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National Oceanic and Atmospheric Administration
National Ocean Service

Data Acquisition & Processing Report

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Time Frame: May - September 2023

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State(s): American Samoa

General Locality: American Samoa and the U.S. Pacific Remote Island Area (PRIA)

2023

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Date:

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Data Acquisition and Processing Report

NOAA Ship *Rainier*
 Chief of Party: Héctor L. Casanova, CAPT/NOAA
 Year: 2023
 Version: 1.0
 Publish Date: 2023-07-27

A. System Equipment and Software

A.1 Survey Vessels

A.1.1 NOAA Ship Rainier (WTEF)

| | | |
|--|------------------------------|--|
| <i>Vessel Name</i> | NOAA Ship Rainier (WTEF) | |
| <i>Hull Number</i> | S221 | |
| <i>Description</i> | Steel hull hydrographic ship | |
| <i>Dimensions</i> | <i>LOA</i> | 70.4 meters |
| | <i>Beam</i> | 12.8 meters |
| | <i>Max Draft</i> | 4.7 meters |
| <i>Most Recent Full Static Survey</i> | <i>Date</i> | 2014-04-20 |
| | <i>Performed By</i> | The IMTEC Group, Ltd. |
| <i>Most Recent Partial Static Survey</i> | <i>Date</i> | 2022-12-21 |
| | <i>Performed By</i> | The IMTEC Group, Ltd. |
| <i>Most Recent Partial Offset Verification</i> | <i>Date</i> | 2023-05-31 |
| | <i>Method</i> | Verification measurements were conducted using steel tapes, steel rulers, fiberglass long tape, laser range finders, carpenter levels, optical levels, plum-bobs, and carpenter squares. |



Figure 1: NOAA Ship RAINIER working off of American Samoa.

A.1.2 RA4 (WZ2574)

| | | |
|---------------------------------------|------------------------------------|---|
| <i>Vessel Name</i> | RA4 (WZ2574) | |
| <i>Hull Number</i> | 2801 | |
| <i>Description</i> | Aluminum hull Jensen survey launch | |
| <i>Dimensions</i> | <i>LOA</i> | 8.8 meters |
| | <i>Beam</i> | 3.7 meters |
| | <i>Max Draft</i> | 1.1 meters |
| <i>Most Recent Full Static Survey</i> | <i>Date</i> | 2008-03-31 |
| | <i>Performed By</i> | NOAA, National Ocean Service, National Geodetic Survey, Geodetic Services Division Instrumentation & Methodologies Branch |

| | | |
|--|---------------|---|
| <i>Most Recent Partial Offset Verification</i> | <i>Date</i> | 2023-03-01 |
| | <i>Method</i> | Spot check verification measurements were conducted using steel tapes, laser range finders, bubble levels, plum-bobs, and collapsible rulers. Measurements concentrated verification between the POS MV antennae and IMU in addition to adjacent launch benchmarks. |



Figure 2: Rainier survey launch RA4 underway for survey operations in Pago Pago Bay, Tutuila; the main island of American Samoa.

A.1.3 RA5 (WZ2575)

| | | |
|---------------------------------------|------------------------------------|---|
| <i>Vessel Name</i> | RA5 (WZ2575) | |
| <i>Hull Number</i> | 2802 | |
| <i>Description</i> | Aluminum hull Jensen survey launch | |
| <i>Dimensions</i> | <i>LOA</i> | 8.8 meters |
| | <i>Beam</i> | 3.7 meters |
| | <i>Max Draft</i> | 1.1 meters |
| <i>Most Recent Full Static Survey</i> | <i>Date</i> | 2008-03-31 |
| | <i>Performed By</i> | NOAA, National Ocean Service, National Geodetic Survey, Geodetic Services Division Instrumentation & Methodologies Branch |

| | | |
|--|---------------|---|
| <i>Most Recent Partial Offset Verification</i> | <i>Date</i> | 2023-03-01 |
| | <i>Method</i> | Spot check verification measurements were conducted using steel tapes, laser range finders, bubble levels, plum-bobs, and collapsible rulers. Measurements concentrated verification between the POS MV antennae and IMU in addition to adjacent launch benchmarks. |



Figure 3: Rainier survey launch RA5 underway near Baker Island in the the U.S. Pacific Remote Island Area.

A.2 Echo Sounding Equipment

A.2.1 Multibeam Echosounders

A.2.1.1 Kongsberg Maritime AS EM2040 (07 version)

The Kongsberg EM2040-07 consists of four units, a transmit transducer, a receive transducer, a processing unit, and a workstation. The EM2040 system includes a 0.7 degree receiver and an option of two different transmitters: 0.4 and 0.7 degrees are available. The "07" version of the system in use on all Rainier launches

features the transmitter of 0.7 degrees. With roll, pitch and yaw stabilization, the transmit fan is divided into three sectors pinging simultaneously at separate frequencies. The system utilizes nearfield focusing on both transmit and receive. Water column logging is also supported.

