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

Data Acquisition & Processing Report

Type of Survey:	Basic Hydrographic Survey
Project Number:	OPR-J311-KR-18
Time Frame:	August – November 2018

LOCALITY

State(s):	Louisiana
General Locality:	Chandeleur Islands

2018

Chief of Party
Paul L. Donaldson
Leidos

LIBRARY & ARCHIVES

Date:

Data Acquisition & Processing Report

OPR-J311-KR-18

Leidos Document Number: 19-TR-001

Changes in this document shall be recorded in the following table in accordance ISO9001:2015 Procedures.

Revisions				
Rev	**Date**	**Pages Affected**	**Approved By**	**Remarks**
0	22 January 2019	All	P. Donaldson	Initial Document

Table of Contents *Page*

APPENDIX I. VESSEL REPORTS
APPENDIX II. ECHOSOUNDER REPORTS
APPENDIX III. POSITIONING AND ATTITUDE SYSTEM REPORTS
APPENDIX IV. SOUND SPEED SENSOR REPORT

List of Tables *Page*

List of Figures *Page*

ACRONYMS

Acronym	**Definition**
ACD	Automatic Contact Detection
ACTA	Advanced Telecommunications Computing Architecture
ACTUV	Anti-Submarine Warfare Continuous Trail Unmanned Vessel
AHB	Atlantic Hydrographic Branch
AIS	Automatic Identification System
AL	Alabama
ASCII	American Standard Code for Information Interchange
BAG	Bathymetric Attributed Grid
CFAR	Constant False Alarm Rate
CCOM	Center for Coastal Ocean Mapping
CCOM-JHC	Center for Coastal Ocean Mapping Joint Hydrographic Center
CI	Confidence Interval
CMG	Course Made Good
CO-OPS	NOAA Center for Operational Oceanographic Products and Surfaces
COLREGS	Convention on the International Regulations for Preventing Collisions at Sea
COR	Contracting Officer’s Representative
CTD	Conductivity, Temperature, Depth
CUBE	Combined Uncertainty and Bathymetric Estimator
DAPR	Data Acquisition and Processing Report
DGPS	Differential Global Positioning System
DPC	Data Processing Center
DPF	Detection Parameters File
DR	Descriptive Report
ECDIS	Electronic Chart Display and Information System
EPF	Error Parameters File
ERS	Ellipsoid Referenced Survey
ERZT	Ellipsoidally Referenced Tide Zones
FMGT	Fledermaus Geocoder Toolbox
Ft	Feet
GPS	Global Positioning System
GSF	Generic Sensor Format
HDCS	Hydrographic Data Cleaning System
HSSD	Hydrographic Surveys Specifications and Deliverables
Hp	Horse power
Hz	Hertz
IHO	International Hydrographic Organization
IMU	Inertial Measurement Unit
ISO	International Organization for Standardization
ISS-2000	Integrated Survey System 2000

ISSC	Integrated Survey System Computer
JD	Julian Day
kHz	Kilohertz
kW	Kilowatt
LOA	Length Over All
m	Meters
MBES	Multibeam Echo Sounder
MVE	MultiView Editor
MVP30	Moving Vessel Profiler 30
NAS	Network Attached Storage
NASA	National Aeronautics and Space Administration
NAVOCEANO	Naval Oceanographic Office
NJ	New Jersey
NCEI	National Centers for Environmental Information
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NTP	Network Timing Protocol
NWLON	National Water Level Observation Network
ONSWG	Open Navigation Surface Working Group
PFM	Pure File Magic
PI	Project Instructions
PMVD	Poor Man’s Vertical Datum
POS/MV	Position Orientation System/Marine Vessels
PRF	Project Reference File
QA	Quality Assurance
QC	Quality Control
RI	Rhode Island
RINEX	Receiver Independent Exchange Format
RPM	Revolutions Per Minute
SABER	Survey Analysis and Area Based Editor
SAT	Sea Acceptance Tests or Swath Alignment Tool
SBET	Smoothed Best Estimate of Trajectory
SN	Serial Number
SSS	Side Scan Sonar
SS-ACQ	Side Scan Acquisition Computer
SSP	Sound Speed Profile
TCARI	Tidal Constituent and Residual Interpolation
TPE	Total Propagated Error
TPU	Total Propagated Uncertainty or Transceiver Processing Unit
TTL	Transistor-Transistor Logic

TVU	Total Vertical Uncertainty
UI	User Interface
UPS	Uninterruptible Power Supply
UNH	University of New Hampshire
UTC	Coordinated Universal Time
XML	Extensible Markup Language
XTF	Extended Triton Format

PREFACE

This Data Acquisition and Processing Report (DAPR) applies to hydrographic project OPR-J311-KR-18. Survey data were collected from August 2018 through November 2018.

For OPR-J311-KR-18 no vertical or horizontal control points were established, recovered, or occupied. Therefore, a Horizontal and Vertical Control Report is not required for this project, and will not be submitted with the final delivery of this project.

The Project Instructions (PI) for OPR-J311-KR-18, reference the April 2018 version of the Hydrographic Surveys Specifications and Deliverables (HSSD). Additional project specific clarifications and guidance are located in Appendix II of the Descriptive Report (DR) for each sheet.

A. EQUIPMENT

A.1 DATA ACQUISITION

Central to the Leidos survey system was the Integrated Survey System Computer (ISSC). The ISSC consisted of a dual 8 core processor computer with the Windows 7 (Service Pack 1) operating system, which ran the Leidos Integrated Survey System 2000 (**ISS-2000**) software. This software provided survey planning and real-time survey control in addition to data acquisition and logging for bathymetry, backscatter, and navigation data. An Applanix Position and Orientation System for Marine Vessels (POS/MV) and Inertial Measurement Unit (IMU) were used to provide positioning, heave, and vessel motion data during these surveys. Side scan sonar (SSS) data were acquired using the Klein Marine Systems, Inc. (Klein) **SonarPro** software running on the Leidos Side Scan Acquisition computer (SS-ACQ) which also consisted of a dual 8 core processor computer with the Windows 7 (Service Pack 1) operating system. The SS-ACQ was integrated with the ISSC for timing and navigation.

A.2 DATA PROCESSING

Post processing was performed on the survey vessels, *M/V Atlantic Surveyor* and *R/V Pathfinder*, and in the Newport, RI, Data Processing Center (DPC). Multibeam echo sounder (MBES) and SSS data were processed and reviewed on computers with the Linux operating system, which ran Leidos' **SABER** (Survey Analysis and Area Based Editor) software.

Onboard the *M/V Atlantic Surveyor* and in the Newport, RI DPC, data were stored on a Network Attached Storage (NAS) system that all computers were able to access. Onboard the *R/V Pathfinder*, data were stored on redundant local drives of the acquisition and the processing computers, and the processed data from *R/V Pathfinder* were transferred to the NAS onboard the *M/V Atlantic Surveyor* at each crew rotation. See Appendix II for a detailed data processing flow diagram.

A.3 SURVEY VESSEL

For this project, Leidos employed two survey vessels, each with the following major data acquisition systems for the survey effort:

- The *M/V Atlantic Surveyor* used a RESON SeaBat T50 MBES, a towed Klein 3000 dual frequency SSS, and an AML Oceanographic Moving Vessel Profiler 30 (MVP30) sound speed profile (SSP) acquisition system
- The *R/V Pathfinder* used a RESON SeaBat 7125 SV2 MBES, and an AML Oceanographic MVP30 SSP acquisition system

Both vessels used an Applanix POS/MV 320 version V5 and IMU type 36. Vessel characteristics are presented in Table A-1, and further details about the vessels, acquisition systems and software, and processing software are provided in the sections below.

Table A-1: Survey Vessel Characteristics for OPR-J311-KR-18

Vessel Name	LOA (Ft)	Beam (Ft)	Draft (Ft)	Maximum Speed (knots)	Gross Tonnage	Power (Hp)	Registration Number
M/V Atlantic Surveyor	110	26	9.0	10	Displacement 68.0 Net Tons Deck Load 65.0 Long Tons	900	D582365
R/V Pathfinder	40	14	3.5 (hull); 5 (pole down)	34 (hull speed); 10 (pole down)	Displacement 12.5 Net Tons	660	N/A

The *M/V Atlantic Surveyor* (Figure A-1) was equipped with an autopilot, echo sounder, Differential Global Positioning System (DGPS), radars, Automatic Identification System (AIS), and two 40 kilowatt (kW) diesel generators. Accommodations for up to twelve surveyors were available within three cabins. The SSS winch and four International Organization for Standardization (ISO) containers were secured on the aft deck. The first 20-foot container was used as the real-time survey data acquisition office, the second 20-foot container was used for the onboard data processing office, and the third 20-foot container was used for spares storage, maintenance, and repairs. A fourth 10-foot ISO container was also mounted on the aft deck which housed an 80 kW generator that provided dedicated power to the SSS winch, ISO containers, and all survey equipment. The POS/MV IMU was mounted approximately amidships, below the main deck, port of the keel. The RESON SeaBat T50 transducer and AML MicroX surface sound speed sensor were hull-mounted approximately amidships, port of the vessel's keel. The MVP30 was mounted on the starboard stern quarter. Configuration parameters, offsets, and installation diagrams for all equipment are included in Section C of this Report.

Figure A-1: The *M/V Atlantic Surveyor*

The *R/V Pathfinder* (Figure A-2) is a Munson 40-7 aluminum catamaran research vessel, equipped with an autopilot, echo sounder, DGPS, radars, AIS, and a Cummins Onan 19 kW generator. The *R/V Pathfinder* is additionally equipped with a suite of instruments utilized for autonomous operation; refer to Section A.3.1 for more information on autonomous operations.

The POS/MV IMU was mounted on the port side interior deck of the vessel, slightly aft of amidships. The RESON SeaBat 7125 SV2 transducer and AML MicroX surface sound speed sensor were pole-mounted through the vessel's bow deck moon pool, approximately on the ship's centerline. The MVP30 was mounted to the port stern quarter on the vessel's swim platform. Configuration parameters, offsets, and installation diagrams for all equipment are included in Section C of this Report.

Figure A-2: The *R/V Pathfinder*

A.3.1 Autonomy Operations, *R/V Pathfinder*

The *R/V Pathfinder*, a Leidos owned and operated vessel, is a surrogate to the Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV), *Sea Hunter*. As the surrogate, it is used to test and develop Leidos' autonomous vessel operations. In 2017, Leidos initiated and developed the alternative mission capability for autonomous bathymetric survey.

The vessel's autonomous system runs on an Advanced Telecommunications Computing Architecture (ACTA) chassis using open source code and a modified version of Leidos' **ISS-2000**, interfaced to navigational and situational awareness sensors, as well as the engine controls during autonomous operations. Sensor fusion algorithms integrate multiple contact sensors together to build a World Model understanding of the contacts around the ship. *R/V Pathfinder* position data are used to track mission progress against a set of mission objectives (e.g. a survey plan) and update the path planner goals as the ship progresses through the mission. Multiple path planning software packages were installed onboard for integration with Leidos' **Survey Planning** program for autonomous execution of the survey mission. For the purposes of an autonomous bathymetric survey, AIS data are considered true, and the AIS operational state is used to determine COLREGS (Convention on the International Regulations for Preventing Collisions at Sea) ability to maneuver.

The *R/V Pathfinder* was manually piloted when departing and arriving to the dock, as well as during times of crew and fuel transfer between vessels. Crew transfers were conducted approximately every 12 hours and fuel transfers were conducted every one to two days.

All data acquisition by the *R/V Pathfinder* was conducted with as little human interaction as possible. For the purposes of this survey, a watchstander was onboard conducting system checks to ensure valid data acquisition. Data processing was conducted on the *R/V Pathfinder* through an autonomous processor which was integrated through the onboard processing computer. Refer to Section B and Section B.1 for more information regarding autonomous processing.

During data acquisition on H13136, the vessel successfully demonstrated the capability to autonomously maintain COLREGS compliance, reacting to real-world "interferers". Demonstrating the ability of the system to divert from a planned survey line during a COLREGS maneuver, and then reacquire the survey line once safe to do so prior to where the initial break in the survey plan was made. Additionally the survey acquisition software autonomously controlled and logged hydrographic data to International Hydrographic Organization (IHO) Order 1a standards. Specific details related to the autonomous survey results will be detailed in the H13136 DR.

A.4 LIDAR SYSTEMS AND OPERATIONS

Leidos did not use a lidar system on these surveys.

A.5 MULTIBEAM SYSTEMS AND OPERATIONS

The real-time MBES acquisition system used for these surveys included each of the following unless otherwise specified:

- Windows 7 workstation (ISSC) for data acquisition, system control, survey planning, survey operations, and real-time Quality Control (QC).
- A RESON SeaBat T50, with an AML MicroX surface sound speed sensor was used for all MBES data collection onboard the *M/V Atlantic Surveyor*. The RESON SeaBat T50 can be operated in Equi-Angle, Equi-Distant, or Intermediate Modes with a sliding scale of 10 to 512 beams. In all configurations the beams were dynamically focused resulting in a 0.5 degree across-track receive beam width and a 1.0 degree along-track transmit beam width with up to a 150 degree coverage angle in Equi-Distant and Intermediate Modes and up to a 165 degree coverage angle in Equi-Angle Mode. The RESON SeaBat T50 was set to the 256 beams Intermediate Mode during survey operations, with a 120 degree swath set by the coverage angle in the controller.
- A RESON SeaBat 7125 SV2, with an AML MicroX surface sound speed sensor was used for all MBES data collection onboard the *R/V Pathfinder*. The RESON SeaBat 7125 SV2 can be operated in Equi-Angle, Equi-Distant, or Intermediate Modes with a sliding scale of 10 to 512 beams. In all configurations the beams are dynamically focused resulting in a 0.5 degree across-track receive beam width and a 1.0 degree along-track transmit beam width with up to a 140 degree coverage angle. The RESON 7125 SV2 was set to the 512 beams Intermediate Mode during survey operations, with a 130 degree coverage angle set

in the controller. The achievable coverage angle was then flagged to a 120 degree swath in **ISS-2000** through cutoff angles applied in real-time.

- Both the RESON SeaBat T50 and the RESON SeaBat 7125 SV2 operated as single frequency systems operating at 400 kilohertz (kHz). The maximum ping rate on the RESON T50 was manually set to 18 hertz (Hz) while the RESON 7125 SV2 maximum ping rate was manually set to 30 Hz. On both vessels, the achievable maximum ping rate was controlled by the range scale, which was chosen automatically with the use a tracker mode in the RESON Sonar User Interface (UI). The tracker mode was configured to automatically select the range, power, gain, absorption, spreading, and pulse length.

RESON SeaBat T50	
System/Component	**Version/Firmware/SN**
T50-R Sonar Processor	SN-3716025
Projector, 200/400 kHz	TC2181, SN-2117070
Receiver, 256Ch, 200/400kHz	EM7218, SN-3216025
Receiver, 256Ch, 200/400kHz	EM7218, SN-4817046
Teledyne RESON Sonar UI	5.0.0.2, 5.0.0.11
7k Center	6.3.0.2
AML MicroX surface sound speed sensor	SN-11439
AML SV-Xchange sensor installed on MicroX surface sound speed sensor	SN-206249

RESON SeaBat 7125 SV2	
System/Component	**Version/Firmware/SN**
7-P Sonar Processor	SN-18240212003
Projector, 200/400 kHz	TC2181, SN-3212078
Receiver, 256Ch, 200/400kHz	EM7216, SN-1512034
Teledyne RESON Sonar UI	4.2.0.20
7k Center	6.2.0.26
AML MicroX surface sound speed sensor	SN-11702
AML SV-Xchange sensor installed on MicroX surface sound speed sensor	SN-206246

- Applanix POS/MV-320 Position and Orientation System Version 5 with a Trimble ProBeacon Differential Receiver was used as the primary positioning sensor on both vessels.

POS/MV-320 Position and Orientation System Version 5 (Primary Positioning)		
System	***M/V Atlantic Surveyor*** **Version/Model/SN**	***R/V Pathfinder*** **Version/Model/SN**
MV-320	Version 5	Version 5
Serial Number	7958	7585
Hardware	1.4-12	1.4-12
Firmware	09.83	09.83
ICD	09.83	09.83
Operating System	6.4.1	6.4.1
IMU Type	36	36

POS/MV-320 Position and Orientation System Version 5 (Primary Positioning)		
System	***M/V Atlantic Surveyor*** **Version/Model/SN**	***R/V Pathfinder*** **Version/Model/SN**
Primary GPSs Type	BD982	BD982
Options	RTK-0, THV-0, DPW-0	RTK-0, THV-0, DPW-0
Trimble ProBeacon Differential Receiver		
Serial Number	0220186953	0220021112

- Navcom C-Nav 3050 Global Positioning System (GPS) Receiver (configured as the secondary positioning sensor) with a Trimble SPS GPS and DGPS Receiver (configured as DGPS input source for the C-NAV).

Navcom C-Nav 3050 (Secondary Positioning)		
Vessel	**Version/Model/SN**	**Version/Model/SN**
M/V Atlantic Surveyor	C-Nav 3050 SN-23469	Trimble SPS356 SN-5527R35049
R/V Pathfinder	C-Nav 3050 SN-23464	Trimble SPS356 SN-4948D53009

- MVP30 with interchangeable AML Sound Velocity, Pressure, and Temperature (Xchange) sensors and a Notebook computer to interface with the ISSC and the deck control unit (see Section A.7 for additional details concerning sound speed and Appendix IV for the AML sensor calibrations).

MVP30	
System	**Version/Model/SN**
MVP	30
Software	2.21
AML MVPX	008688 009010
AML SV Xchange Sensors	204453 205540 206148 206512 206513 206514 206515
AML P Xchange Sensors	304601 305331 305555 305557 305558 305598 305700
AML T Xchange Sensors	400503 404004 404370 404395 404397

- AML Oceanographic Base•X_2 units compatible with the AML sound velocity and pressure Xchange sensors noted above (See Section A.7 and Appendix IV). Both AML Base•X_2 units remained onboard the *M/V Atlantic Surveyor* and the *R/V Pathfinder* (one per vessel) for the duration of the survey season as a backup sensor to the MVP30. The unit aboard the *R/V Pathfinder* was briefly utilized during survey operations on the *R/V Pathfinder* while troubleshooting the MVP30.

System	Version/SN
AML Base•X_2	025410
AML Base•X_2	025586
Seacast Software	4.3.1

- Monarch proximity sensors were used for engine shaft revolutions per minute (RPM) determination allowing for real-time calculation of dynamic draft onboard *M/V Atlantic Surveyor*.
- Notebook computer for maintaining daily navigation and operation logs.
- Uninterrupted power supplies (UPS) for protection of the entire system.

Leidos maintains the ability to decrease the usable MBES swath width for the RESON systems as necessary to maintain data quality and meet the required IHO specifications. During MBES data collection **ISS-2000** applied beam flags to the GSF, designating the swath data as either Class 1 or Class 2 based on the acquired swath beam angle and user set parameters in **ISS-2000**.

Onboard the *M/V Atlantic Surveyor* with the RESON SeaBat T50, the Class 1 parameter was set to ±5 degrees in **ISS-2000**, which applied the Class 1 beam flag to the acquired swath 10 degrees about nadir. Class 2 was then set to 90 degrees, which applied the Class 2 beam flag to all acquired swath data from 5 degrees per side of nadir to the maximum achieved swath beam angle. Within the Sonar UI controller of the RESON SeaBat T50, the maximum coverage angle was then manually set to 120 degrees (60 degrees per side). Onboard the *R/V Pathfinder* with the RESON SeaBat 7125 SV2, the Class 1 parameter was set to 5 degrees in **ISS-2000**, and the Class 2 parameter was set to 60 degrees, while the Sonar UI controller of the RESON SeaBat 7125 SV2 maximum coverage angle was manually set to 130 degrees (65 degrees per side). Swath data flagged as Class 1 or Class 2 were used for grid generation while data outside of Class 2 were flagged as ignore (but were retained for potential future use). Class 1 data were used for grid generation of cross line data used in junction analysis (see Section B.2.2 for details).

