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-Y396-KR-22
Time Frame:	May - December 2022

LOCALITY

State(s):	Wisconsin
General Locality:	Western Lake Michigan

2022

CHIEF OF PARTY
David J. Bernstein, CH, PLS, GISP

LIBRARY & ARCHIVES

Date:

NOAA FORM 77-28
(11-72)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

HYDROGRAPHIC TITLE SHEET

INSTRUCTIONS - The Hydrographic Sheet should be accompanied by this form, filled in as completely as possible, when the sheet is forwarded to the office.

REGISTRY No
H13635
H13636
H13637
H13638
H13639
H13640
H13641
H13642
H13643

FIELD No
Geodynamics LLC

State Wisconsin

General Locality Western Lake Michigan

Sub-Locality Nearshore Port Washington, Nearshore Sheboygan South, Nearshore Sheboygan North, Nearshore Manitowoc, Offshore Manitowoc, 6NM NE of Sheboygan, 9 NM East of Port Washington, Offshore Sheboygan, Offshore Port Washington

Scale 1:5,000 1:40,000 **Date of Survey** May - September 2022

Instructions Dated April 6, 2022 **Project No.** OPR-Y396-KR-22

Vessel R/V Benthos, R/V Substantial

Chief of Party David J. Bernstein, CH, PLS, GISP

Surveyed by Geodynamics LLC

Soundings by echo sounder Kongsberg 2040C

Graphic record scaled by N/A

Graphic record checked by N/A **Automated Plot** N/A

Verification by Atlantic Hydrographic Branch

Soundings in Meters at Low Water Datum (LWD), International Great Lakes Datum 1985 (IGLD85)

REMARKS:
NAD83 (2011), UTM Zone 16 North
Times are in UTC
The purpose of this contract is to provide NOAA with modern, accurate hydrographic
survey data to update the nautical charts of the assigned area.

SUBCONSULTANTS: N/A

NOAA FORM 77-28 SUPERSEDES FORM C&GS-537

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Data Acquisition and Processing Report

Geodynamics LLC
Chief of Party: David J. Bernstein, CH, PLS, GISP
Year: 2022
Version: 1.0
Publish Date: 2022-12-18

A. System Equipment and Software

A.1 Survey Vessels

A.1.1 R/V Benthos

<table>
<tr><td><i>Vessel Name</i></td><td colspan="2">R/V Benthos</td></tr>
<tr><td><i>Hull Number</i></td><td colspan="2">ACD28CATA212</td></tr>
<tr><td><i>Description</i></td><td colspan="2">Geodynamics LLC supplied the R/V Benthos for hydrographic survey operations on OPR-Y396-KR-22. The R/V Benthos is a 9.14 meter catamaran built by Armstrong Marine and conducted 12-hour day operations. The R/V Benthos has the following specifications:</td></tr>
<tr><td rowspan="3"><i>Dimensions</i></td><td><i>LOA</i></td><td>9.14 m</td></tr>
<tr><td><i>Beam</i></td><td>3.20 m</td></tr>
<tr><td><i>Max Draft</i></td><td>0.61 m</td></tr>
<tr><td rowspan="2"><i>Most Recent Full Static Survey</i></td><td><i>Date</i></td><td>2021-03-09</td></tr>
<tr><td><i>Performed By</i></td><td>Mike Ulmer, 3Space Inc</td></tr>
<tr><td rowspan="2"><i>Most Recent Full Offset Verification</i></td><td><i>Date</i></td><td>2021-03-09</td></tr>
<tr><td><i>Method</i></td><td>The R/V Benthos offset survey was verified / conducted by measurement specialists Mike Ulmer of 3Space Inc and a team of Geodynamics hydrographers. Survey instrument offsets were measured using a Leica 402 Laser Tracker with Spatial Analyzer software. All measurements were performed multiple times and in varying combinations to reduce uncertainty and blunders.</td></tr>
</table>

Figure 1: R/V Benthos

A.1.2 R/V Substantial

<table>
<tr><td><i>Vessel Name</i></td><td colspan="2">R/V Substantial</td></tr>
<tr><td><i>Hull Number</i></td><td colspan="2">USZ00221D013</td></tr>
<tr><td><i>Description</i></td><td colspan="2">Geodynamics LLC supplied the R/V Substantial for hydrographic survey operations on OPR-Y396-KR-22. The R/V Substantial is a 18 meter Seaton designed mono-hull vessel built by Marks Marine and conducted 24-hour operations. The R/V Substantial has the following specifications:</td></tr>
<tr><td rowspan="3"><i>Dimensions</i></td><td><i>LOA</i></td><td>18 m</td></tr>
<tr><td><i>Beam</i></td><td>5.48 m</td></tr>
<tr><td><i>Max Draft</i></td><td>2.22 m</td></tr>
<tr><td rowspan="2"><i>Most Recent Full Static Survey</i></td><td><i>Date</i></td><td>2021-03-08</td></tr>
<tr><td><i>Performed By</i></td><td>Mike Ulmer, 3Space Inc</td></tr>
</table>

Most Recent Full Offset Verification	*Date*	2021-03-08
	Method	The R/V Substantial offset survey was verified / conducted by measurement specialists Mike Ulmer of 3Space Inc and a team of Geodynamics hydrographers. Survey instrument offsets were measured using a Leica 402 Laser Tracker with Spatial Analyzer software. All measurements were performed multiple times and in varying combinations to reduce uncertainty and blunders.

Figure 2: R/V Substantial

A.2 Echo Sounding Equipment

A.2.1 Multibeam Echosounders

A.2.1.1 Kongsberg EM2040C Dual

The R/V Benthos was equipped with a dual-head Kongsberg EM2040C Multibeam Echo Sounder System (MBES) with sonar heads pole mounted with a bracket holding the sonar heads at 35°/-35°. Two Kongsberg processing units (PU) were combined to enable dual swath mode capabilities. The R/V Substantial was equipped with a dual-head Kongsberg EM2040C MBES with sonar heads hull mounted at 35°/-35°, again equipped with dual swath mode capabilities. The dual-head EM2040C utilizes 512 discretely formed beams of a selectable sector up to 200° in equidistant operation mode. At 300 kHz, the EM2040C focuses an across-track and along-track beam width of 1° and 1° respectively. The EM2040C operates at a maximum ping rate of 50 Hz and is designed to comply with International Hydrographic Organization (IHO) standards for depth measurements to a maximum range of 450 meters.

<table>
<tr><td><i>Manufacturer</i></td><td colspan="7">Kongsberg</td></tr>
<tr><td><i>Model</i></td><td colspan="7">EM2040C Dual</td></tr>
<tr><td rowspan="12"><i>Inventory</i></td><td rowspan="6"><i>R/V Benthos</i></td><td><i>Component</i></td><td>Port Sonar Head</td><td>Stbd Sonar Head</td><td>Processing Unit 1</td><td>Processing Unit 2</td><td>Hydrographic Workstation</td></tr>
<tr><td><i>Model Number</i></td><td>EM2040C</td><td>EM2040C</td><td>385406</td><td>385406</td><td>Cincoze DS-1202</td></tr>
<tr><td><i>Serial Number</i></td><td>2549</td><td>2548</td><td>20188</td><td>20159</td><td>U743018</td></tr>
<tr><td><i>Frequency</i></td><td>300 kHz</td><td>300 kHz</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td><i>Calibration</i></td><td>2022-05-06</td><td>2022-05-06</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td><i>Accuracy Check</i></td><td>2022-05-06</td><td>2022-05-06</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="6"><i>R/V Substantial</i></td><td><i>Component</i></td><td>Port Sonar Head</td><td>Stbd Sonar Head</td><td>Processing Unit 1</td><td>Processing Unit 2</td><td>Hydrographic Workstation</td></tr>
<tr><td><i>Model Number</i></td><td>EM2040C</td><td>EM2040C</td><td>385406</td><td>385406</td><td>Cincoze DS-1202</td></tr>
<tr><td><i>Serial Number</i></td><td>2513</td><td>2532</td><td>20043</td><td>30034</td><td>U756909</td></tr>
<tr><td><i>Frequency</i></td><td>300 kHz</td><td>300 kHz</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td><i>Calibration</i></td><td>2022-06-17</td><td>2022-06-17</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td><i>Accuracy Check</i></td><td>2022-06-17</td><td>2022-06-17</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
</table>

Figure 3: Kongsberg EM2040C dual-head sonar on the R/V Benthos pole mount

Figure 4: Kongsberg EM2040C dual-head sonar hull mounted on the R/V Substantial with each transducer labeled

Figure 5: Kongsberg EM2040C hull mount on the R/V Substantial

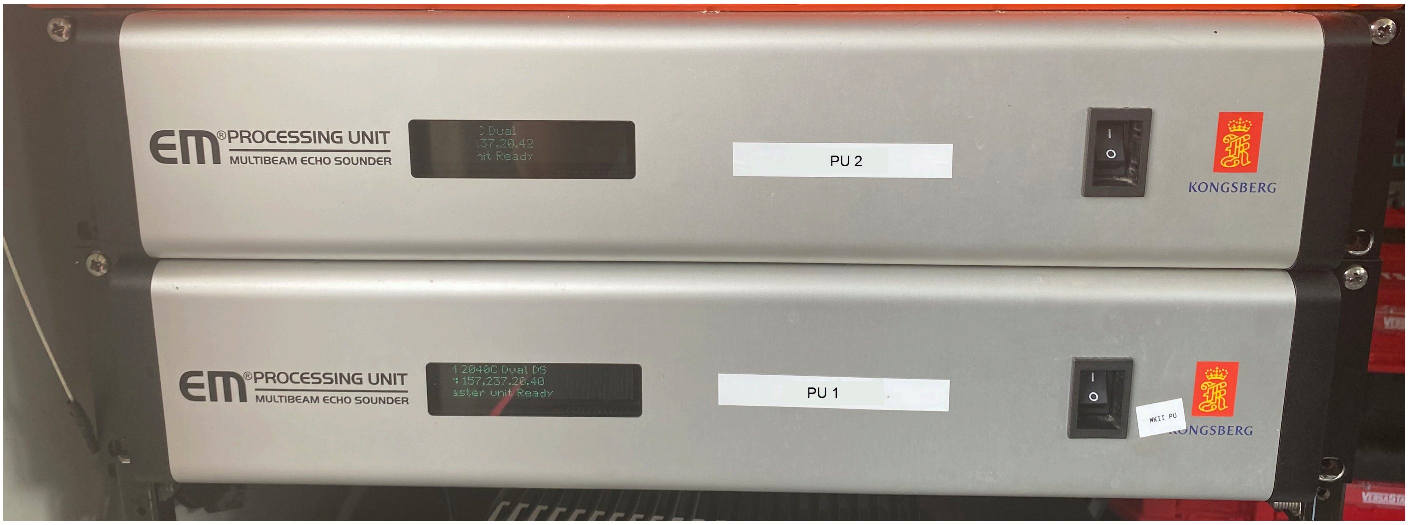

Figure 6: Kongsberg Slim Processing Units (PU) setup in dual swath configuration

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

No water level gauges were utilized for data acquisition.

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 POS MV V5 OceanMaster

Each survey vessel deployed on OPR-Y396-KR-22 utilized an Applanix POS MV system for positioning, attitude, and precise timing of sonar data. The POS MV is a Global Navigation Satellite System (GNSS) aided inertial navigation system that provides georeferencing and motion compensation for hydrographic surveys. The POS MV is comprised of four main components: POS Computer System (PCS), Inertial Measurement Unit (IMU), Primary GNSS Antenna, and the Secondary GNSS Antenna.

