing calibration sites and reference surfaces for similar systems , map services coming
- Reports build on each other; previous settings and performance have been critical at times (e.g., NBP EM122 replacement)
- Contributions from non-MAC sources.

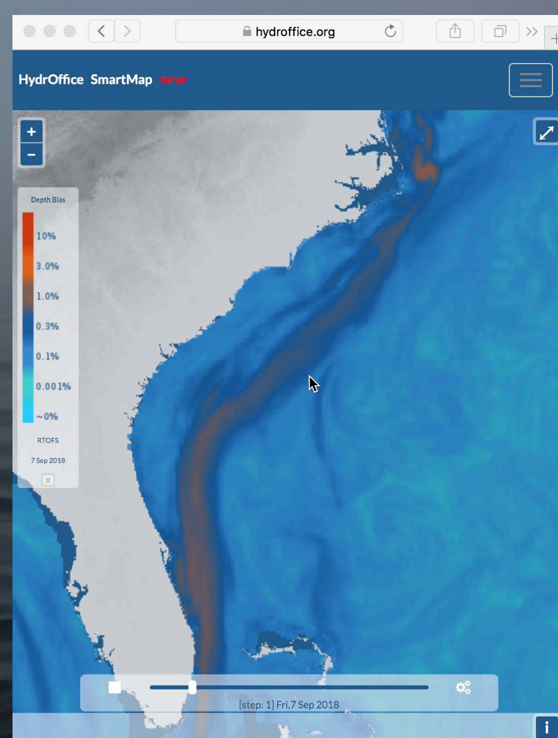


Report Title	Team	Post date
2017 NOAA Ship Rainier Launch SAT	SAT	04-2018
2017 Healy Quality Assessment Report	QAT	03-2018
2017 Kilo Moana Quality Assessment Visit	QAT	03-2018
NOAA Ship Fairweather Launch 2017 SAT	SAT	12-2017
2016 Neil Armstrong Sea Acceptance Trails	SAT	10-2017
2016 Sally Ride System Review	QAT	10-2017
E/V Nautilus Spring 2017 Quality Assessment Report	QAT	09-2017
NOAA Ship Thomas Jefferson 2016 SAT	SAT	01-2017
RV Sikuliaq 2016 Calibration Report	QAT	12-2016
RV Bat Galim 2016 Acoustic Test Report	ANT	06-2016
RV Bat Galim 2016 System Review	SAT	06-2016
RV Hugh Sharp 2016 QAT Visit	QAT	06-2016
Kilo Moana 2015 EM122 MBES Review	QAT	12-2015
Kilo Moana 2015 Acoustic Test Report	ANT	11-2015
Nathaniel B. Palmer 2015 Sea Acceptance Report	SAT	11-2015
Nancy Foster 2015 Sonar Acceptance Report	SAT	10-2015
E/V Nautilus Spring 2014 Quality Assessment Report	QAT	05-2015
E/V Nautilus Spring 2015 Quality Assessment Report	QAT	05-2015
NOAA Ship Fairweather 2015 SAT	SAT	05-2015
Reference Surfaces	QAT	02-2015
Falkor Fall 2014 Quality Assessment Report	QAT	11-2014
Falkor Spring 2014 Quality Assessment Report	QAT	11-2014
Healy 2014 Acoustic Test Report	ANT	11-2014
Nathaniel B. Palmer 2014 Sea Acceptance Report	SAT	11-2014
Sikuliaq 2014 Acoustic Test Report	ANT	11-2014

9. Tools: SmartMap

- Developed and funded by MAC & NOAA
- Present up-to-date sound speed variability from RTOFS and likely effects on multibeam data quality
- Helps operators plan surveys around sound speed forecast and manage profiling regimen
- Useful for planning transit mapping and understanding / correcting transit data

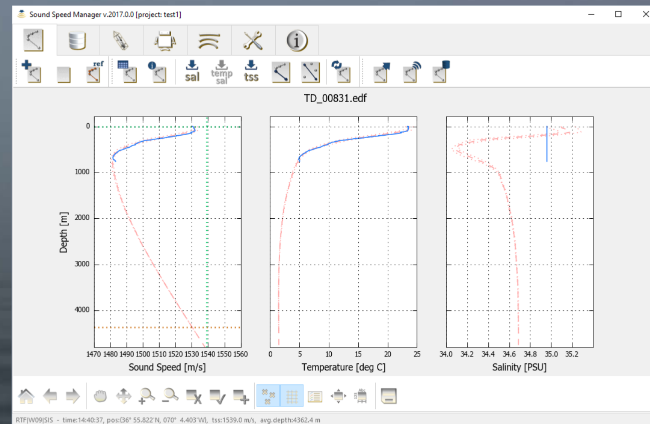
https://www.hydroffice.org/smartmap

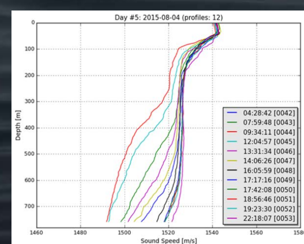


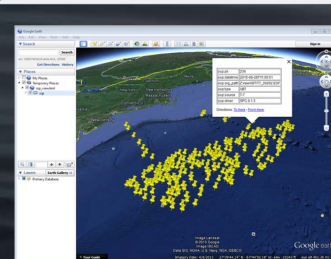
9. Tools: Sound Speed Manager

- Developed and funded by MAC & NOAA
- Simplifies processing and application of sound speed data for wide range of systems
- Warns users when profiles are needed, based on real-time variability and global databases
- Apply RTOFS/WOA data automatically when operators are not available for monitoring
- Archives all profiles in database

https://www.hydroffice.org







Main Takeaways

- **Vessel surveys** must be correct and clearly reported using KM conventions
- **Vessel noise** should be tracked with BISTs for baseline and after shipyard periods
- **Swath coverage** reductions may be first indicators of complications
- **Impedance** should be tracked with BISTs as a proxy for hardware health
- **Routine/opportunistic testing** catches problems early
- **Documentation** is critical as systems and crews change over time