For H13133, H13134, and H13135, Leidos chose to achieve the Complete Coverage requirement outlined in the PI using Option B) 100% side scan sonar coverage with concurrent multibeam bathymetry collection with complete coverage multibeam developments of contacts and features. The resultant achievable MBES bottom coverage was controlled by set survey line spacing and the various water depths within the survey areas. The survey line spacing was 130 meters for use with a SSS range of 75 meters, or 80 meters line spacing for use with a SSS range setting of 50 meters. Using ±60 degrees as the acceptable swath, 100 percent MBES coverage was not achieved in all areas, nor was it required by the PI. However, for H13136 Leidos chose to achieve the Complete Coverage requirement outlined in the PI using Option A) 100% bathymetric bottom coverage with multibeam sonars with complete coverage multibeam developments. For this sheet, line spacing varied based on water depth to achieve 100% multibeam coverage.

All MBES data and associated metadata were collected and stored on the real-time survey computer (ISSC) using a dual logging architecture. This method ensured a copy of all real-time data files were logged to separate hard drives during the survey operations. On the *M/V Atlantic Surveyor* these files were archived to the on-board NAS for initial processing and QC review at the completion of each survey line. On the *R/V Pathfinder*, data were automatically archived to the on-board processing computer at the completion of each survey line which then started the autonomous data processing routines followed by initial watchstander QC review (see Section A.3.1, Section B, and Section B.1 for more details on the autonomous survey acquisition and autonomous data processing).

The Leidos naming convention of MBES GSF files has been established through **ISS-2000.** To provide specific identification of the survey vessel, year, Julian Day (JD) that the data file was collected, and time that the file was created. For example in MBES file "asmba18252_044657.gsf":

- "as" refers to survey vessel *M/V Atlantic Surveyor.*
- 18252 refers to the year 2018, JD 252
- 044657 refers to the time (HHMMSS) the file was created.

File names were generally changed at the end of each line. This protocol provided the ability to easily associate each consecutive MBES GSF file with a specific survey line. Occasionally, when surveying holiday fills and/or item investigations, groups of multiple survey lines of the same type were collected to the same GSF file. If a file was not manually changed between a mainscheme and crossline, the MBES GSF file was split during post processing. This procedure utilized the **SABER** command line program **gsfsplit**. This program provided the ability to split GSF files so that each survey line was unique to a single MBES GSF file or set of files. In all cases, mainscheme and crossline data were delivered in separate GSF files.

When a MBES file needed to be split, a copy of the original GSF file was made and the **gsfsplit** program was then run on the copied file. Using the ping flags stored in the GSF file, **gsfsplit** splits the file midway through the offline pings between survey lines. Each newly created file resulting from the splitting process was given an extension of "a" and "b". Once the file split process was complete, the newly created files were manually renamed in the following manner: the first survey line kept the name and time of the original file and each subsequent survey line was assigned a new name based on the time within the file where the split occurred. GSF file lists were updated to include the split files which were placed in chronological order.

At the end of each survey day all raw real-time data files from the day were backed-up to an external hard drive. All processed data on the field processing computers were backed-up to an external hard drive intermittently throughout the day and by digital magnetic tape approximately every three to five days. The external hard drives and the digital magnetic tape back-ups were shipped approximately every 12-14 days to the Leidos DPC in Newport, RI for further processing and archiving.

Leidos continuously logged MBES data throughout survey operations collecting all data acquired during turns and transits between survey lines. Leidos utilized ping flags within the GSF files to differentiate between online/offline data. Online data refers to the bathymetry data within a GSF file which were used for generating the Combined Uncertainty and Bathymetric Estimator (CUBE) Depth surface. See Section B.1.10 for a detailed description of MBES ping and beam flags. Information regarding the start and end of online data for each survey line is found in the “Watchstander Logs” and “Side Scan Review Log” that are delivered in Separates I of each sheet’s DR.

Lead line comparisons were conducted to provide Quality Assurance (QA) for the RESON SeaBat T50 onboard the *M/V Atlantic Surveyor* and the RESON SeaBat 7125 SV2 onboard the *R/V Pathfinder*. These confidence checks were conducted to comply with Section 5.2.3.1 of the HSSD. Lead line comparison confidence checks were performed as outlined in the following steps:

- The static draft of the survey vessel was measured immediately prior to the beginning of the comparison. The value was entered into the **ISS-2000** real-time parameters for the multibeam (see Section C.1.1 of this Report for a detailed description of static draft).
- Correctors to the multibeam data, such as predicted tides and dynamic draft, were disabled in the **ISS-2000** system.
- A sound speed profile was taken and applied to the multibeam data.
- A timekeeping device was synchronized to the time of the **ISS-2000** data acquisition system in order to accurately record the time for each lead line depth observation made.
- Ten depth measurements were acquired on each side of the vessel at the location of the multibeam transducer.
- The current JD, date, vessel draft value, the multibeam data file(s), and the sound speed profile file were entered in the “Lead Line Comparison Log” (Separates I for each sheet).
- The observed time and depth of each lead line measurement were entered in the “Lead Line Comparison Log”.
- The concurrent multibeam depth measurements recorded in the GSF file were then entered in the “Lead Line Comparison Log”.

Lead line depth measurements were made using a mushroom anchor affixed to a line and a tape measure (centimeter resolution). The measurements taken provide the distance from the seafloor to the top of a 0.02 meter square metal bar protruding from the port and starboard side main deck. At least ten separate depth measurements and corresponding times were recorded for both the port and starboard sides. The measurements were recorded into the spreadsheet which uses the static draft measurement to calculate the water depth.

Once all lead line measurements and times were recorded in the lead line spreadsheet, the Leidos **ExamGSF** program was used to view the data within the multibeam GSF file which was logged concurrently. The depth value recorded in the multibeam file at the time of each lead line measurement and at the appropriate across track distance from nadir was entered into the lead line spreadsheet. The lead line spreadsheet calculated the difference and standard deviation between the observed lead line measurements and the acoustic measurements from the multibeam system. Results of the lead line comparison were reviewed and if any differences or discrepancies were found, further investigation was conducted. Lead line results from the Sea

Acceptance Test (SAT) are presented in Appendix II of this Report and survey data results are presented in Separates I of each sheet's DR.

In addition, confidence checks of the multibeam systems were made by comparing the depth data collected over a common survey line which were run simultaneously by each survey vessel. For these comparisons the *M/V Atlantic Surveyor* and the *R/V Pathfinder* would rendezvous to perform a multi-vessel comparison of the multibeam systems. The vessels would meet, take and apply individual SSP casts, and then proceed to acquire data over a common survey line; one vessel immediately following the other to reduce any tidal or environmental differences. The results of this analysis in close to real-time data processing were in good agreement. As both vessels only collected coincident data within H13136; a comprehensive comparison of all data is presented within H13136 DR.

In accordance with the HSSD and the Project Instructions, Leidos collected MBES backscatter with all GSF data acquired. The MBES settings were checked to ensure acceptable quality standards were met and to avoid any acoustic saturation of the backscatter data. The MBES backscatter data acquired were written to the GSF in real-time by **ISS-2000** and are delivered in the final GSF files for each sheet.

A.6 SIDE SCAN SONAR SYSTEMS AND OPERATIONS

H13133, H13134, and H13135 survey operations were conducted at set line spacing optimized to achieve 100% SSS coverage.

On the *M/V Atlantic Surveyor,* the SSS systems used for these surveys included:

- A towed Klein Marine Systems Inc. (Klein) 3000 digital SSS towfish (Serial Number [SN] 534 and 535) with a Klein K1 K-wing depressor.
- Windows 7 workstation (SS-ACQ) running Klein's **SonarPro** software for data acquisition, side scan system control, logging of SSS data, and real-time QC.
- Klein transceiver processing unit (TPU) (SN 418 and 420).
- MacArtney sheave with cable payout indicator.
- Sea Mac winch with remote controller.
- Uninterrupted power supplies (UPS) for protection of the entire system (except the winch).

The Klein 3000 is a conventional dual frequency SSS system. The 16-Bit digital SSS data were collected at 100 kHz and 500 kHz concurrently. All SSS data delivered are 16-Bit digital data.

The SSS ping rate is automatically set by the TPU based on the range scale setting selected by the user. At a range scale of 75 meters, the ping rate is 10 Hz; at a range scale of 50 meters, the ping rate is 15 Hz. Based on these ping rates, maximum survey speeds were established for each range scale setting to ensure that an object 1m x 1m x 1m on the sea floor would be independently ensonified a minimum of three times per pass in accordance with Section 6.1.2.2 of the HSSD. Based on ping rate, the maximum allowable survey speed would be 6.5 knots at the 75-meter range and 9.7 knots at the 50-meter range.

During survey operations, 16-Bit digital data from the TPU were acquired, displayed, and logged by the Leidos SS-ACQ through the use of Klein's **SonarPro** software. Raw digital SSS data were collected in extended Triton format (XTF) and maintained at full resolution, with no conversion or down sampling techniques applied. SSS data file names were changed automatically after 120 to 180 minutes or manually at the completion of a survey line, whichever occurred first.

These XTF files were archived at the completion of each survey line, to the on-board NAS, for initial processing and QC. At the beginning of each survey day the raw XTF SSS data files from the previous day were backed up to an external hard drive attached directly to the SS-ACQ machine. All processed SSS data on the NAS were backed up to an external hard drive daily and digital magnetic tape approximately every three to five days. The external hard drive and the digital magnetic tape back-ups were shipped to the DPC in Newport, RI, during port calls.

The Leidos naming convention of side scan XTF data files has been established through the structure of Klein's **SonarPro** software to provide specific identification of the survey vessel ("as" for the *M/V Atlantic Surveyor),* JD that the data file was collected, calendar date, and time that the file was created. For example in side scan file "as289_181016162600.xtf":

- "as" refers to survey vessel *M/V Atlantic Surveyor.*
- 289 refers to JD 289.
- 181016 refers to the year, month, and day (YYMMDD).
- 1626 refers to the time (HHMM) the file was created.
- 00 refers to a sequential number for files created within the same minute.

As done with bathymetry data, Leidos continuously logged SSS data throughout survey operations and did not stop and re-start logging at the completion and/or beginning of survey lines. Therefore data were typically collected and logged during all turns and transits between survey lines.

Leidos utilized a time window file to distinguish between times of online and offline SSS data. Online SSS data refers to the data logged within a SSS XTF file that were used in the generation of the 100% or disproval coverage mosaics. Offline SSS data refers to the data logged within a SSS XTF file which were not used for generating either coverage mosaic.

The structure of the time window file was such that each row within the file contained a start and end time for online data. Therefore, offline times of SSS data were excluded from the time window file. The times were represented in each row using date and time stamps for the online times. Also, at the end of each row the associated survey line name was appended to help with processing procedures.

In order to correlate individual SSS files to their associated survey lines, Leidos manually changed SSS file names after the completion of each survey line. Information regarding each survey line name, SSS file used, and the start and end times of online data for each survey line, were logged and contained in the "Watchstander Logs" and "Side Scan Review Log". These logs are delivered in Separates I of each sheet's DR.

The SSS towfish positioning was provided by **ISS-2000** through a **Catenary** program that used cable payout and towfish depth, or cable out and tow angle, to compute towfish positions. The position of the tow point (or block) was continually computed based on the vessel heading and the known offsets from the acoustic center of the MBES system to the tow point (See Appendix I).

The SSS towfish altitude was maintained between 8% and 20% of the range scale (6-15 meters at 75-meter range and 4-10 meters at 50-meter range), in accordance with Section 6.1.2.3 of the HSSD. Leidos maintains the principle that in the event it is required for personnel, vessel, and equipment safety; data collection at towfish altitudes outside of 8% to 20% of the range may be necessary over shoal areas and in the vicinity of charted obstructions or wrecks. Additionally, in areas of a significant density layer it may be necessary to collect data at towfish altitudes outside of 8% to 20% of the range. In any instance where towfish altitude was lower than the required 8% of the range scale, a data gap of the full swath was created or the **SABER** side scan mosaic generation procedure adjusted the usable SSS swath coverage to 12.5% of the towfish altitude. In instances where the towfish altitude exceeded 20% of the range, Leidos took extra care in reviewing the imagery data to meet all specifications and when required created data gaps of the full swath. Additional splits or holiday lines were run as needed to ensure coverage requirements were met.

Periodic confidence checks on linear features (e.g. trawl scars) or geological features (e.g. sand waves or sediment boundaries) were made during data collection to verify the quality of the SSS data across the full sonar record. These periodic confidence checks were made at least once per survey line when possible; however they were always made at least once each survey day in accordance with Section 6.1.3.1 of the HSSD.

For these surveys, a K-wing depressor was attached directly to the towed SSS. The use of the K-wing reduced the amount of cable out, which in turn reduced the positioning error of the towfish and allowed for less inhibited vessel maneuverability in shallow water.

A.7 SOUND SPEED PROFILES

A MVP30 with AML MVPX and Xchange sensors was used to collect SSP data. SSP data were obtained at intervals frequent enough to minimize sound speed errors in the MBES data. The frequency of SSP casts was based on the following:

- When the difference between the observed sound speed at the transducer depth in the currently applied SSP exceeded 2 meters per second (m/s) from the real-time observed surface sound speed measured by a sound speed sensor located at the MBES transducer, or measured by the real-time towed data from the MVPX sound speed sensor.
- Time elapsed since the last applied SSP cast.
- When a visible sound speed artifact was observed in the real-time **ISS-2000** multibeam bathymetry QA display.

Periodically during a survey day, multiple casts were taken along a survey line to identify the rate and location of sound speed changes. Based on the observed trend of sound speed changes along the line where this was done, the SSP cast frequency and locations were modified accordingly for subsequent lines.

The **Environmental Manager** module in **ISS-2000** displayed a real-time time series plot of the sound speed measured at the transducer depth from the currently applied SSP cast and the observed sound speed from the AML MicroX located at the MBES transducer, as well as the calculated difference between these sound speed values. A visual warning was issued to the operator when the difference approached and/or exceeded 2 m/s, as defined in Section 5.2.3.3 of the HSSD. During the surveys it was not always possible to maintain a difference less than 2 meters/second since the MVP30 sound speed sensor was towed behind the vessel where the upper layers of the water column were mixed by the vessel’s propellers. This was most apparent on warm sunny days with little or no wind when the solar radiation heated the surface water causing a large change in sound speed near the surface. In all cases attempts were made to take and apply numerous sound speed profiles as needed. Any significant sound speed related issues will be discussed in each sheet’s DR. Any other environmental factors or occurrences affecting sound speed data, or the ability to meet the 2 m/s requirements of Section 5.2.3.3 of the HSSD, will be documented in the respective sheet’s DR.

Confidence checks of the SSP data were periodically conducted by comparing two or more simultaneous or immediately consecutive casts taken with different sound speed sensors. The SSP casts taken during confidence checks were applied to the MBES file being collected in **ISS-2000** at that time. The application of the profiles allowed **ISS-2000** to maintain a record of each cast. When conducting the SSP comparison casts within the surrounding areas of the survey sheet, one of the comparison cast profiles was commonly applied to the start of the survey line.

Serial numbers and calibration dates are listed below for the sensors used to acquire sound speed data for the OPR-J311-KR-18 project. Copies of the calibration records are in Appendix IV. Sound speed data are included with the survey data delivered for each sheet.

AML Sensor Type	Serial Number	Pre-Survey Calibration Date	Post-Survey Calibration Date
AML SV Xchange	204453	06 March 2018	04 December 2018
AML SV Xchange	205540	27 March 2018	27 December 2018
AML SV Xchange	206148	03 March 2018	06 December 2018
AML SV Xchange	206246	15 December 2017	06 December 2018
AML SV Xchange	206249	01 December 2017	04 December 2018
AML SV Xchange	206512	15 December 2017	06 December 2018
AML SV Xchange	206513	15 December 2017	06 December 2018
AML SV Xchange	206514	15 December 2017	04 December 2018
AML SV Xchange	206515	01 December 2017	06 December 2018
AML P Xchange	304601	05 March 2018	19 December 2018
AML P Xchange	305331	15 February 2018	19 December 2018
AML P Xchange	305555	29 November 2017	19 December 2018
AML P Xchange	305557	29 November 2017	19 December 2018
AML P Xchange	305558	29 November 2017	19 December 2018
AML P Xchange	305598	08 December 2017	19 December 2018
AML P Xchange	305700	01 June 2018	03 January 2019
AML T Xchange	400503	31 May 2018	03 January 2019
AML T Xchange	404004	06 March 2018	05 December 2018

AML Sensor Type	Serial Number	Pre-Survey Calibration Date	Post-Survey Calibration Date
AML T Xchange	404370	12 December 2017	05 December 2018
AML T Xchange	404395	30 November 2017	05 December 2018
AML T Xchange	404397	28 November 2017	05 December 2018

A.8 BOTTOM CHARACTERISTICS

Bottom characteristics were obtained using a WILDCO Petite Ponar Grab (model number 7128-G40) bottom sampler. The locations for acquiring bottom characteristics were provided in the Project Reference File (PRF) received from the National Oceanic and Atmospheric Administration (NOAA). Unless otherwise noted in each sheet's DR the position of the bottom sample was not modified from what was provided within the PRF. At each location a seabed sample was obtained, characterized, and photographed. All photographs were taken with a label showing the survey registration number and sample identification number, as well as a ruler to quantify sample size within the photograph. In addition, Leidos mounted a GoPro Hero camera on the Petite Ponar Grab system (Figure A-3), which was used to obtain short videos of the seafloor during the acquisition of assigned sample locations. Photos and videos are delivered, as available, for each sheet on the delivery drive under the folder "HXXXXX/Processed/Multimedia".

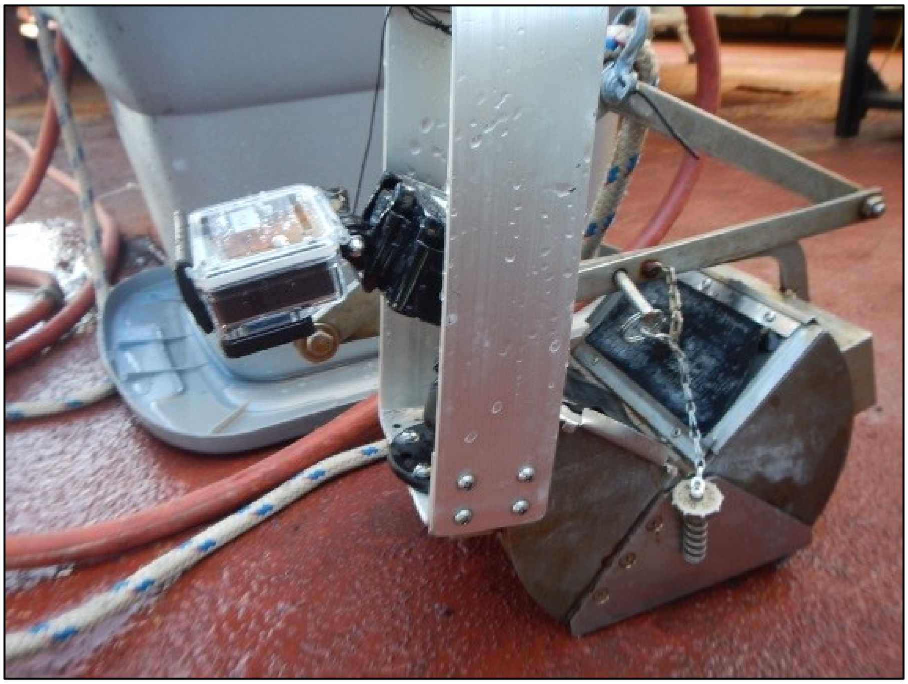

Figure A-3: GoPro Camera Mounted on Petite Ponar Grab

Samples were obtained by manually lowering the bottom sampler, with block and line. Each seabed sample was classified using characteristics to quantify color, texture, and particle size. Note that all bottom samples were collected from the *M/V Atlantic Surveyor*.

