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10. EM302 Swath Coverage
11. EM302 Transducer Impedance
12. EM302 Noise Assessment
13. Sound Speed Manager
14. Executive Summary
17. Appendix 3: POS MV V4 Config.
TN-347 Personnel

- **Multibeam Advisory Committee**
  1. Paul Johnson (UNH CCOM)
  2. Kevin Jerram (UNH CCOM)
  3. KG Fairbarn (UNH CCOM)
  4. Tim Gates (Gates Acoustic Services)

- **Kongsberg Maritime**
  1. Chuck Hohing

- **University of Washington**
  1. Emily Roland
  2. Miles Logsdon
  3. Students (6)

- **TGT Marine Technicians**
  1. Patrick A’Hearn
  2. Jennifer Nomura
  3. Brandi Murphy
  4. Croy Carlin
TN-347 Planning Overview

- The University of Washington’s UNOLS vessel R/V Thomas G. Thompson (TGT) completed its mid-life refit in late 2017 at Vigor Shipyard in Seattle, WA

- The multibeam system was upgraded from an EM300 to an EM302 in two stages:
  1. EM302 topside unit upgrade in 2010 (TRU maintained during the refit)
  2. EM302 array upgrade in 2017 (total array replacement during the refit)

- An Applanix POS MV V5 was installed as the primary vessel positioning / attitude system; the original V4 was maintained as a secondary system

- The Multibeam Advisory Committee (MAC) was asked to coordinate Sea Acceptance Trials (SAT) for the new Kongsberg Maritime EM302 using the primary POS MV V5

- MAC communication with TGT personnel began in fall 2017 with suggestions for IMU plate installation and vessel survey requirements; SAT plans were set in December
TN-347 Onboard Activities

2018-01-08 (Mon)
Board at Pier 66, safety meeting
Start dynamic positioning (DP) system testing (ongoing all day)
**POS MV / EM302 geometry review and configuration**
Install Sound Speed Manager and test XBT workflow
Investigate high noise levels on RX board 4

2018-01-09 (Tues)
DP testing continued en route to Port Angeles
Clarification from Applanix on antenna height configuration
SIS gridding engine failure (restart SIS/reboot PC)
Drop DP test personnel in Port Angeles, transit to calibration site

2018-01-10 (Wed)
**EM302 calibration and verification**
**EM302 deep accuracy crosslines** (TN-144 EM300 reference site)
Noise testing (Gates Acoustic Services*)
TN-347 Onboard Activities

2018-01-11 (Thur)
- Vessel speed / heading noise testing (Gates Acoustic Services*)
- Winch testing
- Start transit toward Seattle
- **Shallow accuracy crosslines** (E/V Nautilus NA070 EM302 ref. site)

2018-01-12 (Fri)
- Winch testing (continued)
- Machinery noise testing (Gates Acoustic Services*)
- Student survey of opportunity
- Arrive Seattle (1600)

*Noise assessment funded by MAC grant and reported separately by Gates Acoustic Services
TN-347 Onboard Activities
Overview: Vessel Survey

- Vessel survey conducted by Westlake Consultants, Inc.
- Preliminary report provided to TGT and MAC on Jan 7
  - NOTE: final Westlake survey report pending as of this report
- Origin of survey reference frame at target on top of POS MV V5 (primary) IMU
- Target on top of V5 IMU is the origin of the common reference frame for all mapping system sensors
- Linear offsets reported in meters using ‘right-handed’ coordinate axes
  - $+X$ forward (agrees with KM/Applanix convention)
  - $+Y$ starboard (agrees with KM/Applanix convention)
  - $+Z$ down (agrees with KM/Applanix convention)
- Angular offsets reported in decimal degrees
  - $+Roll$ with starboard side down (agrees with KM/Applanix convention)
  - $+Pitch$ with bow down (DOES NOT AGREE with KM/Applanix convention)
  - $+Heading$ with bow rotation to starboard (agrees with KM/Applanix convention)
NOTE: Only difference is +pitch with bow down; final Westlake report may match KM/Applanix convention.

Source: Kongsberg EM302 Installation Manual

Overview: Coordinate Systems

Westlake convention

Kongsberg convention

Applanix convention

Transducer heading

The heading of the transducers is measured as the average heading of the two fore-and-aft oriented sides of each transducer array. Thus, the heading of the transmit transducer is the heading along the keel, while the heading of the receiver array is the heading across the keel. For the receive transducer it may be better to measure the heading along the keel, and then subtract 90° to achieve the correct value. The measurement accuracy is required to be within one fifth of the beamwidth of the transmit transducer.

Note however that the measurement accuracy of the relative bearing between the transmit and receive transducers must be better than 0.1°.

Transducer roll and pitch

Roll and pitch measurements are made according to standard conventions with positive pitch angle if the transmitter array's forward end is above the aft end (tilts up), and positive roll if the starboard side of the receiver array is lower than the port side.

Note that the roll and pitch angles to be measured are relative to the horizontal plane as defined by the vessel's coordinate system. I.e. for roll the angle that the transducer's y-axis have with respect to the horizontal and for pitch the angle that the transducers z-axis have with respect to the horizontal plane. The multibeam echo sounder converts the measured angles as entered into the installation menu to rotation angles before use i.e. do not do such a conversion before entering into the system.