On the R/V Benthos and R/V Substantial, positioning and heading were transmitted from the POS MV at 10 Hz and attitude was transmitted at 100 Hz to the Kongsberg sonar over RS232 serial connections. These data were also broadcast to QPS Qinsy software over Ethernet/UDP at 50 Hz for vessel navigation and real-time quality control (QC). To enable post-processing of the position and attitude data from the POSMV system, the data is recorded through ethernet logging to an internal SSD on the acquisition computer and a redundant, USB logged file is also recorded on a flash drive inserted in the POSMV PCS unit itself. For the R/V Substantial, this redundant USB logged position and attitude data file was more often utilized than the ethernet logged data due to data gaps created by network dropouts. The POS MV also computes vessel heave (both instantaneous and ‘delayed’ heave values). The Applanix delayed heave algorithm uses a delayed filtering technique to eliminate many of the artifacts present in real-time heave data. Delayed heave measurements are logged and applied to MBES data in post-processing.

The POS MV also provided precise timing for sonar data to the Kongsberg PU via BNC Pulse Per Second cable. Additionally, a NMEA ZDA message was transmitted at 1 Hz from the POS MV to QPS Qinsy and Kongsberg SIS.

The R/V Benthos utilized POS MV firmware version 10.21 and POSView software version 10.2. The R/V Substantial utilized POS MV firmware version 10.50 and POSView software version 10.5.

During pre-survey calibrations, and when required (equipment failure/change), a POS MV calibration was performed. This calibration included a GNSS Azimuth Measurement System (GAMS) calibration and details can be found in the DAPR Appendix IV.

<table>
<tr><td><i>Manufacturer</i></td><td colspan="6">Applanix</td></tr>
<tr><td><i>Model</i></td><td colspan="6">POS MV V5 OceanMaster</td></tr>
<tr><td rowspan="8"><i>Inventory</i></td><td rowspan="4"><i>R/V Benthos</i></td><td><i>Component</i></td><td>PCS</td><td>Primary GNSS Antenna</td><td>Secondary GNSS Antenna</td><td>IMU</td></tr>
<tr><td><i>Model Number</i></td><td>PCS-100</td><td>540AP</td><td>540AP</td><td>IMU 65</td></tr>
<tr><td><i>Serial Number</i></td><td>11164</td><td>17985</td><td>17989</td><td>3250</td></tr>
<tr><td><i>Calibration</i></td><td>2022-05-06</td><td>2022-05-06</td><td>2022-05-06</td><td>2022-05-06</td></tr>
<tr><td rowspan="4"><i>R/V Substantial</i></td><td><i>Component</i></td><td>PCS</td><td>Primary GNSS Antenna</td><td>Secondary GNSS Antenna</td><td>IMU</td></tr>
<tr><td><i>Model Number</i></td><td>PCS-100</td><td>GA830</td><td>GA830</td><td>IMU 89</td></tr>
<tr><td><i>Serial Number</i></td><td>12029</td><td>17034</td><td>16886</td><td>4947</td></tr>
<tr><td><i>Calibration</i></td><td>2022-06-17</td><td>2022-06-17</td><td>2022-06-17</td><td>2022-06-17</td></tr>
</table>

Figure 7: POS MV V5 OceanMaster system

A.5.2 DGPS

DGPS equipment was not utilized for data acquisition.

A.5.3 GPS

Additional 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

A.5.5.1 Fugro Marinestar Satellite-Based Augmentation System (SBAS)

Each survey vessel deployed on OPR-Y396-KR-22 received G2+ GNSS satellite corrections from the Marinestar worldwide correction system. SBAS settings in the POS MV were configured to receive the G2+ correction at a frequency of 1545.9375 MHz and bit rate of 1200 bits/second.

Manufacturer	Fugro		
Model	Marinestar Satellite-Based Augmentation System (SBAS)		
Inventory	*R/V Benthos*	*Component*	Marinestar SBAS
		Model Number	N/A
		Serial Number	N/A
		Calibration	N/A
	R/V Substantial	*Component*	Marinestar SBAS
		Model Number	N/A
		Serial Number	N/A
		Calibration	N/A

A.6 Sound Speed Equipment

A.6.1 Moving Vessel Profilers

A.6.1.1 AML Oceanographic MVP30-350

The R/V Substantial was outfitted with an AML Oceanographic Moving Vessel Profiler (MVP) used to obtain sound speed profiles at a greater frequency without stopping the survey vessel. The AML MVP30-350 system consists of a sensor free fall fish, an integrated winch and power unit, an overboard towing sheave, and a remote system controller with dedicated operating station running the MVP Controller software. Sound speed profiles acquired with the MVP were imported into HydrOffice Sound Speed Manager (SSM) via ethernet/UDP and then broadcast directly to SIS. On 07/02/2022, the MVP30-350 experienced connection issues due to internal parts and the backup MVP30-350 was then used for the remainder of the project.
The two units are nearly identical other than the latter unit utilizes conductivity, temperature, and pressure (depth) sensors to determine sound speed instead of the time-of-flight sensor (sound speed Xchange sensor) on the original fish. All relevant calibrated pressure, conductivity, temperature and sound velocity sensors associated with each instrument are listed below.

<table>
<tr><td><i>Manufacturer</i></td><td>AML Oceanographic</td></tr>
<tr><td><i>Model</i></td><td>MVP30-350</td></tr>
<tr><td><i>Inventory</i></td><td><table><tr><td><i>R/V Substantial</i></td><td><table>
<tr><td><i>Component</i></td><td>Sound Speed Profiling Instrument</td><td>Sound Speed Profiling Instrument</td><td>SV Sensor</td><td>Pressure Sensor</td><td>Pressure Sensor</td><td>Conductivity Sensor</td><td>Temperator Sensor</td></tr>
<tr><td><i>Model Number</i></td><td>MVP30-350</td><td>MVP30-350</td><td>SV•Xchange</td><td>P•Xchange</td><td>P•Xchange</td><td>C•Xchange</td><td>T•Xchange</td></tr>
<tr><td><i>Serial Number</i></td><td>M12540</td><td>M12962</td><td>209304</td><td>306129</td><td>307233</td><td>503650</td><td>404626</td></tr>
<tr><td><i>Calibration</i></td><td>N/A</td><td>N/A</td><td>2022-03-11</td><td>2022-03-11</td><td>2022-05-10</td><td>2022-05-10</td><td>2022-05-10</td></tr>
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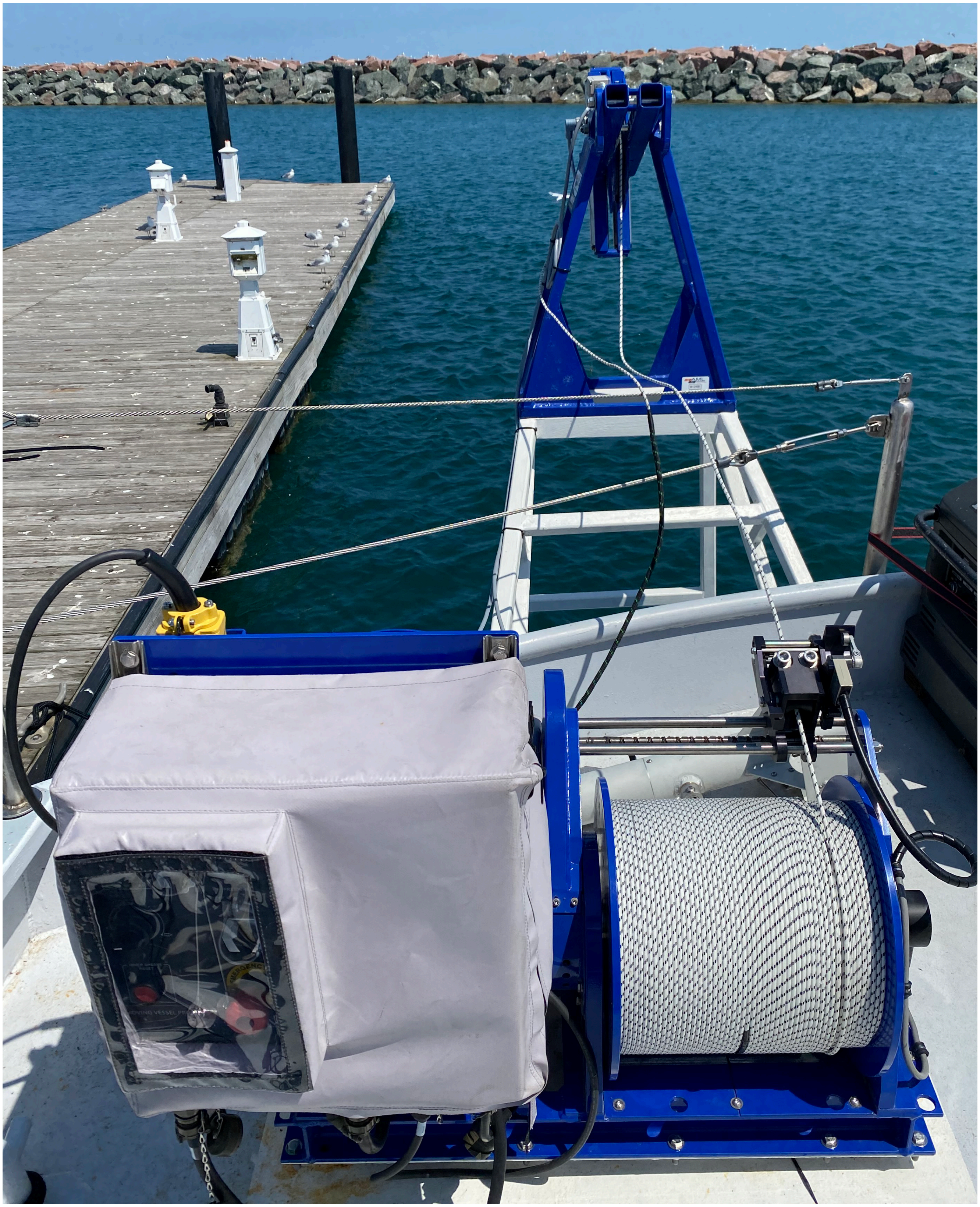