The position of each seabed sample was marked in the **ISS-2000** software and logged as an event in the message file. As the event was logged, it was tagged as a bottom sample event with the unique identification number of the sample obtained. These event records in the message file included position, JD, time, and user inputs for depth, the general nature of the type of seabed sample obtained, and any qualifying characteristics to quantify color, texture, and grain size.

The bottom sample event records saved in the message files from **ISS-2000** were used to populate "Bottom Sample Logs" and "Watchstander Logs". The "Bottom Sample Logs" provided all of the inputs listed above. The real-time "Watchstander Logs" provided a record of the time, sample number, sample depth, and sample descriptors for each individual sample obtained.

Bottom characteristics are included within the S-57 Feature File for each sheet, categorized as Seabed Areas (SBDARE) and attributed based on the requirements of the International Hydrographic Organization (IHO) Special Publication No. 57, IHO Transfer Standard for Digital Hydrographic Data, Edition 3.1, (see Section B.2.6 below for details of the S-57 feature file). Digital images of bottom sample are included in the S-57 Feature File for each sheet, as available.

A.9 DATA ACQUISITION AND PROCESSING SOFTWARE

Data acquisition was carried out using the Leidos **ISS-2000** with **Survey Planning** software for Windows 7 operating systems to control acquisition navigation, data time tagging, and data logging. The version and installation dates for each upgrade are listed in Table A-2.

Table A-2: ISS-2000 Versions and Installations Dates

ISS-2000 with Survey Planning Version	Date Version Installed on *M/V Atlantic Surveyor*	Date Version Installed on *R/V Pathfinder*	Software Use
5.3.0.4.0	10 July 2018	N/A	FAT
5.3.0.6.0	20 July 2018	N/A	FAT/SAT
5.3.0.7.1	03 August 2018	N/A	SAT/General
5.3.0.7.2	N/A	03 September 2018	SAT/General

Survey planning, data processing, and analysis were carried out using the Leidos **SABER** with **Survey Planning** software for Linux operating systems. Periodic upgrades were installed in the Newport, RI DPC and on the survey vessels *M/V Atlantic Surveyor* and *R/V Pathfinder*. The version and installation dates for each upgrade are listed in Table A-3.

Table A-3: SABER Versions and Installations Dates

SABER with Survey Planning Version	Date Version Installed In DPC Newport, RI	Date Version Installed on *M/V Atlantic Surveyor*	Date Version Installed on *R/V Pathfinder*	Software Use
5.4.0.2.0	11 July 2018	10 July 2018	N/A	FAT
5.4.0.4.0	06 August 2018	03 August 2018	N/A	General
5.4.0.4.1	N/A	23 August 2018	03 September 2018	General
5.4.0.5.0	21 September 2018	18 September 2018	N/A	General
5.4.0.5.1	N/A	24 September 2018	N/A	General
5.4.0.5.2	29 November 2018	N/A	N/A	S-57
5.4.0.9.0	28 December 2018	N/A	N/A	General
5.4.0.10.1	16 January 2019	N/A	N/A	General

Klein’s **SonarPro** Version 14.0, was used for SSS data acquisition.

Applanix **POSPac MMS** Version 8.3 Service Pack 1 was used for navigation trajectory generation.

CARIS **HIPS & SIPS** Version 10.4 was used for Ellipsoidally Referenced Tide Zones (ERZT) generation and analysis and for QC of the **SABER** generated S-57 files.

Jeppesen **dKart Inspector** Version 5.1 and Version 6.0 were used for QC of the **SABER** generated S-57 files.

NOAA and University of New Hampshire (UNH) Center for Coastal Ocean Mapping (CCOM) produced **PydroXL Explorer** Version 18.4 was used to apply Tidal Constituent and Residual Interpolation (TCARI) (**PydroGIS**) and to convert SSP files for National Centers for Environmental Information (NCEI) delivery (**Sound Speed Manager**).

National Aeronautics and Space Administration (NASA) provided **Panoply** was used to QC converted SSP files for NCEI delivery.

The NOAA Extended Attribute Files V5_4 was used as the Feature Object Catalog for OPR-J311-KR-18.

A.10 SHORELINE VERIFICATION

Shoreline verification was not required for these surveys.

B. QUALITY CONTROL

A systematic approach to tracking data has been developed to maintain data quality and integrity. Several logs and checklists have been developed to track the flow of data from acquisition through final processing. Several of these documents are included in Separates I of each sheet’s DR.

During data acquisition, survey watchstanders continuously monitored the systems, checking for errors and alarms. Thresholds set in the **ISS-2000** system parameters alerted the watchstander by displaying alarm messages when error thresholds or tolerances were exceeded. Alarm conditions that may have compromised survey data quality were corrected and noted in both the navigation log and **ISS-2000** message files. Warning messages such as the temporary loss of differential GPS, excessive cross track error, or vessel speed approaching the maximum allowable survey speed were addressed by the watchstander and automatically recorded into a message file. Prior to the start of any survey operations and continuously throughout all survey days, the acquisition watchstanders completed checklists to verify critical system settings and ensure valid data collection. While the *R/V Pathfinder* collected survey data autonomously, a watchstander was onboard to ensure valid data collection by completing the system checklists.

During real-time data acquisition, **ISS-2000** applied predicted water level correctors based on the NOAA generated tidal zoning covering the OPR-J311-KR-18 project area, and previously downloaded NOAA predicted tide data from tide station (8735180 Dauphin Island, AL). Also during real-time data acquisition, an Error Parameters File (EPF) within **ISS-2000** was used for the application of Total Propagated Uncertainty (TPU) values to the MBES data. As such, the raw bathymetry data, written to Generic Sensor Format (GSF) files (version 3.08), were fully corrected with uncertainties associated with each sounding at the time of acquisition. See Section B.2 of this Report for more details of the EPF and Leidos' Uncertainty Model.

Following data collection, initial data processing began onboard the *M/V Atlantic Surveyor*. This included the first level of QA in **SABER**; which may include the following:

- Initial swath editing of MBES data flagging invalid pings and beams.
- Application of delayed heave (Applanix *TrueHeave*™), followed by QC of application.
- Confirmation that the SSP files applied to online data were free of noise and within 250 meters (m) of the survey area.
- QC of MBES predicted tide data application from real-time acquisition
- Computation of Total Propagated Uncertainty (TPU) for each depth value in the MBES data.
- Generation of a preliminary Pure File Magic (PFM) CUBE surface.
- Second review and editing of MBES data using the PFM CUBE surfaces.
- Identify significant features for investigation with additional MBES coverage.
- Turning unacceptable data offline.
- Turning additional data online.
- Identification and flagging of significant features and designated soundings.
- Generation of MBES and SSS track line plots.
- Preliminary minimum sounding grids.
- Perform junction analysis (mainscheme depth data to crossline depth data)
- Running SSS data through the **SABER Automatic Contact Detection** (**ACD**) program.
- Application of Trained Neural Network to flag false alarms in SSS detections.
- Hydrographer review of SSS imagery data.
- Hydrographer review of SSS contact files.
- Adjustments to SSS time windows based on data quality.
- Generation of preliminary SSS coverage mosaics.
- Identification of holidays in the SSS coverage.

As referenced in Section A.3.1, autonomous data processing occurred on the *R/V Pathfinder*. At the completion of each survey line; the data were autonomously and automatically archived to the onboard processing computer which then automatically started an autonomous data processing routine in **SABER**. This near-real time autonomous data processing provided the first level of QA in **SABER**, which included, but was not limited to:

- Generation of MBES track line plots.
- QC of MBES predicted tide data application from real-time acquisition
- Application of delayed heave (Applanix *TrueHeave*™), followed by QC of application.
- Computation of TPU for each depth value in the MBES data.

Following the autonomous data processing routine, the watchstander onboard *R/V Pathfinder* was then able to perform initial swath editing (flagging invalid pings and beams, etc…) on the processed MBES data in near real-time. All data from *R/V Pathfinder* were also being automatically and autonomously archived every hour from the processing computer to an external hard drive, which was then used to transfer all data to the NAS onboard the *M/V Atlantic Surveyor* at each crew rotation. Further QA and evaluation of all data were continued onboard the *M/V Atlantic Surveyor*.

On a daily basis, the MBES data were binned into minimum depth layers, populating each bin with the shoalest sounding in that bin while maintaining its true position and depth. The following binned grids were created and used for initial crossline analysis, tide zone boundary comparisons, and day-to-day data comparisons:

- Mainscheme, item, and holiday fill survey lines.
- Crosslines using only near-nadir (±5 degrees, Class 1) data.

These daily comparisons were used to monitor adequacy and completeness of data and sounding correctors.

Approximately once every two weeks a complete backup of all raw and processed survey data were sent to the Leidos DPC in Newport, RI.

Final analysis of the data included at least the following steps:

- Verification of SSS contact files.
- Application of prorated draft to multibeam data.
- Generation of SBET data through Applanix **POSPac MMS** software.
- Application of SBET data to the multibeam data through **SABER**’s **MergeNav**.
- Application of PMVD separation model as water level correctors to multibeam data.
- Computation of TPU for each depth value in the MBES data.
- Generation of a one-meter or two-meter CUBE PFM surface for analysis of coverage, areas with high TPU, and features.
- Perform junction analysis (mainscheme depth data to crossline depth data)
- Perform junction analysis (comparing the current sheet to prior and/or current sheets).
- Generation of final CUBE PFM surface (one-meter or two-meter).
- Comparison with existing charts.
- QC review of SSS data and contacts.
- Generation of final coverage mosaics of SSS data.

- Correlation of SSS contacts with MBES features and/or designated soundings.
- Generation of S-57 feature files.
- Generation of final Bathymetric Attributed Grid(s) (BAG) and metadata products.
- Final QC of all delivered data products.

A flow diagram of Leidos' data processing routines from the acquisition of raw soundings to the final grids and deliverable data can be found in Appendix II Section V. Any reference to SSS data acquisition is only applicable to H13133, H13134, and H13135. H13136 only contains MBES data.

B.1 MULTIBEAM DATA PROCESSING

While discussed in Section B, the R/V Pathfinder utilized autonomous data processing tools; this utility was not used on the M/V Atlantic Surveyor. While the workflow, after ending a survey line, were different between the two vessels, all MBES data were processed using the same techniques.

At the end of each survey line file names were changed in **ISS-2000**, which automatically closed all data files and opened new files for data logging. The closed files were then archived to the on-board NAS or external hard drive and data processing commenced (onboard either the *M/V Atlantic Surveyor* or *R/V Pathfinder*).

Onboard the *M/V Atlantic Surveyor*, the MBES data were then reviewed in Leidos **SABER**'s **MultiView Editor** (**MVE**) program to flag erroneous data such as noise, flyers or fish, and to designate features or designated soundings. **MVE** is a geo-referenced editor, which can project each beam in its true geographic position and depth in both plan and profile views. Positions and depths of features were determined directly from the bathymetry data in the Leidos **MVE** swath editor by flagging the least depth on the object. A bathymetry feature file (CNT) was created using the **SABER Feature/Designated File from GSF** routine. The CNT file contains the position, depth, type of feature, and attributes extracted from the flagged features in the MBES data.

Once the bathymetry data were reviewed and edited, delayed heave was applied to the GSF files. The process to apply delayed heave uses the Applanix *TrueHeave*™ (.thv) files (for further detail refer to Section B.1.1). Leidos refers to *TrueHeave*™ as delayed heave. Next, TPU values were computed for each beam in the GSF files before they were loaded into the PFM CUBE surface. Further review and edits to the data were performed from the CUBE PFM grid. Periodically both the raw and processed data were backed up onto digital tapes and external hard drives.

Onboard the *R/V Pathfinder*, at the completion of the survey line; data processing autonomously began. Delayed heave was applied to the MBES data autonomously followed by computing TPU values for each beam in the GSF file. Data were transferred to the *M/V Atlantic Surveyor* with each crew rotation, approximately every 12 hours, where data were then copied to the *M/V Atlantic Surveyor* NAS. Processing continued on the data while onboard the *M/V Atlantic Surveyor*, with the first sept to build CUBE PFM grids for further review.

Leidos generated smoothed best estimate of trajectory (SBET) files through Applanix **POSPac MMS** software; the SBET data were then applied to the multibeam data through **SABER**'s **MergeNav** program (refer to Section B.1.2).

Following the application of corrected navigation, the MBES data were corrected for water levels using NOAA's provided Poor Man's Vertical Datum (PMVD) separation model through **SABER**'s **Apply GPSZ** program. For additional details refer to Section B.1.3. The final TPU for each beam were then calculated and applied to the bathymetry data.

For each survey sheet, all bathymetry data were processed into either a one-meter or a two-meter node PFM CUBE surface, in accordance with Section 5.2.2.2 of the HSSD, for analysis using **SABER** and **MVE**. The PFM CUBE surface was generated to demonstrate coverage for the entire sheet. All soundings used in development of the final CUBE depth surface had modeled vertical and horizontal uncertainty values at or below the allowable maximum uncertainty as specified in Section 5.1.3 of the HSSD.

During creation of the CUBE surface, two separate uncertainty surfaces are calculated by the **SABER** software; Hypothesis Standard Deviation (Hyp. StdDev) and Hypothesis Average Total Propagated Uncertainty (Hyp. AvgTPU). The Hyp. StdDev is a measure of the general agreement between all of the soundings that contributed to the best hypothesis for each node. The Hyp. Average TPU is the average of the vertical uncertainty component for each sounding that contributed to the best hypothesis for the node. A third uncertainty surface is generated from the larger of these two uncertainties at each node and is referred to as the Hypothesis Final Uncertainty (Hyp. Final Uncertainty).

After creation of the initial PFM CUBE surfaces, the **SABER Check PFM Uncertainty** function was used to highlight all of the cases where computed final node uncertainties exceeded IHO Order 1a. These nodes were investigated individually and typically highlighted areas where additional cleaning was necessary. Nodes found in the final PFM CUBE grid that still exceed uncertainty were addressed in the DR for each sheet. When all GSF files and the PFM CUBE surface were determined to be satisfactory, the PFM CUBE grid was converted to BAG file(s) for final delivery.

B.1.1 Delayed Heave

As discussed in Section B.2, Leidos and **SABER** use the terminology delayed heave to describe Applanix *TrueHeave*™ data collected from the Applanix POS/MV.

At the start of all survey operations, the Applanix POS/MV was configured to log *TrueHeave*™ data. The delayed heave files (.dat) were recorded using **ISS-2000** and archived to the NAS in the same manner as GSF files. The delayed heave data were calculated by the Applanix POS/MV based on an algorithm which used a range of temporally bounding Applanix POS/MV real-time heave data to produce a more accurate value of heave. When the resulting delayed heave values were applied to the multibeam data they reduced heave artifacts present from variables such as sea state and survey vessel maneuvering, which are commonly observed in multibeam data with only real-time heave applied.

When delayed heave corrections were applied to the bathymetric data, each depth value was fully recalculated in **SABER**. This was possible because the raw beam angle and travel time values were recorded in the GSF file. The raw beam angle and travel time values were used along with the vessel attitude (including heave) and re-raytraced. As delayed heave was applied, a history record was written to each GSF file, and the ping flag of each modified ping was updated.

After the application of delayed heave was complete, all bathymetric data were reviewed to verify that the delayed heave values were applied using the **SABER**'s **Check Heave**. This program read through the ping flags of each GSF record to check the application of delayed heave. When the **Check Heave** program found instances where delayed heave was not applied, it output report files which included the GSF filename, as well as the time range for the gap in delayed heave application. The data from the **Check Heave** reports were then used to further investigate all instances of gaps in delayed heave application.

Leidos strived to have delayed heave applied to all soundings of multibeam data, however there were times when this was not possible. Real-time heave was used in place of delayed heave in all instances where there were gaps in the application of delayed heave. All gaps in delayed heave application were fully investigated and the data reviewed to verify that the real-time heave values were appropriate to the surrounding available delayed heave values. Any instances where the absence of delayed heave adversely affected the data will be discussed in the DR for the respective sheet.

B.1.2 Navigation Processing for Multibeam

In order to correct the multibeam data to be vertically referenced to the ellipsoid; during acquisition data were logged from the Applanix POS/MV. Data were logged to the ISSC computer by the POS/MV POSView software and directly through **ISS-2000**; and also logged directly to an external USB drive connected to the POS/MV system. Data at acquisition were not vertically referenced, per guidance from NOAA see Appendix II of each sheet's DR.

Based on the survey location, Leidos utilized Applanix **POSPac MMS** software with the Post-Processed Trimble CenterPoint® RTX^{TM} (Trimble PP-RTX) option for all processing of trajectories. All final solutions applied to the multibeam data were derived from the raw navigation data of the POS/MV. The raw positioning files used to generate final trajectory data are delivered within each sheet's final directory HXXXXX/Raw/Positioning.

The Trimble PP-RTX network is made up of Trimble proprietary base stations, and the Trimble PP-RTX solution is an error model using range and atmospheric corrections, therefore no typical base station Receiver Independent Exchange Format (RINEX) or binary files are produced. Additionally, as all the Trimble proprietary base stations in the network contribute to the solution it is not possible to identify individual stations used for processing each SBET. Therefore, there are no base station data delivered for this project OPR-J311-KR-18.

In **POSPac MMS** the data were processed to NAD83. The Trimble PP-RTX option provides centimeter level post-processed positioning accuracies to the output SBET files. The SBET files were exported from **POSPac MMS** to an American Standard Code for Information Interchange (ASCII) format text file.

After exporting the SBET files from **POSPac MMS**, the files were imported into **SABER Time-Series Viewer** to perform QC and review the trajectory files for spikes. Files were reprocessed in **POSPac MMS** if spikes were observed in the created SBET.

Following this QC, the SBET trajectories were applied to the MBES data through **SABER**'s **MergeNav** program. **MergeNav** replaces the navigation stored in the GSF from data acquisition, and replaces it with the post-processed data from the SBET files. This process also stores the GPS height from the post-processed SBET into the record of each multibeam ping. **SABER** writes a new H/V Nav Error record into the GSF during this process, which includes information about the source of the updated navigation file (SBET) being applied. **SABER** supports a least squares interpolation method between ellipsoidal heights. As Leidos processed all OPR-J311-KR-18 with a least squares bracket of 0 seconds; **MergeNav** utilized a linear interpolation between ellipsoidal heights. The final SBET filename which was applied to the MBES data can be found in the "Multibeam Processing Log" (Separates I) of each sheet's DR.

Final SBET files and the corresponding uncertainty files generated from **POSPac MMS** are provided within each sheet's HXXXXX/Processing/SBET/ directory.

B.1.3 Tides and Water Levels

Per the OPR-J311-KR-18 PI, multibeam data were to be corrected to Mean Lower Low Water (MLLW) utilizing Ellipsoid Referenced Survey (ERS) techniques. The Project Instructions listed that NOAA's Poor Man's Vertical Datum (PMVD) separation model was to be used for final data transformation. The following sections detail an analysis of the PMVD and final water level corrections applied to the OPR-J311-KR-18 MBES data.

B.1.3.1 Water Level Correctors during Data Acquisition

During data acquisition predicted tides were applied through **ISS-2000**. The zoning and water level files were downloaded from the NOAA Center for Operational Oceanographic Products and Services (CO-OPS) Discrete Tidal Zoning Map website and the CO-OPS Tides & Currents website. The tide data for the project were downloaded, as comma delimited text files (.csv), at 6-minute water level data were in meters, and annotated with the Coordinated Universal Time (UTC). During data acquisition the tide gauge in use was 8735180, Dauphin Island, Alabama (AL).