Source: Applanix POS MV Installation Manual
System Geometry Review

Overview: Linear Offsets

Survey report (NOTE: only ‘preliminary’ report available)

- Origin at target on top dead center (TDC) of IMU
- All units in meters
- +X forward
- +Y starboard
- +Z down

Essential sensor offsets

- POS MV V5 IMU target (origin of reference frame)
- POS MV V4 IMU target
- POS MV Antennas
- EM302 TX Array
- EM302 RX Array
- C-Nav 2000 Antenna
- C-Nav 3050 Antenna
Overview: Angular Offsets

Survey report (NOTE: only ‘preliminary’ report available)
- All units in degrees
- +Roll starboard side down
- +Pitch bow down (opposite from KM/Applanix convention)
- +Heading bow to starboard (compass convention)
- Surveyed IMU mounting plate, not IMUs
- Installed angles for both IMUs assumed equal to mounting plate, hence identical results in report

Essential sensor offsets
- POS MV V5 IMU (assumed equal angles to base plate)
- POS MV V4 IMU (assumed equal angles to base plate)
- EM302 TX Array
- EM302 RX Array
1. Trimble antennas installed on aft antenna tower
   1. Source: Bob Laird (Westlake) email, 2018-01-07; see bottom left

2. Westlake surveyed to height of seam on plastic housing
   1. Source: Bob Laird (Westlake) email, 2018-01-07; see bottom left

3. Seam is 0.042 m above base (Antenna Reference Point, ARP)
   1. Source: tape and micrometer measurements of spare Trimble antenna; see bottom right

4. L1 phase center height is used for POS MV antenna lever arm
   1. Source: John Carss (Applanix) email, 2018-01-08

5. L1 phase center is 0.058 m above ARP

6. L1 phase center is 0.058 – 0.042 = 0.016 m above surveyed height
POS MV Antennas: Lever Arms

- Westlake antenna heights adjusted by 0.016 m up (more negative Z) for POS MV configuration at L1 phase center heights

Starboard antenna at L1 phase center for primary POS MV GNSS lever arm:

X: -28.2773 m
Y: 2.9314 m
Z: -12.1908 m

Port antenna at L1 phase center for secondary POS MV GNSS lever arm:

X: -28.2738 m
Y: 0.8017 m
Z: -12.1896 m
C-Nav 3050 used as auxiliary GPS input to POS MV V5, V4, and EM302

1. C-Nav 3050 antenna phase centers are 0.066 and 0.065 m above base

2. Westlake surveyed height of plastic housing lip at 0.024 m above base

3. Mean phase center is 0.0655 – 0.024 = 0.0415 m above surveyed height

4. C-Nav 3050 config. height adjusted by 0.0415 m to -24.4088 m

5. C-Nav 3050 coordinates for POS MV and EM302 auxiliary GPS lever arm:
   - X: -4.0728 m
   - Y: -2.8119 m
   - Z: -24.4088 m
C-Nav 2000 used as secondary auxiliary GPS input to POS MV V4 only

1. C-Nav 2000 phase center heights are 0.020 and 0.044 m above ‘DOG’

2. ‘DOG’ is 0.014 m above Westlake survey height

3. Mean phase center height is \[\frac{(0.020 + 0.044)}{2} + 0.014 = 0.046\] m above surveyed location

4. C-Nav 2000 config. height adjusted by 0.046 m to -24.6737 m

5. C-Nav 2000 coordinates for POS MV V4 secondary auxiliary GPS lever arm:
   
   X: -4.0396 m  
   Y: 0.3499 m  
   Z: -24.6737 m
System Geometry Review

POS MV IMUs: Lever Arms

- Westlake surveyed the target on top dead center of each IMU
- Westlake result were used directly for the lever arm from the origin to each IMU in POS MV configuration (‘Ref to IMU Target’)

### Primary IMU: V5

- X: 0.000 m
- Y: 0.000 m
- Z: 0.000 m

### Secondary IMU: V4

- X: -0.0041 m
- Y: 0.2268 m
- Z: -0.0446 m

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ALL UNITS ARE DECIMAL METERS

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

---

RV TOMMY THOMPSON
SHIP SURVEY SEPTEMBER 2016
COMPLETED AT HIGH ISLAND
SEATTLE, WASHINGTON
Westlake surveyed the installed angles of the **machined IMU base plate**, not the IMU housings.

- For initial configuration, based on the survey data and careful machining of the plate and guide pin holes:
  
  1. **IMU roll and pitch angles are assumed to match the top plane of the machined base plate**
  
  2. **IMU heading angles are assumed to match the alongship edge of the machined base plate**
POS MV IMUs: Installation Angles

- The Westlake results were used directly for the IMU installation angles, *making sure to correct the pitch sign convention*

**Primary IMU: V5**
- Roll: -0.0174°
- Pitch: -0.0744°
- Heading: +0.8012°

**Secondary IMU: V4**
- Roll: -0.0174°
- Pitch: -0.0744°
- Heading: +0.8012°
### System Geometry Review

#### EM302 Arrays: Lever Arms

- Westlake surveyed the center of the face of each array
- The Westlake results were used directly for the lever arm from the origin at the V5 IMU TDC to each array in SIS Installation Parameters

#### EM302 TX Array
- X: 3.7709 m
- Y: 2.1319 m
- Z: 6.2010 m

#### EM302 RX Array
- X: 1.8216 m
- Y: 1.5230 m
- Z: 6.1876 m

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All units are decimal meters.
System Geometry Review

**EM302 Arrays: Installation Angles**

- Westlake surveyed the installed angles of the EM302 arrays after leveling and shimming the frames in dry dock.