Figure 8: AML Oceanographic MVP30-350

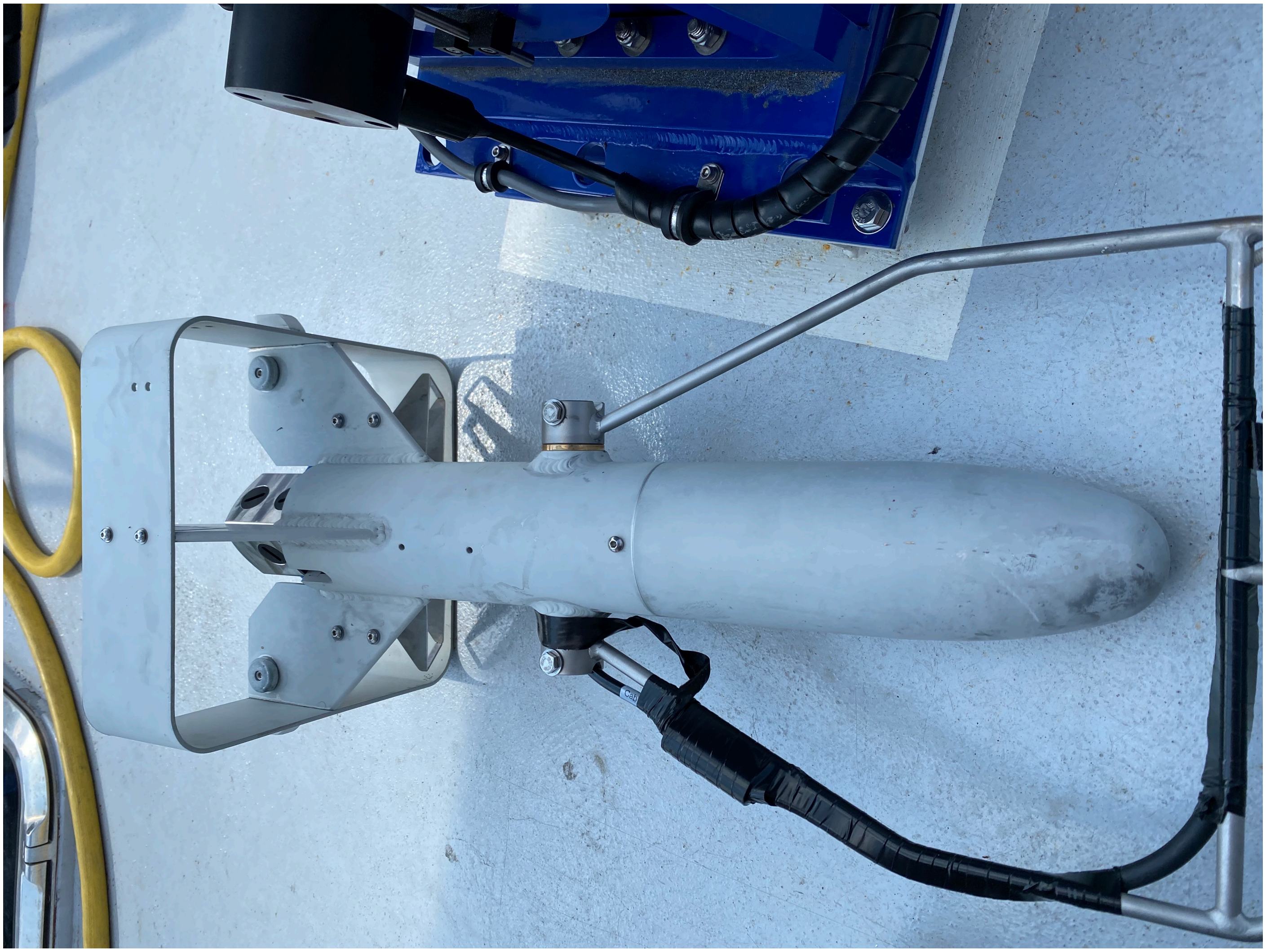

Figure 9: MVP Sensor free fall fish

A.6.2 CTD Profilers

No CTD profilers were utilized for data acquisition.

A.6.3 Sound Speed Sensors

A.6.3.1 AML Oceanographic AML Micro•X with SV•Xchange

Each survey vessel deployed on OPR-Y396-KR-22 utilized an AML Oceanographic Micro•X with SV•Xchange to provide surface sound speed to the Kongsberg PU at 1 Hz over RS232 serial connection. The sensor, installed on the sonar head mount, was powered from a 12 volt power source.

Manufacturer	AML Oceanographic			
Model	AML Micro•X with SV•Xchange			
Inventory	*R/V Benthos*	*Component*	Surface Sound Speed Instrument	SV Sensor
		Model Number	Micro•X	SV•Xchange
		Serial Number	7762	209306
		Calibration	N/A	2022-03-11
	R/V Substantial	*Component*	Surface Sound Speed Instrument	SV Sensor
		Model Number	Micro•X	SV•Xchange
		Serial Number	11427	204291
		Calibration	N/A	2022-03-11

Figure 10: AML Oceanographic Micro•X with SV•Xchange

A.6.3.2 AML Oceanographic AML Base•X2 with SV•Xchange

The AML Base•X2 is a sound speed profiling instrument integrated with time-of-flight sound speed sensors and pressure sensors to collect sound speed profiles. The Base•X2 transferred sound speed profile data to AML Seacast over Wireless Local Area Network (WLAN) connection and RS232 serial cable when needed.

On the R/V Benthos, the Base•X2 was the primary profiling system. On 07/18/22, a different P•Xchange (SN 306187) and SV•Xchange (SN 209578) were placed on the original profiler (SN 26045) because the vessel was nearing the max depth rating of the original pressure sensor.

On 07/29/2022, the primary probe on the R/V Benthos was replaced, and the Base•X2 profiler (SN 26270) and associated sensors were then utilized by the R/V Benthos for the remainder of the project. R/V Substantial utilized this same probe at the beginning of the project from some testing/calibrations.

Manufacturer	AML Oceanographic								
Model	AML Base•X2 with SV•Xchange								
Inventory	*R/V Benthos*	*Component*	Sound Speed Profiling Instrument	SV Sensor	Pressure Sensor	SV Sensor	Pressure Sensor	Sound Speed Profiling Instrument	SV Sensor	Pressure Sensor
		Model Number	Base•X2	SV•Xchange	P•Xchange	SV•Xchange	P•Xchange	Base•X2	SV•Xchange	P•Xchange
		Serial Number	26045	206265	304496	209578	306187	26270	200936	307376
		Calibration	N/A	2022-03-11	2022-03-11	2022-03-11	2022-03-11	N/A	2022-03-11	2022-03-11

Figure 11: AML Oceanographic Base•X2

A.6.4 TSG Sensors

No TSG sensors were utilized for data acquisition.

A.6.5 Other Sound Speed Equipment

No other surface sound speed sensors were utilized for data acquisition.

A.7 Computer Software

Manufacturer	*Software Name*	*Version*	*Use*
QPS	Qinsy	9.4.4	Acquisition
AML Oceanographic	Seacast	4.4.0	Acquisition
AML Oceanographic	MVP Controller	4.3.1	Acquisition
Applanix	POSView	10.20	Acquisition
Applanix	POSView	10.50	Acquisition
Applanix	POS MV Firmware	10.21	Acquisition
Applanix	POS MV Firmware	10.50	Acquisition
Kongsberg	Seafloor Information System (SIS)	4.3.2	Acquisition
Kongsberg	Kongsberg Firmware	1.6	Acquisition
HydrOffice	Sound Speed Manager	2022.1.1	Acquisition
Microsoft	Office 365	2022	Acquisition and Processing
NOAA (HSTB)	Pydro Explorer	19.4 & 22.1	Acquisition and Processing
ESRI	ArcGIS Online	2021	Acquisition and Processing
ESRI	ArcGIS Enterprise	10.8	Acquisition and Processing
ESRI	ArcPro	3.0.2	Processing
Teledyne CARIS	HIPS Professional	11.4.4	Processing
Teledyne CARIS	BASE Editor	5.5	Processing
QPS	Qimera	2.4.8	Processing (Patch Test)
QPS	FMGeocoder Toolbox (FMGT)	7.10.1	Processing
Applanix	POSPac MMS with Trimble Centerpoint RTX	8.7	Processing
Adobe	Acrobat DC	2022.002	Processing
TechSmith	Snagit	2020.1.5	Processing

A.8 Bottom Sampling Equipment

A.8.1 Bottom Samplers

A.8.1.1 Wildco 3-1725-F50, S/N 4510

The Wildco Ponar Dredge sampler was used aboard the R/V Substantial to acquire bottom samples for OPR-Y396-KR-22. Ponar samplers are widely used for sediment sampling on a variety of bottom types such as silt, sand, gravel, consolidated marl, or clay. The Ponar dredge was primarily utilized for sediment samples, but the Petite Ponar was employed if there were limitations of the Ponar dredge due deployment mechanism and line capacity.

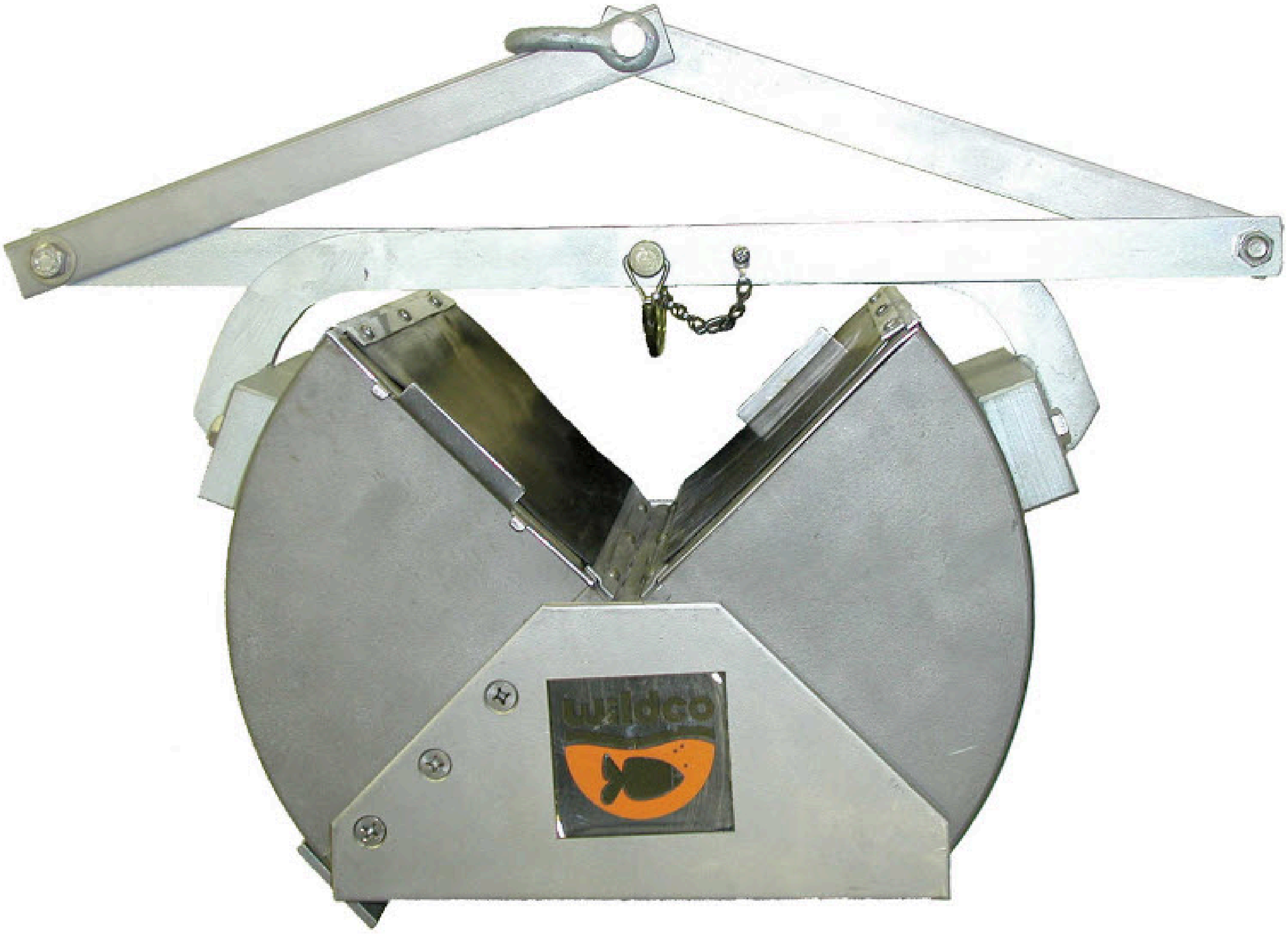

Figure 12: Wildco Ponar Dredge

A.8.1.2 Wildco 1728-G40, S/N 0618

The Wildco Petite Ponar sampler was used aboard the R/V Substantial to acquire bottom samples for OPR-Y396-KR-22. Ponar samplers are widely used for sediment sampling on a variety of bottom types such as silt, sand, gravel, consolidated marl, or clay.

