U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service

Data Acquisition & Processing Report

Type of Survey:	Navigable Area
Project Number:	OPR-R341-KR-19
Time Frame:	June - August 2019

LOCALITY

State(s):	Alaska
General Locality:	Kuskokwim Bay, AK

2019

CHIEF OF PARTY
Andrew Orthmann

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Table of Contents

List of Figures

Data Acquisition and Processing Report

Terrasond, Ltd.
Chief of Party: Andrew Orthmann
Year: 2019
Version: 1
Publish Date: 2019-12-10

A. System Equipment and Software

A.1 Survey Vessels

A.1.1 Qualifier 105 (Q105)

<table>
<tr><td>Vessel Name</td><td>Qualifier 105 (Q105)</td></tr>
<tr><td>Hull Number</td><td>338192000 (MMSI)</td></tr>
<tr><td>Description</td><td>The Q105 is a 105' aluminum-hulled vessel that is owned and operated by Support Vessels of Alaska (SVA). It is home-ported in Homer, Alaska and has been chartered by TerraSond every year since 2013 to complete NOAA task orders as well as other projects along the Alaska coast.

The Q105 carries a USCG COI (200-mile offshore). It is powered by three Detroit D-60 diesel engines and has a 4,000 nautical mile endurance. Features include a 6-ton deck crane, A-frame, davit, survey skiff, and hydraulic over-the-side MBES arm.

On this project, the Q105 surveyed as the primary survey platform, housing all staff and operating on a 24/7 schedule. It was used to collect MBES data including sound speed profiles, deploy offshore tide gauges, collect bottom samples, and deploy/operate the ASV-CW5 vessel. Preliminary (field) data processing was also completed aboard the vessel.</td></tr>
<tr><td>Dimensions</td><td><table><tr><td>LOA</td><td>32 meters</td></tr><tr><td>Beam</td><td>9.1 meters</td></tr><tr><td>Max Draft</td><td>1.8 meters</td></tr></table></td></tr>
<tr><td>Most Recent Full Static Survey</td><td><table><tr><td>Date</td><td>2019-03-23</td></tr><tr><td>Performed By</td><td>TerraSond</td></tr></table></td></tr>
<tr><td>Most Recent Full Offset Verification</td><td><table><tr><td>Date</td><td>2019-06-30</td></tr><tr><td>Method</td><td>Taped applicable offsets</td></tr></table></td></tr>
</table>

Figure 1: The Qualifier 105 (RV). Sand Point, Alaska, 2017.

A.1.2 ASV-CW5 (ASV)

<table>
<tr><td>Vessel Name</td><td>ASV-CW5 (ASV)</td></tr>
<tr><td>Hull Number</td><td>CW76</td></tr>
<tr><td>Description</td><td>The 18' (5.5 m) aluminum-hulled vessel ASV-CW5 (model number CW76), owned and operated by L3Harris ASV, was used to acquire MBES data on this project. The vessel has been used by TerraSond on NOAA task orders in Alaska each year since 2016.

The unmanned vessel is propelled by a single 57 HP Yanmar diesel engine. Once deployed from the larger vessel it was operated in an "unmanned-but-monitored" mode, at ranges of up to 3 km from the larger vessel. It collected MBES data on lines parallel to the Q105 and also surveyed the shallower portions of the survey areas. The vessel worked a 24/7 schedule with an endurance of approximately 4-5 days between refueling.</td></tr>
<tr><td>Dimensions</td><td><table><tr><td>LOA</td><td>5.5 meters</td></tr><tr><td>Beam</td><td>1.7 meters</td></tr><tr><td>Max Draft</td><td>0.9 meters</td></tr></table></td></tr>
<tr><td>Most Recent Full Static Survey</td><td><table><tr><td>Date</td><td>2019-06-29</td></tr><tr><td>Performed By</td><td>TerraSond</td></tr></table></td></tr>
</table>

Most Recent Full Offset Verification	*Date*	2019-06-29
	Method	Taped applicable offsets

Figure 2: ASV-CW5 south of Nunivak Island, Alaska. July, 2019.

A.2 Echo Sounding Equipment

A.2.1 Multibeam Echosounders

A.2.1.1 Teledyne Reson Seabat 7125

A Teledyne Reson Seabat 7125 was used on the ASV-CW5 for multibeam echosounder (MBES) data collection.

The system has three primary components: A transmit (Tx) array, a receive (Rx) array, and a topside processor. On this vessel the wet-end components were hull-mounted on the vessel's keel, approximately midship. Specifications are as follows.

Sonar Operating Frequency: 200 or 400 kHz (400 used this project)
Along Track Transmit Beamwidth: 1 degrees (at 400 kHz)
Across Track Receive Beamwidth: 0.5 degrees (at 400 kHz)
Max Ping Rate: 50 p/s (normally 10 p/s used on this project)
Pulse Length: 30 to 300 microseconds (normally 50-100 used on this project)
Number of Beams: Up to 512 at 400 kHz (512 used on this project)
Max Swath Angle: 140 degrees (at 400 kHz)
Depth Range: 0.5 - 150 m (at 400 kHz)
Depth Resolution: 0.006 m

Accuracy checks on the 7125 MBES included the following items.

1. Echosounder comparisons: Formal comparisons with the Reson 7101 system installed on the Q105 vessel were completed on a regular basis. Gridded data from the two independent systems were analyzed with difference surface methodology and showed them to be in good agreement with each other, agreeing to 0.035 m on average, with a standard deviation of 0.131 m.

2. Crossline comparisons: Crosslines originating with the 7125 compared to mainscheme 7125 (as well as 7101 from the Q105) data to well within IHO Order 1a specifications.

A formal barcheck or leadline was not completed for this sonar due to the difficulty inherent with the procedure on the unmanned vessel. Good agreement with the 7101 on Q105--which did receive a barcheck--was considered to be an adequate accuracy check.

Echosounder comparisons are available in Appendix V. Crossline results are available in each project DR.

<table>
<tr><td>Manufacturer</td><td colspan="5">Teledyne Reson</td></tr>
<tr><td>Model</td><td colspan="5">Seabat 7125</td></tr>
<tr><td rowspan="6">Inventory</td><td rowspan="6">ASV-CW5</td><td>Component</td><td>Topside</td><td>Tx Array</td><td>Rx Array</td></tr>
<tr><td>Model Number</td><td>7125-P</td><td>7125 Tx</td><td>7125 Rx</td></tr>
<tr><td>Serial Number</td><td>18340413031</td><td>4912143</td><td>1713124</td></tr>
<tr><td>Frequency</td><td>n/a</td><td>400 kHz</td><td>n/a</td></tr>
<tr><td>Calibration</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Accuracy Check</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
</table>

A.2.1.2 Teledyne Reson Seabat 7101

A Teledyne Reson Seabat 7101 (with ER projector) was used on the Q105 for multibeam echosounder (MBES) data collection.

The system has two primary components: A transducer sonar head and a topside processor. On this vessel the wet-end components were mounted on a hydraulic arm on the vessel's port side, approximately midship. Specifications are as follows.

Sonar Operating Frequency: 240 kHz
Along-Track Transmit Beamwidth: 1.5 degrees
Across-Track Receive Beamwidth: 1.8 degrees
Max Ping Rate: 40 p/s (normally 10 p/s used on this project)
Pulse Length: 21 to 225 microseconds (normally 50-100 on this project)
Number of Beams: 101 to 511 (511 used on this project)
Max Swath Angle: 150 degrees
Depth Range: 0.5 - 500 m (with ER projector)
Depth Resolution: 0.015 m

Accuracy checks on the 7101 MBES included the following items.

1. A bar check: A formal bar check completed on JD184 and yielded excellent results. Mean echosounder agreement (with vessel offsets applied) to the actual bar depth was 0.030 m for real-time data and 0.007 m for processed results.

2. Echosounder comparisons: Formal comparisons with the Reson 7125 system installed on the ASV-CW5 vessel were completed on a regular basis. Gridded data from the two independent systems were analyzed with difference surface methodology and showed them to be in good agreement with each other, agreeing to 0.035 m on average, with a standard deviation of 0.131 m.

3. Crossline comparisons: Crosslines originating with the 7101 compared to mainscheme 7101 (as well as 7125 from the ASV-CW5) data to well within IHO Order 1a specifications.

4. Two lead line checks on JD234 returned differences from the MBES nadir depth of 0.188 and 0.026 m, results which were deemed acceptable given the variables associated with lead line checks.

Depth checks including bar check and echosounder comparisons are available in Appendix V. Crossline results are available in each project DR.

<table>
<tr><td>Manufacturer</td><td colspan="4">Teledyne Reson</td></tr>
<tr><td>Model</td><td colspan="4">Seabat 7101</td></tr>
<tr><td rowspan="6">Inventory</td><td rowspan="6">Qualifier 105</td><td>Component</td><td>Topside</td><td>Transducer</td></tr>
<tr><td>Model Number</td><td>7101-P</td><td>7101</td></tr>
<tr><td>Serial Number</td><td>18290413019</td><td>1301045</td></tr>
<tr><td>Frequency</td><td>n/a</td><td>240 kHz</td></tr>
<tr><td>Calibration</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Accuracy Check</td><td>N/A</td><td>2019-07-03</td></tr>
</table>

A.2.2 Single Beam Echosounders

No single beam echosounders were utilized for data acquisition.

A.2.3 Side Scan Sonars

No side scan sonars were utilized for data acquisition.

A.2.4 Phase Measuring Bathymetric Sonars

No phase measuring bathymetric sonars were utilized for data acquisition.

A.2.5 Other Echosounders

No additional echosounders were utilized for data acquisition.

A.3 Manual Sounding Equipment

A.3.1 Diver Depth Gauges

No diver depth gauges were utilized for data acquisition.

A.3.2 Lead Lines

No lead lines were utilized for data acquisition.

A.3.3 Sounding Poles

No sounding poles were utilized for data acquisition.

A.3.4 Other Manual Sounding Equipment

No additional manual sounding equipment was utilized for data acquisition.

A.4 Horizontal and Vertical Control Equipment

A.4.1 Base Station Equipment

No base station equipment was utilized for data acquisition.

A.4.2 Rover Equipment

No rover equipment was utilized for data acquisition.

A.4.3 Water Level Gauges

A.4.3.1 Cape Pierce: Sea-Bird Scientific SBE26+, Sea-Bird Scientific SBE37SMP, RBR solo3D, HOBO U20L-04, Septentrio Sepchoke, Septentrio PolaRx5

Water Level Measurement Gauge located at Cape Pierce

Manufacturer	Cape Pierce:
Model	Sea-Bird Scientific SBE26+, Sea-Bird Scientific SBE37SMP, RBR solo3D, HOBO U20L-04, Septentrio Sepchoke, Septentrio PolaRx5

Inventory

Component	Tide Gauge	Conductivity	Tide Gauge	Barometer	GNSS Antenna	GNSS Antenna
Model Number	SBE26+	SBE37SMP	solo3D	U20L-04	Sepchoke	PolaRx5
Serial Number	1049	03711494	201780	2061872	5614	4502788
Calibration	2019-05-17	2019-05-30	2019-05-13	N/A	N/A	N/A

A.4.3.2 Port Moller: Sea-Bird Scientific SBE26+, Sea-Bird Scientific 4M, HOBO U20, Septentrio PolaRx5, NexSens CB-150 buoy hull

Water Level Measurement Gauge located at Port Moller

Manufacturer	Port Moller:
Model	Sea-Bird Scientific SBE26+, Sea-Bird Scientific 4M, HOBO U20, Septentrio PolaRx5, NexSens CB-150 buoy hull

Inventory

Component	Tide Gauge	Tide Gauge	Conductivity Sensor	Barometer	GNSS Antenna	GNSS Receiver	Floatation of GNSS
Model Number	SBE26+	SBE26+	4M	U20	PolaNt-x	PolaRx5	CB-150 buoy hull
Serial Number	0219	0188	41924	20183154	15531	3047773	N/A
Calibration	2018-04-16	2018-07-05	2018-06-22	N/A	N/A	N/A	N/A

A.4.3.3 Naknek: DAA H350XL, DAA H-522, DAA H-355

Water Level Measurement Gauge located at Naknek

<table>
<tr><td>Manufacturer</td><td>Naknek:</td></tr>
<tr><td>Model</td><td>DAA H350XL, DAA H-522, DAA H-355</td></tr>
<tr><td>Inventory</td><td>
<table>
<tr><td>Component</td><td>Tide Gauge</td><td>Tide Gauge</td><td>GOES Transmitter</td><td>GOES Transmitter</td><td>Pump for DCP</td><td>Pump for DCP</td></tr>
<tr><td>Model Number</td><td>H350XL</td><td>H350XL</td><td>H-522</td><td>H-522</td><td>H-355</td><td>H-355</td></tr>
<tr><td>Serial Number</td><td>1043</td><td>1353</td><td>N/A</td><td>1238</td><td>5568</td><td>1801</td></tr>
<tr><td>Calibration</td><td>2019-05-15</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
</table>
</td></tr>
</table>

A.4.3.4 Kulukak Point: RBR solo3D, Sea-bird Scientific SBE26+, Sea-Bird Scientific SBE37SMP, Septentrio Sepchoke, Septentrio PolaRx, HOBO U20L-04

Water Level Measurement Gauge located at Kulukak Point

<table>
<tr><td>Manufacturer</td><td>Kulukak Point:</td></tr>
<tr><td>Model</td><td>RBR solo3D, Sea-bird Scientific SBE26+, Sea-Bird Scientific SBE37SMP, Septentrio Sepchoke, Septentrio PolaRx, HOBO U20L-04</td></tr>
<tr><td>Inventory</td><td>
<table>
<tr><td>Component</td><td>Water Level Measurement</td><td>Water Level Measurement</td><td>Conductivity Sensor</td><td>GNSS Antenna</td><td>GNSS Reciever</td><td>Barometer</td></tr>
<tr><td>Model Number</td><td>solo3D</td><td>SBE26+</td><td>SBE37SMP</td><td>Sepchoke</td><td>PolaRx</td><td>U20L-04</td></tr>
<tr><td>Serial Number</td><td>201779</td><td>0189</td><td>013711496</td><td>5610</td><td>3048310</td><td>20618763</td></tr>
<tr><td>Calibration</td><td>2019-05-13</td><td>2019-05-19</td><td>2019-05-22</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
</table>
</td></tr>
</table>