At the end of each day, **SABER**'s **Check Tides** utility was run to confirm that all the multibeam data were corrected with predicted tides prior to continuing with data analysis.

B.1.3.2 NOAA Provided TCARI and Field Generated ERZT Separation Model

Per the PI, Leidos collected cross check lines across the entire project, in order to evaluate an ERZT separation model to the NOAA provided PMVD separation model. As required in the Statement of Work, Leidos was to apply the NOAA provided TCARI method to the multibeam data. The TCARI method used the harmonic constituents and residuals from historical and operating water level stations to provide precise water level correction for bathymetric surveys from the NOAA tide gauge 8735180, Dauphin Island, AL. For all days of survey on OPR-J311-KR-18 Leidos downloaded verified tides from 8735180, Dauphin Island, AL. The TCARI model which was provided from NOAA was J311KR2018.tc (Figure B-1).

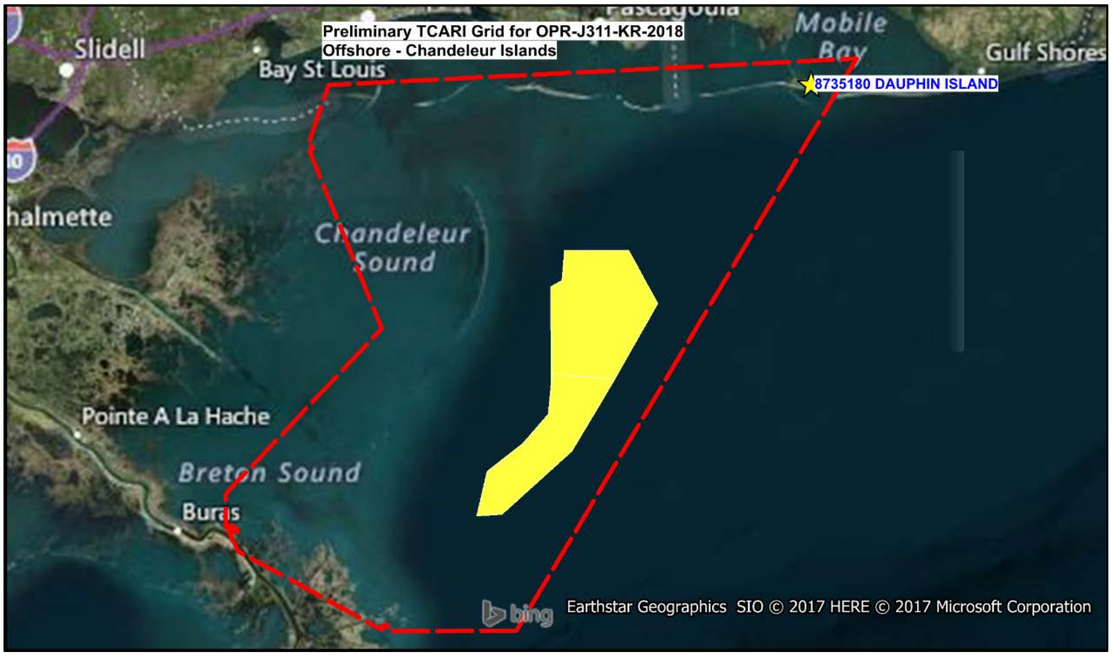

Figure B-1: TCARI Diagram for OPR-J311-KR-18

Prior to applying TCARI, Leidos first applied the post-processed navigation trajectory (SBET) data to the MBES data in **SABER**. Next, the MBES data were imported into the **PydroGIS** application; from the **PydroXL Explorer**. Leidos made no modifications to the provided TCARI grid. TCARI, with final verified water levels, were applied to the check lines from across the entire project. The MBES data were gridded in CARIS **HIPS & SIPS** for QC.

Following the application of TCARI to the check line data; Leidos used **HIPS & SIPS** to generate an ERZT separation model. Leidos built this ERZT separation model at a 500-meter node resolution, to be compared to the NOAA provided PMVD separation model which was also at 500-meter node resolution.

B.1.3.3 NOAA Provided PMVD Separation Model

Leidos was provided with a PMVD separation model from NOAA which encompassed all of OPR-J311-KR-18. This model from NOAA is included in the HXXXXX/Processed/Water_Levels/PMVD_provided_by_NOAA directory on each sheet's delivery drive. The PMVD was generated at 500-meter node resolution. Note that the CARIS CSAR grid which Leidos received had the data transformation from MLLW to NAD83; instead of NAD83 to MLLW.

B.1.3.4 Analysis between the PMVD Separation Model and ERZT Separation Model

Prior to utilizing the PMVD separation model as the source of final water level correctors, per the PI Leidos conducted an analysis between the ERZT separation model and the PMVD separation model. This analysis was conducted in **HIPS & SIPS**; by using a difference grid between the two separation models. The generated statistics are presented below with a histogram of the results (Table B-1 and Figure B-2). The depth range of the cross check lines, with the TCARI applied, was 14.666 meters to 40.368 meters. The resulting minimum allowable Total Vertical Uncertainty (TVU) was 0.535 meters to 0.725 meters. The results provided in Table B-1 confirmed that the difference observed between the ERZT and PMVD were within the minimum allowable TVU; and therefore supported that the PMVD separation model was a valid method for reducing sounding data to chart datum. These findings were presented to NOAA; refer to Appendix II of each sheet's DR.

Table B-1: Summary of ERZT to PMVD Comparison for OPR-J311-KR-18

Comparison	Result
Minimum	-0.185 m
Maximum	0.092 m
Mean	-0.066 m
Standard Deviation	0.046 m
Total Count	381
Histogram bin centres	-0.0465 m
Histogram counts	381

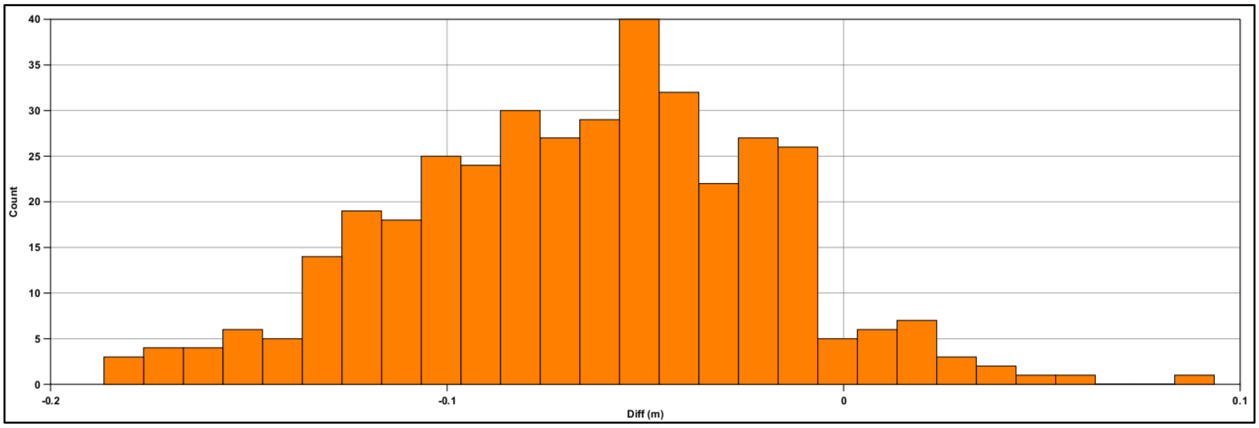

Figure B-2: Results from Comparing the ERZT to PMVD for OPR-J311-KR-18

B.1.3.5 Application of Final Water Level Correctors

In order to correct the MBES data in **SABER**, Leidos exported the NOAA provided PMVD from **HIPS & SIPS** to a comma delimited ASCII format file (HXXXXX/Processed/Water_Levels/). **SABER** was then used to generate two coverage grids, one grid contained the separation values from ellipsoid to chart datum (NAD83 to MLLW), and the second grid was of the uncertainty value associated with the PMVD. This uncertainty value was provided by NOAA with the PMVD, and is presented in Table B-2. Leidos performed extensive analysis to confirm that the

SABER generated PMVD separation model was consistent with the NOAA provided PMVD separation model.

The PMVD separation model was applied in **SABER** through the **SABER Apply GPSZ** program as the final water level correctors to all of OPR-J311-KR-18. **SABER** reads the stored ellipsoidal heights within the GSF record and calculates the difference between the separation model and the ellipsoidal height to generate a GPS tide corrector value. When updated water level correctors (such as a separation model) were applied to the GSF files, the **Apply GPSZ** program removed the previous water level correctors and applied the new correctors. Each time the program was run on the GSF files; a history record was appended to the end of the GSF file documenting the date and water level files applied. During **SABER**'s **Apply GPSZ** the uncertainty from the PMVD separation model was read from the uncertainty coverage file and was inserted into the H/V Nav Error record within the GSF data. For QA, the **SABER Check Tide Corrections in GSF** program was run on all GSF files to confirm that the appropriate water level corrector had been applied to the final MBES data.

After confirmation that final water levels were applied to all bathymetric data, grids were created and analyzed. In addition, mainscheme to crossline junction analysis was performed using the **SABER Frequency Distribution Tool** and the results were analyzed, to identify possible depth discrepancies resulting from the applied water level correctors.

Table B-2: Final PMVD Separation Model File Name and Uncertainty

Surface	Uncertainty
OPR-J311-KR-18_NAD83_PMVD_MLLW.cov	0.097 meters

As the PMVD separation model was used for the final datum transformation, the requirement to request TCARI Final Solutions was waived for OPR-J311-KR-18. Therefore no final tide note was provided from NOAA; however Leidos has provided a final tide note in Appendix I in each sheet's DR.

B.1.4 Multibeam Coverage Analysis

Bathymetric coverage analysis was conducted during initial data processing and on the final CUBE surface to identify areas where (if any) data coverage holidays exceeded the allowable three by three nodes in accordance with Section 5.2.2.3 of the HSSD for Complete Coverage, Option A and Option B. As previously stated in Section A.6, these survey operations were conducted at line spacing optimized to achieve 100% side scan sonar coverage for H13133, H13134, and H13135; and to achieve 100% multibeam coverage for H13136.

The **SABER Gapchecker** utility was run on the CUBE surface to identify and flag any areas of data holidays exceeding the allowable three by three nodes. In addition, the entire surface was visually scanned for holidays. Before closing out field operations, additional survey lines were run to fill any three by three node holidays detected. Results of the bathymetry coverage analysis are presented in each sheet's DR.

All grids for each survey were also examined for the number of soundings contributing to the chosen CUBE hypothesis for each node. This was done by running **SABER**'s **Frequency Distribution Tool** on the Hypothesis Number of Soundings layer. This analysis was done to ensure that at least 95% of all nodes contained five or more soundings, ensuring the requirements for both Complete Coverage Option A and Complete Coverage Option B coverage as specified in Section 5.2.2.3 of the HSSD were met. A complete analysis of the results of the **Frequency Distribution Tool** is provided in the DR for each sheet.

B.1.5 Junction Analysis

Junction analysis was performed by subtracting a grid from a separate reference grid to create a depth difference grid. For instance, if the crossline grid was subtracted from the mainscheme grid (reference layer) then a positive depth difference would indicate that the mainscheme data are deeper than the crossline data, and a negative depth difference would indicate that the mainscheme data are shoaler than the crossline data. The **SABER Frequency Distribution Tool** was used on the resulting depth difference grid for the junction analysis and statistics. The number count and percentage of depth difference values resulting from the **Frequency Distribution Tool** were calculated and reported four ways; as a total of all difference values populating the cells of the difference grid, as the amount of positive difference values populating the cells of the difference grid, as the amount of negative difference values populating the cells of the difference grid, and as the amount of values populating the cells of the difference grid which resulted in a zero difference. This was used to provide an analysis of the repeatability of the multibeam data system. A frequency distribution could not only be run on the overall resulting difference grid but could be run on any subarea of the difference grid. This was done to isolate areas, such as areas of high depth difference, to better evaluate and investigate potential accuracy problems.

Junction analysis results are presented in Separates II of the DR for each sheet.

B.1.5.1 Mainscheme to Crossline Comparisons

During data acquisition, comparisons of mainscheme (±60 degrees, Class 2) to crossline near-nadir (±5 degrees, Class 1) data were conducted daily to ensure that no systematic errors were introduced and to identify potential problems with the survey system. Final junction analysis was again conducted after the application of all correctors and completion of final processing to assess the agreement between the mainscheme and crossline data that were acquired during the survey. Crosslines were acquired at varying time periods throughout the survey period so that the crossline analyses could provide an indication of any potential temporal or systematic issues (if any) that may affect the data. The following binned grids were created and used for junction analysis:

- Mainscheme, item, and holiday fill survey lines (Class 2, ±60° cutoff)
- Crosslines (Class 1 data only, ±5° cutoff)

B.1.5.2 Sheet to Sheet Junctions

Junction analysis was conducted between the sheets listed in Table B-3. These included four junctioning survey sheets assigned in the Project Instructions (H12736, H12953, H12923, and

H12925), and also between sheets for this project where the data have been fully processed (Figure B-3). For junction analysis, the current data were binned at a one-meter or two-meter grid resolution using the CUBE algorithm. For assigned junctioning sheets H12736, H12923, and H12925, the comparison was made with the final deliverable BAGs for that sheet, which were downloaded from the NCEI website. For assigned junctioning sheet H12953, the comparison was made with the final deliverable BAG for that sheet, which was provided by NOAA under OPR-J311-KR-18.

The following binned grids were created and used for junction analysis:

- One-meter or two-meter CUBE PFM or BAGs of all valid data collected by Leidos.
- Four-meter or one-meter BAGs of assigned junctioning sheets.

Table B-3: Sheet Junctions Assigned for OPR-J311-KR-18

Registry Number	Scale	Year	Field Unit	Relative Location	Assigned in PI?
H12736	1:40000	2000	Ocean Surveys, Inc.	SW	Yes
H12923	1:40000	1999	David Evans & Associates, Inc.	W	Yes
H12925	1:40000	2010	David Evans & Associates	W	Yes
H12953	1:40000	2010	David Evans & Associates	NW	Yes

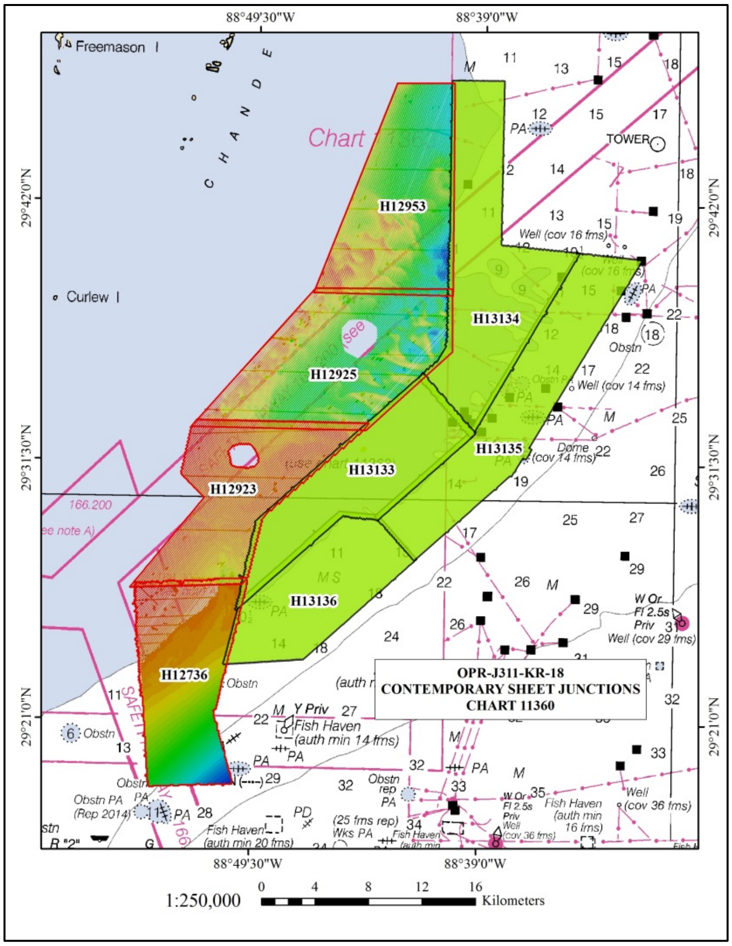

Figure B-3: Sheet Junctions Assigned for OPR-J311-KR-18

B.1.6 Beam-to-Beam Crossing Analysis

A beam-to-beam comparison of crossline data to mainscheme data was not performed. Leidos conducted analysis on a difference surface as discussed in Section B.1.5.

B.1.7 The CUBE Surface

Combined Uncertainty and Bathymetry Estimator (CUBE) is an internationally recognized model that provides the ability to convert bathymetry data and their associated uncertainty estimates into a gridded model. CUBE was developed by Brian Calder and others at the Center for Costal Ocean Mapping Joint Hydrographic Center (CCOM-JHC). Leidos is a member of the CCOM Consortium and the CUBE algorithm has been licensed to Leidos for use in **SABER**.

The CUBE algorithm uses the full volume of the collected data and the propagated uncertainty values associated with each sounding to perform a statistical analysis and calculate an estimated “true depth” at a series of nodes. The depth estimates and the associated uncertainty values at each node are grouped into a series of hypotheses or alternate depth estimates. Each node can have several hypotheses, of which the CUBE algorithm determines the hypothesis that best represents the "true depth" at each node using one of several user-selectable disambiguation methods. For all data processing the "Prior" disambiguation method was used in **SABER**'s implementation of CUBE. Once the "best" hypothesis had been selected for each node, the hypotheses were used to populate a bathymetric surface.

Four processing stages within the CUBE algorithm method; the Scatter Stage, the Gather Stage, the Insertion Stage, and the Extraction Stage were used to create the bathymetric CUBE surfaces.

The Scatter Stage determines which nodes might accept a sounding based on spatial criteria and that sounding's TPU values. This is done by calculating a radius of influence for each sounding, which will always be greater than or equal to the node spacing and less than or equal to the maximum radius. The maximum radius is equal to the 99% confidence limit of the horizontal uncertainty of the sounding. This radius of influence thereby determines the subset of nodes that can be affected by a sounding, by checking the distance of the sounding-to-node-position against the radius. If the distance from the sounding to the node is greater than the radius of influence, the processing of that sounding in the current node will end before the next stage of CUBE begins.

Once the CUBE algorithm defines the nodes that may be affected by a sounding, the Gather Stage then determines which soundings are actually inserted into the node. This is done through the use of a calculated node-to-sounding capture distance for each node in the subset of a sounding. The capture distance is equal to the greater of; 5% of the depth of the current sounding, the node spacing, or 0.50 meters.

For each of the nodes in the subset of a sounding, the sounding is only propagated to a node that falls within both the Scatter Stage radius and the Gather Stage capture distance. Also, the sounding to node propagation distance is additionally limited to a distance less than or equal to the grid resolution divided by the square root of two. This additional propagation distance limitation was included in **SABER**'s implementation of CUBE in order to meet the requirements of Section 5.2.2 of the HSSD. These distance limitations prevent soundings from being propagated far away from their collection points, as well as limiting how far away "bad" (high TPU) data are propagated.

Next, in the Insertion Stage, the soundings are actually added to nodes. **SABER** uses CUBE's "order 0" propagation approach. That is, when a sounding is propagated from its observed location to the node, the sounding depth will remain constant. However, the vertical uncertainty will change. The sounding's vertical uncertainty is increased by a dilution factor calculated from the distance of the sounding to the node and the sounding's horizontal uncertainty. This increase in the sounding's vertical uncertainty is affected by the user-defined distance exponent.