Figure 13: Wildco Petite Ponar

B. System Alignment and Accuracy

B.1 Vessel Offsets and Layback

B.1.1 Vessel Offsets

Static vessel surveys were performed to determine offsets on each vessel deployed on OPR-Y396-KR-22 prior to survey operations. Measurement Specialist, Mike Ulmer of 3Space Inc, performed the most recent static surveys of each vessel. The R/V Benthos and R/V Substantial's static surveys were performed near Geodynamics Headquarters in Beaufort, NC on March 8-9, 2021. These static surveys were performed identically in survey scheme and when possible, the static survey re-occupied a variety of previous vessel reference punch marks to ensure quality of the vessel offsets and reference frame measurements. Additionally, the 3Space Inc team are experts in Metrology and have vigorous QC procedures that were employed throughout the survey to ensure accuracy of the calculated vessel offsets. For the static surveys, all sensor locations were surveyed, as well as several pre-determined punch mark locations across the vessel frame. The static surveys were conducted with a Leica 402 Laser Scanner and Spatial Analyzer software.

The R/V Benthos and R/V Substantial are each configured such that position and attitude are output from the POS MV at the sonar reference point. The sonar reference point is defined as the tangent point between each sonar head in the dual-head configuration. The location and angular offsets from the tangent reference point to each sonar head and waterline are entered into SIS. Identical vessel offsets were input in the Qinsy vessel template database (.DB) file for real-time display of corrected sonar data during acquisition.

Figure 14: Static survey of R/V Substantial

B.1.1.1 Vessel Offset Correctors

Vessel offset correctors were not applied.

B.1.2 Layback

Not applicable as side scan sonar was not acquired.

Layback correctors were not applied.

B.2 Static and Dynamic Draft

B.2.1 Static Draft

This project incorporated an Ellipsoid Referenced Survey (ERS) workflow and as a result, static draft was accounted for in the soundings by using post-processed ellipsoid-based corrections in addition to the real-time corrections. The combined correctors work to factor out the static draft, squat, and settlement of the survey vessel.

B.2.1.1 Static Draft Correctors

Static draft correctors were not applied.

B.2.2 Dynamic Draft

This project incorporated an ERS workflow and as a result, dynamic draft was accounted for in the soundings by using post-processed ellipsoid-based corrections in addition to the real-time corrections. The combined correctors work to factor out the static draft, squat, and settlement of the survey vessel.

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

Multibeam patch tests were performed on each survey vessel to establish installation mounting biases between the attitude reference frame and the sonar reference frame. The patch tests also determined any latency bias between the sonar systems and positioning systems. Patch tests were conducted on each vessel prior to the start of data acquisition and whenever a major system hardware change was made. Patch tests were conducted in accordance with section 5.2.4.1 of the March 2022 Hydrographic Survey Specifications and Deliverables (HSSD). Patch test data were assessed in QPS Qimera by multiple hydrographers to issue an uncertainty associated with the patch test biases. Patch test biases for the R/V Benthos, and R/V Substantial were entered into SIS as well as the Qinsy .DB file. Additionally, these patch test biases are entered into the appropriate locations in the CARIS HVF. To ensure quality in system alignment and the integrity of the sonar data, daily roll lines were collected on the R/V Benthos since this vessel utilized a deployable over-the-side pole mount.

B.3.1.1 System Alignment Correctors

<table>
<tr><td><i>Vessel</i></td><td colspan="3">R/V Benthos</td></tr>
<tr><td><i>Echosounder</i></td><td colspan="3">Kongsberg EM2040C Dual</td></tr>
<tr><td><i>Date</i></td><td colspan="3">2022-05-06</td></tr>
<tr><td rowspan="10"><i>Patch Test Values</i></td><td></td><td><i>Corrector</i></td><td><i>Uncertainty</i></td></tr>
<tr><td><i>Transducer Time Correction</i></td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td><i>Navigation Time Correction</i></td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td><i>Pitch</i></td><td>-0.194 degrees</td><td>0.050 degrees</td></tr>
<tr><td><i>Roll</i></td><td>34.205 degrees</td><td>0.050 degrees</td></tr>
<tr><td><i>Yaw</i></td><td>359.495 degrees</td><td>0.085 degrees</td></tr>
<tr><td><i>Pitch Time Correction</i></td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td><i>Roll Time Correction</i></td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td><i>Yaw Time Correction</i></td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td><i>Heave Time Correction</i></td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td><i>Date</i></td><td colspan="3">2022-05-06</td></tr>
<tr><td rowspan="10"><i>Patch Test Values (Transducer 2)</i></td><td></td><td><i>Corrector</i></td><td><i>Uncertainty</i></td></tr>
<tr><td><i>Transducer Time Correction</i></td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td><i>Navigation Time Correction</i></td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td><i>Pitch</i></td><td>-0.207 degrees</td><td>0.050 degrees</td></tr>
<tr><td><i>Roll</i></td><td>-35.925 degrees</td><td>0.050 degrees</td></tr>
<tr><td><i>Yaw</i></td><td>359.450 degrees</td><td>0.085 degrees</td></tr>
<tr><td><i>Pitch Time Correction</i></td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td><i>Roll Time Correction</i></td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td><i>Yaw Time Correction</i></td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td><i>Heave Time Correction</i></td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
</table>

<table>
<tr><td>Vessel</td><td>R/V Substantial</td></tr>
<tr><td>Echosounder</td><td>Kongsberg EM2040C Dual</td></tr>
<tr><td>Date</td><td>2022-06-17</td></tr>
<tr><td>Patch Test Values</td><td>
<table>
<tr><td></td><td>Corrector</td><td>Uncertainty</td></tr>
<tr><td>Transducer Time Correction</td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td>Navigation Time Correction</td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td>Pitch</td><td>-0.990 degrees</td><td>0.050 degrees</td></tr>
<tr><td>Roll</td><td>37.210 degrees</td><td>0.050 degrees</td></tr>
<tr><td>Yaw</td><td>0.020 degrees</td><td>0.085 degrees</td></tr>
<tr><td>Pitch Time Correction</td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td>Roll Time Correction</td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td>Yaw Time Correction</td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td>Heave Time Correction</td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
</table>
</td></tr>
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<table>
<tr><td>Vessel</td><td>R/V Substantial</td></tr>
<tr><td>Echosounder</td><td>Kongsberg EM2040C Dual</td></tr>
<tr><td>Date</td><td>2022-06-17</td></tr>
<tr><td>Patch Test Values (Transducer 2)</td><td>
<table>
<tr><td></td><td>Corrector</td><td>Uncertainty</td></tr>
<tr><td>Transducer Time Correction</td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td>Navigation Time Correction</td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td>Pitch</td><td>0.500 degrees</td><td>0.050 degrees</td></tr>
<tr><td>Roll</td><td>-35.020 degrees</td><td>0.050 degrees</td></tr>
<tr><td>Yaw</td><td>2.040 degrees</td><td>0.085 degrees</td></tr>
<tr><td>Pitch Time Correction</td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td>Roll Time Correction</td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td>Yaw Time Correction</td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
<tr><td>Heave Time Correction</td><td>0.000 seconds</td><td>0.001 seconds</td></tr>
</table>
</td></tr>
</table>

C. Data Acquisition and Processing

C.1 Bathymetry

C.1.1 Multibeam Echosounder

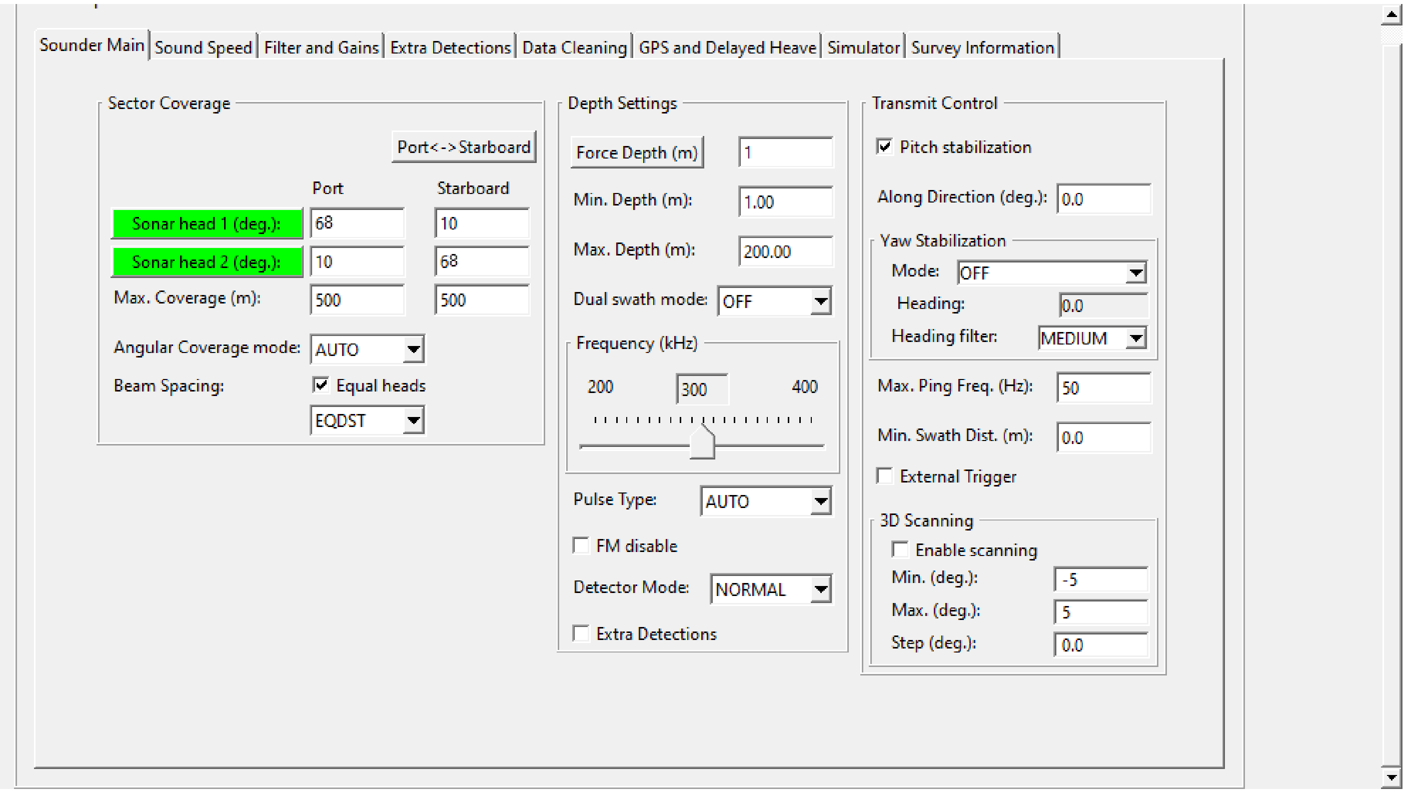
Data Acquisition Methods and Procedures

All data planning, calibrations, acquisition, processing, QC, quality assurance (QA), and reporting were performed under the direct supervision of the Chief of Party. Field data collection and processing were done under the supervision of a highly qualified team including the Chief of Party, Lead Hydrographer, Senior Hydrographer, and Data Processing Manager. Chief of Party David Bernstein, and Lead Hydrographers Ben Sumners, and Nick Damm are all NSPS-THSOA Certified Hydrographers.

Prior to the start of data acquisition, and following static vessel surveys and verification measurements, a series of calibrations and tests took place on each vessel to prepare and validate the setup and integration of all survey systems across all vessels. These procedures included navigation/GAMS calibrations, patch tests, performance checks, echo sounder bar/lead line checks, and a water level float test.