The EM2040 has a frequency range of 200-400 kHz. The single transmitter configuration has three standard modes. The 300 kHz mode (max depth 465 meters, max coverage 640 meters) is used for normal operation, giving an optimum balance between high resolution, depth capability and tolerance of detrimental factors such as water column sediments. The 200 kHz mode (max depth 600 meters, max coverage 880 meters) has the best maximum depth capability. The 400 kHz mode (max depth 300 meters, max coverage 385 meters) provides the finest resolution in shallower depths for detailed inspection of features such as wrecks.

Just prior sailing for the 2023 field season, Rainier's one year old Kongsberg hydrographic work station (HWS) used by the ousted EM710 was used to replace the vintage 6-year old HWS in launch 2801. Launch 2802 retained her old HWS as no newer replacement was available.

| | | | | | | |
|---------------------|-----------------------|-----------------------|----------------|-----------------|---------------|---------------|
| <i>Manufacturer</i> | Kongsberg Maritime AS | | | | | |
| <i>Model</i> | EM2040 (07 version) | | | | | |
| <i>Inventory</i> | 2801 | <i>Component</i> | HWS | Processing unit | TX transducer | RX transducer |
| | | <i>Model Number</i> | MC330 SIS5 Std | 2U | EM2040-07 | EM2040-07 |
| | | <i>Serial Number</i> | 1115 | 40125 | 244 | 367 |
| | | <i>Frequency</i> | N/A | 200-400 kHz | 200-400 kHz | 200-400 kHz |
| | | <i>Calibration</i> | 2023-03-04 | 2023-03-04 | 2023-03-04 | 2023-03-04 |
| | | <i>Accuracy Check</i> | 2023-03-05 | 2023-03-05 | 2023-03-05 | 2023-03-05 |
| | 2802 | <i>Component</i> | HWS | Processing unit | TX transducer | RX transducer |
| | | <i>Model Number</i> | MP 5810 Std | 2U | EM2040-07 | EM2040-07 |
| | | <i>Serial Number</i> | 1103 | 40129 | 262 | 373 |
| | | <i>Frequency</i> | N/A | 200-400 kHz | 200-400 kHz | 200-400 kHz |
| | | <i>Calibration</i> | 2023-03-04 | 2023-03-04 | 2023-03-04 | 2023-03-04 |
| | | <i>Accuracy Check</i> | 2023-03-05 | 2023-03-05 | 2023-03-05 | 2023-03-05 |



Figure 4: The Kongsberg EM2040-07 TX & RX transducers as mounted on one of Rainier's hydrographic survey launches.

A.2.1.2 Kongsberg Maritime AS EM 2040 MKII (04 version)

The Kongsberg EM2040-4 MKII consists of four units, a transmit transducer, a receive transducer, a processing unit, and a hydrographic workstation. The EM2040 system includes a 1.0 degree receiver (at 300 kHz) and an option of two different transmitters: the "04" version offers 0.5 degrees at 300 kHz while the "07" version offers 1.0 degrees at 300 kHz. At its highest settings the "04" version of the system mounted on Rainier features a beamwidth of 0.4 degrees on the transmit and 0.7 degrees on the receive when in 400 kHz mode. Roll is stabilized up to $\pm 15^\circ$ while pitch and yaw are stabilized up to $\pm 10^\circ$. Water column logging is also supported.

The EM2040-4 MKII has a frequency range of 200-400 kHz. The single transmitter configuration has three standard modes. The 300 kHz mode (max depth 465 meters, max coverage 640 meters) is used for normal operation, giving an optimum balance between high resolution, depth capability and tolerance of detrimental factors such as water column sediments. The 200 kHz mode (max depth 600 meters, max coverage 880 meters) has the best maximum depth capability. The 400 kHz mode (max depth 300 meters, max coverage 385 meters) provides the finest resolution in shallower depths for detailed inspection of features such as wrecks.

| | | | | | | |
|---------------------|---------------------------|-----------------------|---------------|---------------|-----------------|---------------------------|
| <i>Manufacturer</i> | Kongsberg Maritime AS | | | | | |
| <i>Model</i> | EM 2040 MKII (04 version) | | | | | |
| <i>Inventory</i> | S221 | <i>Component</i> | TX transducer | RX transducer | Processing Unit | Hydrographic Work Station |
| | | <i>Model Number</i> | EM2040-04 | EM2040-04 | unknown | unknown |
| | | <i>Serial Number</i> | 275 | 2210 | 40281 | 1162 |
| | | <i>Frequency</i> | 200-400 kHz | 200-400 kHz | 200-400 kHz | n/a |
| | | <i>Calibration</i> | 2023-02-22 | 2023-02-22 | 2023-02-22 | 2023-02-22 |
| | | <i>Accuracy Check</i> | 2023-02-23 | 2023-02-23 | 2023-02-23 | 2023-02-23 |



Figure 5: The "hammerhead" gondola built to house the EM304 and EM2040 transducers being prepped for installation on Rainier.