A.4.3.5 Levelock: Sutron Xpert, Paros 6000-30G, Sutron Satlink, DAA H-355

Water Level Measurement Gauge located at Levelock

<table>
<tr><td>Manufacturer</td><td>Levelock:</td></tr>
<tr><td>Model</td><td>Sutron Xpert, Paros 6000-30G, Sutron Satlink, DAA H-355</td></tr>
<tr><td>Inventory</td><td>
<table>
<tr><td>Component</td><td>Water Level Measurement</td><td>Water Level Measurement</td><td>Paros</td><td>Paros</td><td>GOES Transmitter</td><td>Pump for DCP</td><td>Pump for DCP</td></tr>
<tr><td>Model Number</td><td>Xpert</td><td>Xpert</td><td>6000-30G</td><td>6000-30G</td><td>Satlink</td><td>H-355</td><td>H-355</td></tr>
<tr><td>Serial Number</td><td>N/A</td><td>N/A</td><td>100336</td><td>121287</td><td>N/A</td><td>5593</td><td>5598</td></tr>
<tr><td>Calibration</td><td>N/A</td><td>N/A</td><td>2019-03-21</td><td>2019-03-21</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
</table>
</td></tr>
</table>

A.4.3.6 Ishkowik River Entrance: DAA 350XL, DAA H-222, DAA H355

Water Level Measurement Gauge located at Ishkowik River Entrance

Manufacturer	Ishkowik River Entrance:
Model	DAA 350XL, DAA H-222, DAA H355
Inventory	(see below)

Component	Water Level Measurement	Water Level Measurement	GOES Transmitter	GOES Transmitter	Pump for DCP	Pump for DCP
Model Number	350XL	350XL	H-222	H-222	H355	H355
Serial Number	1635	5449	3804	1085	2877	2869
Calibration	2019-03-22	2019-03-29	N/A	N/A	N/A	N/A

A.4.3.7 Cape Mendenhall: Sea-Bird Scientific SBE26+, Sea-Bird Scientific SBE37SMP, AML Cxchange, AML Txchange, HOBO U20

Water Level Measurement Gauge located at Cape Mendenhall

Manufacturer	Cape Mendenhall:
Model	Sea-Bird Scientific SBE26+, Sea-Bird Scientific SBE37SMP, AML Cxchange, AML Txchange, HOBO U20
Inventory	(see below)

Component	Water Level Measurement	Water Level Measurement	Conductivity Sensor	Conductivity Sensor	Temperature Sensor	Barometer
Model Number	SBE26+	SBE26+	SBE37SMP	Cxchange	Txchange	U20
Serial Number	1155	1156	037-11493	450408	450408	20599096
Calibration	2019-04-28	2019-04-28	2019-05-31	N/A	N/A	N/A

A.4.3.8 SW Kuskokwim Bay: Sea-Bird Scientific SBE26+, Sea-Bird Scientific SBE37SMP, AML Cxchange, AML Txchange, HOBO U20

Water Level Measurement Gauge located at SW Kuskokwim Bay

<table>
<tr><td>Manufacturer</td><td>SW Kuskokwim Bay:</td></tr>
<tr><td>Model</td><td>Sea-Bird Scientific SBE26+, Sea-Bird Scientific SBE37SMP, AML Cxchange, AML Txchange, HOBO U20</td></tr>
<tr><td>Inventory</td><td>
<table>
<tr><td>Component</td><td>Water Level Measurement</td><td>Water Level Measurement</td><td>Conductivity Sensor</td><td>Conductivity Sensor</td><td>Temperature Sensor</td><td>Barometer</td></tr>
<tr><td>Model Number</td><td>SBE26+</td><td>SBE26+</td><td>SBE37SMP</td><td>Cxchange</td><td>Txchange</td><td>U20</td></tr>
<tr><td>Serial Number</td><td>1158</td><td>1120</td><td>037-11495</td><td>450425</td><td>450425</td><td>N/A</td></tr>
<tr><td>Calibration</td><td>2019-04-28</td><td>2019-04-28</td><td>2018-04-11</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
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</td></tr>
</table>

A.4.3.9 Cape Corwin: Septentrio AsteRx-SB, Septentrio PolaNT-x MF

GNSS Tide Buoy located at Cape Corwin

<table>
<tr><td>Manufacturer</td><td>Cape Corwin:</td></tr>
<tr><td>Model</td><td>Septentrio AsteRx-SB, Septentrio PolaNT-x MF</td></tr>
<tr><td>Inventory</td><td>
<table>
<tr><td>Component</td><td>GNSS Reciever</td><td>GNSS Antenna</td></tr>
<tr><td>Model Number</td><td>AsteRx-SB</td><td>GNSS Antenna</td></tr>
<tr><td>Serial Number</td><td>5101175</td><td>15531</td></tr>
<tr><td>Calibration</td><td>N/A</td><td>N/A</td></tr>
</table>
</td></tr>
</table>

A.4.4 Levels

No levels were utilized for data acquisition.

A.4.5 Other Horizontal and Vertical Control Equipment

No other equipment were utilized for data acquisition.

A.5 Positioning and Attitude Equipment

A.5.1 Positioning and Attitude Systems

A.5.1.1 Applanix POSMV Wavemaster II

Applanix POSMV Wavemaster II systems were used on both survey vessels to provide positioning and attitude data.

The primary components of each system are two GNSS antennas, a IP68-rated (submersible) inertial measurement unit (IMU), and a topside processor. On each vessel, the POSMV IMU was co-located with the MBES sonar as closely as possible and the GNSS antennas were mounted in locations that gave a clear view of the sky.

On the Q105, the POSMV utilized firmware version SW09.96-Oct03/18. The ASV firmware version SW09.03-Nov21/16. POSView version 9.02 was used as the POSMV interface on both vessels.

For each system, calibrations consisted of an initial GAMS (GPS-azimuth measurement subsystem) calibration and alignment with the MBES frame of reference via standard patch test methodology.

<table>
<tr><td>Manufacturer</td><td colspan="6">Applanix</td></tr>
<tr><td>Model</td><td colspan="6">POSMV Wavemaster II</td></tr>
<tr><td rowspan="8">Inventory</td><td rowspan="4">Qualifier 105</td><td>Component</td><td>IMU</td><td>Processor</td><td>GNSS Antenna 1</td><td>GNSS Antenna 2</td></tr>
<tr><td>Model Number</td><td>Type 82</td><td>Wavemaster II</td><td>AT1675-540TS</td><td>AT1675-540TS</td></tr>
<tr><td>Serial Number</td><td>4862_18250177</td><td>10095</td><td>13945</td><td>13946</td></tr>
<tr><td>Calibration</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="4">ASV-CW5</td><td>Component</td><td>IMU</td><td>Processor</td><td>GNSS Antenna 1</td><td>GNSS Antenna 2</td></tr>
<tr><td>Model Number</td><td>Type 45</td><td>Wavemaster II</td><td>AT1675-540TS</td><td>AT1675-540TS</td></tr>
<tr><td>Serial Number</td><td>3171</td><td>7793</td><td>9857</td><td>9861</td></tr>
<tr><td>Calibration</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
</table>

A.5.2 DGPS

A.5.2.1 Hemisphere AtlasLink

Each survey vessel was outfit with a Hemisphere AtlasLink receiver to provide real-time GNSS corrections to the vessel POSMV.

Both AtlasLink receivers used firmware version 5.3.10.

In all cases the real-time correctors from these units were replaced for final deliverables through application of post-processed kinematic (PPK) SBET data from Applanix POSPac, as described elsewhere in this report.

<table>
<tr><td>Manufacturer</td><td colspan="3">Hemisphere</td></tr>
<tr><td>Model</td><td colspan="3">AtlasLink</td></tr>
<tr><td rowspan="8">Inventory</td><td rowspan="4">Qualifier 105</td><td>Component</td><td>Antenna</td></tr>
<tr><td>Model Number</td><td>AtlasLink</td></tr>
<tr><td>Serial Number</td><td>18918172</td></tr>
<tr><td>Calibration</td><td>N/A</td></tr>
<tr><td rowspan="4">ASV-CW5</td><td>Component</td><td>Antenna</td></tr>
<tr><td>Model Number</td><td>AtlasLink</td></tr>
<tr><td>Serial Number</td><td>18918133</td></tr>
<tr><td>Calibration</td><td>N/A</td></tr>
</table>

A.5.3 GPS

GPS equipment was not utilized for data acquisition.

A.5.4 Laser Rangefinders

Laser rangefinders were not utilized for data acquisition.

A.5.5 Other Positioning and Attitude Equipment

No additional positioning and attitude equipment was utilized for data acquisition.

A.6 Sound Speed Equipment

A.6.1 Moving Vessel Profilers

A.6.1.1 Teledyne Oceanscience RapidCast

A Teledyne Oceanscience RapidCast system was used on the Q105 to deploy a sound speed profiler while underway during survey operations.

The system utilized RapidCast Interface Software V1.5.1 for configuring and controlling the system.

The ASV-CW5 was not equipped with a sound speed profiling system.

Manufacturer	Teledyne Oceanscience		
Model	RapidCast		
Inventory	*Qualifier 105*	*Component*	Sound Speed Deployment Winch
		Model Number	RapidCast
		Serial Number	147
		Calibration	N/A

Figure 3: RapidCast system in use on the Q105.

A.6.2 CTD Profilers

No CTD profilers were utilized for data acquisition.

A.6.3 Sound Speed Sensors

A.6.3.1 Valeport rapidPro SVT Sound Speed Profiler

A Valeport rapidPro SVT was used on the Q105 to collect sound speed profiles on this project.

The sensor, which was designed to be used with the Oceanscience RapidCast deployment system, features a relatively fast measurement rate (32 Hz) to adequately sample sound speed through the water column when dropping at rates of up to 5 meters per second.

A second rapidPro SVT was kept aboard as a spare. Use of the spare profiler was not necessary during this project and it was therefore not used to correct survey data. However, it was used periodically as a check on the primary sensor as discussed in the Data Quality Management section of this report.

Valeport RapidSV Interface software (version 1.0.5.9) was used to interface with and download data from the sensors.

SVP comparisons between the two sensors are available with the project DRs. Calibration reports are available in Appendix II.

<table>
<tr><td>Manufacturer</td><td colspan="4">Valeport</td></tr>
<tr><td>Model</td><td colspan="4">rapidPro SVT Sound Speed Profiler</td></tr>
<tr><td rowspan="4">Inventory</td><td rowspan="4">Qualifier 105</td><td>Component</td><td>Sound Speed Profiler (primary)</td><td>Sound Speed Profiler (spare/ check)</td></tr>
<tr><td>Model Number</td><td>rapidPro SVT</td><td>rapidPro SVT</td></tr>
<tr><td>Serial Number</td><td>71027</td><td>71026</td></tr>
<tr><td>Calibration</td><td>2019-06-06</td><td>2019-06-06</td></tr>
</table>

A.6.4 TSG Sensors

A.6.4.1 AML Oceanographic Micro-X with SV-XChange Surface Sound Speed Sensor

Both vessels utilized AML Oceanographic sound speed sensors to measure sound speed at the multibeam sonar heads. This data stream was interfaced directly with the Reson MBES system to provide sound speed for beam-forming purposes.

Each sensor consisted of an AML Micro-X housing with a SV-XChange sensor tip. In these systems, the sensor tip (not the housing) carries the calibration.

As a QC check, during each sound speed profile cast the value reported by the surface speed sensor aboard the Q105 was noted in the acquisition log for comparison with the sound speed profile's value at the same depth. These compared well, with the mean difference of 0.13 m/s with a standard deviation of 0.50 m/s. Results are available with each project DR.

<table>
<tr><td>Manufacturer</td><td colspan="4">AML Oceanographic</td></tr>
<tr><td>Model</td><td colspan="4">Micro-X with SV-XChange Surface Sound Speed Sensor</td></tr>
<tr><td rowspan="8">Inventory</td><td rowspan="4">Qualifier 105</td><td>Component</td><td>Surface Sound Speed Sensor - Housing</td><td>Surface Sound Speed Sensor - Sensor</td></tr>
<tr><td>Model Number</td><td>Micro-X</td><td>SV-XChange</td></tr>
<tr><td>Serial Number</td><td>10873</td><td>207522</td></tr>
<tr><td>Calibration</td><td>N/A</td><td>2019-02-13</td></tr>
<tr><td rowspan="4">ASV-CW5</td><td>Component</td><td>Surface Sound Speed Sensor - Housing</td><td>Surface Sound Speed Sensor - Sensor</td></tr>
<tr><td>Model Number</td><td>Micro-X</td><td>SV-XChange</td></tr>
<tr><td>Serial Number</td><td>11980</td><td>207548</td></tr>
<tr><td>Calibration</td><td>N/A</td><td>2019-02-13</td></tr>
</table>

A.6.5 Other Sound Speed Equipment

No surface sound speed sensors were utilized for data acquisition.

A.7 Computer Software

Manufacturer	*Software Name*	*Version*	*Use*
QPS	QINSy	8.18.3	Acquisition
Teledyne Reson	7k Sonar UI	4.5.10.9 (Q105), 6.2.0.26 (ASV)	Acquisition
Sea Bird	Sea-Bird Seasoft	2.0	Acquisition
Teledyne Oceanscience	RapidCAST Interface	1.5.1	Acquisition
Applanix	POSView	9.02	Acquisition
L3Harris-ASV	ASView	2019	Acquisition
Valeport	RapidSV Interface	1.0.5.9	Acquisition
Applanix	POSPac MMS	8.3.6925.32723	Processing
NOAA/UNH/CCOM	Sound Speed Manager	2019.1.2	Processing
Teledyne CARIS	HIPS & SIPS	10.4.16	Processing
ESRI	ArcGIS ArcMap	10.2.1	Processing
QPS	Fledermaus FMGT	7.9.0	Processing
NOAA	Pydro	19.4	Processing

A.8 Bottom Sampling Equipment

A.8.1 Bottom Samplers

A.8.1.1 Wildco Petite Ponar Stainless Steel Grab

A Wildco Petite Ponar Stainless Steel grab sampler was used aboard the Q105 for grab samples. The 2400 mL volume sampler was manually lowered to the ocean bottom at assigned locations to obtain samples that assisted with determining the nature of the seafloor.

B. System Alignment and Accuracy

B.1 Vessel Offsets and Layback

B.1.1 Vessel Offsets

For this project, the top-center of the Applanix POSMV IMU served as the Central Reference Point (CRP) on each vessel.

The IMU was co-located as closely as possible with the sonar heads. On the Q105 this resulted in the IMU being submerged on the same mounting arm as the MBES, and on the ASV the IMU was mounted inside the vessel directly on the keel, just above the MBES head.

The co-location of the CRP and MBES sonars greatly reduced the complexity of the vessel surveys, which were completed with measuring tape methods on June 28, 2019 on the ASV and July 2nd, 2019 on the Q105.

Offset from the CRP down to the MBES was measured directly by tape to a physical point on the sonar, from where the manufacturer-provided acoustic center offsets provided in the system user manuals were applied.

Offset from the CRP up to the static draft (measure-down) point--or point from where draft measurements would be made--was also measured directly by tape.

Offset from the CRP up to the POSMV antennas were also directly measured by tape on the ASV. On the Q105, which had a large POSMV lever arm, a value derived by laser scanner in March 2019 was used initially but refined following mobilization using Applanix POSPac software.