Line plans were developed based on optimal multibeam coverage and quality. Data acquisition used survey lines for tracking. However, lines were mostly used as a reference for data-driven acquisition, in which case captains used ~25% overlap sectors in the helm map to guide navigation. Features identified in the field and during on-site data processing were further investigated with additional MBES data coverage when deemed necessary, to adequately develop the feature. Bathymetric data acquisition around engineered shoreline, structures, reefs, rocks, and shoals were collected with special care and safety to provide the most accurate least depths and required coverage. All vessels utilized Qinsy for navigation, monitoring of system health, data logging, real-time progress tracking, and QC assessments. Using a custom NMEA output driver and Wireless Wide Area Network (WWAN) connection, vessel tracking information was streamed over an ESRI GeoEvent Server to a Survey Information Management System (SIMS) hosted through ArcGIS Online. This combined progress tracker and dashboard system provided real-time situational awareness of each vessel and calculated various project tracking metrics, providing critical guidance for management and hydrographers in real-time. Each vessel and survey system were optimized for data collection to meet the requirements of the Project Instructions (PI) and HSSD. The R/V Benthos operated on a 12-hour day operation schedule while the R/V Substantial operated on a 24-hour schedule. The R/V Benthos and R/V Substantial were configured with dual-head EM2040C systems with dual swath capability. Sonar systems were aided by the POS MV, which provided real-time QC of position and attitude data, and logged ancillary POSPac data (.000 files) for post-processing. Frequency Modulated (FM) Mode was enabled on each sonar through velocity aiding from the POS MV. All Kongsberg systems were controlled with SIS software and operated at 300 kHz. Additionally, all Kongsberg systems had absorption coefficients adjusted for freshwater in SIS and operated in “Normal” mode with “Auto” pulse width. Multibeam bathymetry data collected with the Kongsberg EM2040C systems were stored in the .ALL file.

Throughout the survey, a series of QC measures were taken to ensure that the survey data met the specifications of the PI and HSSD. Hydrographers on R/V Benthos collected a daily set of “roll lines” to assess any potential biases ensued from daily deployment of the over-the-side sonar mount. Vessel speed and sonar coverage were monitored and adjusted when environmental conditions negatively impacted data quality. Vessel to vessel overlap was accomplished whenever possible for additional QC and crosslines were collected by multiple vessels.



Sector Coverage

	Port	Starboard
Sonar head 1 (deg.):	68	10
Sonar head 2 (deg.):	10	68
Max. Coverage (m):	500	500

Angular Coverage mode: AUTO

Beam Spacing: ☑ Equal heads

EQDST

Depth Settings

Force Depth (m) 1

Min. Depth (m): 1.00

Max. Depth (m): 200.00

Dual swath mode: OFF

Frequency (kHz) 200 300 400

Pulse Type: AUTO

☐ FM disable

Detector Mode: NORMAL

☐ Extra Detections

Transmit Control

☑ Pitch stabilization

Along Direction (deg.): 0.0

Yaw Stabilization

Mode: OFF

Heading: 0.0

Heading filter: MEDIUM

Max. Ping Freq. (Hz): 50

Min. Swath Dist. (m): 0.0

☐ External Trigger

3D Scanning

☐ Enable scanning

Min. (deg.): -5

Max. (deg.): 5

Step (deg.): 0.0

Figure 15: General SIS Runtime parameters window for R/V Benthos

Data Processing Methods and Procedures

Multibeam data processing were accomplished with Charlene, CARIS HIPS, and POSPac MMS. Initial data processing consisted of data transfer, file conversion, application of delayed heave and associated rms, SBET/SMRMSG generation and application, georeference bathymetry (application of GPS Tide, sound velocity corrections, and TPU calculation), and CUBE surface generation (Phase 1). Immediately following acquisition, data were transferred via Charlene from portable solid-state drives (SSD) to the network attached server (NAS) hosting an array of SSDs. Charlene is an automated file transfer and batch data processing utility within Pydro Explorer developed by the National Oceanic and Atmospheric Administration (NOAA) Hydrographic Systems and Technology Branch (HSTB). Charlene automated the Phase 1 processing steps such that an initial surface and related QC data were generated before the next survey day. Phase 1 QC included assessing initial QC Tools results, SBET QC, surface inspection, assessment of data quality and system performance, and daily survey reporting.

Phase 2 processing began with a thorough QC of data quality using the CUBE surfaces followed by data cleaning and feature identification/designation.

Phase 3 processing included QC and finalization of features/designations and bathymetric surfaces. During this stage, rigorous QC was performed to ensure completeness and adequacy of the final deliverables and associated reporting.

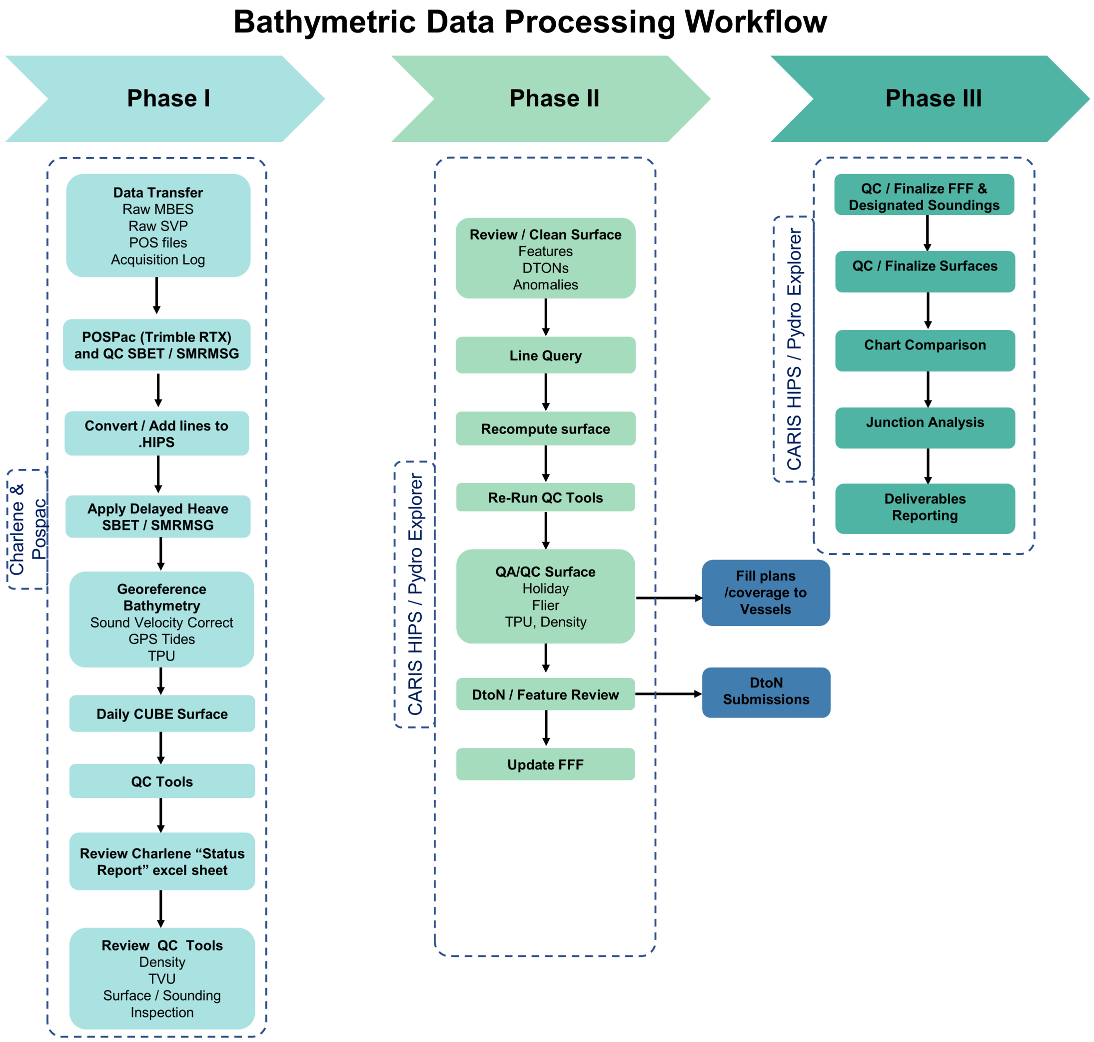


Figure 16: Bathymetric data processing workflow

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

All bathymetric surfaces were computed from fully corrected data in CARIS HIPS using CUBE algorithms specified in the CUBEParams_NOAA_2022.xml and standards specified in section 5.2.2 of the HSSD. Parent surfaces and depth controlled finalized surfaces were provided in CSAR format for each survey.

C.1.4.2 Depth Derivation

Prior to finalizing surfaces, data were thoroughly and redundantly reviewed for completeness and adherence to specifications in the HSSD. Outer beam clipping filters and manual data cleaning were utilized to clean erroneous swath data that adversely affected the surface. Some portions of lines were clipped in the Navigation Editor if the data were unnecessary or recovered. Processed soundings and features were reviewed in Subset Editor using both 2D and 3D views to ensure accurate designation of critical soundings were performed. Line queries were performed to ensure all data had consistent and complete correctors applied. Finalized surfaces were computed utilizing the “Apply Designated Sounding” function such that the surface represented each designated sounding depth. Uncertainty of the finalized surface was assigned from either uncertainty or standard deviation, whichever is greater.

C.1.4.3 Surface Computation Algorithm

The 2022 NOAA CUBE Parameters were used for CUBE surface computation. Surface generation used the following settings:

Gridding Method: CUBE
Bounding Polygon Type: Buffered
IHO Order: 1a
Disambiguation Method: Density and Local
Cube Configuration: NOAA_1m, NOAA_2m, NOAA_4m, NOAA_8m (with respect to depth range and coverage requirements)

C.2 Imagery

C.2.1 Multibeam Backscatter Data

<u>Data Acquisition Methods and Procedures</u>

Multibeam backscatter data collected with the Kongsberg EM2040C systems were stored in the .ALL file, which is directly importable into QPS FMGT. Data were acquired at 300 kHz with no major changes to settings. Hydrographers utilized real-time displays of backscatter and saturation to help assess any potential system-wide backscatter issues. Backscatter calibrations were acquired for this project although these calibrations were not processed for normalization values because it was deemed unnecessary (product was sufficient without these values). The vessels collected data on a preset line in the same direction with each possible combination of vessel, frequency, and pulse length. This data is submitted within the deliverable package in the MBES_Calibration_Data folder.

Data Processing Methods and Procedures

Backscatter files were routinely processed in the field for QA purposes with QPS FMGT. The .ALL files were paired with HDCS files created in CARIS to create mosaics. Mosaics were then reviewed regularly to assure adequate coverage and quality of the backscatter.

In post-processing following bathymetric edits, a new FMGT project was created for each sheet / vessel / sonar frequency. In this case, only 300 kHz was utilized, so the projects are only split by sheet/vessel. Metadata within the .ALL files ensures that sonar-specific characteristics are captured during mosaic processing. The .ALL files are again paired with HDCS files from CARIS, this time HDCS files with final bathymetric edits, and GSF files are generated.

Crosslines or other data contributing error or artifact to the backscatter mosaic were not included in the project if possible. If crosslines aided in coverage, the crosslines remained in the mosaic. A mosaic was created for each project from the paired .ALLs and HDCS files. The backscatter mosaic's minimum resolution was dependent on the acquisition frequency using the equation that was provided in PI Appendix 2. The minimum resolution utilized was 2 m for 300 kHz. The mosaic was exported as a floating point GeoTIFF grid with a value for no data set to -9999.

GSF data files were assessed for existence and consistency and the mosaics were inspected in ArcPro for coverage and quality.

For more specifics on backscatter for this project, refer to PI Appendix 2 and accompanying correspondence in regards to requirements / clarifications.