Addition of a sounding to a node starts by insertion of the sounding's depth, vertical uncertainty, and propagated variance into a node-based queue structure. Each node has a queue where soundings are written prior to calculation of a hypothesis. The queue is used to delay the impact of outliers on the hypothesis. Currently, the queue limit within **SABER** is 11 soundings. CUBE will not calculate a depth hypothesis for a node until all available soundings have entered the queue or there are at least 11 soundings in that node's queue.

As each sounding enters the queue, the queue is sorted by depth. Once 11 or all available soundings are in the queue, CUBE finds the median sounding for that group of soundings and inserts the sounding and its propagated variance into the node. Once the median sounding has been written to the node, another sounding is inserted into the queue and all soundings are resorted by depth. CUBE continues this process using batches of 11 soundings until there are no more soundings to insert into the node's queue. At this point, the algorithm will continue sorting the queue by depth using any soundings that remain, finding the median of the last ten soundings in the queue, then the last nine soundings, etc., until every sounding has been incorporated into a hypothesis. This process keeps possible fliers at the high and low ends of the queue until all other soundings have been processed, which has the net effect of creating a stronger hypothesis earlier in the process.

For each sounding to be inserted into a node, CUBE will determine if the sounding qualifies to be included in an existing hypothesis. If it qualifies for more than one hypothesis, CUBE will choose the hypothesis that will have the smallest change in variance when updated with the new sounding. If the statistical analysis within CUBE determines that the sounding does not fall into an existing hypothesis, then it will create a new hypothesis. Each sounding propagated to a certain node will influence one and only one hypothesis for that node. However, each sounding may affect multiple nodes.

Once all of the soundings have been propagated to nodes and inserted into depth hypotheses, CUBE will populate a bathymetric surface with the "best" hypothesis from each node in the Extraction Stage. If each node has only one depth hypothesis, then that hypothesis will be used for the surface. If there are multiple hypotheses for a node, **SABER**'s CUBE implementation extracts the "best" hypothesis from the nodes using one of three user-selected disambiguation methods to determine the best estimate of the true depth.

As previously mentioned, of the three available user-selectable disambiguation methods included in **SABER**'s implementation of CUBE, the "Prior" disambiguation method was used for all data processing of this project's surveys. This method, which is the simplest of the three methods, looks for the hypothesis with the greatest number of soundings and selects it as the "best" depth estimate. This method does not take the cumulative uncertainty of each hypothesis into consideration; it is strictly a count of the soundings in each hypothesis. If two hypotheses have the same number of soundings the program will choose the last hypothesis.

The "Prior" disambiguation method calculates the hypothesis strength based on a ratio of the number of samples in the "best" hypothesis and the samples in the next "best" hypothesis. This value is interpreted as the closer to zero, the more certainty of this hypothesis representing the true bottom. As the ratio values approach 5.0, that certainty diminishes rapidly. Any values less than zero are set to zero.

During the Extraction Stage, CUBE will also convert the running estimate of variance values that it has been calculating into a standard deviation and then into the Confidence Interval (CI) specified. The 95% CI was used for this project's surveys.

The Hypothesis Strength in conjunction with the number of hypotheses, the uncertainty of each hypothesis, and the number of soundings in each hypothesis are all helpful in determining the confidence in the final depth estimate for each node.

SABER has incorporated CUBE processing into the PFM layer structure. As an option when building a PFM layer, the user can choose to run the CUBE process which adds a series of additional surfaces to the PFM layer:

- *CUBE Depth*, which contains the depth value from the node's best hypothesis (unless there is an over-ride).
- *Node Shoal Depth,* which contains the shoalest depth of the soundings in the chosen CUBE hypothesis.
- *Node Number of Hypotheses*, which shows the number of hypotheses that were generated for each node.
- *Hypothesis Standard Deviation*, which shows the CUBE algorithm's calculated depth uncertainty for the best hypothesis of a node. This is reported at the CI selected by the user during the PFM build process (95% CI for all surveys). This is simply a measure of how well the soundings that made up a hypothesis compare to each other. It is not a measure of how good the soundings are.
- *Node Hypothesis Strength*, which shows a node-by-node estimate for how strongly supported a hypothesis depth estimate is. This value is calculated as follows: a ratio of the number of samples in the "best" hypothesis and the samples in the next "best" hypothesis is generated. The ratio is subtracted from an arbitrary limit of 5. The hypothesis strength is interpreted as the closer this value is to zero, the stronger the hypothesis. If the resulting product is less than zero, it will be reported as a zero.
- *Hypothesis Number of Soundings*, which reports the number of soundings that were used to calculate the best hypothesis.
- *Hypothesis Average TPU,* is a second uncertainty value calculated by **SABER**, not the CUBE algorithm. This value is computed by taking the average of the vertical component of the TPU for each sounding that contributed to the best hypothesis for the node. It provides an alternative method for describing the likely depth uncertainty for nodes. The average TPU value does provide a measure of how good the soundings are that made up the hypothesis.
- *Hypothesis Final Uncertainty,* this surface is populated with the greater value of the Hypothesis Standard Deviation and the Hypothesis Average TPU surfaces.

Once built, the different PFM surfaces were displayed, analyzed, and edited using **SABER**. All PFM surfaces were used throughout the data processing stages to aid in analysis, interpretation, and editing of the survey data, as well as for QA/QC tools to ensure specifications of the HSSD were met. When all survey data were finalized, Leidos built a final PFM using the CUBE option. Then Leidos converted the PFM grid to a BAG file using the **SABER Convert PFM to BAG** utility. This process exports the CUBE Depth surface and Hypothesis Final Uncertainty surface, as well as additional child layers, to the BAG as outlined in HSSD Section 5.2.1. The BAG files are described in the next section (Section B.1.8).

B.1.8 Bathymetric Attributed Grids

A Bathymetric Attributed Grid (BAG) is a bathymetry data file format developed by the Open Navigation Surface Working Group (ONSWG). This group developed the BAG file format in response to the growing need within the hydrographic community for a nonproprietary data exchange format for bathymetric grids and associated uncertainty data.

One of the key requirements for Navigation Surfaces, and hence for BAG layers, is that all depth values have an associated uncertainty estimate and that these values must be co-located in a gridded model, which provides the best estimate of the bottom. To meet this requirement Leidos has implemented a combined CUBE/BAG approach in **SABER** (see Section B.1.7 for a detailed description about the CUBE Surface). In this approach, **SABER** creates BAG layers by converting the CUBE Depth surface, the associated Hypothesis Final Uncertainty surface, and optionally several other surfaces of a PFM grid to a BAG.

This process was done through the use of the **Convert PFM to BAG** utility in **SABER**. This utility allowed user-selected surfaces of a PFM to be converted into one or more BAG files. For example, the PFM depth surface was converted to the BAG file's depth surface, and the PFM uncertainty surface was converted to the BAG file's uncertainty surface.

Note that by definition, BAG files contain elevations not depths; however many software packages display a BAG elevation surface as a depth (positive values indicating water depth).

In addition to the depth and uncertainty surfaces, other child layers can also be converted to the BAG. These surfaces have been grouped with the BAG file structure.

The Elevation Solution Group is made up of the following three surfaces:

- *shoal elevation* - the elevation value of the least-depth measurement selected from the sub-set of measurements that contributed to the elevation solution.
- *number of soundings* - the number of elevation measurements selected from the sub-set of measurements that contributed to the elevation solution.
- *stddev* - the standard deviation computed from all elevation values which contributed to any hypothesis within the node. Note that the *stddev* value is computed from all measurements contributing to the node, whereas *shoal elevation* and *number of soundings* relate only to the chosen elevation solution.

The Node Group is made up of the following two surfaces:

- *hypothesis strength* - the CUBE computed strength of the chosen hypothesis
- *number of hypotheses* - the CUBE computed number of hypotheses

For OPR-J311-KR-18 all BAG files were generated with the Corrector surface populated with the PMVD separation model.

The **SABER Convert PFM to BAG** utility populates each layer of the BAG from the corresponding layer of the CUBE PFM and maintains the PFM grid resolution. The final delivered BAG files for this project are version 1.5.1, uncompressed, and include both the Elevation Solution Group surfaces and the Node Group surfaces. Note that a maximum size of each BAG file was 4 GB, which may result in more than one BAG file being delivered for a sheet.

Each generated BAG file also has a separate extensible markup language (XML) metadata file which **SABER** created as the BAG was generated. **SABER** automatically populates each generated metadata file with data specific to the BAG such as the UTM projection, bounding coordinates, horizontal datum, and node spacing. The generated XML metadata files were edited to include additional information such as the responsible party, name of the dataset, person responsible for input data, and other information specific to the project and survey sheet which was not automatically populated by **SABER**.

The edits made to each metadata file were then written back to each corresponding BAG file using the **Update BAG Metadata XML** utility in **SABER**. Although any or all of the fields within the generated metadata files can be edited within a text editor program, **SABER** does not allow the BAG files to be updated with any metadata XML file where the values in the automatically populated fields have been changed from the values stored in the BAG files. To ensure all metadata information were correctly edited, updated, written back to the BAG files, and stored within the BAG files each BAG metadata XML file was re-exported for QC purposes.

The **Compare BAG to PFM** utility in **SABER** was used for QC of data within each generated BAG layer. This tool provided the ability to compare all surfaces from each node within the BAG files to the surface values of the same node within the PFM. This was done to ensure that all values were exported and generated correctly in the BAG files, and that no values were dropped during the generation of the BAG files.

B.1.9 S-57 Feature File

Included with each sheet's delivery is an S-57 Feature File made in accordance with the IHO Special Publication No. 57, IHO Transfer Standard for Digital Hydrographic Data, Edition 3.1, (IHO S-57) and Section 7.3 of the HSSD.

The S-57 Feature File was generated through **SABER** using the SevenCs ECDIS (Electronic Chart Display and Information System) Kernel. The ECDIS Kernel is based on the IHO S-57 as well as the IHO Special Publication S-52 Specifications for Chart Content and Display Aspects of ECDIS (S-52); which details the display and content of digital charts as well as establishing presentation libraries. Leidos implements the SevenCs ECDIS Kernel as a building block, the Kernel maintains the presentation libraries used to create the S-57 Feature Files and retains the IHO requirements, while Leidos maintains the source code which drives the use of the SevenCs ECDIS Kernel so that S-57 Feature Files can be created through **SABER**.

Leidos modified the **SABER** S-57 libraries to allow for the addition of the NOAA Extended Attributes, as specified in Appendix G of the HSSD. Each feature within the S-57 Feature File has the availability to populate any of the Extended Attributes documented within the HSSD. When appropriate the NOAA Extended Attributes have been classified for each feature within the S-57 Feature File.

In accordance with Section 7.3.5 of the HSSD, all aids to navigation that fell within the surveyed areas of Project OPR-J311-KR-18 are discussed within the DR for the appropriate sheet and included in the respective sheet's final S-57 Feature File, if necessary. Also per HSSD Section 1.7, any observed seep or pipelines will be discussed within the DR for the appropriate sheet but will not be included in the sheet's final S-57 Feature File.

Feature depths were attributed within the S-57 Feature File as value of sounding (VALSOU) and were maintained to millimeter precision. All features addressed within each sheet were retained within that sheet's respective S-57 Feature File. For all features, the requirements from the IHO S-57 standard were followed, unless otherwise specified in Section 7.3 of the HSSD. Also, following the IHO S-57 standard each sheet's S-57 Feature File is delivered in the WGS84 datum and is unprojected with all units in meters.

In addition, the Feature Correlator Sheets were exported as JPEG files and included under the NOAA Extended Attribute "images".

Each sheet's S-57 Feature File was subjected to ENC validation checks using Jeppesen's **dKart Inspector** and quality controlled with **dKart Inspector** and CARIS **HIPS & SIPS**.

B.1.10 Multibeam Ping and Beam Flags

Flags in **SABER** come in four varieties: Ping flags, Beam flags, PFM depth record flags, and PFM bin flags. Ping and beam flags are specific to the GSF files, where they are used to attribute ping records and the individual beams of each ping record. Beam flags are used to describe why soundings are invalid and rejected, how they were edited, if they meet various cutoff criteria, etc. These same flags also contain descriptors used to indicate that a sounding is a selected sounding and why it is a selected sounding (feature, designated sounding, least depth, etc.).

There are sixteen bits available in GSF for ping flags so the flags are written to the files using 16-bit binary numbers. The ping flag bits are separated into two groups: Ignore bits and Informational bits. Bits zero through eleven are the Ignore bits. If bit zero is set, the ping is flagged as invalid. Bits 1 through 11 specify the reason(s) why the ping was flagged invalid. If only bit zero is set, the ping is flagged due to no bottom detection. However, if any of the bits 1 through 11 are set, bit zero will also be set. Bits 12 through 15 are Informational flags, and they describe actions that have been performed on a ping, such as applying delayed heave or a tide corrector. Bits 12 through 15 can be set regardless of whether or not any of bits zero through 11 are set. Bit 13 defines whether or not the GPS-based vertical control was applied. Bits 14 and 15 are used in conjunction with each other to describe the source of the tide corrector applied to a ping.

Eight bits are available in the GSF file for beam flags. The eight bit beam flag value stored in GSF files is divided into two four-bit fields. The lower-order four bits are used to specify that a beam is to be ignored, where the value specifies the reason the beam is to be ignored. The higher-order four bits are used to specify that a beam is selected, where the value specifies the reason why the beam is selected.

Leidos and CARIS have collaborated to provide the ability to import multibeam GSF files into CARIS. Table B-4 represents commonly used definitions for these GSF beam flags, as well as their mapping to CARIS depth flag codes. Table B-5 represents commonly used definitions for these GSF ping flags, as well as their mapping to CARIS profile flag codes.

Note that there is not a one-for-one match between CARIS Profile and Depth flags and GSF Ping and Beam flags. Therefore, upon the import of multibeam GSF files into CARIS, GSF defined flags such as: delayed heave applied, the applied tide type in use, and Class 1 not being met are not available in CARIS. As detailed in Table B-4 and Table B-5, no flag is applied in CARIS to the HDCS (Hydrographic Data Cleaning System) files, upon import from GSF, for these GSF ping and beam flags.

Table B-4: Mapped GSF Beam Flags and CARIS Flag Codes

GSF Beam Flags		CARIS HIPS Flag	
Bitmask	Comments	Name	Comments
0000 0010	Selected sounding, no reason specified.	PD_DEPTH_DESIGNATED_MASK	Indicates that the user has explicitly selected this sounding as a designated sounding.
0000 0110	Selected sounding, it is a least depth.	PD_DEPTH_DESIGNATED_MASK	Indicates that the user has explicitly selected this sounding as a designated sounding.
0000 1010	Selected sounding, it is a maximum depth.	PD_DEPTH_DESIGNATED_MASK	Indicates that the user has explicitly selected this sounding as a designated sounding.
0001 0000	Does NOT meet Class 1 (informational flag).	No flag to be applied to HDCS files upon import from GSF.	
0001 0010	Selected sounding, average depth.	PD_DEPTH_DESIGNATED_MASK	Indicates that the user has explicitly selected this sounding as a designated sounding.
0010 0010	Selected sounding, it has been identified as a feature.	PD_DEPTH_DESIGNATED_MASK	Indicates that the user has explicitly selected this sounding as a designated sounding.
0100 0010	Spare bit Field.	N/A	
1000 0010	Selected sounding, it has been identified as a designated sounding.	PD_DEPTH_DESIGNATED_MASK	Indicates that the user has explicitly selected this sounding as a designated sounding.
0000 0001	Null Invalidated – No detection was made by the sonar.	PD_DEPTH_REJECTED_MASK	Indicates that this sounding has been rejected. The reason may or may not be indicated by the other bits. This bit is inherited from the Observed Depths file but can be changed by HDCS.
0000 0101	Manually edited (i.e., MVE).	PD_DEPTH_REJECTED_BY_SWATHED_MASK	Indicates that the sounding has been rejected in the swath editor. Soundings which are rejected in this manner are not visible in older versions of HDCS, but are visible in the newer PC based software.
0000 1001	Filter edited.	PD_DEPTH_REJECTED_MASK	Indicates that this sounding has been rejected. The reason may or may not be indicated by the other bits. This bit is inherited from the Observed Depths file but can be changed by HDCS.
0010 0001	Does NOT meet Class 2.	PD_DEPTH_REJECTED_MASK	Indicates that this sounding has been rejected. The reason may or may not be indicated by the other bits. This bit is inherited from the Observed Depths file but can be changed by HDCS.

GSF Beam Flags		CARIS HIPS Flag	
Bitmask	Comments	Name	Comments
0100 0001	Resolution Invalidated – Exceeds maximum footprint.	PD_DEPTH_REJECTED_MASK	Indicates that this sounding has been rejected. The reason may or may not be indicated by the other bits. This bit is inherited from the Observed Depths file but can be changed by HDCS.
1000 0001	This beam is to be ignored, it exceeds the IHO standards for Horizontal OR Vertical error.	PD_DEPTH_REJECTED_BY_TOTAL_PROPAGATION_ERROR (TPE)	Indicates that the reason for rejection was because the beam failed Total Propagation Error (TPE).

Table B-5: Mapped GSF Ping Flags and CARIS Flag Codes

GSF Ping Flags		CARIS HIPS Flag	
Bitmask	Comments	Name	Comments
0000 0000 0000 0001	IGNORE PING	PD_PROFILE_REJECTED_MASK	Indicated that the profile has been rejected. It implies that all soundings within the profile are also rejected.
0000 0000 0000 0011	OFF LINE PING	PD_PROFILE_REJECTED_MASK	Indicated that the profile has been rejected. It implies that all soundings within the profile are also rejected.
0000 0000 0000 0101	BAD TIME	PD_PROFILE_REJECTED_MASK	Indicated that the profile has been rejected. It implies that all soundings within the profile are also rejected.
0000 0000 0000 1001	BAD POSITION	PD_PROFILE_BAD_NAVIGATION_MASK	Indicates that the profile is rejected because of bad navigation reading. This flag is not currently being used.
0000 0000 0001 0001	BAD HEADING	PD_PROFILE_BAD_GYRO_MASK	Indicates that the profile is rejected because of bad gyro reading. This flag is not currently being used.
0000 0000 0010 0001	BAD ROLL	PD_PROFILE_BAD_ROLL_MASK	Indicates that the profile is rejected because of bad roll reading. This flag is not currently being used.
0000 0000 0100 0001	BAD PITCH	PD_PROFILE_BAD_PITCH_MASK	Indicates that the profile is rejected because of bad pitch reading. This flag is not currently being used.
0000 0000 1000 0001	BAD HEAVE	PD_PROFILE_BAD_HEAVE_MASK	Indicates that the profile is rejected because of bad heave reading. This flag is not currently being used.
0000 0001 0000 0001	BAD DEPTH CORRECTOR	PD_PROFILE_BAD_DRAFT_MASK	This is set by the merge function, and indicates that the profile is rejected because vessel draft cannot be interpolated.
0000 0010 0000 0001	BAD TIDE CORRECTOR	PD_PROFILE_BAD_TIDE_MASK	Indicates that the profile is rejected because of bad tide reading. This flag is not currently being used.
0000 0100 0000 0001	BAD SVP	PD_PROFILE_BAD_SVP_MASK	This is a mirror of the bit in the observed depths file, where the SV correction functions are implemented. It indicates that the profile is rejected because of interpolation errors during the SV correction procedure.
0000 1000 0000 0001	NO POSITION	PD_PROFILE_REJECTED_MASK	Indicates that the profile has been rejected. It implies that all soundings within the profile are also rejected.
0001 0000 0000 0000	DELAYED HEAVE APPLIED	No flag to be applied to HDCS files upon import from GSF.	
0010 0000 0000 0000	GPSZ APPLIED	No flag to be applied to HDCS files upon import from GSF.	
0100 0000 0000 0000	Combine with bit 15 represents applied tide type.	No flag to be applied to HDCS files upon import from GSF.	
1000 0000 0000 0000	Combine with bit 14 represents applied tide type.	No flag to be applied to HDCS files upon import from GSF.	