Note that per CARIS Technical Bulletin "HIPS and SIPS Technical Note Sound Velocity Correction for Teledyne Reson 7k Data", the HVF files for the 7101 and 7125 MBES systems were configured as dual-head with separate Rx and Tx array offsets even though they were physically single-head systems. The offsets for the separate Rx and Tx acoustic centers were derived from the user manuals for the systems.

Refer to Appendix III for vessel offset survey results.

B.1.1.1 Vessel Offset Correctors

<table>
<tr><td>Vessel</td><td colspan="4">Qualifier 105</td></tr>
<tr><td>Echosounder</td><td colspan="4">Teledyne Reson SeaBat 7101 MBES</td></tr>
<tr><td>Date</td><td colspan="4">2019-07-02</td></tr>
<tr><td rowspan="15">Offsets</td><td rowspan="7">MRU to Transducer</td><td></td><td>Measurement</td><td>Uncertainty</td></tr>
<tr><td>x</td><td>-0.019 meters</td><td>0.010 meters</td></tr>
<tr><td>y</td><td>-0.006 meters</td><td>0.010 meters</td></tr>
<tr><td>z</td><td>0.460 meters</td><td>0.020 meters</td></tr>
<tr><td>x2</td><td>-0.019 meters</td><td>0.010 meters</td></tr>
<tr><td>y2</td><td>0.289 meters</td><td>0.010 meters</td></tr>
<tr><td>z2</td><td>0.376 meters</td><td>0.020 meters</td></tr>
<tr><td rowspan="6">Nav to Transducer</td><td>x</td><td>-0.019 meters</td><td>0.010 meters</td></tr>
<tr><td>y</td><td>-0.006 meters</td><td>0.010 meters</td></tr>
<tr><td>z</td><td>0.460 meters</td><td>0.020 meters</td></tr>
<tr><td>x2</td><td>-0.019 meters</td><td>0.010 meters</td></tr>
<tr><td>y2</td><td>0.289 meters</td><td>0.010 meters</td></tr>
<tr><td>z2</td><td>0.376 meters</td><td>0.020 meters</td></tr>
<tr><td>Transducer Roll</td><td>Roll</td><td>0.000 degrees</td><td></td></tr>
</table>

Vessel	ASV-CW5			
Echosounder	Teledyne Reson SeaBat 7125			
Date	2019-06-28			
Offsets			*Measurement*	*Uncertainty*
	MRU to Transducer	*x*	0.000 meters	0.010 meters
		y	-0.557 meters	0.010 meters
		z	0.683 meters	0.010 meters
		x2	0.000 meters	0.010 meters
		y2	-0.377 meters	0.010 meters
		z2	0.707 meters	0.010 meters
	Nav to Transducer	*x*	0.000 meters	0.010 meters
		y	-0.557 meters	0.010 meters
		z	0.683 meters	0.010 meters
		x2	0.000 meters	0.010 meters
		y2	-0.377 meters	0.010 meters
		z2	0.707 meters	0.010 meters
	Transducer Roll	*Roll*	0.000 degrees	

B.1.2 Layback

Layback calculations are not applicable to this project.

Layback correctors were not applied.

B.2 Static and Dynamic Draft

B.2.1 Static Draft

Vessel static draft (waterline) measurements were taken to correct for the depth of the vessel’s sonars below the water level. Draft was measured when sea conditions were calm enough to obtain a high confidence value. Measurements were also taken whenever the potential to significantly change the draft was experienced, such as after fueling or adjustments in ballast.

On the Q105, a static draft ("measure-down") was recorded in the following manner: With the vessel at rest, a calibrated (corrected/checked by tape) plastic pole was used to measure the distance from a designated measure-down (MD) point to the water. The MD point was located on the vessel rail/gunwale directly above the CRP on the vessel's port side, midship.

On the ASV-CW5, the static draft was recorded in the following manner: Draft markings on the vessel's starboard side were visually examined when the vessel was alongside the Q105, and the value at their intersection with the water was noted. The draft marks represented the vertical distance from the MD point, which was the vessel's deck directly above the CRP.

For each vessel, the CRP to waterline correction value was computed by subtracting the above measurement from the known offset between the CRP and MD point. The resulting value was entered as a waterline offset in the CARIS HVF file. This value was always negative in this configuration since the CRP on both vessels was under the water level.

Note only initial corrections are shown below for each vessel due to the inability to include all values in the XML DAPR. However, the following images show all the waterline correction values entered into the CARIS HVF files for each vessel.

	Date	Time	Apply	Waterline (m)	Comments
1	2019-173	00:00	Yes	-1.558	Value from JD183 - SW Kuskokwim Bay BMPG deployment, predated to cover Homer post-mob seatrials & tests
2	2019-178	10:42	Yes	-1.558	pre-project Kulukak Pt BMPG deployment
3	2019-178	22:45	Yes	-1.568	pre-project Cape Pierce BMPG deployment
4	2019-183	22:48	Yes	-1.558	SW Kuskokwim Bay BMPG deployment
5	2019-184	02:27	Yes	-1.508	
6	2019-184	07:00	Yes	-1.458	Bar Check
7	2019-185	22:05	Yes	-1.508	Cape Mendenhall BMPG deployment
8	2019-185	23:52	Yes	-1.508	Cape Mendenhall BMPG deployment, 2nd check
9	2019-195	23:05	Yes	-1.508	
10	2019-196	23:50	Yes	-1.558	post fueling, Bethel
11	2019-198	23:10	Yes	-1.508	Cape Corwin GPS buoy deployment
12	2019-224	00:13	No	-1.428	not applied, noted as bad in acq log

Figure 4: CARIS HVF Waterlines from Static Draft Measurements - Q105

	Date	Time	Apply	Waterline (m)	Comments
1	2019-173	00:00	Yes	-0.215	Taken JD180 @ 23:30, predated here
2	2019-188	01:28	Yes	-0.195	Calm conditions
3	2019-221	20:30	Yes	-0.165	After refueling

Figure 5: CARIS HVF Waterlines from Static Draft Measurements - ASV-CW5

B.2.1.1 Static Draft Correctors

Vessel		ASV-CW5	Qualifier 105
Date		2019-06-22	2019-06-22
Loading		0.025 meters	0.012 meters
Static Draft	*Measurement*	-0.215 meters	-1.558 meters
	Uncertainty	0.025 meters	0.02 meters

B.2.2 Dynamic Draft

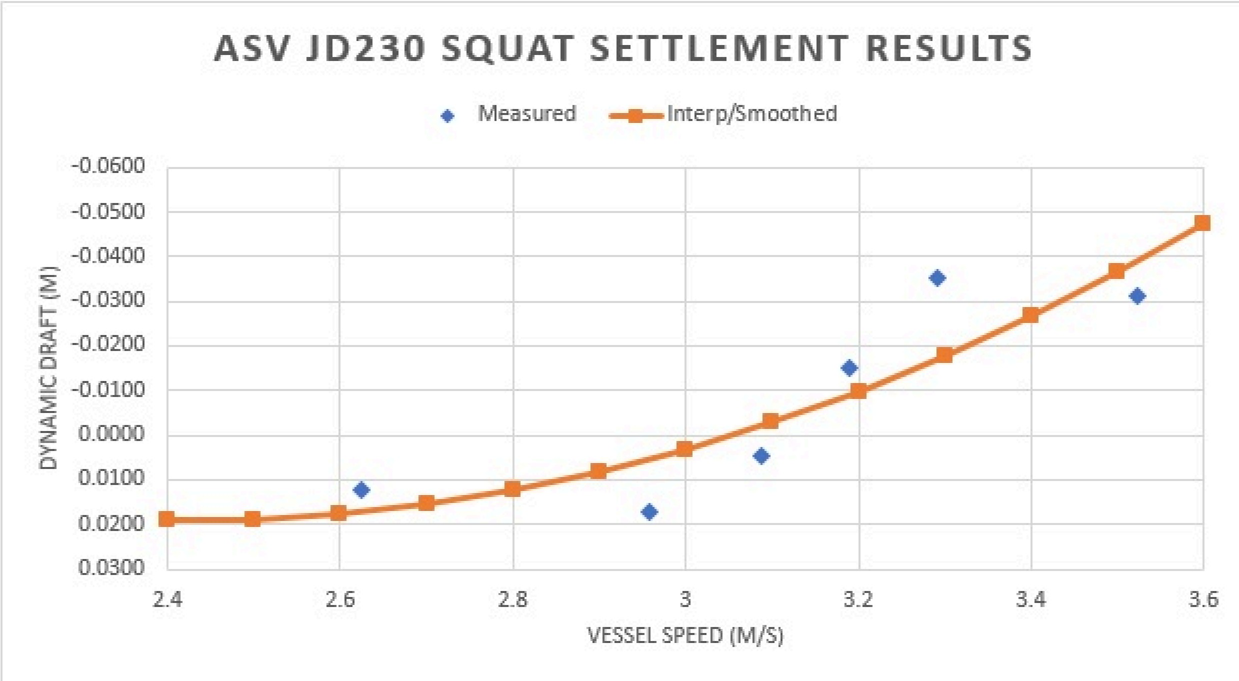
Dynamic Draft was measured using Squat-Settlement test methodology. However, the results were not directly applied to the data since as an ERS survey the effects of dynamic draft are already accounted for in the vertical positioning of the vessel CRP.

Corrections for dynamic draft were determined for each vessel by means of a squat settlement test. PPK GPS methods were used to produce and extract the GPS altitudes from the test. Corrections were determined for a range that covered normal vessel speeds experienced while surveying. The values were checked against results obtained on the same vessels in prior years, with results comparing well--usually to 0.03 m or better.

The tests were competed on JD230. During the squat settlement test, the vessel logged raw POSMV attitude and positioning data to a POS file. A survey line was run in each direction at incrementing engine RPM/speed. Between each line set, as well as at the start and end of the test, a “static” was collected whereby the vessel would sit with engines in idle and log for a minimum of 2 minutes. The survey crew would note the time and speed of each event.

The POS file was post-processed in Applanix POSPac software to produce the PPK positioning data, which was exported to text and brought into Excel. Using the event notes, the positioning data was separated and grouped according to RPM/speed range and static. Each range was averaged to remove heave and motion. A polynomial equation was computed that best fit the static periods and then used to remove the tide component from each altitude. The residual result was the difference from static or dynamic draft. Finally, the results were averaged for each direction to eliminate any affect from the current, wind or other factors.

Four RPM/speed values were tested on the Q105, while six were tested on the ASV-CW5. These were interpolated to 0.1 meter/seconds to develop a smooth dynamic draft corrector chart, shown in the following images.



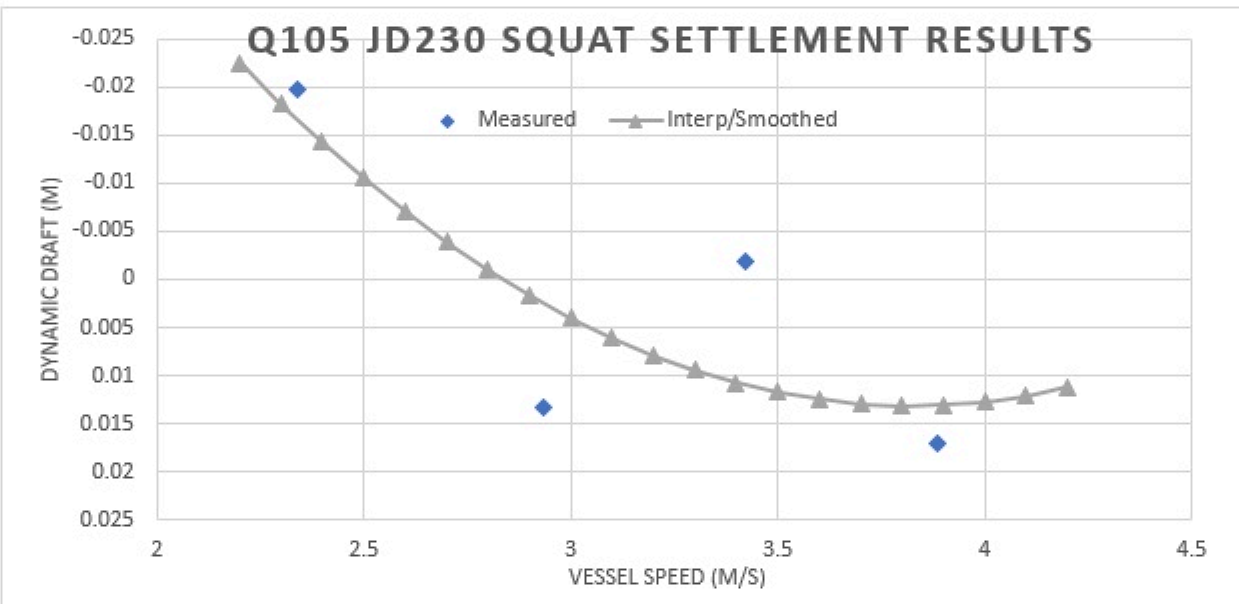


Figure 6: Graph of dynamic draft results.

B.2.2.1 Dynamic Draft Correctors

Dynamic draft correctors were not applied.

B.3 System Alignment

B.3.1 System Alignment Methods and Procedures

Patch tests were conducted on both vessels to establish latency, pitch, roll, and yaw alignment values between the POSMV and the MBES systems. Patch tests were completed on site on JD195, and again near the end of the project on JD231 to reconfirm the initial values. Note that the JD195 patch test results were pre-dated in the CARIS HVFs to cover lines collected before the date of the patch test.

Industry-standard patch test procedures--summarized below--were used to determine latency, pitch, roll, and yaw correctors.

To determine latency, a survey line was run twice – in the same direction – at low and high speeds over the feature. The data was examined in CARIS HIPS Calibration mode. Any horizontal offset of the features indicated latency between the positioning and sounding systems. A correction (in seconds) that improved the match-up was determined and entered into the HVF.

Note that the timing correction (if any) was entered into the HVF for the Transducer1 sensor instead of the navigation sensor, which resulted in the correction being applied to all positioning and attitude data (not just navigation). This was desirable because latency, determined with the POSMV, is system-wide and affects all output data. The sign of the value found also needed to be reversed since the correction was being added to the Transducer1 sonar times, instead of the navigation sensor. For this project, latency was indiscernible in the patch test data for both vessels and no correction was necessary.

To determine pitch offset, a third line was run back over the feature at low speed in the same direction as the first line. The first and third lines were examined for feature alignment. Any remaining horizontal offsets of bottom features in this line set, following latency correction, indicated the pitch offset between the attitude and sounding systems. The value that best compensated for the pitch misalignment was entered into the HVF.

Yaw offset was then determined following the corrections for latency and pitch. Survey lines run in opposite directions with outer beams overlapping the feature were examined. Any remaining horizontal offset of corresponding beams indicated a yaw offset between the sounder and motion sensor reference frames. A value that improved match-up was determined and entered into the HVF.