- The Westlake results were used directly for the array installation angles in SIS Installation Parameters making sure to correct the pitch sign convention and add 360° to achieve a positive heading angle.

**EM302 TX Array**

- Roll: +0.5082°
- Pitch: -0.0727°
- Heading: +359.9875° (SIS requires 0-360°, no negatives)

**EM302 RX Array**

- Roll: +0.0420°
- Pitch: +0.1346°
- Heading: +359.8410° (surveyed major axis of array) – 90° (transverse orientation of array) = +0.1590° heading of RX array in SIS convention (i.e., RX array heading slightly to port); add 360° because SIS requires positive angle)
The Westlake report did not include waterline (required for SIS configuration), so an estimate was made using dockside draft marks and converting the draft into the vessel reference frame with origin at the V5 IMU, as follows:

1. Pre-cruise draft marks near the alongship position of the arrays (e.g., at the gondola, left) indicated a vessel draft of 17.5 ft, or 5.334 m; it is assumed the draft refers to the gondola depth at this alongship location.

2. Assuming the EM302 arrays are flush with the gondola, the vertical offset of the gondola face is taken as the mean vertical offset of the arrays in the vessel reference frame (mean array Z = 6.194 m downward from origin at V5 IMU).

3. The waterline is then taken as 6.194 – 5.334 = 0.860 m below the origin of the vessel reference frame; because Z is positive downward in the vessel reference frame, this results in a waterline offset of +0.860 m in SIS.
POS MV V5 Configuration

Lever Arms & Mounting Angles

1. Ref. to IMU Target set to Westlake offsets for V5 IMU target (origin)

2. IMU Frame w.r.t. Ref. Frame set to Westlake angles (with correction for pitch sign convention)

3. Ref to Primary GNSS set to Westlake offsets for starboard (primary) POS MV antenna with height adjustment for L1 phase center

4. Ref. to Vessel set to origin / V5 IMU target for data output at origin of common reference frame

5. Ref. to Centre of Rotation set to alongship and vertical position of IMU on vertical plane through vessel centerline
POS MV V5 Configuration

Lever Arms & Mounting Angles

1. Ref. to Aux. 1 GNSS set to Westlake offsets for port (secondary) POS MV antenna with height adjustments for L1 phase center

2. Ref. to Aux. 2 GNSS set to Westlake offsets for C-Nav 3050 antenna with height adjustment for mean phase center
POS MV V4 Configuration

**Lever Arms & Mounting Angles**

1. Ref. to IMU set to Westlake offsets for V4 IMU target (origin)

2. IMU Frame w.r.t. Ref. Frame set to Westlake angles (with correction for pitch sign convention)

3. Ref to Primary GPS set to Westlake offsets for starboard (primary) POS MV antenna with height adjustment for L1 phase center

4. Ref. to Vessel set to origin / V5 IMU target for data output at origin of common reference frame

5. Ref. to Centre of Rotation set to alongship and vertical position of IMU on vertical plane through vessel centerline
1. Ref. to Aux. 1 GPS set to Westlake offsets for port (secondary) POS MV antenna with height adjustments for L1 phase center

2. Ref. to Aux. 2 GPS set to Westlake offsets for C-Nav 2000 antenna with height adjustment for mean phase center
1. After antenna calibration, multiple GAMS calibrations were performed for the V5 and V4 while underway.

2. The GAMS solutions for antenna baseline vectors converged quickly (on the order of 10 s) and the resulting baseline vector typically estimated the secondary antenna position to within a few mm of the survey result.

3. The Baseline Vector field was set as the surveyed dX, dY, and dZ from the primary antenna to the secondary antenna (note inadvertent small rounding difference in the Y components).
EM302 Calibration

Site Selection and Data Collection

1. Calibration sites were selected based on availability of seafloor features with optimal slopes and bathymetric relief within the operating area; the sites had been used previously for calibration of the EM302 aboard E/V *Nautilus*.

2. Lines were run at 6 kts in the order of pitch, roll, heading.

3. XBTs were collected at various times throughout calibration; however, the frequency of XBT profiles was limited by the small number of probes on board.

4. The calibration was performed using the POS MV V5 as the primary position / attitude feed to the EM302.

5. If needed, the ‘backup’ POS MV V4 will require a similar process for calibration before it is put into service as the primary position / attitude feed to the EM302.
Pre-Calibration Configuration

1. All *Attitude 1* angular offsets were set to zero in *SIS Installation Parameters* prior to data collection.

2. Calibration data were examined by Johnson, Jerram, Fairbarn, and Hohing using patch test tools in SIS and Qimera; results were agreed upon by multiple personnel.