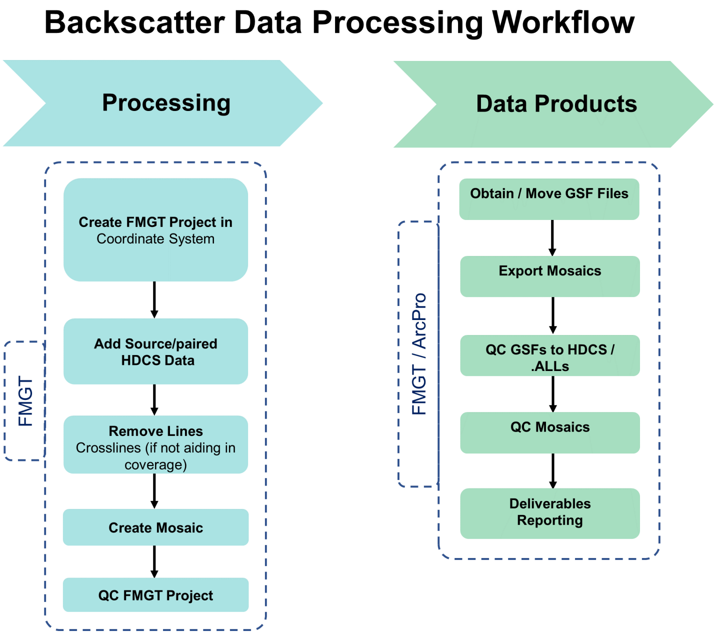


Figure 17: Backscatter data processing workflow

]

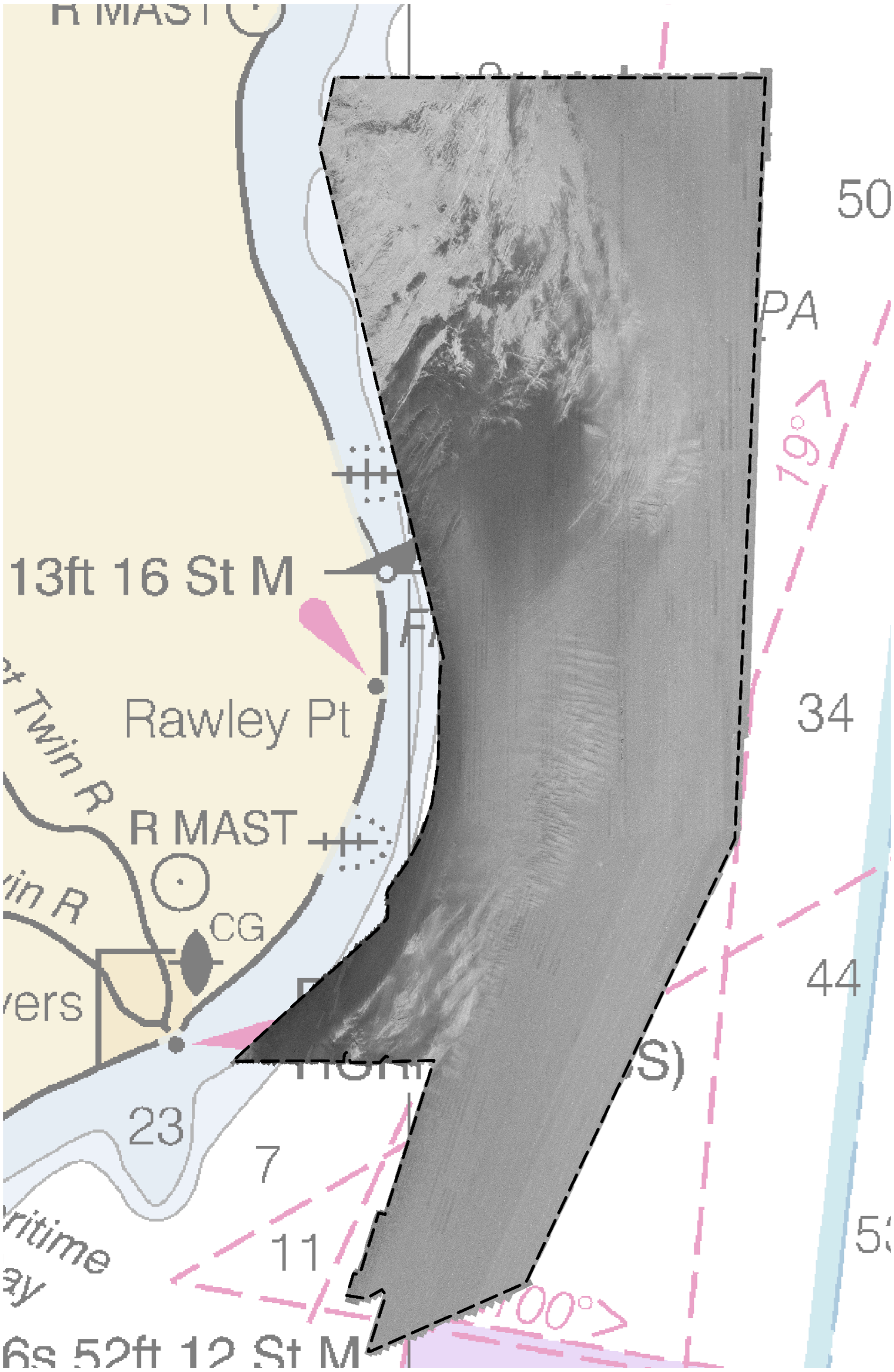


Figure 18: Example map of the backscatter deliverable mosaic created with QPS FMGT.

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

DGPS data was not acquired.

C.3.1.3 Other Horizontal Control Equipment

Data Acquisition Methods and Procedures

All survey vessels received G2+ GNSS satellite corrections from the Fugro Marinestar SBAS directly through the Applanix POS MV to provide real-time corrections to positioning. The Marinestar G2+ service provides corrections for GPS and GLONASS from a network of base stations around the world via geo-stationary satellites. Solution status was continuously monitored through the POSView controller software for dropouts or degraded accuracy.

Data Processing Methods and Procedures

For all hydrographic survey activities, POSPac data were collected through the POSView controller via Ethernet Logging and/or USB Logging. All position and attitude data were post-processed in POSPac MMS software using Trimble Centerpoint RTX solutions. The SBET was applied in CARIS HIPS to overwrite all position data, and improve upon the real-time Marinestar G2+ accuracies while minimizing Total Horizontal Uncertainty (THU). The application of the SBET in CARIS HIPS also transforms the data into the required horizontal datum. For all processed positions and data products (other than S-57 Final Feature File), the horizontal datum is North American Datum of 1983 (NAD83) (2011) Universal Transverse Mercator (UTM) Zone 16N, as required by the HSSD. Reference the corresponding Horizontal and Vertical Control Report (OPR-Y396-KR-22_HVCR.pdf) for more information.

C.3.2 Vertical Control

C.3.2.1 Water Level Data

Data Acquisition Methods and Procedures

All surveys utilized an ERS workflow to reduce ellipsoid derived depths to chart datum.

All survey vessels received G2+ GNSS satellite corrections from the Fugro Marinestar SBAS directly through the Applanix POS MV to provide real-time corrections to ellipsoid heights. Solution status was continuously monitored through the POSView controller software for dropouts or degraded accuracy.

As dictated in the PI, water levels were determined from ellipsoid measurements throughout this ERS and soundings were reduced to Low Water Datum (LWD) by way of a provided VDatum Separation (SEP) model. Following pre-survey calibrations, a “float test” was performed with the R/V Benthos to ensure the quality of the GNSS corrections, SEP model, and survey systems integrations. The vessel remained stationary while nearby National Ocean Service (NOS) Water Level Station 9087057 - Milwaukee, WI, recorded the LWD elevation of the water surface. This information was compared to the near real-time water level data collected at Station 9087057 for the same time period and showed good agreement. Reference the corresponding Horizontal and Vertical Control Report (OPR-Y396-KR-22_HVCR.pdf) for more information.

Data Processing Methods and Procedures

NOAA’s HSD OPS provided a VDatum SEP model package with the PI, the LWD IGLD85 SEP model within this package was utilized. All ellipsoid data were post-processed using the Applanix POSPac MMS software. Post-processed corrections were implemented with Trimble’s CenterPoint RTX service. The SBET was applied in CARIS HIPS to overwrite all position data, improve upon the real-time Marinestar G2+ accuracies to minimize Total Vertical Uncertainty (TVU), and transform the data to the desired vertical datum before SEP model application. The NAD83_2011-LWD_IGLD85 SEP model was then utilized in CARIS HIPS to reduce the sonar data to LWD.

C.3.2.2 Optical Level Data

Optical level data was not acquired.

C.4 Vessel Positioning

Data Acquisition Methods and Procedures

Vessel position, attitude, and trajectory data were acquired and logged with an Applanix POS MV v5. All vessels had the offsets between the Primary GNSS antenna and IMU Reference Point precisely measured and entered into the POSView controller software prior to data acquisition (see DAPR Appendix III). Additionally, vessel offsets to the tangent point of the sonar heads were entered into POSView as the Sensor 1 offset location. Prior to the start of surveys, GAMS calibrations were performed to align the Secondary GNSS antenna with the Primary GNSS antenna and IMU alignment with respect to the vessel reference frame. See DAPR Appendix IV for additional information on vessel offsets, configuration, and calibration. For the duration of the project, all survey vessels maintained subscriptions with Fugro’s Marinestar Global Correction System and received G2+ corrections. Position, attitude, and trajectory data were logged via Ethernet Logging and/or USB Logging whenever survey activities occurred. This included five minutes before and after acquisition for adequate post-processing of kalman filtered data.

Data Processing Methods and Procedures

All position and attitude data were post-processed using Applanix POSPac MMS software and Trimble CenterPoint RTX corrections to produce an SBET file with centimeter level positioning accuracy. Post-processed solutions were reviewed for position and elevation RMS accuracies and altitude consistencies prior to exporting the SBET at the MBES systems’ reference point. The SBET position data were applied to the sounding data in CARIS HIPS and further reviewed for error or inconsistencies in the post-processed data. All integrated SBETs were accompanied with a SMRMSG file for post-processed position error contributions to TPU estimates.

C.5 Sound Speed

C.5.1 Sound Speed Profiles

Data Acquisition Methods and Procedures

All sound speed instruments utilized AML Oceanographic Xchange sensors, which were calibrated within one year of survey operations. Calibration certificates can be viewed in DAPR Appendix II.

On the R/V Benthos sound speed profiles were collected using Base•X2 instruments equipped with pressure and time-of-flight sound speed sensors. Casts were routinely conducted approximately every two hours or less, and no greater than four hours, depending on conditions. Profilers were deployed and recovered by hand using a Cannon Lake-Troll Manual downrigger spooled with 300lb braided ultra-high-molecular-weight polyethylene line, recording samples at 1 Hz. Once retrieved, profile data were automatically sent to SeaCast via WLAN connection. SeaCast was setup to calculate sound velocity for freshwater, use UTC time, record in meters, split the up/down cast, and delete out of range or invalid points. Casts were reviewed and the down casts were then exported as .vel files to a folder monitored by Qinsy. The .vel files were applied automatically in Qinsy and imported into the SSM database, attributed a position from a SSM/SIS communication link, and then transmitted to SIS as an extended .ASVP file. The R/V Benthos' daily casts were exported as an .SVP file from SSM for post-processing.

The R/V Substantial was equipped with an AML MVP mounted on the stern. The MVP integrated position and real-time depth via serial data communication from Qinsy. The free fall fish was deployed approximately every 30 - 120 minutes, depending on location, bathymetry, and water properties. The initial free fall fish was equipped with pressure and time-of-flight sound speed Xchange sensors and the secondary fish with conductivity, temperature, and pressure (depth) sensors. The system recorded samples on deployment at 1 Hz and was programmed to automatically retrieve when it was a set distance from the seafloor. Casts were transferred via TCP connection to the acquisition station for QC and application to sonar data. The casts were then imported into the SSM database, transmitted to SIS as an extended .ASVP file, and then exported as a .vel file to a folder monitored by Qinsy. Daily casts were exported as a single .SVP file from SSM for post-processing.