Roll offset was then determined. The same survey line run twice over flat bottom topography, in opposite directions, was examined. Any vertical offset of outer beams indicated a roll offset between the sounder and motion sensor reference frames. A value that brought the data into alignment was determined and entered into the HVF.

Patch test data received standard corrections and processing prior to examination in CARIS HIPS prior to determining the calibration values.

The results of the JD231 (end of project) patch test were the same as the initial patch test completed on JD195, revealing no discernible change in the patch test alignment values over the course of the project.

Note that even though the 7101 and 7125 MBES systems on the vessels were single-head systems, they were configured as dual-head systems in the CARIS HVF per CARIS' Technical Bulletin "HIPS and SIPS Technical Note Sound Velocity Correction for Teledyne Reson 7k Data". Alignment values were therefore entered only under "Transducer 1" in the HVF (with no alignment values entered for the non-existent "Transducer 2") while horizontal and vertical offsets were entered under "SVP 1" and "SVP 2".

B.3.1.1 System Alignment Correctors

Vessel	Qualifier 105		
Echosounder	Teledyne Reson SeaBat 7101		
Date	2019-07-14		
Patch Test Values		*Corrector*	*Uncertainty*
	Transducer Time Correction	0.000 seconds	0.001 seconds
	Navigation Time Correction	0.000 seconds	0.001 seconds
	Pitch	0.800 degrees	0.010 degrees
	Roll	0.450 degrees	0.010 degrees
	Yaw	3.800 degrees	0.010 degrees
	Pitch Time Correction	0.000 seconds	0.001 seconds
	Roll Time Correction	0.000 seconds	0.001 seconds
	Yaw Time Correction	0.000 seconds	0.001 seconds
	Heave Time Correction	0.000 seconds	0.001 seconds

Vessel	ASV-CW5		
Echosounder	Teledyne Reson SeaBat 7125		
Date	2019-07-14		
Patch Test Values		*Corrector*	*Uncertainty*
	Transducer Time Correction	0.000 seconds	0.001 seconds
	Navigation Time Correction	0.000 seconds	0.001 seconds
	Pitch	-1.000 degrees	0.010 degrees
	Roll	1.600 degrees	0.010 degrees
	Yaw	0.600 degrees	0.010 degrees
	Pitch Time Correction	0.000 seconds	0.001 seconds
	Roll Time Correction	0.000 seconds	0.001 seconds
	Yaw Time Correction	0.000 seconds	0.001 seconds
	Heave Time Correction	0.000 seconds	0.001 seconds

C. Data Acquisition and Processing

C.1 Bathymetry

C.1.1 Multibeam Echosounder

Data Acquisition Methods and Procedures

General Acquisition Systems Configuration

Q105 and ASV-CW5 acquisition systems were configured nearly identically.

Both vessels utilized Intel-based Windows 7 PCs for acquiring data. On the Q105, two PCs were used: One PC devoted to note-taking, monitoring deck cameras, and acquiring POSMV data running Applanix POSView, with the other PC to acquire multibeam data using QPS QINSy and Teledyne RESON Sonar UI software. On the more space-limited ASV-CW5, one PC was used for all data acquisition.

QPS QINSy data acquisition software was used to log all bathymetric data and to provide general navigation for survey line tracking. QPS QINSy was configured with inputs that included positioning and attitude data from the POSMV via network, bathymetric and backscatter data from the Reson SeaBat MBES via network, and 1-PPS timing over coax cable with 1 Hz ZDA timing string via serial cable from the POSMV.

Teledyne Reson Sonar UI software was used to monitor, configure, and tune the MBES systems. Inputs into the software included surface sound speed via serial cable and a 1-PPS timing over coax cable with 1 Hz ZDA timing string via serial cable from the POSMV.

ASV-CW5 Operations

Operations on the unmanned ASV-CW5 vessel were semi-autonomous, whereby the vessel would be directed to follow pre-defined survey lines without human intervention. However, the vessel was still monitored constantly, with two technicians dedicated to it at all times: One technician was responsible for monitoring and directing the vessel's operations, the other for monitoring and controlling the survey systems.

Obstacle avoidance, including avoidance of other vessels, depended on constant monitoring and frequent intervention by the remote vessel operator. Tools for this purpose included a streaming camera view from ASV, on-board radar, AIS system, and a forward-looking sonar. The MBES system was relied upon for water depth under the vessel. In addition, the bridge crew on the Q105 would monitor the area in front of the ASV for potential interactions, informing the ASV crew and communicating with other vessels as necessary.

The ASV-CW5 worked in a normal range of 3 km or less of the Q105. This facilitated visual monitoring and radio link strength for streaming of vessel and survey system data. The proximity also made it possible to perform all sound speed profile casts from the Q105, for which the ASV-CW5 was not configured to collect.

Since the survey PC aboard the ASV-CW5 was not directly accessible, its display was continuously streamed via wireless network to the Q105 using a remote desktop connection. This allowed the survey technician to monitor and control the systems in a manner similar to the conventional setup aboard the Q105. Raw files (XTF, DB, QPD, and POSMV) were logged locally on the ASV survey computer, which made data logging immune to radio dropouts.

Transfer of a survey line's associated raw data files (XTF, DB, and QPD) from the ASV-CW5 to the Q105 commenced soon after the collection of each line was completed. POSMV files were also transferred across the link whenever logging was stopped, approximately every 12 hours. Radio bandwidth was usually sufficient to transfer data as fast as new data was being acquired. This made it possible to process the data soon after acquisition without the need to wait to physically download it, which allowed potential issues to be detected relatively quickly. Occasionally, in shallow water with high MBES ping rates, the rate of data transfer could fall behind the rate of data acquisition, creating a backlog of un-transferred raw data aboard the ASV. When this occurred, the survey crew prioritized transfer of file types to only those necessary for immediate processing (XTF), and queued DB and POSMV files for later transfer—either by radio or USB hard drive when the ASV was physically accessible.

Although the ASV-CW5 could autonomously follow pre-defined (and relatively straight) survey lines, the current generation of technology used on this project did not have the capability to autonomously navigate based on water depth. Therefore, in nearshore shallow/complex areas where straight survey lines were not possible, constant intervention by the remote operator was necessary, with the ASV effectively operating as a remote-controlled vessel. In the data records, straight tracklines (offshore, generally deeper water) were collected in autonomous mode, while sinuous and/or nearshore tracklines were collected in remote-controlled mode.

Recon Data

The majority of this survey was in an area that was uncharted, and areas that were charted were highly changeable or poorly charted. Satellite bathymetry provided by NOAA, which inferred relative depth differences, was used as a starting point but was not reliable enough for allow full survey operations to begin without ground truthing.

Therefore, it was necessary to perform reconnaissance or "recon" lines in many areas when first arriving in an unsurveyed area that otherwise had no obvious starting point for survey. Using the satellite bathymetry as general guide, both vessels would follow the suspected channels while logging MBES data. The ASV-CW5, having considerably less draft and more maneuverability, would scout ahead of the larger vessel, often zig-zagging to better develop depth limits in the area. Then, working from the recon line as a starting point, the ASV-CW5 would begin collecting mainscheme lines at the required line spacing, with the Q105 joining production whenever possible.

Since the Q105 was usually following the ASV-CW5 while recon was being performed, MBES data the Q105 logged during these times was often redundant because it was collected directly over the ASV data. Most Q105 recon lines were therefore excluded from the primary CARIS projects so as to not count towards the required project-wide LNM budget, and were instead placed into a "Recon" CARIS project, which was not submitted with the survey deliverables. Note that these excluded lines are still entered for tracking purposes in the logsheets kept by acquisition and processing personnel even though the lines themselves are not included with the survey deliverables.

Some recon lines lines, however, were retained in the primary CARIS projects in cases where they were deemed to add value to the survey - for example when they could serve as a crossline for QC purposes.

Recon lines are normally perpendicular to the mainscheme and usually have "recon" in their filename, though some may have names that include "explore" or "transit".

QPS QINSy Navigation and MBES Collection

The software features many quality assurance tools, which were taken advantage of during this survey.

Using the raw echosounder depth data, the acquisition software generated a real-time digital terrain model (DTM) during data logging that was tide and draft corrected. The DTM was displayed as a layer in a plan-view layer. The vessel position was plotted on top of the DTM, along with other common data types including shape files containing survey lines and boundaries, nautical charts, waypoints, and shoreline features as necessary. Note that the DTM was only used as a field quality assurance tool and was not used during subsequent data processing. Tide and offset corrections applied to the DTM and other real-time displays had no effect on the raw data logged and later imported into CARIS HIPS. Final tide and offset corrections were applied in CARIS HIPS.

In addition to the DTM and standard navigation information, QINSy was configured with various tabular and graphical displays that allowed the survey crew to monitor data quality in real-time. Alarms were setup to alert the survey crew immediately to certain quality-critical situations. These included alarms for loss of time sync and critical data streams from the POSMV and Reson sonars.

Data Coverage and Density

Effort was made to ensure coverage and density requirements described in the HSSD were met.

Work was done to “Set Line Spacing” (“Option A: Multibeam Sonar Set Line Spacing without Concurrent Side Scan Sonar Coverage”) standards as described in the HSSD. MBES backscatter was also acquired during all MBES data acquisition. Per the project Work Instructions, line spacing was assigned at 100, 200, or 400 meters depending on the survey sheet.

A line plan, with lines at the required spacing by area, was developed prior to commencement of operations. An east-west oriented line plan was generated as well as a north-south line plan. The orientation most suitable to weather conditions or bottom topography was utilized during operations. Line plans were periodically modified on the fly as necessary, usually by the addition of splits to develop shoals and previously charted soundings, or addition of diagonal crosslines.

Coverage was monitored relative to the line plans as well as the assigned survey area boundaries in real-time in the QPS QINSy acquisition software. When running lines, each vessel navigated the line as closely as possible while surveying, with the Q105 generally able to maintain average off-track errors of 5 m or less, and the ASV-CW5 1 m or less. Care was taken during run-ins and run-outs to collect data at least to the survey boundaries.

Data density requirements were met through close attention to vessel speed, ping rates, and use of best possible across-track beam density. Ping rate was capped at a relatively high rate (10 pings / second) while vessel speeds were moderated (less than 8 knots, but usually 6 to 6.5 knots, and less in shallow water) to control pings-per-meter on the seafloor. Across-track density for MBES was maximized by utilizing the “best coverage” beam mode on the 7101 and 7125 sonars, generating up to 511 (on the 7101) or 512 (on the 7125) beams spaced equidistant across the swath for every ping, which was the maximum capability of the MBES systems. This combination of ping rate and beam mode allowed the systems to generate up to 5,120 soundings per second and at the speeds used on this project exceed density specifications for the required grid resolutions.

Coverage and density were confirmed by processing in CARIS HIPS. Following application of preliminary correctors, filters, and manual cleaning, CUBE BASE surfaces, at the required resolutions, were generated and examined for coverage and density. When identified, holidays or other gaps were re-run unless deemed unsafe due to water depth or other conditions.

Data Processing Methods and Procedures

Bathymetric (MBES) Data Processing

Initial data processing was carried out in the field aboard the Q105. Final data processing and reporting was completed in the office following the completion of field operations.

Following transfer from the acquisition, raw bathymetric data was converted, cleaned and preliminary tide and GPS corrections were applied in accordance with standard TerraSond processing procedures--customized as necessary--for this survey. This was accomplished in near real-time, immediately after each line was acquired, providing relatively rapid coverage and quality determination.

Following the completion of field operations and prior to deliverable creation, final data processing was completed at TerraSond’s Palmer, Alaska office. This included a comprehensive review of all collected data for completeness and accuracy of corrections, application of final tides and TPU, final cleaning and surface review, compilation of reports, S-57 deliverables, and generation of final products.

Checks and data corrections applied by data processors for MBES data were recorded to a log sheet in Microsoft Excel. Logsheets were then output to PDF format and are available with each project DR.

Conversion into CARIS HIPS and the HIPS Vessel File

CARIS HIPS was the primary software used for bathymetric processing for this project. The XTF (eXtended Triton Format) files written by QINSy were imported into CARIS HIPS using the “Triton XTF” conversion wizard. Import options selected during conversion included importing coordinates as geographic, automatic timestamping, use of the ship ping header for navigation, and gyro data from attitude packets. No soundings were rejected during conversion.

During conversion, raw data was converted under the appropriate HVF (HIPS Vessel File) corresponding to the vessel that acquired the bathymetric data. The HVF contains time-based, vessel-specific static vessel offsets, configurations, and error estimates that are utilized by CARIS HIPS during various processes including SVP, TPU computation, and Merge.

CARIS HIPS created a directory structure organized by project (area), vessel, and Julian day. Sensors were parsed from the input raw data files, allowing them to be reviewed and edited separately from each other.

HIPS Vessel Files (HVF) - Dual Head Configuration

The CARIS HVFs (HIPS Vessel Files) for this project were setup in a dual-head configuration to ensure proper application of offsets and sound speed correction. This was done per CARIS' technical bulletin "HIPS and SIPS Technical Note for Sound Velocity Correction for Teledyne Reson 7k Data" even though the systems were in fact single head. Per the bulletin, this was necessary because QINSy was configured to log "new" style (Reson 7027) bathymetric records.

Note that in this configuration vessel offsets appear only under the SVP1 and SVP2 sensors in the HVF, not under the Transducer 1 and Transducer 2 sensors as they might for other sonar configurations. Angular corrections derived from the patch tests are still included under Transducer 1 (but not the non-existent Transducer 2).

Waterline

To correct for the depth of the transducer, the HVF for each vessel was updated with a new waterline value prior to processing. The static draft, or computed distance from the vessel CRP to the water level with the vessel at rest (computed as described previously in this report), was entered as a waterline correction in the CARIS HVF. Values were occasionally pre-dated in the HVF when necessary.

Static draft measurements were logged in an Excel logsheet, which was exported to PDF and is available with each DR.

Load Attitude / Navigation Data

On this project, positioning and attitude data was processed using post-processed kinematic (PPK) methodology. The PPK process (described later in this report) produced smoothed best estimate of trajectory (SBET) files, which contain a significantly improved navigation and attitude solution over the real-time.

SBETs were loaded into lines using CARIS HIPS "Import Auxiliary Data" utility. During the loading process, the option to import "Applanix SBET" was selected, and all available records were imported (navigation, gyro, pitch, roll, and GPS height). Data rate was set to ‘0’ to use the data at the default rate within the SBET, which on this project was produced at 50 Hz.

Through this process, each line’s original, real-time attitude and navigation records were superseded in CARIS HIPS by the records in the SBET files. In rare cases where SBETs were not available (noted in the applicable DRs), CARIS HIPS reverted to using real-time records.

Dynamic Draft Corrections

Dynamic draft corrections were determined for this project using squat-settlement tests, but were not applied to the data.