3. Results of each test were updated in the *SIS Installation Parameters* for *Attitude 1* angular offsets prior to the subsequent test in order to reduce effects of coupling.

4. After calibration, the lines were run again for verification; adjustments were small or zero during both stages, suggesting high confidence in the results.

5. No latency test was performed, as it is not clear that any small positioning latency would be evident in deep water; no latency-related bathymetric artifacts were noted.
EM302 Calibration

Results: Pitch

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

1. Initial calibration result: -0.18 °
2. Verification adjustment: -0.02 °
3. Final pitch offset: -0.20° in SIS
EM302 Calibration

Results: Roll

1. Initial calibration result: +0.01°
2. Verification adjustment: 0.00°
3. Final roll offset: +0.01° in SIS

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

- NOTE: an additional roll bias of a few thousandths of a degree is evident in the verification data; however, SIS rounds Installation Parameter angles to the hundredth of a degree, rounding the final result to +0.01°
EM302 Calibration

Results: Heading

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

1. Initial calibration result: -0.05°
2. Verification adjustment: +0.05°
3. Final heading offset: 0.00° in SIS
1. The small *Attitude 1* angular offsets reflect a high-quality vessel offset survey and consistent integration across the POS MV V5 and EM302 configurations.

2. The *Installation Parameters: Angular Offsets* shown at left should be maintained until any modification is made to the V5 IMU or arrays, or another calibration becomes necessary.
Accuracy: Overview

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

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

3. Accuracy assessments during sea acceptance trials provide a baseline for performance at the beginning of the system’s service life, contributing to the knowledgebase for fleet-wide mapping system performance.

4. Routine accuracy assessments (e.g., during MAC Quality Assessment Testing) provides a critical window into performance over the system’s service life and may help to identify early signs of component failure.
5. For a complete evaluation, accuracy data should be collected in all operational modes over reference surfaces in depths appropriate for those modes.

6. Due to time constraints and availability of reference surfaces in appropriate depth ranges, most accuracy assessments during SATs and QATs cover only a few of the available modes.

7. ‘Deep’ and ‘Shallow’ operational modes for the EM302 were tested during TN-347 using two reference surfaces in significantly different depth ranges.

8. In order to save a significant amount of time for data collection, both accuracy assessment sites were selected based on the availability of existing reference surfaces in the vicinity of northwest WA.
EM302 Accuracy Testing

Deep Accuracy: Overview

1. Swath accuracy over ‘deep’ terrain (relative for the 30-kHz EM302) was assessed by running a series of crosslines over a ‘deep’ reference surface in 1250-2500 m depths collected with the original EM300 aboard TGT in 2002 during TN-144

2. The reference surface was gridded at 50 m (upper left figure) and masked for several parameters:
   1. Grid cells with <10 soundings were removed from the reference surface (upper right figure)
   2. Grid cells with slopes >5° were removed from the reference surface (lower left figure)
   3. The remaining grid cells with ≥10 soundings and slopes ≤5° were used for analysis of the TN-347 deep accuracy crossline data (lower right figure)
EM302 Accuracy Testing

Deep Accuracy: Data Collection

1. Crosslines were oriented to maximize coverage across the masked reference surface.

2. An XBT profile was collected prior to crosslines.

3. Deep accuracy crosslines were run in three settings, starting with the most conventional configuration for the environment (changes from previous settings are red).

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<thead>
<tr>
<th>Crossline Setting</th>
<th>Ping Mode</th>
<th>Swath Mode</th>
<th>Pulse Form</th>
<th>Yaw Stabilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting 1</td>
<td>Deep</td>
<td>Dual Swath (Dynamic)</td>
<td>FM Enabled*</td>
<td>RMH**</td>
</tr>
<tr>
<td>Setting 2</td>
<td>Auto</td>
<td>Dual Swath (Dynamic)</td>
<td>CW</td>
<td>RMH**</td>
</tr>
<tr>
<td>Setting 3</td>
<td>Deep</td>
<td>Single Swath</td>
<td>FM Enabled*</td>
<td>RMH**</td>
</tr>
</tbody>
</table>

*With FM enabled, in this depth range, the EM302 used a ‘MIX’ transmission with CW inner sectors and FM outer sectors. With FM disabled, only CW pulse forms were used for all sectors (e.g., Setting 2).

** RMH = Relative Mean Heading
EM302 Accuracy Testing

Deep Accuracy: Results Overview

- Example plots are shown at left; results for each setting are presented in more detail in the following slides.

- Crossline soundings were compared to the masked reference surface, where applicable, and results were grouped by beam angle in 1° bins across the swath.

- In general, the mean depth bias (red line) remains below 0.1% of water depth (% WD) across most of the swath.

- In general, the depth standard deviation (blue lines) remains below:
  - 0.10% WD to at least 45°
  - 0.20% WD to at least 55°
  - 0.25% WD to 60°

- At TX sector boundaries (approx. ±32-35°) with FM enabled, the mean depth bias tends to jump by ~0.05% WD and the depth standard deviation tends to jump by ~0.025% WD.