Figure 6: The Kongsberg EM2040-4 MKII TX and RX transducers as mounted in Rainier's sonar gondola.

A.2.1.3 Kongsberg Maritime AS EM 304 MKII

The Kongsberg EM 304 MKII is a 20-32 kHz multibeam echo sounder that supports simultaneous collection of multibeam, backscatter, and water column data. This echo sounder has a depth range of 10 meters to full ocean depth. With a maximum swath width of 140°, a coverage swath of 7700m is obtainable in 1400m depths and a coverage swath of 12400m may be had in 6000m depths. The transmit fan is divided into up to 16 individual sectors in dual swath mode. This allows for control of the transmit fan, enabling real time active stabilization up to $\pm 10^\circ$ to correct for any yaw and pitch movement of the vessel. Roll stabilization up to $\pm 15^\circ$ is applied on the receiving beams. A dual swath mode which generates two individual “pings” with a small difference in tilt between them results in higher sounding density in the alongtrack direction.

The Kongsberg EM 304 MKII system consists of transducers, a transmitter unit, a receiver unit, a processing unit, and a hydrographic work station. The EM 304 MKII uses separate transducer arrays for transmitting and receiving sound pulses. Rainier’s two transducer arrays are mounted in a “T” shaped Mills Cross configuration inside a hammerhead shaped gondola. The receiver transducer array is located in the “hammer” section of the gondola and aligned 90 degrees to the keel. The transmit transducer array trails behind the receiver transducer array and is aligned parallel to the keel. The EM 304 MKII is a modular system with variable numbers of individual transducer modules assembled into receiver and transmit arrays in mounting frames. The actual number of modules chosen determines the number of beams per ping in

addition to the size in degrees of each individual beam. Rainier's system contains 12 modules in the transmit array and 8 modules in the receiver array which results in a system with 1600 beams per ping (0.6° and 0.9° RX).

The EM 304 MKII transmitter unit contains all of the transmit electronics, like control processors, power amplifiers, power supply, capacitor battery and Ethernet interface. The EM 304 MKII receiver unit contains all the receive electronics, like control processor, amplifiers, analog-to-digital converters, power supply and Ethernet interface. Both units use twisted pair Ethernet cables for data communication with the processing unit. Each unit is enclosed in individual vibration dampened, wall-mounted steel cabinets in an enclosed, air conditioned sonar room one deck below the plot room.

The EM 304 MKII processing unit is located in a computer rack in the plot room and process the signals to and from the transmitter and receiver units. The processing unit performs the receiver beamforming, bottom detection, and motion and sound speed corrections. It contains all interfaces for time-critical external sensors such as vessel attitude (roll, pitch, heading and heave), vessel position and external clock. The processing unit controls the transmitter and receiver units via Ethernet communication, and is also interfaced to the hydrographic work station via Ethernet. A 48V output from the processing unit is used for remote on/off control of the transmitter and receiver units.

The hydrographic work station is the operator station of the EM 304 MKII and located in a computer rack in the plot room. It is a dedicated Microsoft Windows computer running only the factory installed Kongsberg Seafloor Information System (SIS) program and necessary related software. SIS is the software and user interface used for real time monitoring and control of the EM 304. All necessary sensor interfaces, data displays for quality control and sensor calibration, seabed visualization, and data logging are available in user configurable windows.

| | | | | | | |
|---------------------|-----------------------|-----------------------|-------------|------------|-----------------|--------------------------|
| <i>Manufacturer</i> | Kongsberg Maritime AS | | | | | |
| <i>Model</i> | EM 304 MKII | | | | | |
| <i>Inventory</i> | S221 | <i>Component</i> | Transmitter | Receiver | Processing Unit | Hydrographic Workstation |
| | | <i>Model Number</i> | 489042 | 426615 | unknown | unknown |
| | | <i>Serial Number</i> | 101 | 122 | 11006 | 1166 |
| | | <i>Frequency</i> | 20-32 kHz | 20-32 kHz | 20-32 kHz | n/a |
| | | <i>Calibration</i> | 2023-02-20 | 2023-02-20 | 2023-02-20 | 2023-02-20 |
| | | <i>Accuracy Check</i> | 2023-02-21 | 2023-02-21 | 2023-02-21 | 2023-02-21 |



Figure 7: The Kongsberg EM 304 MKII TX and RX transducers as mounted in Rainier's sonar gondola.

A.2.2 Single Beam Echosounders

No single beam echosounders were utilized for data acquisition.

A.2.3 Side Scan Sonars

No side scan sonars were utilized for data acquisition.

A.2.4 Phase Measuring Bathymetric Sonars

No phase measuring bathymetric sonars were utilized for data acquisition.

A.2.5 Other Echosounders

No additional echosounders were utilized for data acquisition.

A.3 Manual Sounding Equipment

A.3.1 Diver Depth Gauges

No diver depth gauges were utilized for data acquisition.

A.3.2 Lead Lines

No lead lines were utilized for data acquisition.

A.3.3 Sounding Poles

No sounding poles were utilized for data acquisition.