As an Ellipsoid Referenced Survey (ERS) project, vertical changes in vessel displacement were captured in the GPS data for the vessels and are therefore corrected for without the need to apply separate Dynamic Draft Corrections. The HVF files therefore do not contain Dynamic Draft Correction tables.

Multibeam Swath Filtering

Prior to manual review and cleaning, all multibeam data was filtered using CARIS HIPS “HIPS Data Filters > Apply > Bathymetry” function.

All soundings were filtered based on Reson MBES quality flags and angle from nadir. Soundings flagged as 0, 1, and 2 were “rejected” automatically in filtering, which left only high quality (3, being both co-linear and bright) soundings. Beams greater than 65 degrees from nadir were also rejected. This removed a large amount of water column noise and reduced the amount of manual editing necessary.

Merge

The “Merge” process was run on all lines in CARIS HIPS. During this process, “GPS” was selected as the tide source to ensure the “GPSTide” record computed previously was used for tidal correction, and the Heave Source was set to “Delayed” to utilize the “Delayed Heave” records loaded previously.

Multibeam Swath Editing

Initial cleaning of multibeam data was done in the field using CARIS HIPS Swath Editor.

Following application of filters and other correctors, soundings were examined for spikes, fliers, or other abnormalities, and obviously erroneous soundings (fliers) were rejected.

A secondary review of all lines in Swath Editor was also completed in the office following completion of field operations, and prior to review in CARIS Subset mode. Cleaning status was tracked in the processing section of an Excel logsheet, included with each DR.

GPS Height Smoothing

GPS altitude for each POSMV file was inspected in POSPac using the QC plots. Each CARIS HIPS line file was also inspected for GPS Height drift in attitude editor. It was found that some POS files had short duration spikes or longer drifts from the mean height of the file exceeding 0.2 meters. To remedy these, all POS files with identified altitude spikes were dumped to a text file, exporting every 50th record (1 Hz). A 6-minute moving average was then run over the altitude data in Excel, which smoothed out most drifts and spikes while preserving the data trend. The averaged (smoothed) altitudes were then exported to a text file and imported back into the affected HIPS line file using CARIS HIPS Generic Data Parser (GDP) utility. Affected lines had GPSTide recomputed, with the option to apply Dynamic Heave set to "None" since the smoothing process (at 1 Hz) effectively removed heave data from the GPS heights. Lines were then remerged.

For some files, the 6-minute average did not fully remove the GPS Height spikes. To resolve this, GPSHeight spikes were manually interpolated in HIPS Attitude Editor using the "Reject with interp" option.

These can be differentiated in the CARIS HIPS data by the fact that their height records are at 1 Hz instead of the project standard 50 Hz, which indicates heights were loaded from an SBET.

Lines with smoothed heights are itemized in the appropriate DRs. Text files containing the smoothed heights loaded through GDP are included with the survey deliverables as well.

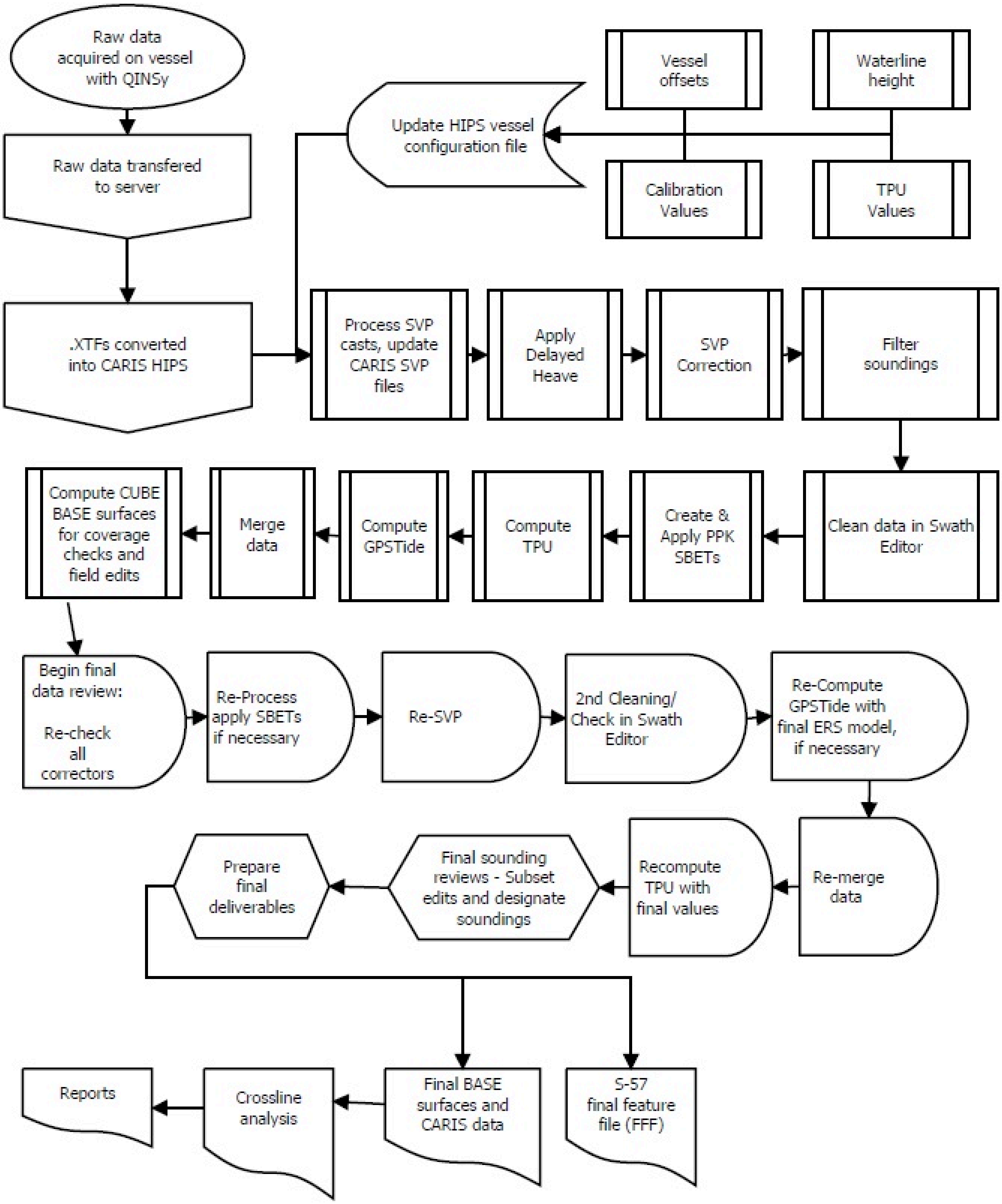


Figure 7: Processing flow diagram.

C.1.2 Single Beam Echosounder

Single beam echosounder bathymetry was not acquired.

C.1.3 Phase Measuring Bathymetric Sonar

Phase measuring bathymetric sonar bathymetry was not acquired.

C.1.4 Gridding and Surface Generation

C.1.4.1 Surface Generation Overview

The final depth information for this survey is submitted as a collection of surfaces gridded from the sounding data. Surfaces were generated in CARIS HIPS 10.4.16 in CSAR format, and represent the seafloor at the time of survey with depths relative to chart datum (MLLW).

Resolutions of the BASE surfaces were created in accordance with the HSSD based on coverage type and depth. Coverage types required on this survey were “Set Line Spacing” (Option A, Section 5.2.2.4 in the HSSD). As all depths were less than 80 m, only 4 m resolution surfaces were created for final deliverables.

C.1.4.2 Depth Derivation

Surface filters, sounding suppression parameters, and data decimation parameters were not used to derive depths.

C.1.4.3 Surface Computation Algorithm

CUBE (Combined Uncertainty and Bathymetric Estimator) was used as the gridding algorithm for all surfaces. Per NOAA/CCOM definition, CUBE is "an error-model based, direct DTM generator that estimates the depth plus a confidence interval directly on each node point of a bathymetric grid."

NOAA standard CUBE parameters for 4 m resolution surfaces were utilized. This included a 2.83 m limit on the capture distance of soundings contributing to each grid node, which corresponds to the resolution (4 meters) divided by the square root of 2. The CUBE parameters (XML format) are included with the final CARIS deliverables.

During surface computation, “Density and Locale” was chosen as the “disambiguity” method. “Order 1a” was selected as the IHO S-44 Order type.

Each surface was “finalized” in CARIS HIPS prior to submittal. During this process, final uncertainty was determined using the “Greater of the Two” (Uncertainty or Std. Dev. at 95% C.I.) option. Maximum and minimum depth cutoffs were entered based on the HSSD requirements for the resolution (0 to 80 m for all 4 m resolution surfaces on this project). The option to apply designated soundings was selected, which forced the final surfaces to honor these soundings where applicable.

C.2 Imagery

C.2.1 Multibeam Backscatter Data

Data Acquisition Methods and Procedures

MBES Backscatter

MBES backscatter was collected continuously during MBES operations.

DB and QPD ("DTM result") files, which are compatible with QPS Fledermaus Geocoder Toolbox (FMGT), are provided with the survey deliverables to allow backscatter processing. Basic beam quality filters (reject flags 0, 1 and 2) were applied to the QPD files in QINSy in real-time.

Note that XTF files on this project do not contain backscatter records; these were intentionally configured to contain bathymetric sounding data-only in order to reduce file sizes from redundant recording of backscatter data to both DB and XTF files.

Data Processing Methods and Procedures

During field operations, the presence and quality of backscatter records in the raw MBES files was confirmed by periodic random checks through processing in FMGT.

Following completion of field acquisition, backscatter was processed and mosaics were generated in FMGT at 1 meter resolution. The mosaics (GeoTIFF format) are provided with the processed survey deliverables.

DB and QPD Files were imported into FMGT, which automatically pairs the files based on the name. FMGT extracts the backscatter data stored in the DB and the bathymetry DTM in the QPD, then creates a merged GSF file inside the project that is used in backscatter processing.

The MBES backscatter intensity is dependent on the sonar operation settings (Power, Pulse Length, Gain, Absorption, Spreading) used at the time of acquisition. When different sonar operation settings are used, it causes a shift in the decibel intensity of the acquired data. To account for this in FMGT, several "settings parameter" configurations were created for each sonar type and for each combination of sonar operating settings. DB and QPD files were imported and assigned the appropriate "settings parameter" as tracked in the survey acquisition log, and a preliminary mosaic at 1 meter resolution was generated. The most frequently used "settings parameter" (i.e. the sonar operation settings used for the majority of the survey) was selected as a reference (0 decibel offset). Using the intensity differences between lines visible in the preliminary mosaic, all other "settings parameter" configurations were assigned a static decibel offset to match the intensity of the reference. This brought the files for all vessels and all sonar operation settings onto the same intensity level. A 1 meter mosaic was then re-created and exported as a greyscale geotiff.

Note that backscatter processing and mosaic generation was not a requirement of this survey. The mosaics may therefore have flaws or holidays which could be addressed through further processing. However, they are of sufficient quality to show the relative changes in seafloor type.

C.2.2 Side Scan Sonar

Side scan sonar imagery was not acquired.

C.2.3 Phase Measuring Bathymetric Sonar

Phase measuring bathymetric sonar imagery was not acquired.

C.3 Horizontal and Vertical Control

C.3.1 Horizontal Control

C.3.1.1 GNSS Base Station Data

GNSS base station data was not acquired.

C.3.1.2 DGPS Data

Data Acquisition Methods and Procedures

The POSMV positioning systems on both vessels were configured to receive DGPS correctors.

On the ASV-CW5, the POSMV was configured to utilize DGPS corrections via a Hemisphere AtlasLink receiver. The AtlasLink system provides RTK-level positioning via L-band satellites. The "H10" subscription package was used for this project, which advertises 95% 8-cm accuracy 3D positioning (with 4 cm RMS). The RTK-level positioning provided relatively tight real-time vertical positioning to assist with determining when the ASV-CW5 had reached the required 3.5 m depth contour while surveying.

The Q105 was also configured with an AtlasLink receiver. However, it was used only briefly at the start of operations and was disconnected due to periodic loss of satellites stemming from the receiver mounting location on the vessel, which was shadowed by the vessel mast. FAA WAAS DGPS corrections were used instead for real-time positioning on the Q105 via the POSMV's internal WAAS receiver.

Real-time positioning (from both AtlasLink and WAAS) were WGS84-based.

In all cases, DGPS corrections were replaced with post-processed positions in NAD83 (2011).

Data Processing Methods and Procedures

All positions were post-processed in Applanix POSPac software, which is described in more detail in the Vessel Positioning section of this report.

Note that CARIS projects have their project geodetic settings set to "NA83" (NAD83), not NAD83(2011). This was done because in the versions of CARIS used on this project (10.3 and 10.4) a NAD83(2011) option was unavailable for the navigation sensor in the CARIS HVF. Only "NA83" is available for the navigation sensor. Using "NA83" for both the navigation sensor as well as in the project settings ensures HIPS does not perform a conversion on the imported SBET positions, which are already NAD83(2011), and also ensures final data and surfaces are indeed in the desired NAD83(2011) system

C.3.2 Vertical Control

C.3.2.1 Water Level Data

Data Acquisition Methods and Procedures

Nine tertiary tide stations were installed for this project. Four of these stations were located in the Kuskokwim Bay and Nunivak Island regions near the survey area. The five other stations were located in Bristol Bay. A combination of vented pressure sensors, non-vented pressure sensors, GNSS Tide Buoy and a tilted laser were used to measure water levels. The orifice for the vented pressure sensors were secured to the seafloor or river bed. The non-vented pressure sensors were deployed on oceanographic anchors. The GNSS Tide Buoy was moored in place with a Danforth anchor. The water levels from each station were tied to a global reference frame via differential levels and GNSS observations. Conductivity and temperature sensors were deployed with each of the non-vented pressure sensors. The equipment was calibrated by the manufacturer prior to deployment. Pre-deployment and post-deployment tests were also performed on the equipment to monitor for sensor drift.

Refer to the HVCR and accompanying appendices for additional detail.

Data Processing Methods and Procedures

Final tides were completed using ERS (Ellipsoid-Referenced Survey) techniques. NAD83(2011) ellipsoid-based altitudes, loaded from PPK SBET files, were reduced to MLLW in CARIS HIPS using the Compute GPSTide routine in conjunction with the NAD83 to MLLW separation model provided by NOAA for this purpose.

Data from the pressure sensors were converted from PSI to meters by correcting for water density and gravity. The non-vented pressure sensors were also corrected for barometric pressure. Water levels from the GNSS Tide Buoy were resolved using baseline processing. The stability of each water level sensor was assessed by either differential levels or differences between simultaneous water level readings. Tidal datums for each location were computed using a control station and at least one calendar month of data.

A total water level error estimate was assigned to each water level record using the methodology outlined in the "CO#OPS Policy for Management and Dissemination of External Source Water Level Data Revised December 2015".