Example of swath accuracy as a percentage of water depth (left) and depth (right) with NOAA thresholds.

Results for each setting are presented in the following slides.
EM302 Accuracy Testing

Deep Setting 1 (DUAL/DEEP/MIX)


Red: Mean Depth Bias  Blue: Depth Std. Dev.

Unpredictability 95% CI (m)

Order 1
Special Order

Red: Mean Depth Bias  Blue: Depth Std. Dev. (top: 2σ ~ 95% CI)

Order 1
Special Order

Order 2

Order 2

Special Order
EM302 Accuracy Testing

Deep Setting 2 (DUAL/AUTO/CW)


Red: Mean Depth Bias  Blue: Depth Std. Dev.  (top: 2\(\sigma\) ~ 95% CI)

Order 2
Order 1
Special Order
EM302 Accuracy Testing

Deep Setting 3
(SINGLE/DEEP/MIX)


Red: Mean Depth Bias  Blue: Depth Std. Dev.

Red: Mean Depth Bias  Blue: Depth Std. Dev. (top: 2σ ~ 95% CI)

Order 2
Order 1
Special Order
Deep Accuracy: Sound Speed

- An XBT profile was collected to 760 m prior to deep accuracy crossline data collection.
- All XBTs were processed in Sound Speed Manager using World Ocean Atlas 2013 (WOA13) regional/seasonal salinity data to generate sound speed profiles; these profiles were extended and formatted per Kongsberg requirements and applied during data collection.
- The profile applied during deep accuracy data collection did not adequately capture the variability in the area, resulting in refraction-related biases in the preliminary accuracy results.
- This may be due in part to differences between realtime salinity and the WOA13 data directly offshore from the Strait of Juan de Fuca, and in part to the age of XBT probes.
- Adjustments were made to the sound speed profile (e.g., Qimera SVP Editor, left) to suppress refraction-related biases and more clearly represent the echosounder performance alone.
EM302 Accuracy Testing

Shallow Accuracy: Overview

1. Swath accuracy over ‘shallow’ terrain (relative for the 30-kHz EM302) was assessed by running a series of crosslines over a reference surface in 155-175 m depths collected with the EM302 aboard E/V Nautilus in 2016 during NA070

2. The reference surface was gridded at 5 m (upper left figure) and masked for several parameters:
   1. Grid cells with <10 soundings were removed from the reference surface (upper right figure)
   2. Grid cells with slopes >5° were removed from the reference surface (lower left figure)
   3. The remaining grid cells with ≥10 soundings and slopes ≤5° were used for analysis of the TN-347 shallow accuracy crossline data (lower right figure)
EM302 Accuracy Testing

**Shallow Accuracy: Data Collection**

1. Crosslines were oriented perpendicular to the original reference surface survey lines in order to reduce any potential coupling of EM302 biases across the swath.

2. An XBT profile was collected prior to crosslines.

3. Shallow accuracy crosslines were run in four settings, starting with the most conventional configuration for the environment (changes from previous settings are **red**):

<table>
<thead>
<tr>
<th>Crossline Setting</th>
<th>Ping Mode</th>
<th>Swath Mode</th>
<th>Pulse Form</th>
<th>Yaw Stabilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting 1</td>
<td>Shallow</td>
<td>Dual Swath (Dynamic)</td>
<td>CW</td>
<td>RMH*</td>
</tr>
<tr>
<td>Setting 2</td>
<td>Shallow</td>
<td>Single Swath</td>
<td>CW</td>
<td>RMH*</td>
</tr>
<tr>
<td>Setting 3</td>
<td>Shallow</td>
<td>Dual Swath (Dynamic)</td>
<td>CW</td>
<td>Off</td>
</tr>
<tr>
<td>Setting 4</td>
<td>Shallow</td>
<td>Single Swath</td>
<td>CW</td>
<td>Off</td>
</tr>
</tbody>
</table>

*RMH = Relative Mean Heading*
EM302 Accuracy Testing

Shallow Accuracy: Results Overview

- Example plots are shown at left; results for each setting are presented in more detail in the following slides.

- Crossline soundings were compared to the masked reference surface, where applicable, and results were grouped by beam angle in 1° bins across the swath.

- In general, the mean depth bias (red line) remains below 0.2% of water depth (% WD) across most of the swath.

- In general, the depth standard deviation (blue lines) remains below:
  - 0.15% WD to at least 45°
  - 0.20% WD to at least 55°
  - 0.25% WD to 60°

Example of swath accuracy as a percentage of water depth (left) and depth (right) with NOAA thresholds

Results for each setting are presented in the following slides.
EM302 Accuracy Testing

Shallow Setting 1
(DUAL/SHALLOW/CW/RMH)

Red: Mean Depth Bias  Blue: Depth Std. Dev.

Order 2
Order 1
Special Order

Red: Mean Depth Bias  Blue: Depth Std. Dev.

Order 2
Order 1
Special Order
EM302 Accuracy Testing

R/V Thomson – EM302 Shallow Accuracy – Single/Shallow/CW/RMH

Red: Mean Depth Bias  Blue: Depth Std. Dev.