A.3.4 Other Manual Sounding Equipment

No additional manual sounding equipment was utilized for data acquisition.

A.4 Horizontal and Vertical Control Equipment

A.4.1 Base Station Equipment

No base station equipment was utilized for data acquisition.

A.4.2 Rover Equipment

No rover equipment was utilized for data acquisition.

A.4.3 Water Level Gauges

A.4.3.1 AXYS Technologies Inc. Hydrolevel Mini

The NOAA tide buoy is a wave-following, tilt-compensated GPS buoy system intended to obtain water level measurements away from shore. The tide buoy system offers the advantage of being a highly mobile system that is quick and easy to install as opposed to a traditional shore station that requires a large investment in terms of time and manpower to stage and install the gauge, tide staff, and benchmarks. For project OPR-T382-RA-23 Rainier has been given the task of deploying the tide buoy for 90-days in one of the following three locations; 1) Howland Island and Baker Island, 2) Swains Island and Rose Atoll, or 3) 2014 VDatum Assessment Station Locations at American Samoa. Rainier ultimately decided on option 3 and deployed the tide buoy near Ofu Island, an outlying island in the American Samoa archipelago.

The NOAA tide buoy is the wave-following spherical buoy design “Hydrolevel Mini” from AXYS Technologies Inc. The stainless steel hull measures 0.6 m (25.5 in.) in diameter and under full battery payload weights approximately 156 lb (71 kg). A GPS antenna, navigation light, and Iridium antenna are surface-mounted on the buoy exterior. Power for up to 20 days is provided by two 12 V/ 60 Ah rechargeable Lithium-Iron-Phosphate (LiFePO₄) battery packs. For longer deployments an additional 30 days can be gained by adding a 60 non-rechargeable, 3.6-V / 19-Ah lithium thionyl chloride (Li-SOCl₂) batteries.

The instrument package of the NOAA tide buoy consists of an Ashtech MB100 L1/L2 receiver and a LORD Corp. MicroStrain 3DM-GX1 heading, roll & pitch sensor. The 3DM-GX1 combines a set of three orthogonal angular rate gyros and DC accelerometers & magnetometers to produce the motion measurement. An AXYS Watchman 500 on-board computer records dual-frequency (L1/L2) all-in-view GPS code and carrier Observations from the GPS receiver and attitude data motion sensor to a Compact Flash storage drive. Periodic datagrams are sent out via Iridium satellite.

The Watchman 500 logging computer saves three different types of data, a *.txt file of periodic system health datagrams, “Tilt” files from the MicroStrain tilt sensor, and “Output” containing raw binary GPS data. The raw GPS files are renamed, sorted, and converted to RINEX. The time-binned GPS session files are then imported into Applanix POS GNSS, a GPS post-processing program contained in the POSpac Mobile Mapping Suit.

The output of GPS post-processing is a time series of instantaneous antenna reference point (ARP) ellipsoid heights. Since wave action lowers the buoy antenna relative to its nominal upright height from the waterline, tilt data are used to apply a correction to the ARP height time series. This correction results in a time series of instantaneous water-level ellipsoidal heights.

| | | |
|---------------------|------------------------|-----------|
| <i>Manufacturer</i> | AXYS Technologies Inc. | |
| <i>Model</i> | Hydrolevel Mini | |
| <i>Inventory</i> | <i>Component</i> | Tide buoy |
| | <i>Model Number</i> | TRIAXYS |
| | <i>Serial Number</i> | TMB00230 |
| | <i>Calibration</i> | N/A |



Figure 8: The Hydrolevel Mini GPS buoy system deployed off Ofu Island in American Samoa.

A.4.4 Levels

No levels were utilized for data acquisition.

A.4.5 Other Horizontal and Vertical Control Equipment

No other equipment were utilized for data acquisition.

A.5 Positioning and Attitude Equipment

A.5.1 Positioning and Attitude Systems

A.5.1.1 Applanix POS MV 320 V5

Rainier and all of her launches are outfitted with the Applanix POS MV 320 version 5. The POS MV version 5 offers a number of key new features including:

- Full GNSS support, by using all available GPS and GLONASS satellites.
- Improved Real Time Kinematic (RTK) performance over long baselines using the most advanced Trimble algorithms.
- Removable USB media slot, providing convenient, portable and robust logging of GNSS and inertial observables for processing in POSpac MMS.

The POS MV is a GNSS-aided inertial navigation system, which provides a blended position solution derived from both an Inertial Motion Unit (IMU) and an integrated GNSS receiver. The IMU and GPS receiver are complementary sensors, and data from one are used to filter and constrain errors from the other. This inter-dependence results in higher position accuracy and fewer errors.

Position accuracy is displayed in real time by the POS MV software and is monitored to ensure that positioning accuracy requirements as outlined in the NOS Hydrographic Surveys Specifications and Deliverables (HSSD) were not exceeded. In addition, the POS MV software displays HDOP and the number of satellites used in position computation. Data acquisition is generally halted when an HDOP of 2.5 is exceeded or the number of satellites available drop below four. However, because positional accuracy can be maintained by the POS MV through short GPS outages with the help of the IMU, data acquisition is not halted during short periods of time when the HDOP and number of satellites used exceeded stated parameters.