B.2 SURVEY SYSTEM UNCERTAINTY MODEL

The Total Propagated Uncertainty (TPU) model that Leidos has adopted had its genesis at the Naval Oceanographic Office (NAVOCEANO), and is based on the work by Rob Hare and others ("Error Budget Analysis for NAVOCEANO Hydrographic Survey Systems, Task 2 FY 01", 2001, HSRC FY01 Task 2 Final Report). The TPU model used by **SABER** estimates each of the components that contribute to the overall uncertainty that is inherent in each sounding. The model then calculates cumulative system uncertainty (Total Propagated Uncertainty). The data needed to drive the error model were captured as parameters taken from the **SABER** EPF, which is an ASCII text file typically created during survey system installation and integration. The parameters were also obtained from values recorded in the multibeam GSF file(s) during data collection and processing. One of these values was the separation uncertainty; listed in Table B-6 and Table B-8 as SEP Uncertainty. During **SABER**'s **Apply GPSZ** (detailed in Section B.1.3.5) the uncertainty from the PMVD separation model was inserted into the H/V Nav Error record within the GSF data. When the H/V Nav Error Record is populated with an uncertainty; that value overrides the uncertainty provided in the EPF. Therefore, the multibeam data for OPR-J311-KR-18 had the static value 0.097m utilized when calculating the overall TPU.

While the input units vary, all uncertainty values that contributed to the cumulative TPU estimate were eventually converted to meters by the **SABER Calculate Errors in GSF** program. The TPU estimates were recorded as the Horizontal Uncertainty and Vertical Uncertainty at the 95% confidence level for each beam in the GSF file. During application of horizontal and vertical uncertainties to the GSF files, individual beams where either the horizontal or vertical uncertainty exceeded the maximum allowable IHO S-44 5th Edition Order 1a specifications were flagged as invalid. As a result, all individual soundings used in development of the final CUBE depth surface had modeled vertical and horizontal uncertainty values at or below the allowable IHO S-44 5th Edition, Order 1a uncertainty.

Table B-6 through Table B-9 show the values entered into the **SABER** EPF used with this project for both survey vessels. All parameter uncertainties in this file were entered at the one sigma level of confidence, but the outputs from **SABER**'s **Calculate Errors in GSF** program are at the two sigma or 95% confidence level. Sign conventions are: X = positive forward, Y = positive starboard, Z = positive down.

Table B-6: *M/V Atlantic Surveyor* EPF for the RESON SeaBat T50

Parameter	Value	Units
VRU Offset – X	0.504	Meters
VRU Offset – Y	0.144	Meters
VRU Offset – Z	-1.685	Meters
VRU Offset Error – X (uncertainty)	0.007	Meters
VRU Offset Error – Y (uncertainty)	0.015	Meters
VRU Offset Error – Z (uncertainty)	0.013	Meters
VRU Latency	0.00	Millisecond
VRU Latency Error (uncertainty)	1.00	Milliseconds
Heading Measurement Error (uncertainty)	0.02	Degrees
Roll Measurement Error (uncertainty)	0.02	Degrees
Pitch Measurement Error (uncertainty)	0.02	Degrees
Heave Fixed Error (uncertainty)	0.05	Meters

Parameter	Value	Units
Heave Error (% error of height) (uncertainty)	5.00	Percent
Antenna Offset – X	4.828	Meters
Antenna Offset – Y	-0.452	Meters
Antenna Offset – Z	-8.104	Meters
Antenna Offset Error – X (uncertainty)	0.007	Meters
Antenna Offset Error – Y (uncertainty)	0.015	Meters
Antenna Offset Error – Z (uncertainty)	0.013	Meters
Estimated Error in Vessel Speed (uncertainty)	0.0300	Knots
Percent of Speed Contributing to Speed Error	0.00	Percent
GPS Latency	0.00	Milliseconds
GPS Latency Error (uncertainty)	1.00	Milliseconds
Horizontal Navigation Error (uncertainty)*	0.75	Meters
Vertical Navigation Error (uncertainty)*	0.20	Meters
Surface Sound Speed Error (uncertainty)	1.00	Meters/second
SVP Measurement Error (uncertainty)	1.00	Meters/second
Static Draft Error (uncertainty)	0.01	Meters
Loading Draft Error (uncertainty)	0.02	Meters
Settlement & Squat Error (uncertainty)	0.05	Meters
Predicted Tide Measurement Error (uncertainty)	0.20	Meters
Observed Tide Measurement Error (uncertainty)	0.11	Meters
Unknown Tide Measurement Error (uncertainty)	0.50	Meters
Tidal Zone Error (uncertainty)	0.20	Meters
SEP Uncertainty	0.15	Meters

*NOTE: These values would only be used if not included in the GSF file

Table B-7: *M/V Atlantic Surveyor* RESON SeaBat T50 Sonar Parameters

Parameter	Value	Units
Transducer Offset – X	0.00*	Meters
Transducer Offset – Y	0.00*	Meters
Transducer Offset – Z	0.00*	Meters
Transducer Offset Error – X (uncertainty)	0.007	Meters
Transducer Offset Error – Y (uncertainty)	0.015	Meters
Transducer Offset Error – Z (uncertainty)	0.013	Meters
Roll Offset Error (uncertainty)	0.05	Degrees
Pitch Offset Error (uncertainty)	0.05	Degrees
Heading Offset Error (uncertainty)	0.05	Degrees
Model Tuning Factor	6.00	N/A
Amplitude Phase Transition	1.0	Samples
Latency	0.00	Milliseconds
Latency Error (uncertainty)	1.00	Milliseconds
Installation Angle	0.0	Degrees

Table B-8: *R/V Pathfinder* EPF for the RESON 7125 SV2

Parameter	Value	Units
VRU Offset – X	-5.315	Meters
VRU Offset – Y	-1.367	Meters
VRU Offset – Z	-2.344	Meters
VRU Offset Error – X (uncertainty)	0.004	Meters
VRU Offset Error – Y (uncertainty)	0.015	Meters

Parameter	Value	Units
VRU Offset Error – Z (uncertainty)	0.013	Meters
VRU Latency	0.0	Millisecond
VRU Latency Error (uncertainty)	1.0	Milliseconds
Heading Measurement Error (uncertainty)	0.02	Degrees
Roll Measurement Error (uncertainty)	0.02	Degrees
Pitch Measurement Error (uncertainty)	0.02	Degrees
Heave Fixed Error (uncertainty)	0.05	Meters
Heave Error (% error of height) (uncertainty)	5.00	Percent
Antenna Offset – X	-4.426	Meters
Antenna Offset – Y	-1.186	Meters
Antenna Offset – Z	-4.463	Meters
Antenna Offset Error – X (uncertainty)	0.004	Meters
Antenna Offset Error – Y (uncertainty)	0.015	Meters
Antenna Offset Error – Z (uncertainty)	0.013	Meters
Estimated Error in Vessel Speed (uncertainty)	0.03000	Knots
Percent of Speed Contributing to Speed Error	0.0	Percent
GPS Latency	0.0	Milliseconds
GPS Latency Error (uncertainty)	1.0	Milliseconds
Horizontal Navigation Error (uncertainty)*	0.75	Meters
Vertical Navigation Error (uncertainty)*	0.20	Meters
Surface Sound Speed Error (uncertainty)	1.0	Meters/second
SVP Measurement Error (uncertainty)	1.00	Meters/second
Static Draft Error (uncertainty)	0.01	Meters
Loading Draft Error (uncertainty)	0.02	Meters
Settlement & Squat Error (uncertainty)	0.05	Meters
Predicted Tide Measurement Error (uncertainty)	0.20	Meters
Observed Tide Measurement Error (uncertainty)	0.11	Meters
Unknown Tide Measurement Error (uncertainty)	0.50	Meters
Tidal Zone Error (uncertainty)	0.20	Meters
SEP Uncertainty	0.15	Meters

*NOTE: These values would only be used if not included in the GSF file

Table B-9: *R/V Pathfinder* RESON 7125 SV2 Sonar Parameters

Parameter	Value	Units
Transducer Offset – X	0.00*	Meters
Transducer Offset – Y	0.00*	Meters
Transducer Offset – Z	0.00*	Meters
Transducer Offset Error – X (uncertainty)	0.004	Meters
Transducer Offset Error – Y (uncertainty)	0.015	Meters
Transducer Offset Error – Z (uncertainty)	0.013	Meters
Roll Offset Error (uncertainty)	0.05	Degrees
Pitch Offset Error (uncertainty)	0.05	Degrees
Heading Offset Error (uncertainty)	0.05	Degrees
Model Tuning Factor	6.0	N/A
Amplitude Phase Transition	1.0	Samples
Latency	0.0	Milliseconds
Latency Error (uncertainty)	1.0	Milliseconds
Installation Angle	0.0	Degrees

B.3 SIDE SCAN SONAR DATA PROCESSING

Side scan sonar data processing was a multi-step process consisting of updating the navigation and heading in the XTF files, running the **Automatic Contact Detection** (**ACD**) program, applying a Trained Neural Network, and reviewing the imagery, contacts, and data coverage.

B.3.1 Side Scan Navigation Processing

The **SABER Navup** and **xtf_io** routines were used to re-navigate the SSS towfish in order to provide more accurate towfish positions. The **Navup** routine replaced the towfish positions (sensor X and sensor Y fields) recorded in the original SSS XTF file with the final towfish positions derived from the catenary data files recorded during acquisition by **ISS-2000**. The **xtf_io** routine created track lines, computed and applied a unique heading for each ping record (as opposed to the 1 Hz position and heading data recorded during data acquisition). Each record in the catenary file included:

- Time
- Towfish position
- Cable out
- Layback
- Towfish velocity
- Towfish heading
- Towfish depth
- Tow angle

All SSS data are delivered with completely corrected SSS positions. Towfish track plots were generated by extracting the towfish position at 1-second intervals for QC of the **Navup** and **xtf_io** processes.

B.3.2 Side Scan Contact Detection

SSS contact detection was performed using the **ACD** program within **SABER**.

The **ACD** program was run to identify seafloor contacts from the side SSS data and also included processes to correct the bottom tracking (towfish altitude) in each XTF file. The software was designed to detect a contact at least one cubic meter in size. For each detection, parameters such as shape and texture were extracted as well as measurement of the length, width, and height. This process consisted of three major stages, altitude correction (i.e. bottom tracking), contact detection, and Trained Neural Network application.

B.3.2.1 Contact Detection

The **ACD** software used a split-window normalization algorithm commonly referred to as constant false alarm rate (CFAR) detection. In order to avoid thousands of false detections in sand-wave fields, the detection processing included a two-dimensional median wave-number filter to suppress sand waves and other periodic background interference before shadow processing. This process was done using a Detection Parameters File (DPF) input into **SABER** (detailed in Table B-10). A peak and shadow score were calculated independently, and then combined, to produce an overall total contact score. If the overall score was above a defined threshold, then a detection was triggered. This process ran independently on all channels within the XTF file.

The image processing phase then processed each detection that was generated. This phase extracted parameters from each detection (e.g. shape and texture), normalized the parameters, and automatically measured the length, width, and height of each detection. Once the parameters were extracted from the images associated with each detection, the program normalized and prioritized those parameters for use in the subsequent neural network phase which classified the detections.

Table B-10: DPF Used for ACD

General Detection Parameter	Value		Units
Pings to Process	2048		Pings
Detection Box Width	200		Samples
Detection Box Length	40		Pings
Max Number of Detections	25		Detections
Bottom Track Box Height	10		Pings
Bottom Track Box Width	10		Samples
Bottom Track Box threshold	25		N/A
Bottom Track Alert Threshold	10		N/A
Bottom Track Alert Interval	10		N/A
Reject Columns	2		% Across Track Samples to Clip
Geometric Correction Limit	2.5		N/A
Detect Ping Difference	10		Pings
Detect Sample Difference	50		Samples
Frequency Parameter	**Low Frequency Value**	**High Frequency Value**	**Units**
Peak Noise Detect Length	10	10	Pings
Peak Noise Detect Width	49	49	Samples
Peak Noise Mask	25	25	Pings
Peak Min Threshold	2.2	1.5	Multiplier
Peak Max Length	5	5	Pings
Peak Min Length	2	2	Pings
Shadow Noise Detect Length	10	10	Pings
Shadow Noise Detect Width	24	24	Samples
Shadow Noise Mask	25	25	Pings
Shadow Max Threshold	0.75	0.70	Multiplier
Shadow Detect Length	3	3	Pings
Shadow Detect Width	27	27	Samples
Detect Search Box Length	5	5	Pings
Detect Search Box Width	11	11	Samples
Area Detect Threshold	88	100	N/A
Hamming Filter Width	30	30	Samples
Shadow Score Width	3	3	Samples

B.3.2.2 Apply Trained Neural Network File

Once the detections were selected, a Trained Neural Network file was applied to classify the detections as either a contact or clutter (false alarm). For this project, the neural network file used was: Neural_Net_Atlantic_RFH_Gulf_C_Ratio_60A_40R.nnt. This file contained data from four previous NOAA sheets:

- Sheet F H11241 (2003) Klein 2000
- Sheet H H11455 (2005) Klein 3000
- Sheet R H12094 (2010) Klein 3000
- Sheet C H11785 (2008) Klein 3000

These sheets provided a broad range of data across two sonar types and various bottom types. The Neural Network file was created by taking a random selection of detections from each sheet and creating a ratio of 60 percent accepted detections (true detections) and 40 percent rejected detections (false alarms). The number of image parameters the Neural Network used was determined by two primary criteria, the Mahalanobis distance (Figure B-4) and pair-wise covariance. The Mahalanobis distance is a measure of the statistical distance between two classes based simply on their normal distributions; while the covariance is a measure of how similar the two parameters are. After numerous test cycles 20 parameters were chosen.

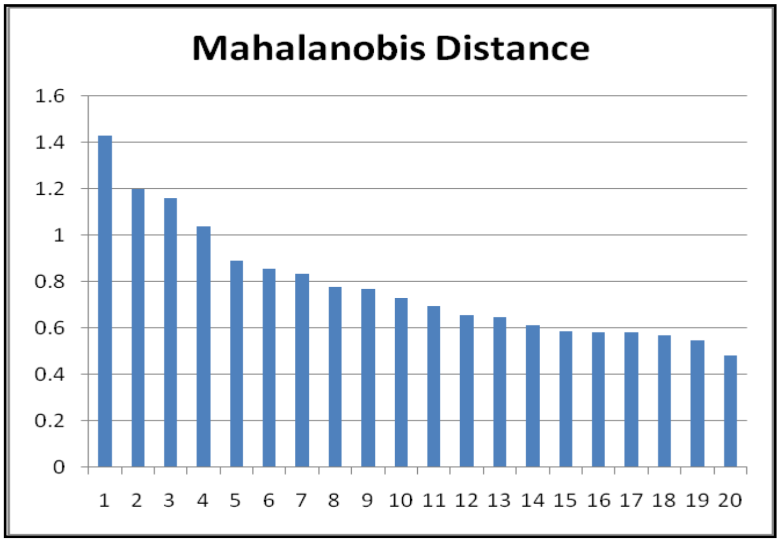

Figure B-4: Mahalanobis Distance of Top Twenty Parameters

When the Trained Neural Network file was applied to the detection files, the program assigned a network activation number to each detection. The network activation number ranged between zero and one, with zero being clutter and one being a contact. For values that fell between zero and one, a user assigned value (decision method) determined which detections were classified as contacts (equal to or greater than the decision method) or as clutter (below decision method). The decision method value used for this project was 0.90. This value was determined during the alpha and beta software test cycles by analyzing numerous pre-processed datasets. The beta distributions fit to the network activations from the entire neural network training dataset were plotted in Figure B-5 with the decision method in green. This shows that, by using a decision method of 0.90, most of the detections classified as contacts will fall above this value.

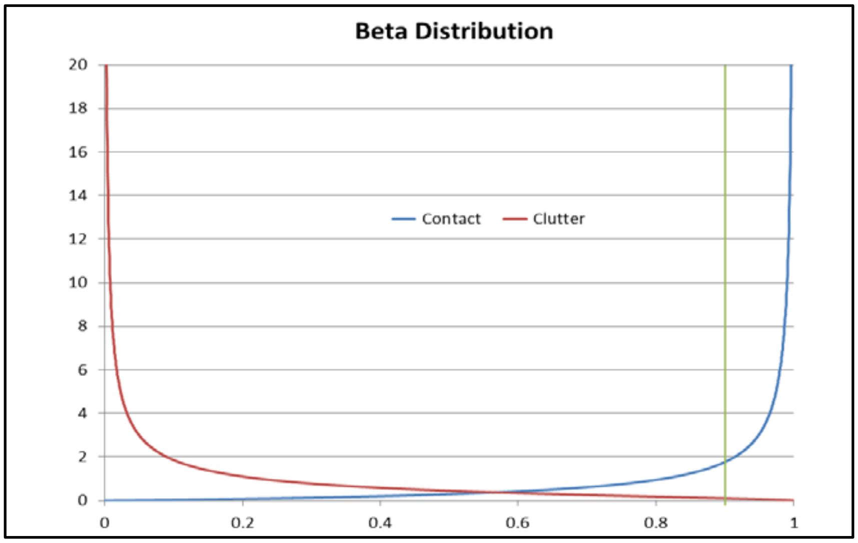

Figure B-5: Decision Method Based on Beta Distributions

B.3.3 Side Scan Data Quality Review

After each survey day, a hydrographer reviewed the side scan sonar data for quality, bottom tracking, and contacts using **SABER**'s **Imagery Review** and **Contact Review** programs. Within **Imagery Review**, the contact detections were overlain on the side scan sonar record. The side scan data within **Imagery Review** was down sampled using the Average Display Method. This was chosen since it provided the best general-purpose review settings. Down sampling is necessary because the number of pixels displayed is constrained by the width of the display window and the screen resolution. During review, the hydrographer assessed the overall quality of the data and defined any holidays in the data where the quality was insufficient to clearly detect seafloor contacts across the full range scale. The times and descriptions for any defined data holidays were entered into a "Side Scan Review Log" which was created and maintained for each sheet. The times of all noted side scan data gaps were also incorporated into the side scan data time window files that were then used to depict the data gap within the applicable side scan coverage mosaic as discussed in Section A.6. Data holidays were generally characterized by:

- Surface noise (vessel wakes, sea clutter, and/or waves)
- Towfish motion (yaw and heave)
- Towfish altitude requirements
- Acoustic noise
- Density layers (refraction)
- Electrical noise

The "Side Scan Review Log" for each sheet was maintained throughout final data processing. It incorporated all of the relevant information about each side scan data file, including the line begin and line end times, survey line name, corresponding multibeam file name(s), line azimuth, and any operator notes made during data acquisition. System-status annotations were recorded in the logs at the beginning of survey operations in each sheet, upon returning to the survey area, and at the JD rollover of each continuous survey day. These system-status annotations included; the mode of tuning (auto tuning was used throughout all survey operations), the tow point, the side scan range scale setting, the watchstander's initials, the side scan model in use, whether or not a depressor was in use on the side scan, weather conditions and sea state. These and any other necessary annotations were continuously updated throughout survey operations as needed in accordance with Section 8.2.3 of HSSD. Each sheet's "Side Scan Review Log" is included in Separates I of the sheet's DR.