Shallow Setting 2
(SINGLE/SHALLOW/CW/RMH)

R/V Thomson – EM302 Shallow Accuracy – Single/Shallow/CW/RMH

Order 2
Order 1
Special Order

Red: Mean Depth Bias  Blue: Depth Std. Dev.

Order 2
Order 1
Special Order
EM302 Accuracy Testing

**Shallow Setting 3**
*(DUAL/SHALLOW/CW/OFF)*

- Red: Mean Depth Bias
- Blue: Depth Std. Dev.

Graphs showing depth accuracy data for different orders: Order 1, Order 2, and Special Order.
EM302 Accuracy Testing

Shallow Setting 4 (SINGLE/SHALLOW/CW/OFF)

Red: Mean Depth Bias  Blue: Depth Std. Dev.

Order 2  Order 1  Special Order
An XBT profile was collected to full water depth prior to shallow accuracy crossline data collection.

All XBT data were processed in Sound Speed Manager using World Ocean Atlas 2013 (WOA13) regional/seasonal salinity data to generate sound speed profiles; these profiles were extended and formatted per Kongsberg requirements and applied during data collection.

The sound speed profile applied during accuracy data collection did not adequately capture the variability in the area, resulting in refraction-related biases in the preliminary accuracy results; these are particularly severe beyond ±60°.

This may be due in part to differences between realtime salinity and the limited WOA13 data in the highly dynamic Strait of Juan de Fuca, and in part to the age of XBT probes.

Adjustments were made to the sound speed profile (e.g., Qimera SVP Editor at left) to try to suppress refraction-related biases and more clearly represent the echosounder performance alone.
EM302 Swath Coverage

Results: Overview

During all transits for TN-347, the EM302 was run in automatic ping mode with swath angle limits of ±75° in order to let the system select its preferred mode and attempt to maximize swath coverage.

The outermost port and starboard valid soundings were plotted for all pings to evaluate trends in the achieved swath width versus depth.

Soundings that appeared to be outliers relative to the surrounding bathymetry were removed from analysis; likewise, soundings that had abnormally high or low backscatter strengths (characteristic of slopes facing toward or away from the EM302) were also ignored.

The results provide a baseline swath coverage curve in depths of approximately 5-2450 m; this curve is useful for survey planning and comparison to future swath coverage data.

Note that transits were conducted at 12-14 kts rather than a typical survey speed of 8-10 kts.
EM302 Swath Coverage

Results: Overview

A similar EM302 swath coverage dataset was collected in the vicinity of TN-347 by E/V Nautilus during expedition NA070 in 2016; the NA070 soundings are included as gray background points, at left.

In general, the TN-347 EM302 swath coverage matches or exceeds the NA070 EM302 swath width over similar terrain, even at higher transit speed.

However, it must be noted that NA070 was carried out in an elevated sea state resulting in reduced swath performance due to bubble wash-down and ambient noise.

Comparison to other EM302 swath coverage plots indicates expected performance for a new system.

Future reductions in swath width versus depth (over similar terrain) may indicate array degradation and/or increased noise levels, necessitating further investigation.

EM302 transit data should be routinely collected in automatic ping mode with wide-open swath angles to provide comparison throughout the life of the system.
EM302 Swath Coverage

Results: Comparison to NA070
EM302 Swath Coverage

Results: Comparison to NA070
Results: TN-347 and Transit to NZ

Following TN-347, the Thompson transited to New Zealand and continued to collect EM302 data in automatic ping mode with swath angle limits of ±75° to develop a more complete swath coverage dataset.

EM302 data were collected over a wide variety of terrain in depths of up to ~7200 m, providing an excellent baseline for swath coverage across all of the system’s ping modes (mode changes are especially notable as ‘steps’ in the curve at ~3000 m and ~5000 m).

Building on the shallower dataset collected during TN-347, with comparison to other EM302 installations, the NZ transit data indicate expected performance to ~6500 m; deeper data are particularly sparse and outside the intended / routine mapping depth range for this system.
The EM302 transmitter element impedance can be checked through the transceiver’s Built-In Self-Test (BIST) routines, providing a useful proxy for the condition of the TX array.

The BIST results include some additional electronics and differ from direct measurements of transmitter element impedance (e.g., performed by Kongsberg technicians at the element terminals).

In general, the TX Channels BIST results indicate acceptable impedance results across the majority of elements.

TX Slot 9, Channel 6 indicates an ‘open’ circuit condition (white); this result was duplicated in multiple BISTs collected through the telnet interface and may stem from an element failure or cabling issue, which should be investigated by Kongsberg support.
EM302 RX Channels Impedance

BIST Results: RX Array Elements

- RX Channel Built-In Self-Tests (BISTs) were collected on 2018-02-22 during a transit to monitor impedance of the EM302 RX array elements and receiver channels.
- BIST results do not replace direct measurement of each element at its terminals, but provide a proxy for overall health of the array and receiver electronics.
- Routine RX Channel BISTs may aid early detection of element degradation or changing vessel noise parameters (see separate Gates Acoustic Services report).
- RX element impedance values at left show no open or short-circuit conditions (confirming repair of cable pin for board 4, ch. 15 after TN-347).
EM302 RX Channels Impedance  BIST Results: Receiver Channels

- Receiver impedance values at left (2018-02-22) show relatively uniform levels across all channels and confirm no open or short-circuit conditions at the start of the system’s service life.
Additional RX element data collected on 20 March 2018 show persistent, elevated noise levels on certain channels of RX Board 4, consistent with RX Channel BISTs shown on previous slides.