Ellipsoidally Referenced Zoned Tides (ERZT) (as well as conventional discrete tide zones) were also computed for this project but were used for comparison purposes only.

PPK and ComputeGPS tide procedures are described elsewhere in this report. Refer to the project HVCR for additional information on tide correction methodology as well as comparison results.

C.3.2.2 Optical Level Data

Optical level data was not acquired.

C.4 Vessel Positioning

Data Acquisition Methods and Procedures

Positioning and Attitude Data

Positioning and attitude data was computed during acquisition with Applanix POSMV systems. This data included horizontal position, vertical position, and attitude data consisting of heave, pitch, roll, and heading (gyro).

The POSMV systems were configured to output positioning and attitude data in real-time to the QPS QINSy acquisition software at a rate of 50 Hz. The real-time positions were written to DB and XTF file by QINSy for later import into CARIS HIPS during processing.

Raw POSMV data was also logged at a rate of 50 Hz to POS (.000) file continuously during data acquisition operations, with a new file created approximately every 12 hours. All data packets necessary for Delayed Heave and Applanix POSPac post-processing were included in the records. Care was taken to ensure the POS files were logged for at least two minutes before and after applicable survey lines to allow for the application of Delayed Heave as well as post-processed solutions from Applanix POSPac.

Note real-time positioning data (horizontal and vertical) was superseded with application of post-processed positioning, as described below. However, post-processed attitude data was not applied.

Data Processing Methods and Procedures

Apply Delayed Heave

In processing, CARIS HIPS' "Import Auxiliary Data" utility was utilized to load lines with the "Delayed Heave" record. Delayed Heave was imported at the default data rate (25 Hz) from POS (.000) files logged during acquisition.

Along with the Delayed Heave data, Delayed Heave RMS error records were also imported during this process so that final TPU computations could utilize RMS error.

Delayed Heave records were then utilized by CARIS HIPS over real-time heave for final heave correction. In rare cases (noted in the applicable DRs) some lines did not receive application of Delayed Heave because of POS file issues, typically caused by occasional software crashes that prematurely ended the POS file logging prior to reaching the 2-minute logging requirement after survey lines. In these cases the lines utilized real-time heave instead.

In CARIS HIPS, options to apply Delayed Heave were utilized during both Sound Velocity Correction and Merge. The option to apply Delayed Heave was also used on the vast majority of survey lines during the Compute GPSTide process, with exceptions noted in the applicable DRs.

Post-Processed Kinematic (PPK) Navigation and Attitude

Final position and attitude data for this project were post-processed.

The project was not located within a region of USCG DGPS coverage. As described elsewhere in this report, SBAS corrections (AtlasLink H10 and FAA WAAS) corrections were used for real-time positioning but were replaced in final processing with PPK positions.

PPK processing for this project utilized Applanix POSPac MMS software. POSPac produced SBET format .OUT files, which were loaded into all lines during processing. This superseded real-time navigation (position and GPS height). Note that SBET files also contain post-processed roll, pitch, and gyro (heading) records but these were not applied in processing.

To process POS files to produce an SBET, a POSPac MMS project was first established based on a pre-defined template with project-specific settings. Project-specific settings consisted of custom SBET output using a decimated data rate of 50 Hz (from the default 200 Hz) and output datum of NAD83 (2011). One project was set up for each POS file, and the POS file was imported into the project. The correct antenna type (AT1675-540TS) was selected.

Trimble PP-RTX methodology was used for POSPac processing. PP-RTX is a subscription-based service available within POSPac, based on Trimble CenterPoint RTX, that utilizes Precise Point Positioning (PPP) to post-process data without the use of base stations. Advertised accuracies are 0.1 m RMS Horizontal and 0.2 m RMS vertical. However, on this project, reported RMS errors were generally better than advertised – usually at the 0.1 m level vertically.

Applanix Smart Base (ASB) mode was also utilized for position confidence checks as well as a small number of survey lines which exhibited better vertical agreement using ASB. Vessel position confidence checks are described in the Data Quality Management section of this report. Specific lines and POS files processed using ASB are itemized in the applicable DR.

Following PP-RTX generation, the POSPac Inertial processor function was run.

After completion of the inertial processor, QC plots of RMS error and vessel altitude were examined for spikes and other anomalies. The real-time position was compared visually to the post-processed position in the POSPac MMS planview window as a check for gross positioning error. QC reports showing performance metrics were then created for each POSPac project and are available with the project HVCR.

Finally, Smooth Best Estimate of Trajectory (SBET) files were exported from POSPac. The option to produce “Custom Smoothed BET” was used to produce an SBET in the NAD83 (2011) reference frame at 50 Hz. This made it so that all final positions were NAD83 (2011) per the 2019 HSSD.

Note: Applanix POSPac would crash on import on a handful of POS files logged on board the Q105. These were initially addressed in the field by splitting the POS file on import into multiple SBETs and processing around the issue, and recollecting any MBES data that was acquired coincident with the gap between the two SBETs. Applanix was consulted, and they stated that although the cause of the software crashes was not clear, the latest version of POSPac MMS (8.4) could successfully process the files. Therefore, following completion of survey operations, V8.4 was used to reprocess the affected POS files and the resulting SBETs were applied to the data. These SBETs have "Reproc-v8.4" in their filenames.

Load Navigation Data (SBETs)

SBETs were loaded into lines using CARIS HIPS “Import Auxiliary Data” utility. During the loading process, the option to import “Applanix SBET” was selected, and the option to import only "Navigation" and "GPS Height" were selected. Data rate was set to ‘0’ to use the data at the default rate within the SBETs, which on this project were produced at 50 Hz. The option to allow partial coverage of SBETs to lines was also used, which resulted in coverage gaps from missing SBET data (if applicable) during coverage review and subsequent rerun of the affected lines or sections of lines while still in the field.

Through this process, each line’s original, real-time horizontal and vertical positions were superseded in CARIS HIPS by the records in the SBET files. Note that pitch, roll, and gyro (heading) data was not loaded into lines from the SBETs.

Compute GPSTide

Following loading of PPK altitude data from the SBET files, CARIS HIPS’ “Compute GPSTide” function was run on all lines. This created a GPSTide record within each survey line. Options to apply dynamic heave, vessel waterline, and the NOAA-provided ellipsoid separation model were used so that the GPSTide record reflects the elevation of the vessel waterline above MLLW.

Note that "Delayed Heave" was used as the heave source since the vast majority of lines were loaded with this record. Rare lines without Delayed Heave used real-time heave during this computation instead. These cases are noted in the applicable DR(s).

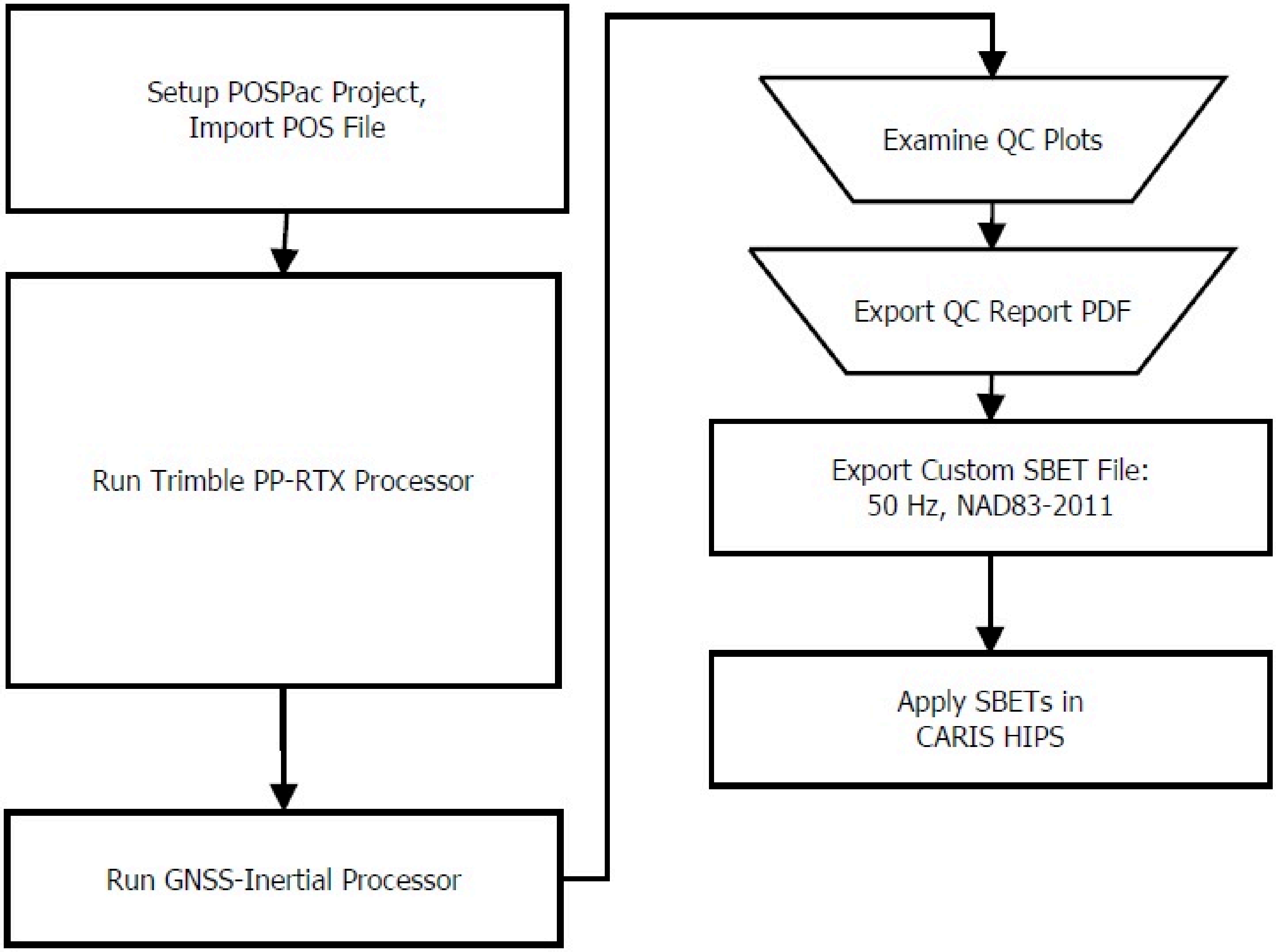


Figure 8: Generalized POSPac processing workflow.

C.5 Sound Speed

C.5.1 Sound Speed Profiles

Data Acquisition Methods and Procedures

Sound speed casts were taken from the Q105 using an Oceanscience RapidCAST system, which utilized a Valeport rapidPro SVT sensor. Note the ASV-CW5 was not equipped to acquire SV profiles: All ASV-CW5 MBES data was corrected using the profiles acquired aboard the Q105. This was possible because the unmanned vessel always worked within radio range of the Q105, which was approximately 3 km or less.

When deployed, the sensor free-falls through the water column at a rate of about 2-3 m/s. The fall is arrested when the brake is automatically applied by the winch software. The sensor is then winched back aboard the vessel, and the stored profile data downloaded over Bluetooth wireless radio to Valeport Connect software.

During the cast, sensor depth is estimated by the RapidCAST software based on the manufacturer’s algorithm utilizing line tension measured at the winch, free-fall time, and other factors. Survey personnel set a desired target depth and the system would typically achieve the target depth with a margin of error of +/- 5% to 10%. Due to the margin of error on the system’s estimates of the probe depth, conservative target depths were entered into the system to avoid striking bottom. This resulted in profiles that were at least 80% of the water depth, but not extending completely to the seafloor. However, effort was made to ensure at least one cast per 24 hours (or more) extended to 95% of the water depth.

Sound speed profiles in their raw format were logged as ".vp2" (Valeport Connect) format. In addition to depth and sound speed, VP2 files contained various metadata including UTC timestamp and geographic position generated from the Valeport sensor's GPS.

Sound speed casts were completed approximately every 2 hours. The sound speed sensor on the sonar head (surface sound speed) was also monitored continuously and compared automatically in QINSy software to the prior sound speed profile. When the software indicated a 2 m/s or greater differential, another cast was performed.

Additionally, line lengths were limited (generally 30 km or less) before completing a line turn to keep the survey vessels in the same general geographic proximity as the casts. This led to a collection of well distributed casts that minimized both the distance and time between bathymetric data and applicable sound speed profiles. When depth varied significantly along a survey line, preference was given to casting in the deeper portion of the line to obtain as much of the water column profile as possible.

Sound speed profiles were applied in CARIS HIPS using the methodology by nearest in distance, with a time interval equal to four hours. Exceptions were rare and are described in the applicable DR.

Data Processing Methods and Procedures

Sound speed profiles (also known as "SV casts") were processed in HydroOffice Sound Speed Manager (V2019.1.2).

Each VP2 files logged in acquisition was imported into Sound Speed Manager (SSM). SSM presented a graph of depth versus sound speed, which was examined for spikes (fliers) and to confirm that the desired cast depth was achieved. The VP2 was edited when necessary to remove fliers, and then exported to CARIS ".SVP" format and amended to the master CARIS SVP files by survey area prior to sound speed correction. The profile data was also exported to the acquisition software (QPS QINSy) in order to allow QINSy to alert the acquisition crew if sound speed had changed by greater than 2 m/s between casts.

In CARIS HIPS, each line was corrected for sound speed using CARIS HIPS “Sound Velocity Correct using CARIS Algorithm” utility. The CARIS-format .SVP file corresponding to the survey area was selected. To prevent the use of sound speed profiles that were too old or distant relative to the bathymetric data, “Nearest in Distance Within Time” was used for the profile selection method. For the time constraint, 4 hours was used.

In addition to the profile selection method, options applied during sound velocity correction were; setting heave source to “Delayed” (to apply Delayed Heave records loaded earlier), and including the option to “Use Surface Sound Speed” (if available).

Note that the same profiles used to correct Q105 data were also used to correct ASV-CW5 data because the ASV-CW5 always worked near the Q105.

C.5.2 Surface Sound Speed

Data Acquisition Methods and Procedures

Surface sound speed data was acquired using AML Oceanographic Micro-X sensors mounted on the MBES sonar heads. These were configured to continuously feed sound speed data directly to the MBES systems for internal beam forming purposes.

The surface sound speed value updated in real-time in the Reson 7k Sonar UI interface software. The software was set to alarm upon loss of sound speed data, and during data collection, the value was checked for reasonableness regularly by the survey crew. The acquisition software, QPS QINSy, was also set to alert the acquisition crew if there was significant change (greater than 2 m/s) in the surface sound speed value relative to the previous sound speed profile.

In addition, a formal check was carried out whenever a sound speed profile was collected, which was approximately every 2 hours during data collection. During this check, the surface sound speed value shown in the Reson 7k Sonar UI was noted in the Acquisition Log and then compared to the sound speed profile value at the same depth as the sensor (approximately 2 meters on the Q105).

Results of the surface sound speed checks are available with the project DRs.