B.3.4 Side Scan Contact Analysis

During side scan data review, the hydrographer used the **Contact Review** program to review each contact detection and was able to either accept it as a real contact or reject it (i.e. contacts created on fish or multiple contacts on a large object). The hydrographer could also override the automatic measurements of the contact's length, width, and height or generate new contacts. Selected contacts and pertinent information for each contact was documented in the "Side Scan Review Log". Significant side scan contacts were chosen based on size and height, or a unique sonar signature. In general, contacts with a computed height greater than 50 centimeters were typically selected, however this was also depth dependent. Contacts with a unique sonar signature (e.g. size, shape, and reflectivity) were typically selected regardless of height. Contacts made within **SABER** were saved to an XML file. Contact specific information including year, date, time, position, fish altitude, ground range, contact measurements, and any remarks were contained in the XML file. These data can also be found within the delivered Side Scan Sonar Contacts S-57 file for each sheet.

The **SABER Contact Review** program opens the contact and all surrounding displayed side scan data at full resolution. The hydrographer can choose to zoom in or out to review the contact. When measuring contacts within **Contact Review**, the length is always the along track dimension and the width is always the across track dimension. Therefore it is possible to have a width measurement that is longer than the length measurement.

Some of the guidelines followed by the hydrographer for contact generation and documentation included the following. Wrecks and large objects were positioned at their highest point based on the observed acoustic shadow. Similarly, contacts for debris fields were positioned on the tallest measured object in the debris field. Contacts were also made on exposed cables, pipelines, and sewer outfalls, regardless of height. In addition to contacts, the "Side Scan Review Log" also includes entries for many non-significant seafloor objects (e.g., fishing gear, small objects, etc.) that were identified during the side scan data review.

Bathymetric feature and side scan contact correlation was conducted in **SABER**. The XML file was viewed in **SABER** as a separate data layer along with the PFM grid, and the multibeam feature file (CNT). By comparing the bathymetry with the side scan contact data, both datasets could be evaluated to determine the significance of an object and the potential need to create additional side scan contacts or bathymetric features. This correlation updated the CNT file with the type of feature (obstruction, wreck, etc.) and the XML file with the correlated feature number and depth.

SABER generated side scan contact images for each contact within the XML and they are delivered for each sheet under the "HXXXXX/Processed/Multimedia" folder on the delivery drive, and referenced in the Side Scan Sonar Contacts S-57 file NOAA Extended Attribute "images" field. Also, for a subset of side scan contacts that have been correlated to a multibeam feature (maximum of two side scan contact images for each feature); the images are visible in the Feature Correlator Sheets referenced in the S-57 Feature File NOAA Extended Attribute "images" field.

B.3.5 Side Scan Sonar Contacts S-57 File

Leidos also generated an S-57 file for each sheet to display the SSS contacts. The Side Scan Sonar Contacts S-57 file (.000) was generated through the same process used to build each sheet's final S-57 Feature File, described in Section B.1.9, except with side scan contact information incorporated instead of multibeam feature information.

Within the Side Scan Sonar Contacts S-57 file, side scan contacts were represented using an object from the Cartographic Object Classes: Cartographic Symbol ($CSYMB). Side scan contacts in the final contact XML for each sheet were delivered in the respective Side Scan Sonar Contacts S-57 file, regardless of the contact's significance. The information field (INFORM) of each cartographic symbol provides specific information such as the contact name, length, width, height, shadow length, range scale, ground range, altitude, and whether or not the contact was correlated to a bathymetric feature, and the survey line name. Also for contacts correlated to a bathymetric feature or object in the final S-57 Feature File, the charting recommendations for the feature or object are listed under the NOAA Extended attribute, recommendations (recomd) field, as it appears in the sheet's final S-57 Feature File. The NOAA Extended Attribute "images" field of each cartographic symbol details an associated JPEG image for the side scan contact it represents.

B.3.6 Side Scan Coverage Analysis

As stated in the HSSD, 100% side scan coverage in not sufficient for disproval of assigned or charted features. Therefore, an additional 100% side scan coverage was obtained over the specified search radius for assigned objects as well as the specified search radius for disproving charted objects. The disproval coverage was verified by generating two separate coverage mosaics. The first 100% side scan coverage consisted of all initial survey lines, while the disproval side scan coverage consisted of any additional coverage over discrete objects. To accomplish this, a time window file listing the times of all valid online side scan data was created along with separate side scan file lists for the 100% coverage, and disproval coverage mosaics. Using **SABER**, the time window file and the side scan file lists were then used to create one-meter cell size mosaics in accordance with Section 8.2.1 of the HSSD. The two coverage mosaics were reviewed independently using tools in **SABER** to verify data quality and swath coverage. During data acquisition, preliminary coverage mosaics were also used to plan additional survey lines to fill in any data gaps. All final delivered coverage mosaics are determined to be complete and sufficient to meet the Project Instructions for side scan sonar coverage, unless otherwise noted in a sheet's DR.

Each side scan coverage mosaic is delivered as a geo-referenced image (an image file [.tif] and a corresponding world file [.tfw]).

C. CORRECTIONS TO ECHO SOUNDINGS

The data submitted are fully corrected with uncertainties associated with each sounding. Therefore, the CARIS vessel file will be all zeros. See Section B.2 of this Report for details of the Uncertainty Model and EPF which details the uncertainties of each item.

Figure C-1 shows the *M/V Atlantic Surveyor* sensor configuration and the vessel offsets for the RESON SeaBat T50. The 2018 vessel offsets are tabulated in Table C-1. All measurements are in meters. The RESON SeaBat T50 was hull-mounted approximately amidships, just port of the keel. Offset measurements were made from the POS/MV IMU to the acoustic center of the MBES system's transducer array. See Appendix I for details on the vessel offsets survey.

Figure C-2 shows the *R/V Pathfinder* sensor configuration and the vessel offsets for the RESON 7125 SV2. The 2018 vessel offsets are tabulated in Table C-2. All measurements are in meters. The RESON 7125 SV2 was pole-mounted from the bow deck moon pool, at approximately the ship's center line. Offset measurements were made from the POS/MV IMU to the acoustic center of the MBES system's transducer array. See Appendix I for details on the vessel offsets survey.

The Leidos **ISS-2000** and the POS/MV software utilize a coordinate system where "Z" is defined as positive down, "X" is defined as positive forward, and "Y" is defined as positive to starboard. Table C-1 and Table C-2 document sensor offsets that were entered into the POS/MV (offsets referenced to the IMU) or **ISS-2000** (offsets referenced to the sonar acoustic center) software.

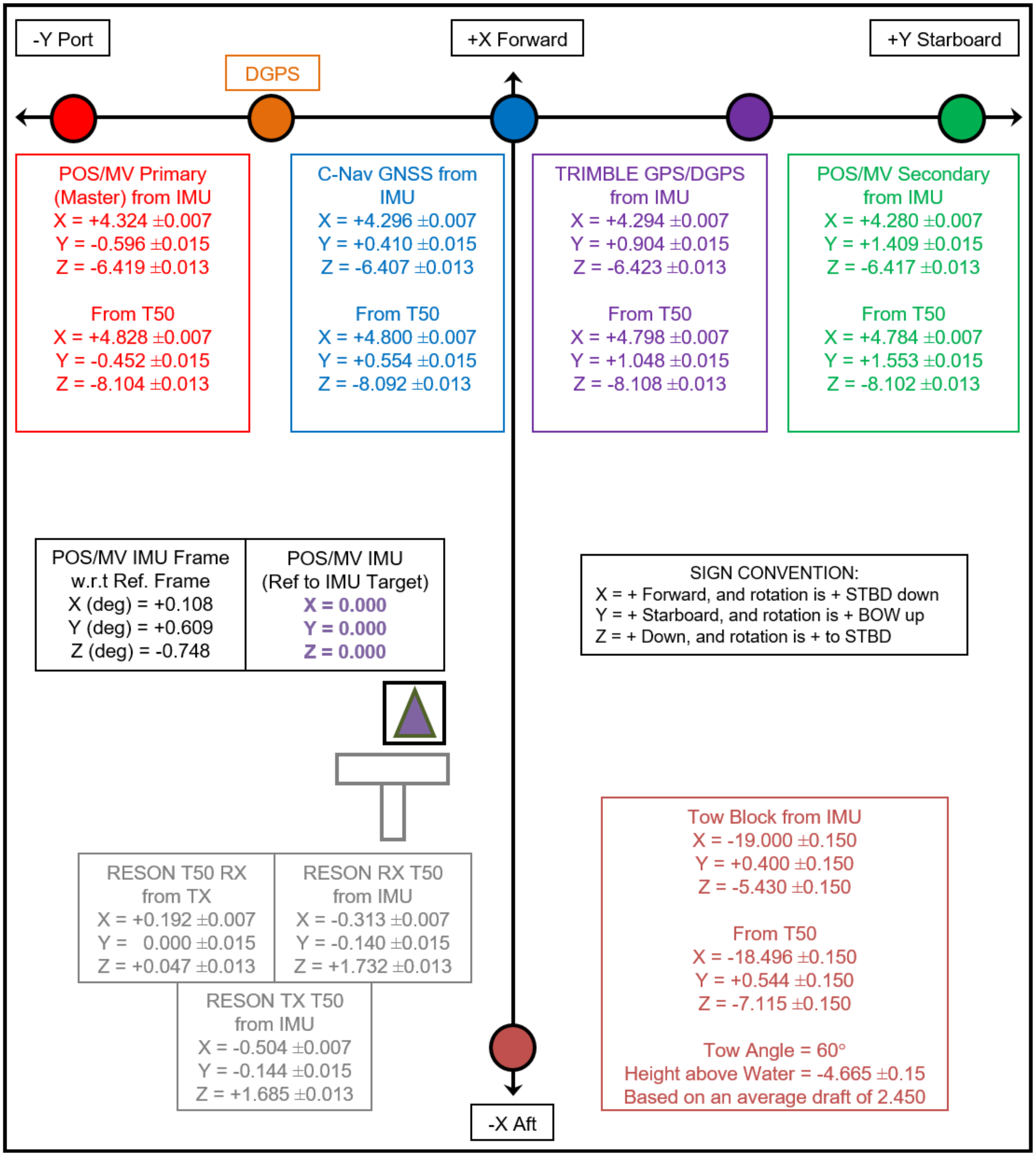

Figure C-1: Configuration and Offsets of *M/V Atlantic Surveyor* Sensors for the RESON T50 (Measurements in Meters with 1-Sigma Uncertainty)

Table C-1. *M/V Atlantic Surveyor* RESON T50 Antenna and Transducer Offsets Relative to the POS/MV Version 5 IMU Reference Point (Measurements in Meters with 1-Sigma Uncertainty)

Sensor	Offset in ISS-2000		Offset in POS/MV	
Ref. to IMU Target (POS/MV IMU Top Dead Center)			X	0.000m
			Y	0.000m
			Z	0.000m
POS/MV IMU Frame w.r.t Ref. Frame (POS/MV IMU Mounting Angles)			X	+0.108 degrees
			Y	+0.609 degrees
			Z	-0.748 degrees
Ref. to Primary GNSS Lever Arm (IMU to Master GA830 Antenna L1)			X	+4.324 ±0.007m
			Y	-0.596 ±0.015m
			Z	-6.419 ±0.013m
Ref. to Vessel Level Arm (IMU to RESON T50 Transducer)			X	-0.504 ±0.007m
			Y	-0.144 ±0.015m
			Z	+1.685 ±0.013m
Ref. to Center of Rotation Lever Arm (IMU to vessel CG)			X	-0.900m
			Y	+0.365m
			Z	-0.712m
Ref. to Sensor 1 Lever (IMU to RESON T50 Transducer)			X	-0.504 ±0.007m
			Y	-0.144 ±0.015m
			Z	+1.685 ±0.013m
RESON T50 RX from TX	X	+0.192 ±0.007		
	Y	0.000 ±0.015		
	Z	+0.047 ±0.013		
Navcom C-Nav 3050 GPS Antenna from RESON T50 Transducer	X	+4.800 ±0.007m		
	Y	+0.554 ±0.015m		
	Z	-8.092 ±0.013m		
A-Frame Tow Block (X and Y from RESON T50 Transducer. Z is height above water).	X	-18.496 ±0.150m		
	Y	+0.544 ±0.150m		
	Z	-4.665 ±0.150m		

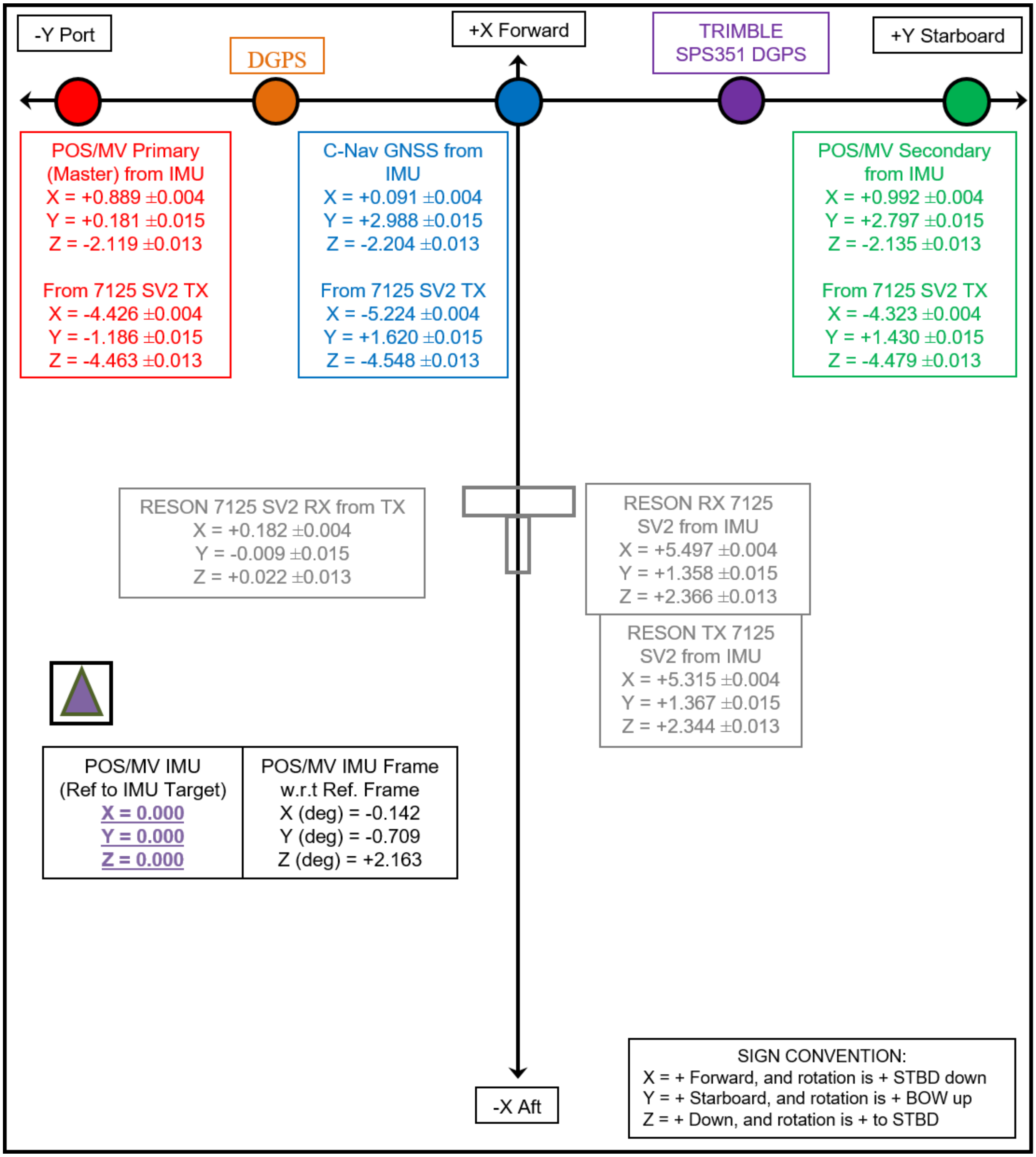

Figure C-2: Configuration and Offsets of *R/V Pathfinder* Sensors for the RESON 7125 SV2 (Measurements in Meters with 1-Sigma Uncertainty)

Table C-2. *R/V Pathfinder* RESON 7125 SV2 Antenna and Transducer Offsets Relative to the POS/MV Version 5 IMU Reference Point (Measurements in Meters with 1-Sigma Uncertainty)

Sensor	Offset in ISS-2000		Offset in POS/MV	
Ref. to IMU Target (POS/MV IMU Top Dead Center)			X	0.000m
			Y	0.000m
			Z	0.000m
POS/MV IMU Frame w.r.t Ref. Frame (POS/MV IMU Mounting Angles)			X	-0.142 degrees
			Y	-0.709 degrees
			Z	+2.163 degrees
Ref. to Primary GNSS Lever Arm (IMU to Master GA830 Antenna L1)			X	+0.889 ±0.004m
			Y	+0.181 ±0.015m
			Z	-2.119 ±0.013m
Ref. to Vessel Level Arm (IMU to RESON 7125 SV2 Transducer)			X	+5.315 ±0.004m
			Y	+1.367 ±0.015m
			Z	+2.344 ±0.013m
Ref. to Center of Rotation Lever Arm (IMU to vessel CG)			X	+2.530m
			Y	+1.550m
			Z	+1.000m
Ref. to Sensor 1 Lever (IMU to RESON 7125 SV2 Transducer)			X	+5.315 ±0.004m
			Y	+1.367 ±0.015m
			Z	+2.344 ±0.013m
RESON 7125 SV2 RX from TX	X	+0.182 ±0.004m		
	Y	-0.009 ±0.015m		
	Z	+0.022 ±0.013m		
Navcom C-Nav 3050 GPS Antenna from RESON 7125 SV2 Transducer	X	-5.224 ±0.004m		
	Y	+1.620 ±0.015m		
	Z	-4.548 ±0.013m		

C.1 STATIC AND DYNAMIC DRAFT MEASUREMENTS

C.1.1 Static Draft

Figure C-3 shows the draft determination for the *M/V Atlantic Surveyor*. When installed, the RESON SeaBat T50 transducer was hull-mounted approximately 3.44 meters below the vessel's main deck. To determine the draft, a 0.02 meter square metal bar was placed on the deck so that it extended out far enough to allow a direct measurement to the water line. The distance from the top of the metal bar to the water surface was measured and subtracted from the transducer hull depth to determine the draft of the transducer's acoustic center.

For the *M/V Atlantic Surveyor*, static draft measurements were taken on each side of the vessel at every port call; both before departure and after arrival, in order to prorate the daily draft accounting for fuel and water consumption (see Section C.1.1.1). The two draft measurements (port and starboard) and the resulting draft value were recorded in the "Watchstander Logs" as well as in a separate vessel "Draft Log". If the static draft value changed from the previously noted value, the new value was entered into the **ISS-2000** system. The observed and prorated static draft for each survey is included with the survey data in Separates I of the DR for each sheet.