- Swath accuracy performance suggests minimal impact of the RX Board 4 noise on bathymetry.
- However, the RX Board 4 noise levels may impact water column data and should be addressed directly with Kongsberg support to determine the root cause.
A potentially major limitation of multibeam performance can stem from elevated noise levels due to hull design, engines and other machinery, sea state, biofouling, electrical interference, etc.

The SAT included a series of tests to identify contributions to the noise environment perceived by the EM302 receiver array due to specific machinery, vessel speed, and vessel heading relative to the prevailing swell.

These tests were run using the EM302 Built-In Self-Test (BIST) routines for RX Noise and RX Spectrum under each configuration, speed, and heading of interest to characterize the vessel’s platform noise environment immediately after midlife refit and engine replacement.

These platform noise tests and results are described in a separate report by Gates Acoustic Services.
Sound Speed Manager was installed on the SIS workstation to improve the workflow for processing and applying sound speed data:

- regional and seasonal temperature and salinity profiles are incorporated from the World Ocean Atlas 2013 (WOA13)

- WOA13 data can be readily compared to XBT and CTD profiles, and WOA13 salinity data can be applied to XBT profiles if salinity data from nearby CTD profiles are not available or not applicable

- New sound speed profiles can be reviewed quickly; compared against historic profiles in the region; edited if outliers exist (e.g., seabed impact); adjusted with surface sound speed sensor output; extended with WOA13 data; exported in Kongsberg (and other) formats; and loaded remotely into SIS

- Info and updates: https://www.hydrooffice.org/soundspeed/main
EM302 SAT Executive Summary

1. The MAC worked with shipboard technicians during TN-347 to review all system geometry and vessel survey data to configure the EM302 and POS MV systems in preparation for calibration.

2. The EM302 was calibrated for residual angular offsets using the POS MV V5 as the primary positioning/attitude system; verified results were configured in SIS for Attitude 1 motion sensor installation angles, and should remain unchanged until modifications are made to the sensors or there is evidence that another ‘patch test’ is necessary.

3. The Westlake survey appears to be very high in quality of results and clarity of presentation, and should provide the basis for future vessel surveys; the relatively small calibration results provide a high degree of confidence in the survey results and their interpretation for EM302 and POS MV configurations.

4. If the primary (V5) POS MV becomes unsuitable for multibeam operations, the EM302 will need to be calibrated using the secondary (V4) POS MV through a similar process; the results determined during this SAT, using the primary (V5) POS MV as the primary feed to the EM302, do not directly apply for the secondary (V4) system.

5. In addition to calibration, EM302 data were collected for deep and shallow accuracy assessments over existing reference surfaces; RX noise testing; and swath coverage analysis during transits offshore and back to Seattle.
6. Swath accuracy assessments were conducted over existing reference surfaces in deep and shallow environments using a total of seven operational settings; results indicate expected, acceptable performance, with some attention required for sound speed corrections during upcoming survey operations.

7. Refraction artifacts were evident in all accuracy crossline data, requiring manual adjustment of the sound speed profiles in order to suppress swath-wide trends due to refraction errors and better isolate the distribution of soundings representing echosounder-level performance.

8. The root cause of these refraction artifacts is not fully understood; additional testing should include simultaneous CTD and XBT casts, with comparison to the flow-through surface sound speed sensor to identify any discrepancies.

9. Transit data collected on and off the continental shelf were used to establish baseline swath width performance, with expected and acceptable results over the TN-347 depth range of 5-2450 m; data collected during the transit from WA to NZ added considerably to the baseline performance curve through depths up to ~6500 m, indicating expected performance.

10. TX Channel BISTs (a proxy for transmitter element impedance) indicate an open circuit condition for TX Slot 9, Ch. 6; this is not expected to compromise performance but should be investigated with Kongsberg support.
11. A series of tests were conducted to identify sources of shipboard noise that could potentially negatively impact EM302 performance; these tests and results are reported separately by Gates Acoustics Services.

12. Troubleshooting during the SAT identified a faulty cable pin connector on the cable leading into RX board 4; Chuck Hohing and Kongsberg corrected the issue after TN-347, as shown in the RX Channels BIST results.

13. The POS MV and EM302 configurations outlined in this report and appendices should be maintained until any sensors are modified; the post-TN-347 configurations have been exported to the local machines on board and backed up by the MAC in case of future need.

14. The baseline performance of the EM302 aboard TGT appears to meet or exceed that of other EM302s evaluated by the MAC; it is suggested that routine (e.g., annual or opportunistic) assessments will help to ensure high-quality data collection throughout its service life.