In addition to position, the Applanix POS MV also provides accurate navigation and attitude data to correct for the effects of heave, pitch, roll and heading. When using differential correctors, the POS MV generates attitude data in three axes (roll, pitch and heading) to an accuracy of 0.02° or better. Heave measurements supplied by the POS MV maintain an accuracy of 5 cm or 5% of the measured vertical displacement (whichever is greater) for movements that have a period of up to 20 seconds. The Heave Bandwidth filter was configured with a damping coefficient of 0.707. The cutoff period of the high pass filter was determined by estimating the swell period encountered on the survey grounds. These values ranged from 8 seconds (flat

water) to 20 seconds (long period ocean swell), with values of 8 or 12 seconds typically. Currently the ship system is set to 20 seconds and the launches are set to 8 seconds.

Applanix “TrueHeave” values are also recorded. The TrueHeave algorithm uses a delayed filtering technique to eliminate many of the artifacts present in real time heave data. When using differential correctors, the POS MV generates heave measurements with an accuracy of 2 cm or 2% of the measured vertical displacement (whichever is greater) for movements that have a period of up to 35 seconds.

Heading accuracy is monitored by the hydrographer in real time. Persistent heading accuracy issues would prompt further investigation of primary and secondary received satellite observations, and heading calibration through GNSS Azimuth Measurement System (GAMS).

Raw GNSS observables are logged on Rainier and all of her survey launches, including navigation, primary GNSS data, IMU data, and other messages listed in section C.4. These data are used to post process POS MV data to produce superior position and attitude data and can be used to produce a Post-Processed Kinematic (PPK) GPS solution. When using PPK methods, the POS MV generates roll and pitch data with an accuracy of 0.008° and heading data with an accuracy of 0.02°. However, PPK attitude is not applied in post processing since this would overwrite timing offsets implemented in SIS Installation Parameters. Horizontal position is accurate to +/- 8 mm + 1 ppm x baseline length while vertical position is accurate to +/- 15 mm + 1 ppm x baseline length.

| | | | | |
|---------------------|---------------|----------------------|---------------|---------------|
| <i>Manufacturer</i> | Applanix | | | |
| <i>Model</i> | POS MV 320 V5 | | | |
| <i>Inventory</i> | S221 | <i>Component</i> | PCS | IMU |
| | | <i>Model Number</i> | POS MV 320 V5 | POS MV 320 V5 |
| | | <i>Serial Number</i> | 7273 | 353 |
| | | <i>Calibration</i> | 2023-02-22 | 2023-02-22 |
| | 2801 (RA4) | <i>Component</i> | PCS | IMU |
| | | <i>Model Number</i> | POS MV V5 | IMU 7 |
| | | <i>Serial Number</i> | 7264 | 4442 |
| | | <i>Calibration</i> | 2023-03-06 | 2023-03-06 |
| | 2802 (RA5) | <i>Component</i> | PCS | IMU |
| | | <i>Model Number</i> | POS MV V5 | IMU 7 |
| | | <i>Serial Number</i> | 7162 | 4446 |
| | | <i>Calibration</i> | 2023-03-06 | 2023-03-06 |

A.5.2 DGPS

DGPS equipment was not utilized for data acquisition.

A.5.3 GPS

Additional GPS equipment was not utilized for data acquisition.

A.5.4 Laser Rangefinders

A.5.4.1 Laser Technology Inc. Impulse 200 LR

The Impulse 200 LR (long range) is a hand-held, light weight laser ranging instrument which includes onboard calculation ability for height, horizontal, and vertical distance. The typical max range to a non-reflective target is 500 meter (1,640 foot) with range accuracy of 3-5 centimeters. Two AA batteries supply up to 20 hours of use. Aiming is simplified with a 1X red-dot scope. In addition to measuring the distance to shoreline features, this instrument is also used to measure the waterline of Rainier.

| | | | |
|---------------------|-----------------------|----------------------|-----------------|
| <i>Manufacturer</i> | Laser Technology Inc. | | |
| <i>Model</i> | Impulse 200 LR | | |
| <i>Inventory</i> | N/A | <i>Component</i> | Hand-held laser |
| | | <i>Model Number</i> | 200LR |
| | | <i>Serial Number</i> | 108786 |
| | | <i>Calibration</i> | 2023-05-08 |

A.5.5 Other Positioning and Attitude Equipment

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

A.6 Sound Speed Equipment

A.6.1 Moving Vessel Profilers

A.6.1.1 AML Oceanographic MVP200 Moving Vessel Profiler (MVP)

Rainier is equipped with an AML Oceanographic MVP200 Moving Vessel Profiler (MVP). This system consists of a sensor fish, a conductor cable, a computer controlled high speed hydraulic winch, and a cable metering system. In the underway mode, the sensor fish is towed behind the ship and periodically is allowed to free-fall near vertical through the water column recording sound velocity profiles. This enables Rainier to take sound speed casts without stopping the ship. To take deeper SV casts and take full advantage of all the cable on the drum, the ship must come to a stop. While stationary, 600 meter deep sound speed casts may be collected as opposed to a maximum of 235 meters deep when the ship is in typical survey mode and underway at 10 knots.