Data Processing Methods and Procedures

Surface sound speed data was not processed. It was utilized in acquisition only, for internal beam forming purposes by the Reson 7101 and 7125 MBES systems.

C.6 Uncertainty

C.6.1 Total Propagated Uncertainty Computation Methods

CARIS HIPS was used to compute total propagated uncertainty (TPU) for all soundings as well as uncertainty for the final grids.

The CARIS HIPS TPU computation assigned a horizontal and vertical error estimate to each sounding based on the combined error of all contributing components. These error components include uncertainty associated with navigation, gyro (heading), heave, tide, latency, sensor offsets, and individual sonar model characteristics. Stored in the HVF, these error sources were obtained from manufacturer specifications, determined during the vessel survey (sensor offsets), or while running operational tests (patch test, squat settlement). Note that all values are entered at 1-sigma, per CARIS guidance, while CARIS reports TPU at 2-sigma. HVF entries and their justification are shown below.

Sonar Type: Teledyne RESON SeaBat 7125 (400 kHz 512 beams) for the ASV-CW5, Teledyne RESON Seabat 7101 (511 beams) for the Q105
Motion Gyro: 0.02 degrees -- CARIS TPU values for Applanix POSMV 320 (2 m baseline)
Heave: 5% of Heave Amplitude or 0.05m, whichever is greater -- CARIS TPU values for Applanix POSMV 320
Roll and Pitch: 0.01 degrees for the ASV-CW5 -- CARIS TPU values for Applanix POSMV 320 (RTK), 0.02 degrees for the Q105 -- CARIS TPU values for Applanix POSMV 320 non-RTK
Position Nav: 0.1 m -- PPK position processing results report RMS errors that were better than 0.10 m on average
Timing (all systems): 0.001 seconds -- estimated overall synchronization error using 1-PPS with all position, attitude, and bathymetric packets time stamped at their source
Offset X and Y: 0.01 m -- estimated measurement error from vessel survey for X and Y
Offset Z: 0.01 m on the ASV-CW5, 0.02 m on the Q105 -- estimated measurement error for Z on the ASV-CW5, standard deviation of bar-check results on the Q105
Vessel speed: 2 m/s -- estimated maximum speed of water currents experienced during survey operations
Loading: 0.025 m on the ASV-CW5, 0.012 m on the Q105 -- mean difference between subsequent static draft measurements
Draft: 0.025 m on the ASV-CW5, 0.02 on the Q105 -- estimated accuracy of the visually observed static draft measurements
Delta Draft: 0.01 m -- estimated uncertainty of squat settlement results
MRU Align StdDev Gyro and Roll/Pitch -- 0.01 degrees, overall accuracy estimate of patch test results for gyro, pitch, and roll

The TPU computation also incorporated error estimates for tide and sound speed which were entered at the time of TPU computation. These values are noted in the applicable DR.

Final CUBE surfaces include an "Uncertainty" layer that shows the estimated uncertainty for the depth value of each cell. Surfaces were finalized in CARIS HIPS with the "Uncertainty Source" selected as "Greater of the two values", which ensured final uncertainty values for the surfaces were the larger of either surface uncertainty or standard deviation (at 2-sigma).

C.6.2 Uncertainty Components

C.6.2.1 A Priori Uncertainty

Vessel		Qualifier 105	ASV-CW5
Motion Sensor	*Gyro*	0.02 degrees	0.02 degrees
	Heave	5.00% 0.05 meters	5.00% 0.05 meters
	Roll	0.02 degrees	0.01 degrees
	Pitch	0.02 degrees	0.01 degrees
Navigation Sensor		0.10 meters	0.10 meters

C.6.2.2 Real-Time Uncertainty

Vessel	*Description*
Qualifier 105	During final TPU computation, the Uncertainty Source for "Vertical" was chosen to be "Delayed Heave" in order to utilize the Delayed Heave RMS error values that were imported with Delayed Heave. Lines without Delayed Heave (noted in the applicable DR) utilized "Vessel" values for vertical error instead.
ASV-CW5	During final TPU computation, the Uncertainty Source for "Vertical" was chosen to be "Delayed Heave" in order to utilize the Delayed Heave RMS error values that were imported with Delayed Heave. Lines without Delayed Heave (noted in the applicable DR) utilized "Vessel" values for vertical error instead.

C.7 Shoreline and Feature Data

Shoreline and feature data was not acquired.

C.8 Bottom Sample Data

Data Acquisition Methods and Procedures

Locations for bottom samples were assigned by NOAA via the S-57 format Project Reference File (PRF). Assigned locations were given a name for reference, imported, and displayed in the acquisition software.

To collect the samples, the Q105 would navigate as close as possible to each assigned location. With the vessel at full stop, the survey crew on the back deck would set a spring-loaded Van Veen grab sampler and lower it quickly to the seafloor. A GPS position fix was taken when then sampler was noted to touch bottom. Back on the surface, the sampler was opened, and the contents analyzed to determine its “SBDARE” (Seabed Area) S-57 attributes including “NATSUR” (nature of surface), “NATQUA” (qualifying terms), and “COLOUR”. Time of acquisition was noted, and a photo was taken of each sample. Following analysis, the sample was discarded overboard.

If no sample was obtained, the vessel was repositioned if it had moved more than 100 m from the planned location, and another attempt made. Attempts at collecting a bottom sample would be made at least three times. If no sample was obtained after three attempts, the vessel would move on. An attempt was only considered valid if the grab sampler had returned to the surface in the closed state. For this project, samples were successfully obtained at the vast majority of assigned locations, with exceptions noted in the applicable DR, and encoded with a “NATSUR” as “Unknown”.

Given that most of this survey area was previously uncharted, many of the assigned bottom sample locations were positioned in areas too shallow to approach. When this occurred a sample was taken as close as practical in order to achieve the same overall quantity of samples.

During analysis, sample particle dimensions were not actually measured. Instead, careful estimations were done visually and by touch. Samples determined in the field to have particle sizes smaller than sand (silt and/or clay) were encoded with “NATSUR” as “mud” and “NATQUA” as “soft” when encoding S-57 attributes, though field comments may retain the original determination of silt or clay. Similarly, samples determined in the field to be pebbles or gravel (“NATSUR”) with field determinations for “NATQUA” as course, medium, or fine were encoded with “volcanic” for “NATQUA” to conform with allowable NATSUR/NATQUA combinations in the HydrOffice QC Tools manual.

If multiple constituents were present in the sample, only the three most prevalent were noted. Constituents were encoded in order of most predominant first.

Field results were recorded in a Bottom Sample logsheet, which is included with the project DRs.

Figure 9: Bottom sample collection with the Van Veen sampler on the Q105.

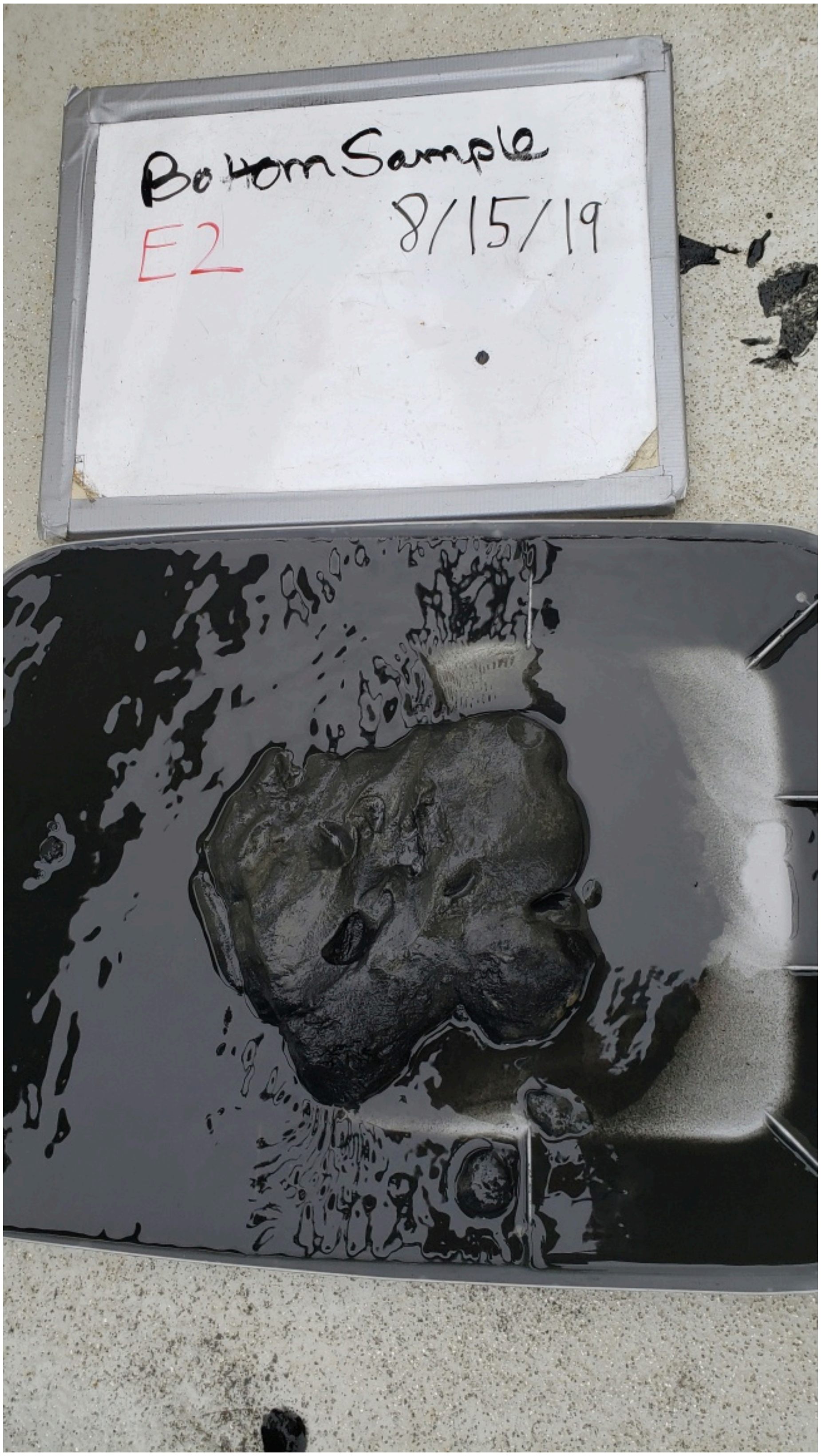


Figure 10: Example bottom sample from this project.

Data Processing Methods and Procedures

Bottom samples were added to the Final Feature File (FFF) in CARIS HIPS.

In CARIS, an SBDARE S-57 point object was created for each bottom sample. The object position was encoded to be the actual position of the sample as noted in the Bottom Sample Logsheet. Applicable information was entered for Nature of Surface, Nature of Surface - Qualifying Terms, Color, Source Date, Source Indication, Description, and Recommendations. Notes from the acquisition log were kept in the Remarks field.

D. Data Quality Management

D.1 Bathymetric Data Integrity and Quality Management

D.1.1 Directed Editing

Initial field cleaning of multibeam data was done in the field using CARIS HIPS Swath Editor. Following application of filters, soundings were examined for spikes, fliers, or other abnormalities, and obviously erroneous soundings (fliers) were rejected. A second examination of all lines in Swath Editor was also completed following field operations in the office. Cleaning status was tracked in a processing log along with processing comments or notes, if any. Logsheets are available with the project DRs.

Following application of final correctors including final tides, an examination of soundings was completed in CARIS HIPS Subset Editor, in context of bathymetric surfaces generated using the CUBE (Combined Uncertainty and Bathymetric Estimator) algorithm.

In CARIS HIPS, CUBE surfaces were first generated based on the depth resolution standards and CUBE parameters conforming to the 2019 HSSD. The CUBE surfaces were “finalized” using depth ranges for resolution specified in the HSSD. Surfaces were then loaded as a reference layer and examined in subset mode simultaneous with the contributing soundings. Only the CUBE surface appropriate for the depth and coverage type being examined was loaded (4 m resolution for this project).

To prevent unnecessary and excess rejection of soundings, requirements in the HSSD were adhered to during the subset editing process. Specifically, only soundings that caused the CUBE surface to error from the obvious seafloor position by an amount greater than the allowable TVU (total vertical uncertainty) at that depth were rejected. It is important to note that this surface-focused approach leaves noisy ‘accepted’ soundings that can exceed the TVU allowance, however, the final deliverable is the surface (not the soundings) and meets TVU specifications.

For editing consistency, the data was reviewed in subset with set visualization parameters. Data was examined looking along-track through the data, which is standard practice for examining bathymetry in subset. The subset view slice length was limited to approximately 5-8 lines, and slice width was constrained to about 25-50 m, based on ruggedness of the seafloor being examined. Vertical exaggeration in the subset window was manually set so the vertical scale graticule displayed in increments of 0.50 m, which approximated allowable TVU and served as a reference to the reviewer. Subset tiles were used to track editing progress, with care taken to ensure all data was examined.

The “Deep” and “Shoal” layers of the CUBE surfaces were also examined. These layers readily portrayed extreme fliers, which were subsequently loaded into subset and rejected to ensure they were not included in future re-computations of the CUBE surfaces. The “Node Standard Deviation” layer was also used to indicate areas with potentially high amounts of noisy soundings. Areas showing 1 m or greater standard deviation were examined and cleaned where necessary, although areas of rugged bottom naturally demonstrated higher standard deviations.

D.1.2 Designated Sounding Selection

On occasion, designated soundings were flagged on the shoalest point of features not well modeled by the CUBE surface during subset editing. As specified in the HSSD, the shoalest sounding on a feature was designated only when the difference between the CUBE surface and reliable shoaler sounding(s) was more than 1 m as well as at least the maximum allowable TVU at that depth. Additionally, if a sounding on a feature was within 2 mm at survey scale (80 meters for most of the project's surveys) of a shoaler part of the surface (or a shoaler designated sounding), it was not designated.

D.1.3 Holiday Identification

Requirements for holidays in for "Set Line Spacing", "Option A" were followed under this survey, referencing Section 5.2.2.4 of the 2019 HSSD.

Following application of preliminary correctors, filtering, and the first pass of manual edits in CARIS Swath Editor, 4 m resolution CUBE surfaces were generated and systematically examined for holidays.

Holidays were considered to be along-track gaps of at least 12 m. This corresponded to the requirement that no holidays may span more than 3 nodes along-track in depths less than 20 m. When identified these holidays were recollected in the field if depths were greater than 3.5 m and it was safe to do so.

D.1.4 Uncertainty Assessment

Uncertainty of final grids was assessed through use of QCTools v3.1.1 "Grid QA v5" utility. For each grid cell in the final surfaces, the utility examined the uncertainty value and determined if it fell within allowable TVU for the depth. It then presented statistics that included the percentage of grid cells with allowable TVU as well as the minimum and maximum values for uncertainty found. Results are available with each project DR.