15. The MAC is available by email any time at mac-help@unols.org to assist with multibeam-related questions and planning for future data quality assessments.
Appendix 1: Post-TN347 EM302 Configuration
Appendix 1: Post-TN347 EM302 Configuration
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Appendix 1: Post-TN347 EM302 Configuration
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Appendix 1: Post-TN347 EM302 Configuration
Appendix 1: Post-TN347 EM302 Configuration

![Installation parameters screenshot](image)

- **Clock Setup**
  - **Source**: External ZDA Clock
  - **Offset (sec.)**: 0
  - **1PPS Clock Synchronisation**: Falling Edge
Appendix 1: Post-TN347 EM302 Configuration
Appendix 1: Post-TN347 EM302 Configuration
Appendix 1: Post-TN347 EM302 Configuration
Appendix 1: Post-TN347 EM302 Configuration
Appendix 2: Post-TN347 POS MV V5 Configuration
### Appendix 2: Post-TN347 POS MV V5 Configuration

![POS MV V5 Configuration Screen](image)

<table>
<thead>
<tr>
<th>Status</th>
<th>Accuracy</th>
<th>Attitude</th>
<th>Accuracy (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>POS Mode: Nav: Full</td>
<td>Attitude</td>
<td>Roll (deg)</td>
<td>0.730</td>
</tr>
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<td>IMU Status: OK</td>
<td>Heading</td>
<td>Pitch (deg)</td>
<td>0.231</td>
</tr>
<tr>
<td>Nav Status: Marinestar GNSS G</td>
<td>Position</td>
<td>Heading (deg)</td>
<td>93.648</td>
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<tr>
<td>GAMS Online</td>
<td>Velocity</td>
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<td></td>
</tr>
<tr>
<td>Ethernet Log: Idle</td>
<td>Heave</td>
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<tr>
<td>Disk Status: Idle</td>
<td>Speed (knots): 13.090</td>
<td>Track (deg): 91.886</td>
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</tr>
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<td>Disk Usage: 0%</td>
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</table>

<table>
<thead>
<tr>
<th>Position</th>
<th>Velocity</th>
<th>Accuracy (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude: 48°11′55.0476″ N</td>
<td>North (m/s): -0.222</td>
<td>Accuracy (m): 0.223</td>
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<td>Longitude: 123°05′41.7900″ W</td>
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<td>Altitude (m): -18.814</td>
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<table>
<thead>
<tr>
<th>Dynamics</th>
<th>Events</th>
<th>Time</th>
<th>Count</th>
</tr>
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<tbody>
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<tr>
<td>Transverse: 0.009</td>
<td>Event 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical: 0.013</td>
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</tr>
<tr>
<td>Accel. (m/s²): -0.037</td>
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<tr>
<td></td>
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<td></td>
<td></td>
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</tbody>
</table>
Appendix 2: Post-TN347 POS MV V5 Configuration

![POS MV V5 Configuration Interface]

<table>
<thead>
<tr>
<th>Status</th>
<th>Accuracy</th>
<th>Attitude</th>
<th>Accuracy (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>POS Mode</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Nav</td>
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<td></td>
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</tr>
<tr>
<td>IMU Status</td>
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</tr>
<tr>
<td>GAMS</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ethernet Log</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Disk Status</td>
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<td></td>
<td></td>
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<tr>
<td>Disk Usage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Position</td>
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</tr>
<tr>
<td>Latitude</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Longitude</td>
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<tr>
<td>Altitude (m)</td>
<td>-19.476</td>
<td>0.214</td>
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<td>Dynamics</td>
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<tr>
<td>Angular Rate (deg/s)</td>
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</tr>
<tr>
<td>Longitudinal</td>
<td>-0.112</td>
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</tr>
<tr>
<td>Transverse</td>
<td>0.144</td>
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<tr>
<td>Vertical</td>
<td>-0.070</td>
<td>-0.124</td>
<td></td>
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<tr>
<td>Dynamics</td>
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<td></td>
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</tr>
<tr>
<td>Accel. (m/s²)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Events**
  - Event 1
  - Time: 14:51:42.000000 UTC
  - Count: 1359874
  - Event 2
  - Time: 14:51:42.000000 UTC
  - Count: 1359874

![Statistics]

- **Statistics**
  - POS Version: MV-320 VER6.5N88017, HW1 1-12.5W09.29-5Eu2017.JCD09 27.056 4.1.1.MU64 POS6.17.5G16.17.HT101
  - Accuracy (m/s): 0.026
  - Accuracy (deg): 0.021

- **Options**
  - RTK/0, DPW-0

![Monitor]

- **Monitor Details**
  - 2018-01-12 14:51:45 UTC
  - 14:52:03 GPS
Appendix 2: Post-TN347 POS MV V5 Configuration

<table>
<thead>
<tr>
<th>Status</th>
<th>Accuracy</th>
<th>Attitude</th>
<th>Roll (deg)</th>
<th>Pitch (deg)</th>
<th>Accuracy (deg)</th>
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<tbody>
<tr>
<td>POS Mode</td>
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<tr>
<td>Nav Status</td>
<td>Marinestar GNSS GPS</td>
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</tr>
<tr>
<td>GAMS</td>
<td>Online</td>
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<tr>
<td>Ethernet Log</td>
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<td>Disk Status</td>
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<td>Disk Usage</td>
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<td>Position</td>
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<td>Latitude</td>
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<td>123°02′28.408″ E</td>
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