The actual sensor package contained within the towfish is an Applied Microsystems Micro CTD. The unit consists of a 4-electrode conductivity sensor accurate to +/-0.01 mS/cm (milliSiemens/cm) with a resolution of 0.001 mS/cm, a temperature (precision aged thermistor) sensor accurate to +/-0.005° C with a resolution of 0.001° C, and a pressure (temperature compensated strain gauge) sensor accurate to +/-0.05% FS (full scale) with a resolution of 0.005% FS. The Micro CTD supplied with the MVP200 is rated at 1000-dBar.

In the past, the MVP200 experienced several failures of the Micro CTD caused by the unprotected conductivity sensor unit protruding from the side of the towfish being sheared off. The likely cause was determined to be loose floating kelp snagging on the delicate conductivity sensor and causing it to break off. In an effort to mitigate this issue, the manufacture was contacted and provided Rainier with stainless steel sensor guards similar to those found on the MVP30.

To start out the 2023 field season the dependability of the MVP200 has been erratic at best. Messenger detection errors often caused the MPV to pause casts, often in mid retrieval forcing manual intervention. Although some minor issues such as loose tape around the messenger were corrected no root cause has been found. Continued operation of the machinery seems to have improved the reliability and the unit is now in a somewhat trustworthy state. Rainier has also suffered the failure of two microCTDs and is now on her third. For the first failure (s/n 7510, DN078) the microCTD started producing SV values that were 10-20 m/s different from the surface SV readings. After retrieval from the water the microCTD was observed to be covered with slime, perhaps from a school of jellyfish. The second failure (s/n 7511, DN101) was characterized by extremely noisy live SV values, jumping back and forth several meters per second.

| | | | | | | |
|---------------------|-------------------------------------|----------------------|------------|------------|------------|------------|
| <i>Manufacturer</i> | AML Oceanographic | | | | | |
| <i>Model</i> | MVP200 Moving Vessel Profiler (MVP) | | | | | |
| <i>Inventory</i> | <i>S221 Rainier</i> | <i>Component</i> | CTD | CTD | CTD | CTD |
| | | <i>Model Number</i> | Micro CTD | Micro CTD | Micro CTD | Micro CTD |
| | | <i>Serial Number</i> | 7511 | 7510 | 8614 | 8565 |
| | | <i>Calibration</i> | 2023-01-24 | 2023-01-24 | 2018-12-13 | 2018-01-24 |