D.1.5 Surface Difference Review

D.1.5.1 Crossline to Mainscheme

Crossline to Mainscheme comparisons did not utilize difference surface methodology. Instead, crossline soundings were compared to a surface that consisted only of mainscheme lines. The crossline analysis was conducted using CARIS HIPS “Line QC report” routine. Each crossline was selected and run through the process, which calculated the depth difference between each accepted crossline sounding and a “QC BASE” surface created from the mainscheme data. The QC BASE surface was created as a CUBE surface at 4 m resolution in the same manner as the final surfaces, but with the important distinction that the QC BASE surface excluded crosslines to not bias the QC report results. Differences in depth were grouped by beam number and statistics computed, which included the percentage of soundings with differences from the BASE surface falling within IHO Order 1. When at least 95% of the soundings exceed IHO Order 1, the crossline was considered to “pass,” but when less than 95% of the soundings compare within IHO Order 1, the crossline was considered to “fail.” A 5% (or less) failure rate was considered acceptable since this approach compares soundings to a surface (instead of a surface to a surface), allowing for the possibility of noisy crossline soundings that adversely affect the QC results while not necessarily affecting the final surfaces. Results were placed into Excel spreadsheets and exported to PDF reports. One report was made and named for each crossline. Results of crossline comparison and the reports are available with each project DR. Note that crosslines can be any line that transects mainscheme data. They were usually intentionally ran as crosslines and as a result have "XL" in their filename in the survey records. However, on many occasions a recon or even a line originally intended as mainscheme was determined to be a good crossline due to significant numbers of crossings, and was selected in processing for crossline comparison purposes. These "crosslines" may not have "XL" in their filename, but all lines used as crosslines are itemized by name in each DR.

D.1.5.2 Junctions

Junction comparison was completed using difference surface methodology. QCTools v3.1.1 "Compare Grids" utility (v19.4) was utilized to complete the comparison. For each Current survey, overlapping final surfaces for junctioning surveys (both Current and Prior) were selected and ran through the utility. For each intersecting grid cell, the utility computed the difference between the depth values and then determined if the difference fell within the allowable TVU for the depth, and presented the results in graphical format. Junction results are available with each DR.

D.1.5.3 Platform to Platform

Echosounder Depth Comparison (Multi-Vessel)

MBES data collected with the ASV-CW5 was compared to MBES data collected with the Q105 using difference surface methodology in the same manner described above for Junction comparisons.

These echosounder depth comparisons were completed regularly during the project. During these checks, overlapping data from each vessel that was collected as close in time as possible (in some cases minutes apart) was selected and examined. This allowed for a direct comparison of results obtained by independent survey platforms for the same seafloor while minimizing the potentially confounding temporal factors of tide or bottom change.

In addition to differencing the results in the "Compare Grids" utility, the overlap was examined in CARIS Subset mode. Results were summarized in a "Echosounder Depth Comparison" logsheet, which is available with the project DRs and Appendix V.

D.1.6 Other Validation Procedures

Traceability and Integrity Overview

The traceability and integrity of the echosounder data, position, and other supporting data was maintained as it was moved from the collection phase through processing. Consistency in file naming combined with the use of standardized data processing sequences and methods formed an integral part of this process.

CARIS HIPS and SIPS was used for bathymetric data processing tasks on this project. CARIS HIPS was designed to ensure that all edits, adjustments and computations performed with the data followed a specific order and were saved separately from the raw data to maintain the integrity of the original data.

Quality control checks were performed throughout the survey on all survey equipment and survey results. The following sections outline the quality control efforts used throughout this project in the context of the procedures used, from acquisition through processing and reporting.

D.1.7 Other Validation Procedures

File Handling

A file naming convention was established prior to survey commencement for all raw files created in acquisition. Files were named in a consistent manner with attributes that identified the originating vessel, survey sheet, and Julian day. The file naming convention assisted with data management and quality control in processing. Data was more easily filed in its correct location in the directory structure and more readily located later when needed. The file naming system was also designed to reduce the chance of duplicate file names in the project.

Files that were logged over Julian day rollovers were named (and filed) for the day in which logging began. This convention was adhered to even if most of the file was logged in the “new” day.

During data collection, the raw data files were logged to a local hard drive in a logical directory structure (based on file type and Julian day) on the acquisition PCs. On the Q105, after logging of each file was complete it was copied to a network share on the vessel server that was available to the processors. Data processors then moved the files to their permanent storage location on the server, where the data was backed-up and processing began.

ASV-CW5 data was transferred over a radio link after each line, or on rare occasion transferred to the Q105 server via USB drives whenever the unmanned vessel was back aboard. Deletion of files on the acquisition PCs was done only when necessary and only following confirmation of successful transfer to the Q105 vessel file server as well as backup to secondary USB hard drives.

At the end of the project following vessel demobilization, the vessel file server containing all project data was moved to TerraSond's Palmer, Alaska office and integrated into the office IT system, where automated backups were configured, and processing and reporting continued.

D.1.8 Other Validation Procedures

Logsheets

Logs were kept during survey operations by the survey crew during both acquisition and processing. On this project, logs were kept in Excel format with all times and dates in UTC.

A log entry was made for all important files and events that occurred during survey data acquisition operations, especially those with the potential to impact data quality. In addition to communicating metadata useful to data processing, acquisition logsheets tracked the existence of files to data processing personnel to help ensure files were not missed. Processing logsheets were used to track the progress of the various processes utilized during data processing and helped with handoffs between various processing personnel. Logsheets also serve as the survey records for archival purposes.

The logsheets kept during acquisition included:

* MBES Acquisition Logsheet: This captured information pertaining to the online acquisition of MBES data, and included the file name, survey area, date, start and end times, vessel speed and heading, general sonar settings such as power and gain, and any comments on abnormal situations or observations such as the influence of adverse weather on data quality and equipment or software issues. Note that while only one entry was made in the logsheet for each survey line, a survey line may consist of multiple files or segments due to QPS QINSy's automatic splitting of files as they increased in size. Separate sheets were kept for each vessel.

* SVP Logsheet: Information captured included the filename of the cast, date, time, applicable survey area(s), geographic position, approximate depth of the profile, as well as comments (if any). In addition, the sound speed as measured by the MBES surface sensor at the time of the cast was noted and compared to the value obtained from the cast at the same depth, which served as reality check on both the surface sound speed sensor and SVP profiler sensor. This was kept for the Q105 only since the ASV-CW5 did not collect SVP profiles.

* POS Acquisition Logsheet: This tracked the name of the POS file, start and end times, and any comments or observations. Separate sheets were kept for each vessel.

* Static Draft Logsheet: This sheet recorded the static draft ("measure-down") value obtained by the survey crew along with its date, time, and any comments including the quality of the observation. Separate sheets were kept for each vessel.

* Depth Check Logsheet: This sheet recorded the results of any lead lines or bar checks. As described elsewhere in this report, these checks were completed only on the Q105.

* Event Log: Events of general importance were recorded in the Event Log. This included items such as weather conditions and crew change-outs (shift-changes), and events that document chronological gaps in the survey records such as launch and recovery of the ASV-CW5, weather downtime, tide gauge deployments, and transit to/from port for resupplies.

Logsheets kept during processing included:

* MBES Processing Logsheet: For each survey line, this logsheet tracked the progress of processing in CARIS HIPS, including application of corrections and status of manual editing. Steps tracked included conversion, SVP correction, filtering, application of Delayed Heave and SBET, Compute GPSTide, TPU, and Merge. The status of two reviews in HIPS Swath Editor was also logged. Processing comments were kept for any abnormal situations encountered. The initials of the survey staff member completing the process or task was also kept.

* POS Processing Logsheet: For each POS (POSMV) file, this logsheet tracked POSPac processing completed and any notes or observations.

Times entered into logsheets were manually entered and may differ slightly from corresponding times within the digital files.

Shorthand letter identifiers for the various survey sheets were commonly used throughout the logsheets. These were as follows:

Sheet 'A' = H13246
Sheet 'B' = H13247
Sheet 'C' = H13248
Sheet 'D' = H13249
Sheet 'E' = H13250
Sheet 'F' = H13251
Sheet 'G' = F00770

Logs were exported to PFD format and included with the applicable DRs for reference.

D.1.9 Other Validation Procedures

Bar Checks

A bar check was used to determine and refine sonar Z offsets, and to check the relative accuracy of the echosounder and processing systems. This was completed on the Q105 on JD184 (7/3/19) while on anchor due to weather in Security Cove, Kuskokwim Bay. The ASV-CW5 did not receive a bar check due to the difficulty involved with this check on the unmanned vessel – MBES data was compared directly to Q105 data instead (see multi-vessel echosounder comparisons below).

To perform the bar check, a rectangular steel grate was hung by cable from the vessel's gunwale directly above the MBES sonar on the vessel's port side. The cable was marked at an interval of 0.5 m from the bar, determined by measuring tape. A sound speed profile was collected, and static draft (gunwale to the waterline) was measured.

With QINSy logging and the sonar tuned to track the bar instead of the bottom, the bar was lowered in 0.5 m increments directly below the transducer while bar depth and time were noted in the depth check logsheet. Bar check depths ranged from 3.15 to 7.15 m and were limited by the ability to track the bar and the depth under the vessel while on anchor.

The bar depth was read relative to the gunwale, and later corrected to the waterline using the static draft measurement for comparison to the processed results.

Bar checks were processed in CARIS HIPS. The heave data record was removed, MBES data was sound speed corrected using the associated profile, and waterline measurement (static draft) applied. Depth of the bar relative to the waterline was extracted from HIPS in swath editor and compared to the actual bar depth at that time.

Processed bar depths (CARIS results) compared to actual bar depths to 0.007 m on average with a standard deviation of 0.019 m. The computed acoustic center Z value, which used the observed nadir value from the MBES corrected for known vessel offsets to the measure-down point, compared to 0.030 m on average with a standard deviation of 0.019 m.

Results were considered excellent given the variables of a bar check. The bar check processing logsheet in Appendix V of this report.

D.1.10 Other Validation Procedures

Lead Lines

A lead line check was completed twice on the Q105 to check for gross error in the absolute accuracy for the echosounder and processing systems. The check was done on JD232 while tied up dockside in Bethel, Alaska and again on JD234 while on anchor near Wosnesenski Island.

The check was accomplished by lowering a measuring tape outfit with a 3 lb. weight to the seafloor from the static draft measure-down point and noting the value. The real-time (or raw) sonar depth at nadir was simultaneously noted. The two measurements were corrected to the water level using the established vessel offsets and the static draft measurement and compared.

The JD232 test returned a significant difference of 0.776 m (lead line deeper). However, this check was considered a bad test and should be disregarded because the survey crew noted significant slope and current adversely affecting the lead line.

The JD234 test was completed under better conditions with relatively flat seafloor and little current. Two consecutive checks were done, the first returning a difference from the MBES of 0.188 m and the second returning a difference of 0.026 m, with the lead line slightly deeper on both.

Results of the JD234 test were considered acceptable given the variables inherent in a lead line check. The lead line logsheet is available in Appendix V of this report.

D.1.11 Other Validation Procedures

SVP Comparisons

An SVP comparison was used to check the accuracy and consistency of the sound velocity profiler data. In the test, data from the primary sound speed profiler was compared to one other independent, recently calibrated sound speed profiler. Both profilers were lowered simultaneously to the seafloor, with the probes taped together so that the sensors were located as close as possible to each other. Results were then compared in Excel by graphical examination and computation of mean difference and standard deviation.

On this project, two formal confidence check was completed in this manner, on JD196 and again on JD215. The JD196 check was completed while tied up in Bethel Alaska in relatively shallow water, while the JD215 check was completed on anchor during weather downtime in Security Cove in slightly deeper water. Two Valeport rapidPro SVT profilers (the primary profiler SN71027 and backup profiler SN71026) were used in each check. The JD196 check extended to a depth of about 1.9 meters and returned a mean difference of 0.62 m/s with a standard deviation of 0.21 m. The JD215 check extended to a depth of about 6 meters and returned a mean difference of 0.28 m/s, with a standard deviation of 0.16 m.

Overall SN71027 read slightly greater sound speed than SN71026. However, the differences of 0.28 to 0.62 m/s were considered to be well within acceptable margins given that an error in sound speed of 0.62 m results in a change in computed depth of less than 1 cm at nadir in 20 m water depth, which was generally the deepest depth experienced on this project.

As described earlier in this report, formal comparisons were also undertaken at each SVP cast between the surface sound speed sensor on the Q105 and the profile.

The SVP Comparisons were exported to PDF format and are available with the project DRs.

D.1.12 Other Validation Procedures

Vessel Positioning Confidence Checks

As discussed elsewhere in this report, POSMV data was post-processed in Applanix POSPac MMS using Trimble PP-RTX methodology. As check on PP-RTX positioning to ensure vessel positioning was consistent regardless of processing method used, and as an overall accuracy check of vessel positioning, vessel position confidence checks were accomplished by processing with an alternative POSPac processing method and comparing to the primary method. These checks were accomplished on a weekly basis.

To complete the check for each vessel, a random POS file was selected from each week and re-processed with Applanix SmartBase (ASB). This was compared to the same POS file processed with PP-RTX. The two independent post-processed solutions were differenced in POSPac MMS's "Navdif" utility. A difference plot was produced, which was recorded on a vessel positioning confidence form along with the comparison parameters and observations.

Results were good, with average differences agreeing to 0.1 m or better, demonstrating consistent results regardless of the processing method used.

The vessel positioning confidence checks were exported to PDF format and are available with the project DRs.

D.2 Imagery data Integrity and Quality Management

Imagery data integrity and quality management were not conducted for this survey.

E. Approval Sheet

All operations contributing to the completion of this project were conducted under my direct supervision with frequent personal checks of progress and adequacy.

This report, digital data, and accompanying records have been closely reviewed and are considered complete and adequate per the Statement of Work and Project Work Instructions.

Other reports submitted for this survey include the Descriptive Report (one for each survey sheet) and the Horizontal and Vertical Control Report.

Approver Name	Approver Title	Date	Signature
Andrew Orthmann, C.H.	TerraSond Charting Program Manager	12/14/2019	Andrew Orthmann Digitally signed by Andrew Orthmann Date: 2019.12.14 15:58:35 -09'00'

List of Appendices:

Mandatory Report	***File***
Vessel Wiring Diagram	OPR-R341-KR-19_DAPR_Appendices.pdf
Sound Speed Sensor Calibration	OPR-R341-KR-19_DAPR_Appendices.pdf
Vessel Offset	OPR-R341-KR-19_DAPR_Appendices.pdf
Position and Attitude Sensor Calibration	OPR-R341-KR-19_DAPR_Appendices.pdf
Echosounder Confidence Check	OPR-R341-KR-19_DAPR_Appendices.pdf
Echosounder Acceptance Trial Results	OPR-R341-KR-19_DAPR_Appendices.pdf