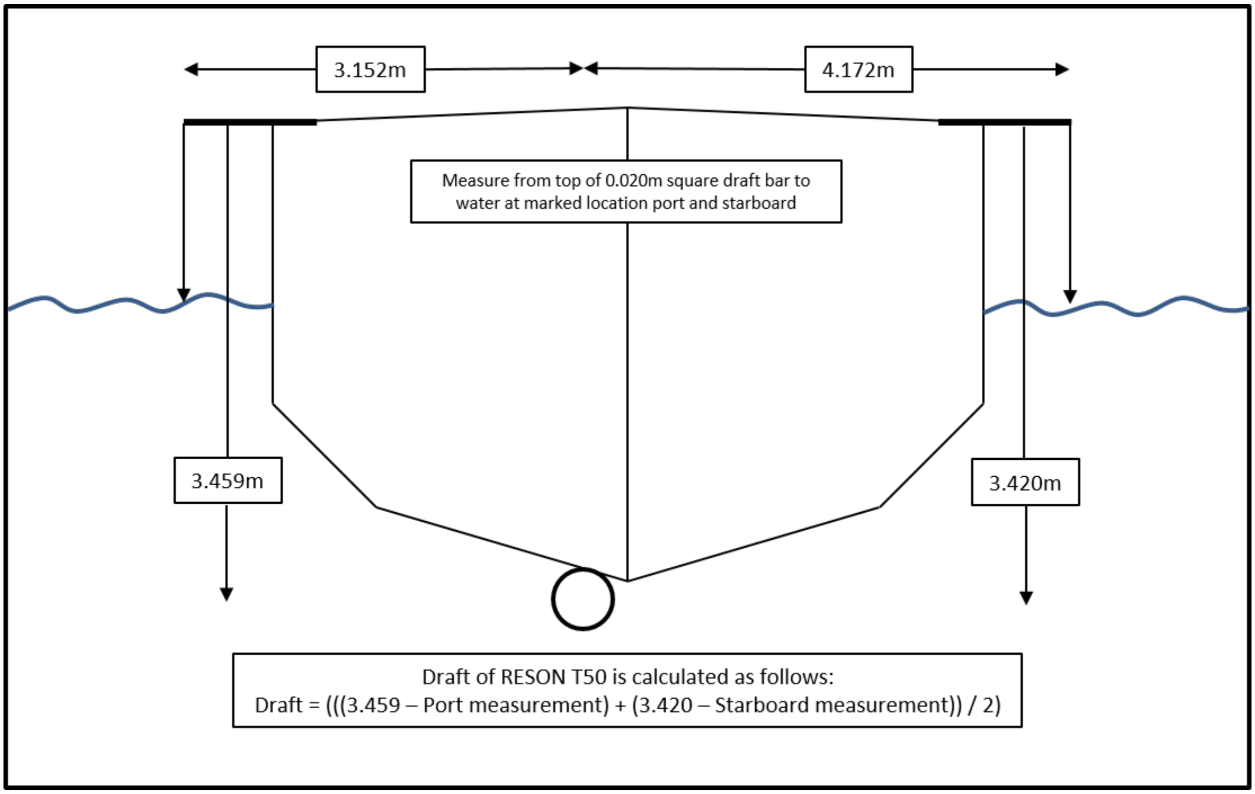

Figure C-3: *M/V Atlantic Surveyor* RESON SeaBat T50 Draft Determination

For the *R/V Pathfinder*, static draft measurements were taken on each side of the vessel while at dock prior to commencing survey operations. The two draft measurements (port and starboard) and the resulting draft value were recorded in the “Watchstander Log” as well as in a separate vessel Draft Log. During survey operations for OPR-J311-KR-18, *R/V Pathfinder* was being refueled at sea, by the *M/V Atlantic Surveyor*, every one to two days, and the vessel was being re-provisioned with food and water at every 12-hour crew rotation. Based on characteristics of the vessel and Leidos’ previous years of experience onboard the *R/V Pathfinder*, it was known that the change in the survey vessel draft was minimal over these short spans of time between refueling and re-provisioning. Therefore, a single static draft value was applied to all final MBES data, as it was not necessary to prorate the daily draft to account for fuel and water consumption.

Figure C-4 shows the draft determination for the *R/V Pathfinder*. The RESON 7125 SV2 transducer was pole-mounted through the bow deck moon pool and was located approximately 2.81 meters below the vessel’s main deck gunwale. To determine the draft, a 0.02 meter square metal bar was placed on the main deck gunwale so that it extended out far enough to allow a direct measurement to the water line. The distance from the top of the metal bar to the water surface was measured and subtracted from the transducer hull depth to determine the draft of the transducer's acoustic center.

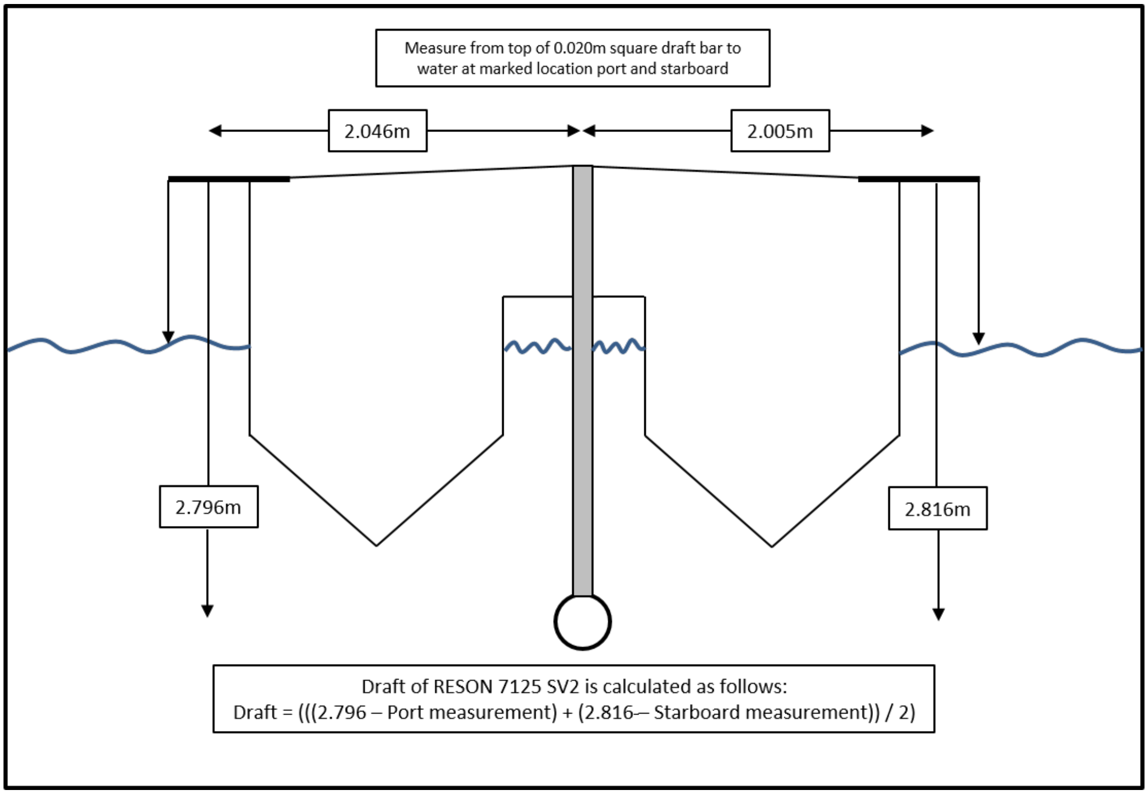

Figure C-4: *R/V Pathfinder* RESON 7125 SV2 Draft Determination

C.1.1.1 Prorated Static Draft

An initial processing step of the Leidos data processing pipeline is to apply, if necessary, prorated static draft values to all bathymetric data. This was done to account for the change in the survey vessel draft during consecutive survey days, primarily due to fuel and water consumption. For these survey operations, Leidos only implemented the prorated static draft procedure for MBES data collected by the *M/V Atlantic Surveyor*.

As mentioned in Section C.1.1, the static draft was measured and recorded both prior to departure for the survey site, and immediately upon arrival to port after each survey leg. These two observed static draft measurements for each survey leg were then used to calculate the amount of change in the vessel static draft (in meters) observed over that survey leg. For a given period of survey, the change in vessel static draft divided by the number of consecutive days of survey resulted in the amount of change in vessel static draft per day. This daily change in the static draft was then subtracted from the observed static draft value at the beginning of that specific period of survey. This resulted in a unique prorated static draft value for each consecutive survey day that was then applied in post processing to the data for that day. When the JD rollover occurred in the middle of a survey line, the first file of the new day was given the same prorated draft as the previous day. This procedure ensured that the static draft for every survey line was constant and did not cause a vertical jump in the survey depths.

This method was only used when continuous survey operations were conducted between the static draft measurements observed immediately prior to departure and immediately upon arrival to port. It assumed a constant amount of fuel and onboard water was consumed per day of continuous survey operations, thereby providing the ability to calculate a constant rate of change in the survey vessel draft per day.

The **Apply Correctors Offsets** tool within **SABER** was used to apply the calculated prorated draft value to multibeam GSF files as appropriate. This process of applying a new prorated draft offset to the multibeam data was captured within the history record of each multibeam GSF file.

Once prorated static draft had been applied to the multibeam data, the **Apply Correctors Offsets** tool within **SABER** was then used to report all the current offsets applied to the data within the multibeam GSF files. This was done to ensure the expected prorated static draft values were correctly applied to all multibeam data.

The observed and prorated static draft for each survey is included with the survey data in Separates I of each sheet’s DR. The static draft applied to each individual GSF file is reported in the “Multibeam Processing Log” for each sheet.

C.1.2 Dynamic Draft

Dynamic draft values were confirmed during the Sea Acceptance Tests (SAT) performed for each survey vessel. The methods used to determine, evaluate, and apply dynamic draft corrections to the collected MBES data are discussed in detail within Appendix I Section III.

C.1.3 Speed of Sound

A MVP30, originally manufactured by Brooke Ocean and now a part of AML Oceanographic, along with a suite of AML Oceanographic MVPX, Sound Velocity (SV), Pressure (P), and Temperature (T) Xchange sensors, was used to determine sound speed profiles for corrections to multibeam sonar soundings.

Confidence checks were obtained periodically (approximately every two to three weeks) with two or more consecutive sound speed profile (SSP) casts acquired with different SSP sensors. After downloading the SSP comparison casts, graphs, and tabulated lists were used to compare the corresponding SSP data.

During multibeam acquisition, SSP casts were uploaded to **ISS-2000** immediately after they were taken. In **ISS-2000**, the profiles were reviewed for quality, edited as necessary, compared to the preceding casts, and then applied (loaded into the multibeam system for use).

Once applied, the multibeam system used the SSP data for depth calculation and ray tracing corrections to the multibeam data. If sounding depths exceeded the cast depth, the **ISS-2000** used the deepest sound speed value of the profile to extend the profile to the maximum depth.

Factors considered in determining how often a SSP cast was needed included shape and proximity of the coastline, sources and proximity of freshwater, seasonal changes, wind, sea state, water depth, observed changes from the previous profiles, and differences in the surface sound speed of the current profile compared to a separate surface sound speed sensor collocated with the multibeam sonar. At a minimum, SSP casts were taken just prior to commencing data acquisition, at approximately two-hour intervals during data acquisition, and immediately following data acquisition.

Quality control tools in **ISS-2000**, including real-time displays of color-coded coverage and a multibeam swath waterfall display, were used to monitor how the sound speed affected the multibeam data. By using these techniques any severe effects due to sound speed profiling could be observed and corrected during real-time data acquisition. Proper sound speed application and effects were also analyzed throughout the survey during post processing.

Concatenated SSP data that has been formatted for use in CARIS are delivered in a separate folder on the delivery drive; “HXXXXX/Processed/SVP/CARIS_SSP”. The CARIS SSP files (.svp) were named based on the designated purpose of the individual SSP casts contained within each of the concatenated files. The purposes were:

- Used for Final Surfaces
- Used for Comparison
- Used for Lead Line
- Used for Closing

For the NCEI sound speed data submission, SSP casts were imported into the **Pydro Explorer Sound Speed Manager** utility. All individual sound speed profile files were converted to the *.nc file extension and fields were populated with the project, survey, survey unit, and instrument. As with the CARIS SSP data, sound speed data files were broken out into four sub-folders, which correspond to the purpose of each cast. For QC, converted SSP files were reviewed in **Panoply**. The NCEI sound speed data will be submitted prior to the last sheet of the project.

C.2 MULTIBEAM CALIBRATIONS

A Sea Acceptance Test (SAT) was conducted independently for each survey vessel and sonar installation prior to the start of each vessel’s data acquisition on this project. For additional details and results on SAT operations conducted refer to Appendix II Section II.

SAT operations included at least, but were not limited to, the following:

- Ping timing test to verify that no timing errors existed within the survey system
- Multibeam patch test to determine bias values for roll, pitch, and heading
- Beam-by-beam analysis of the multibeam data performed with the **SABER ACCUTEST** program
- Small survey to analyze multibeam accuracies after the installations.

During the July – August 2018 SAT for the *M/V Atlantic Surveyor,* a running average was used in the dynamic draft determination. The 2018 SAT dynamic draft on the *R/V Pathfinder*, was the first to be done since major changes to the vessel were made, therefore a running average of historical settlement and squat values were not available. The settlement and squat determinations are referenced in Section C.1.2 of this Report and in accompanying Appendix I Section IV.

Navigation positioning, heading, heave, roll, and pitch were provided by the Applanix POS/MV 320 version 5, IMU36, Inertial Navigation. Resolution and accuracy of the systems are:

- Heave Resolution 1 cm, Accuracy greater of 5 cm or 5% of heave amplitude
- Roll Resolution 0.01º, Accuracy 0.02º
- Pitch Resolution 0.01º, Accuracy 0.02º

The Applanix *TrueHeave*™ option was used to record delayed heave for application in post processing (see Section B.1.1 for details of delayed heave and the application process).

C.2.1 Timing Test

Leidos has developed a timing test procedure to evaluate the entire survey acquisition system for any timing errors. These timing tests were conducted during the SAT performed for each survey vessel. These tests demonstrated that all RESON SeaBat (T50 and 7125 SV2) ping times collected by **ISS-2000,** as logged GSF data files, matched the corresponding ping trigger event recorded from the RESON sonar processor. This further demonstrated that the overall timing of the complete data acquisition system, as controlled from the POS/MV navigation system, the NTP server, and **ISS-2000**, was within acceptable accuracy thresholds. These procedures and the results are discussed in detail within Appendix II Section III.

C.2.2 Multibeam Bias Calibration (Alignment)

Leidos' Patch Test (Alignment) has been developed for the determination of system biases for roll, pitch, and heading (gyro). For each type of bias, multiple comparisons were made to assure the most accurate results. Data were also collected from the same lines after the biases were entered into the acquisition system to verify their accuracy. All alignment data files were processed in **SABER** using standard post processing procedures, such as removing noise and applying delayed heave prior to bias determination.

A roll bias results in a cross-track vertical and small horizontal displacement. The roll bias test compared the depths from two lines of MBES data collected on the same transect run in opposite directions over a relatively flat, smooth bottom. The lines were run in pairs, at least two times in reciprocal directions at the same speed for each pair. The **SABER Swath Alignment Tool** was then used to further analyze the data and compare the across track beams over the flat smooth bottom in order to determine a final roll bias value.

A pitch bias results in an along-track horizontal and small vertical displacement. The pitch bias test compared the depths from two lines of MBES data collected on the same transect run in opposite directions perpendicular to a smooth sloping bottom or over a distinct feature. The lines were run in pairs, at least two times in reciprocal directions at the same speed for each pair. The

SABER Swath Alignment Tool was then used to further analyze the data and compare the along track, near nadir beams over the bottom slope or distinct feature in order to determine a final pitch bias value.

A heading bias results in a cross-track horizontal displacement. The heading bias test compared the depths from two MBES lines collected on two separate transects run in opposite directions over a distinct feature or perpendicular to a slope. The two separate transects were spaced to achieve approximately 50% overlap in the MBES swath from each line. The lines were at least collected four times, running each line in opposite directions at same speed and then re-running each line in the reciprocal direction at the same speed. The **SABER Swath Alignment Tool** was then used to further analyze the data and compare the along track overlapping beams over the distinct feature or perpendicular to a slope to determine a final heading bias value.

Roll, pitch, and heading biases were determined on 05 August 2018 (JD 217) for the RESON SeaBat T50 installed on the *M/V Atlantic Surveyor* (Table C-3). These biases were again determined on 22 August 2018 (JD 234) after arrival to the Gulf of Mexico, which resulted in changes to the pitch and roll bias values (Table C-4). After the reinstallation of the RESON SeaBat T50, alignments were confirmed on 14 September 2018 (JD 257) (see Appendix II for details).

After bias values were determined and confirmed as final, they were entered into the **ISS-2000** configuration file used for data acquisition and applied in real-time to all bathymetry data acquired.

Table C-3: Multibeam Files Verifying Alignment Biases Calculated using the Swath Alignment Tool – 05 August 2018 RESON SeaBat T50 on the *M/V Atlantic Surveyor*

Component	Multibeam files (pairs)		Result
Pitch	asmba18217_105515.gsf	asmba18217_110544.gsf	+0.79°
Roll	asmba18217_105515.gsf	asmba18217_110544.gsf	+0.43°
Heading	asmba18217_122056.gsf	asmba18217_123558.gsf	+1.80°

Table C-4: Multibeam Files Verifying Alignment Biases Calculated using the Swath Alignment Tool – 22 August 2018 RESON SeaBat T50 on the *M/V Atlantic Surveyor*

Component	Multibeam files (pairs)		Result
Pitch	asmba18234_023747.gsf	asmba18234_025709.gsf	+1.08°
Roll	asmba18234_023747.gsf	asmba18234_025709.gsf	+0.47°
Heading	asmba18234_030724.gsf	asmba18234_032035.gsf	+1.80°

Roll, pitch, and heading biases were determined on 13 October 2018 (JD 286) for the RESON 7125 SV2 installed on the *R/V Pathfinder;* and confirmed on 27 October 2018 (JD 300) after adjustments were made to the pole mount (See Appendix II). The results are presented in Table C-5.

Table C-5: Multibeam Files Verifying Alignment Biases Calculated using the Swath Alignment Tool – 13 October 2018 RESON SeaBat 7125 SV2 on the *R/V Pathfinder*

Component	Multibeam files (pairs)		Result
Pitch	pfmba18286_154650.gsf	pfmba18286_155303.gsf	-1.64°
Roll	pfmba18286_153230.gsf	pfmba18286_153827.gsf	-0.75°
Heading	pfmba18286_162704.gsf	pfmba18286_163048.gsf	-2.06°

C.2.3 Multibeam Accuracy

Leidos has developed standard procedures as part of the SAT to confirm that the multibeam system accuracies meet all applicable specifications and quality standards. Examples of these procedures conducted during each SAT include the **SABER ACCUTEST**, as well as the performance of a mini survey.

The **SABER ACCUTEST** procedure performs a detailed beam-to-beam analysis of the multibeam data. For this test, two orthogonal survey lines were established and each line was run at the same speed multiple times in each direction. A CUBE PFM grid of the ±10 degrees near-nadir beams was generated. Every beam across the entire swath of each ping was compared to the referenced CUBE Depth surface created with the near nadir beams. The results are presented in the Appendix II Section IV of this Report.

The mini survey procedure mirrors the efforts that would be conducted on a full scale survey project to provide an end to end test of all acquisition and data processing systems to demonstrate the system capability and functionality while operating in survey mode. Typically these mini surveys are performed over a feature and surrounding area. Following data acquisition, standard processing procedures are followed to evaluate the data against all applicable specifications and quality standards. The data processing routine followed the pipeline as detailed in the flow diagram within Appendix II Section V of this Report. The mini survey which was performed for each vessel on this project results are presented in Appendix II Section IV of this Report. All results showed that the systems met the accuracy and uncertainty standards stated in Section 5.1.3 of the HSSD.

C.3 TIDES AND WATER LEVELS

The PMVD separation model was the source of final water level corrections for OPR-J311-KR-18, which reduced the MBES sounding data to MLLW through ERS procedures as documented in Section B.1.3.

D. APPROVAL SHEET

As Chief of Party, field operations for this hydrographic survey were conducted under my direct supervision, with frequent personal checks of progress and adequacy. This Report and accompanying deliverable data items have been closely reviewed and are considered complete and adequate as per the Statement of Work.

This Report and all accompanying records and data are approved. All records are forwarded for final review and processing to the Processing Branch.

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

Reports concurrently submitted to NOAA for this project include:

Report Name	**Report Date Sent**
H13133_DR.pdf	2019-01-22

Approver Name	Approver Title	Approval Date	Signature
Paul L. Donaldson	Chief Hydrographer	01/22/2019	Paul L. Donaldson Digitally signed by Paul L. Donaldson Date: 2019.01.18 21:33:19 -05'00'