Data Processing Methods and Procedures

Sound speed profiles collected during acquisition were thoroughly reviewed for date, time, location, depth of cast, and erroneous data. Profiles were then stored in each vessel's Raw and Processed SVP folders and also a master cast file, which stored all SVPs collected within a particular survey area (multi-vessel). In CARIS HIPS, sound speed profiles contained in the master SVP file were applied using the “Nearest in Distance within Time” approach, either utilizing 1, 2, or 4 hours. In CARIS HIPS, sound speed profiles contained in the master SVP file were applied using the “Nearest in Distance within Time” approach, either utilizing 1, 2, or 4 hours. Occasionally, daily cast or specific sets of casts were applied in post-processing instead of the master cast to further improve sound velocity corrections.

C.5.2 Surface Sound Speed

Data Acquisition Methods and Procedures

For real-time beam forming and sound speed depiction of the upper water column, vessels used a Micro•X sound speed instrument mounted at the sonar heads. The Micro•X transmitted sound speed data (m/s) through a serial RS232 connection at 1 Hz. The systems received the surface sound speed data on the operator station through SIS.

Data Processing Methods and Procedures

In both Qinsy and SIS, an alarm was set to warn the hydrographer when real-time surface sound speed and the most recent profile differed by more than 2 m/s. Real-time surface sound speed was plotted geographically in SSM on each vessel for additional QC and guidance of operations. In CARIS HIPS, the "Use Surface Sound Speed" option was checked in the georeference bathymetry process.

C.6 Uncertainty

C.6.1 Total Propagated Uncertainty Computation Methods

TPU was calculated to provide an assessment of quality for the position and depth of individual soundings. Many aspects of the TPU model are based on manufacturer RMS values, while others can be more accurately modeled and minimized throughout the mobilization, acquisition, and processing phases.

The HVF contains all of the 1-sigma RMS values for the survey equipment used throughout the project for each vessel. Values for the position and attitude uncertainties are provided by Applanix, while uncertainty values with respect to sonars and frequencies are built-in to the HIPS device library and also .all files. To more accurately model position uncertainties, inputs for position/navigation and GPS height were overwritten with 1-sigma RMS values stored in the SMRMSG file associated with each SBET file. Additionally, upon the application of delayed heave, 1-sigma RMS values for heave were applied when the .000 file is applied in CARIS. Other values stored within the HVF include lever arm distances, measurement error, and patch test uncertainties. Potential uncertainties with lever arms were minimized by performing static vessel surveys using laser tracking methods to locate sensors with respect to each other and the vessel reference frame to within millimeters. Uncertainties for the alignment of sensors were minimized by integrating SBET solutions to more accurately determine biases from the patch tests. Patch tests were evaluated by multiple hydrographers to issue standard deviation values for Motion Reference Unit (MRU) alignment for gyro and roll/pitch biases, which was placed in the HVF accordingly.

During acquisition, careful consideration was made to minimize artifacts and their contribution to uncertainty. Hydrographers made considerable efforts to reduce the impact of sound speed issues during acquisition. These efforts included increasing the frequency of casts, closely monitoring real-time swath “smiling” or “frowning”, utilizing alerts for surface-to-profile sound speed deviation, observing the real-time standard deviation map display, and utilizing SSM to track spatial changes in surface sound speed along with profile location. When sound velocity had drastic spatial variation, the survey approach would be constrained to areas of similar water properties to avoid large refraction issues.

TPU calculations are performed using the CARIS HIPS Compute TPU process. The Compute TPU process utilizes the a-priori uncertainty estimates, the “real-time” estimates from the SMRMSG data, delayed heave RMS, information from the CARIS sonar device library and .all files, and static values set for water level and sound speed uncertainty to calculate the estimated horizontal and vertical TPU for each sounding.

Uncertainty of the SEP model used to reduce soundings from NAD83 (2011) to LWD was provided in the PI (0.045m at 2 sigma) and entered into the “Tide Zoning” field of the Compute TPU process. Uncertainty input to “Sound Speed - Measured” was derived from the field tolerance of 2 m/s deviance between surface and profile sound speed and the temporal distribution of casts. The "Sound Speed - Surface" value of 0.05 m/s reflects manufacturer accuracy at 2-sigma.

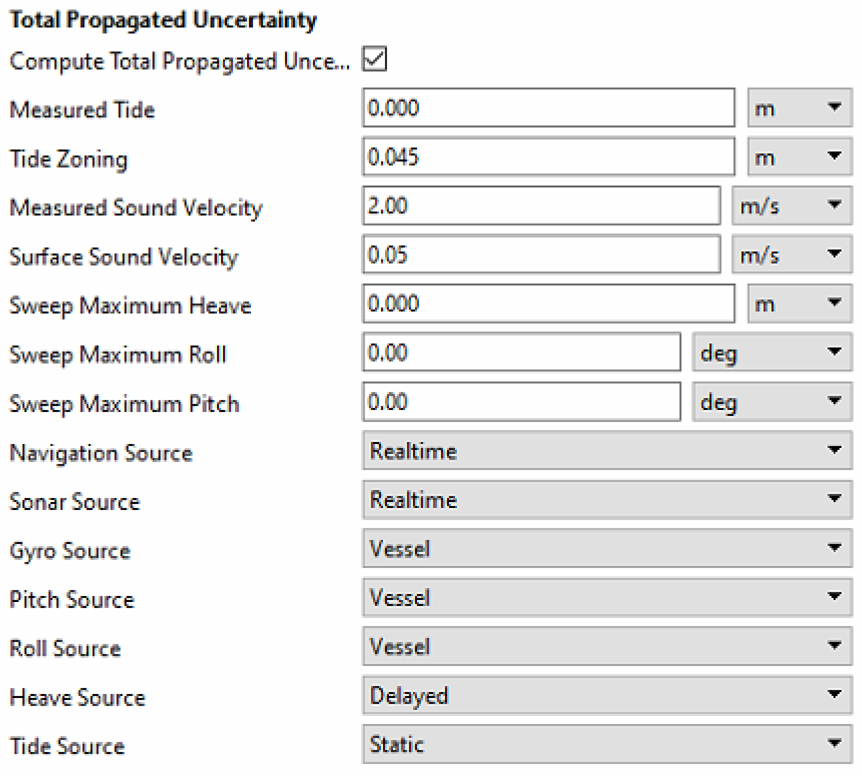
C.6.2 Uncertainty Components

C.6.2.1 A Priori Uncertainty

Vessel		R/V Benthos	R/V Substantial
Motion Sensor	*Gyro*	0.02 degrees	0.02 degrees
	Heave	5.00% 0.05 meters	5.00% 0.05 meters
	Roll	0.01 degrees	0.01 degrees
	Pitch	0.01 degrees	0.01 degrees
Navigation Sensor		0.10 meters	0.10 meters

C.6.2.2 Real-Time Uncertainty

Vessel	*Description*
R/V Benthos & R/V Substantial	Real-time sonar uncertainties are provided via raw .ALL files.



Total Propagated Uncertainty

Compute Total Propagated Unce...	☑	
Measured Tide	0.000	m
Tide Zoning	0.045	m
Measured Sound Velocity	2.00	m/s
Surface Sound Velocity	0.05	m/s
Sweep Maximum Heave	0.000	m
Sweep Maximum Roll	0.00	deg
Sweep Maximum Pitch	0.00	deg
Navigation Source	Realtime	
Sonar Source	Realtime	
Gyro Source	Vessel	
Pitch Source	Vessel	
Roll Source	Vessel	
Heave Source	Delayed	
Tide Source	Static	

Figure 19: Uncertainty estimates parameters in the CARIS HIPS TPU Dialog within the georeference bathymetry process

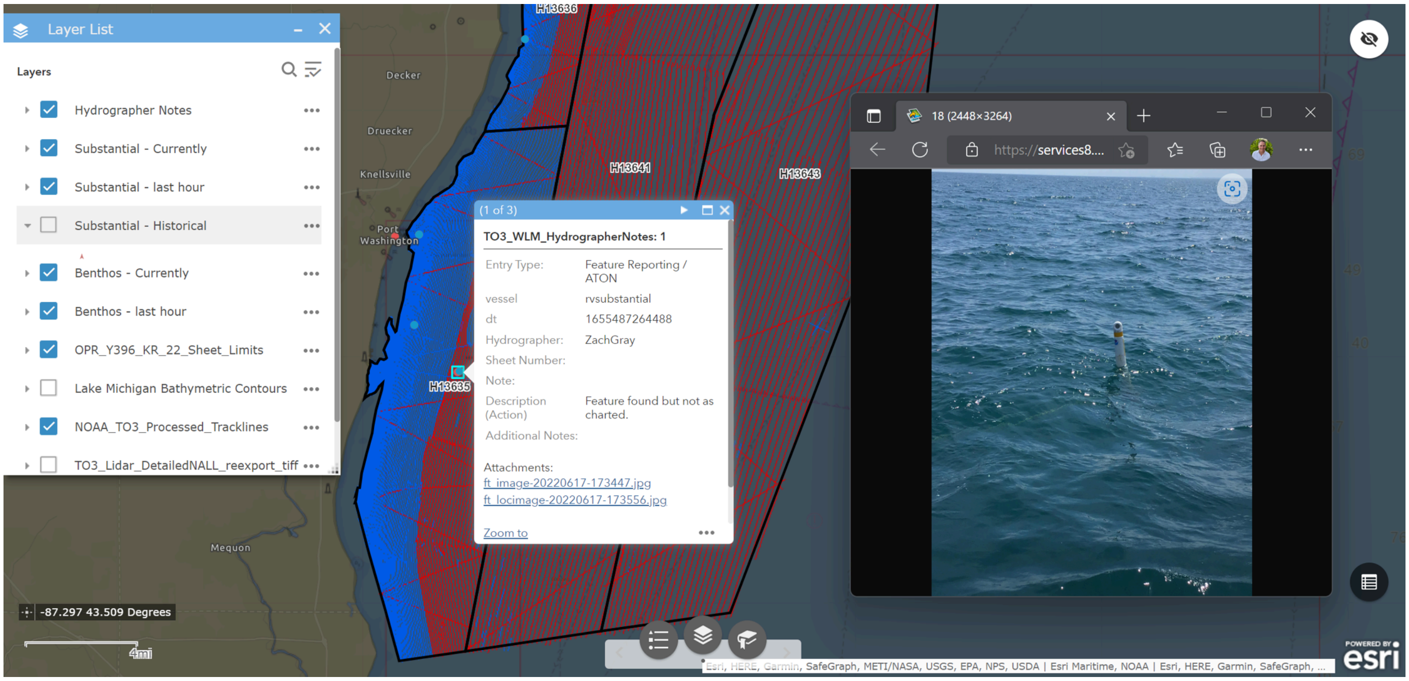
C.7 Shoreline and Feature Data

Data Acquisition Methods and Procedures

No shoreline investigations or shoreline data collection were required for OPR-Y396-KR-22.

Assigned features and new features identified during multibeam data acquisition were investigated and developed in accordance with the HSSD and guidance from the HSD Project Manager/COR. Additional MBES coverage was acquired when necessary to adequately determine the least depth of features.

Above water features that were not developed with multibeam bathymetry were documented through an internally developed and customized ArcGIS Survey 123 mobile data collection application. The application reduced error, streamlined the workflow, and quality controlled feature development from collection to delivery in the Final Feature File (FFF). Hydrographers recorded feature attributes through a series of guided questions using predefined selections that eliminated erroneous descriptions and guaranteed completeness and accuracy required to attribute the FFF. GPS-tagged photos for each feature were acquired and associated with the corresponding feature when stored in the PMA, where the Lead Hydrographer and Data Processing Manager reviewed each feature in near real-time.



Layer List

Layers

☑ Hydrographer Notes
☑ Substantial - Currently
☑ Substantial - last hour
☐ Substantial - Historical
☑ Benthos - Currently
☑ Benthos - last hour
☑ OPR_Y396_KR_22_Sheet_Limits
☐ Lake Michigan Bathymetric Contours
☑ NOAA_TO3_Processed_Tracklines
☐ TO3_Lidar_DetailedNALL_reexport_tiff

(1 of 3)

TO3_WLM_HydrographerNotes: 1

Entry Type:	Feature Reporting / ATON
vessel	rvsubstantial
dt	1655487264488
Hydrographer:	ZachGray
Sheet Number:	
Note:	
Description (Action)	Feature found but not as charted.
Additional Notes:	

Attachments:
ft_image-20220617-173447.jpg
ft_locimage-20220617-173556.jpg

Zoom to

18 (2448×3264)

https://services8....

Figure 20: Processing Manager Application showing assigned and documented features

Data Processing Methods and Procedures

Feature data processing consisted of addressing all assigned features in the Composite Source File (CSF) provided with the PI package and adding all new features to a single .000 S-57 file for each survey. All multibeam data were reviewed for features, and least depths over navigationally and/or potentially significant features were flagged as “designated soundings” in CARIS HIPS. Development of each feature was completed in accordance with the HSSD including S-57 attribution and hydrographer remarks/ recommendations. Each feature included in the FFF was supplied a unique identifier, attributed in the Unique ID field of the FFF. Associated images in the FFF utilized the unique identifier as a filename, followed by letters if there were more than one associated image.

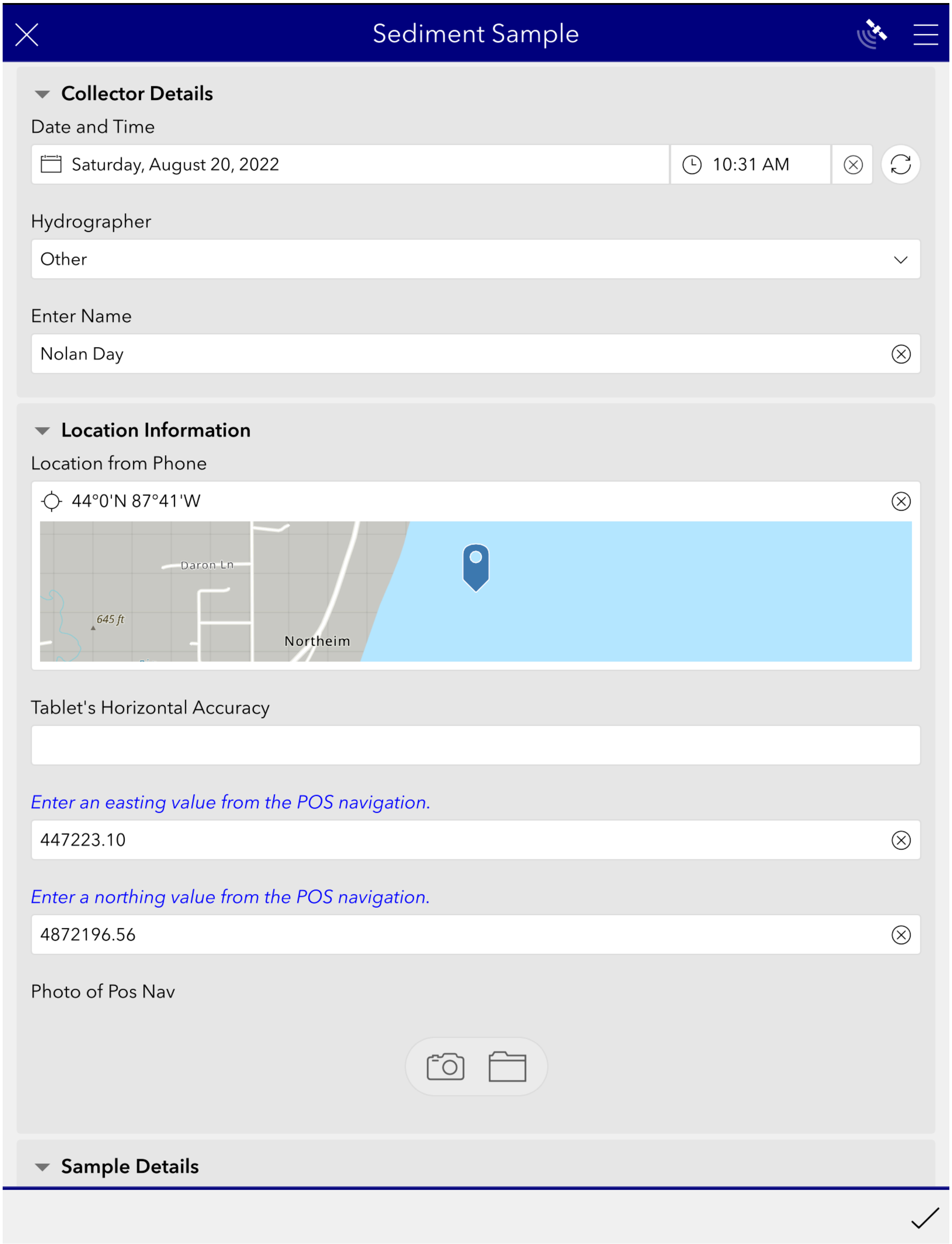
C.8 Bottom Sample Data

Data Acquisition Methods and Procedures

Predetermined bottom sample locations within each sheet were provided in the Project Reference File (PRF) prior to the start of field work. These locations were modified based on mosaiced multibeam backscatter data (see Project Correspondence). Each sample was collected successfully aboard R/V Substantial using a Wildco ponar dredge and a Wildco petite ponar grab sampler.

To reduce error, streamline the workflow, and QC the bottom samples from collection to delivery in the FFF, Geodynamics utilized another ArcGIS Survey 123 mobile data collection application. The application's schema was designed to facilitate collection and storage of well-organized and accurate field notes. Hydrographers recorded sample locations, name and NATSUR / NATQUA attributes through a series of guided questions using predefined selections that eliminated erroneous descriptions and guaranteed completeness and accuracy as per the HSSD. GPS tagged photos for each sample were acquired and associated with the corresponding sample when stored in the PMA, where the Lead Hydrographer and Data Processing Manager reviewed each sample in near real-time.

Figure 21: Bottom Sample collected and documented in H13637



Collector Details

Date and Time

Saturday, August 20, 2022

10:31 AM

Hydrographer

Other

Enter Name

Nolan Day

Location Information

Location from Phone

44°0'N 87°41'W

Tablet's Horizontal Accuracy

Enter an easting value from the POS navigation.

447223.10

Enter a northing value from the POS navigation.

4872196.56

Photo of Pos Nav

Sample Details

Figure 22: Screen capture of Survey 123 bottom sample application during collection in H13637

Data Processing Methods and Procedures

Bottom sample data and GPS-tagged photos stored in the PMA were transferred to a CARIS .hob file for processing and QA. All bottom samples can be found in the FFF.

D. Data Quality Management

D.1 Bathymetric Data Integrity and Quality Management

D.1.1 Directed Editing

Direct editing of soundings were performed to clean spurious and erroneous data that adversely affected the final surface and depth determination of features. In addition to visual assessment and cleaning from the bathymetric surface, many derivative layers computed from the bathymetric surface and sounding data were used to guide data cleaning, assess quality, and illustrate adherence to the HSSD. Node standard deviation, standard deviation, uncertainty, and TVU-ness were surface layers commonly used in data cleaning and quality assessments. In addition to a visual inspection, all CUBE surfaces were analyzed using HydrOffice QC Tools Flier Finder tool to assure data does not contain fliers (anomalous data as defined by QC Tools flier finding algorithms #2-5). The tool was run with the standard presets and results were used to guide data editing.

D.1.2 Designated Sounding Selection

Designated sounding selection followed specifications in the HSSD. The CARIS HIPS Subset Editor was utilized to view soundings and the CUBE surface in 2D and 3D. Erroneous sounding data were cleaned, and a least depth was designated when necessary. Routinely and before surface finalization, the critical soundings layer in CARIS HIPS, which contains designated soundings, was regenerated for QA/QC purposes.

D.1.3 Holiday Identification

All CUBE surfaces were analyzed using HydrOffice QC Tools Holiday Finder to determine if the surface contained holidays, as described in section 5.2.2 of the HSSD. The tool scanned the CUBE surfaces to identify any holidays and generated an S-57 file to represent the locations of holidays. Another method of holiday evaluation was to visually pan the CUBE surfaces to identify holidays. The hydrographer would often alter the surface display (color ranges, symbology, shading) to help aid in identifying coverage gaps.

During survey operations, holidays were compiled into a shapefile line plan and loaded into Qinsy on each vessel for recovery.

D.1.4 Uncertainty Assessment

All finalized CUBE surfaces were analyzed using the HydrOffice QC Tools Grid QA tool to assure at least 95% of the surface grid nodes meet TVU specifications. Results of the Grid QA tool are illustrated in a graphical representation of the surface uncertainty statistics.

D.1.5 Surface Difference Review

D.1.5.1 Crossline to Mainscheme

Crosslines were evaluated in CARIS HIPS with a detailed visual inspection followed by a thorough statistical analysis. To conduct the statistical analysis, a CUBE surface was generated with strictly mainscheme data and another, separate CUBE surface was generated with only crossline data. The mainscheme and crossline surfaces were analyzed using the Compare Grids tool in Pydro Explorer, which generated a difference surface and associated statistics. In addition to the direct statistics from the surface differencing, the tool assessed the difference surface statistics and computed the proportion of TVU consumed by the mainscheme-to-crossline differences per surface node.

D.1.5.2 Junctions

As required in the PI, junction analyses were conducted between overlapping data from OPR-Y396-KR-22 surveys and existing surveys. The inputs for this tool were the CUBE surfaces for each individual survey at matching resolutions. The tool outputs a difference surface and the statistical results are illustrated in a graphical representation of the surface difference statistics. Additional inspection of junctions were performed using the 2D and 3D views in Subset Editor.

D.1.5.3 Platform to Platform

Vessel to vessel confidence checks were acquired to assess confidence between each survey vessel and their respective survey systems. Confidence checks were assessed in CARIS HIPS by evaluating the agreement of sounding data as well as assessing statistics derived from vessel to vessel surface differences. Results of confidence tests can be found in DAPR Appendix V.

D.2 Imagery data Integrity and Quality Management

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

E. Approval Sheet

This report and the accompanying data deliverable are respectfully submitted.

As Chief of Party, field operations contributing to the accomplishment of Surveys H13635, H13636, H13637, H13638, H13639, H13640, H13641, H13642 and H13643 were conducted under my direct supervision, with frequent personal checks of progress and adequacy. This report and accompanying data deliverable have been closely reviewed and are considered complete and adequate as per the Statement of Work (April 25, 2022).

The survey data meets or exceeds requirements as set forth in the Hydrographic Surveys Specifications and Deliverables 2022, Project Instructions (April 06, 2022), and Statement of Work (April 25, 2022). These data are adequate to supersede charted data in their common areas.

Approver Name	Approver Title	Date	Signature
David J. Bernstein, CH, PLS, GISP	Chief of Party	12/18/2022	David J. Bernstein Digitally signed by David J. Bernstein Date: 2022.12.18 08:50:22 -05'00'

List of Appendices:

Mandatory Report	***File***
Vessel Wiring Diagram	I_Vessel_Wiring_Diagrams.pdf
Sound Speed Sensor Calibration	II_Sound_Speed_Sensor_Calibration_Reports.pdf
Vessel Offset	III_Vessel_Offset_Reports.pdf
Position and Attitude Sensor Calibration	IV_Position_Attitude_Sensor_Calibration_Reports.pdf
Echosounder Confidence Check	V_Echo_Sounder_Confidence_Check_Reports.pdf
Echosounder Acceptance Trial Results	N/A