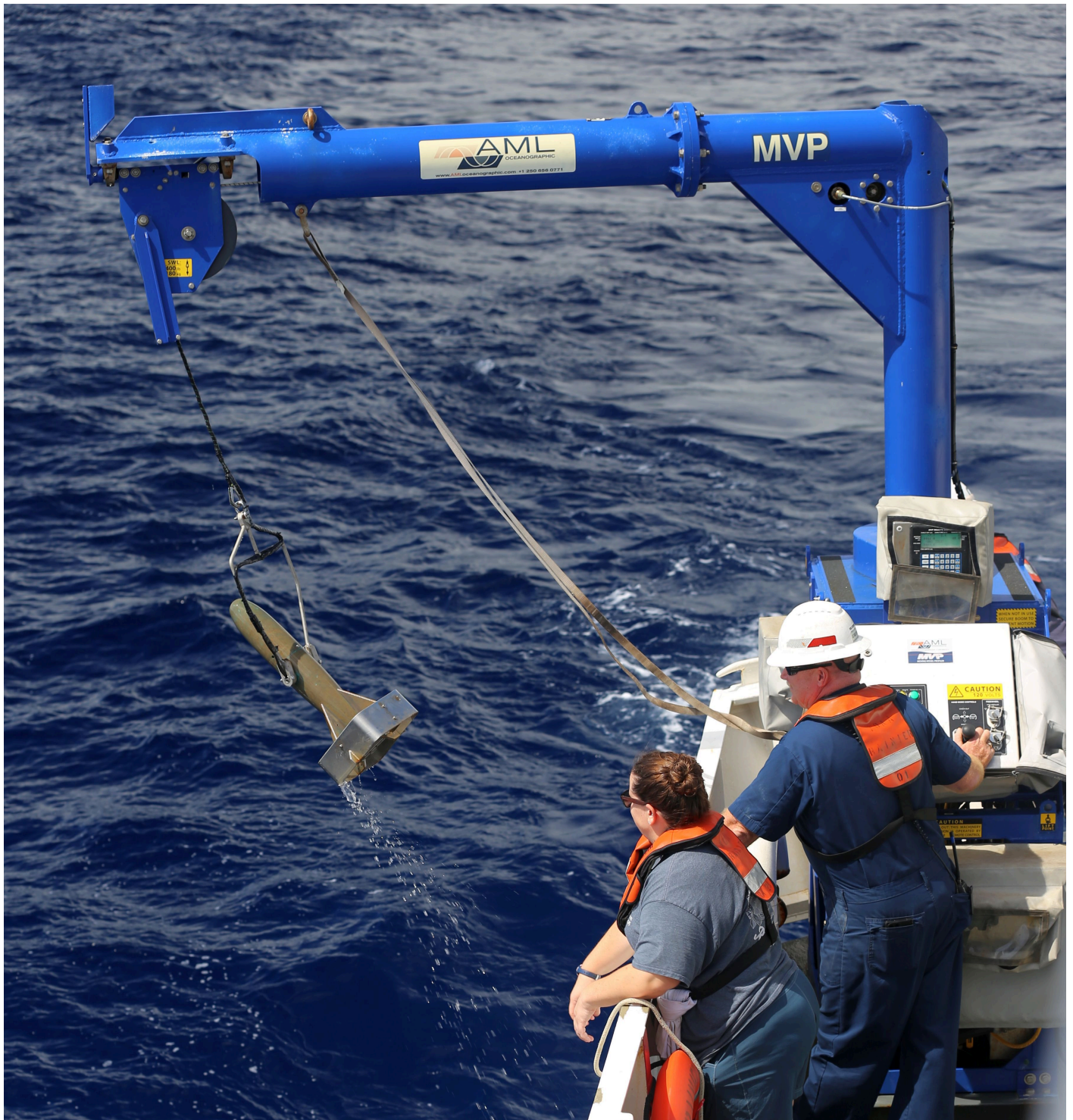


Figure 9: Retrieving the towfish of the MVP200

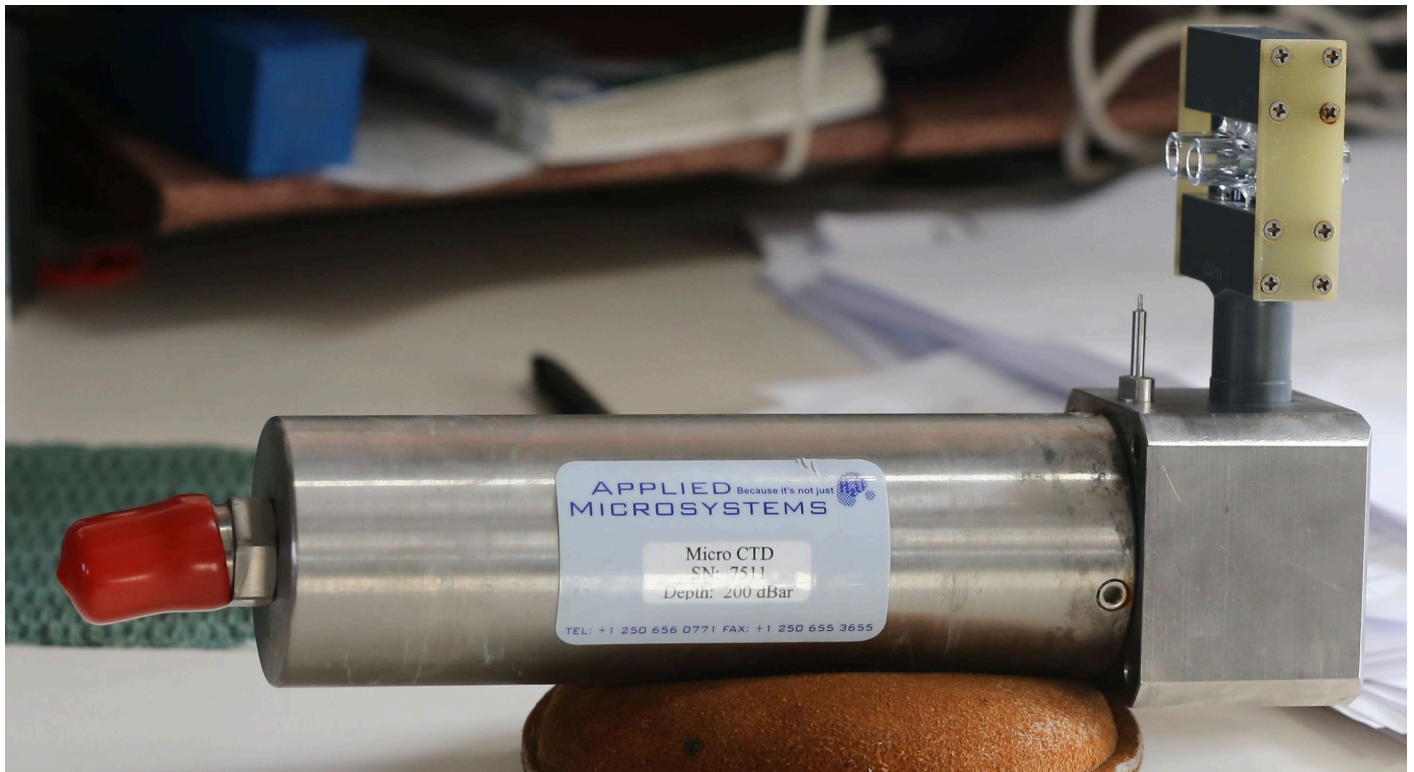


Figure 10: An Applied Microsystems Micro CTD

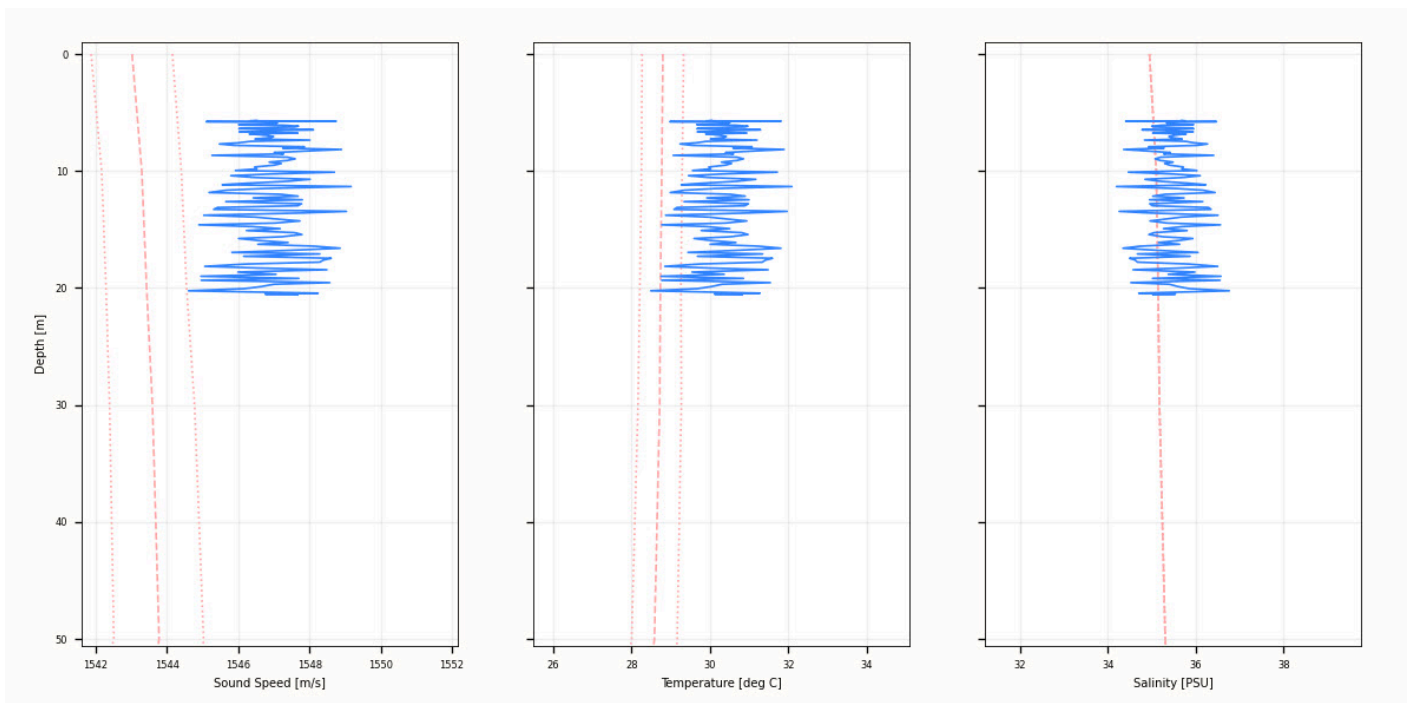


Figure 11: An example of erratic SV values seen during the failure of the second Micro CTD lost to Rainier this season due to electronic issues.

A.6.2 CTD Profilers

A.6.2.1 SEA-BIRD Electronics, INC SBE 19 SEACAT

The SEACAT SBE 19 profiler measures the electrical conductivity and temperature of seawater versus pressure. The aluminum housing allows for use in depths up to 3400 meters (11,150 feet). The sampling rate is set by command to the instrument with a maximum rate of 2 scans per second. Data are temporarily saved on an internal 64 Kbytes of solid-state memory which allows 1.5 hours of recording while sampling at two scans per second. The profiler is self-powered with 6 alkaline batteries which provide up to 48 hours of continuous operation.

The SEACAT embodies sensor elements (Pyrex cell and pressure-protected thermistor) and a Wein-bridge oscillator interface technique using multiplexing. This technique allows a single oscillator to service both temperature and conductivity measurements. The pressure sensor is a Senso-Metrics Series SP-91 strain-gauge sensor. Set-up, check-out, and data extraction are performed without opening the housing via an external computer connected to a bulkhead connector at the base of the profiler with a serial cable.

To ease quick identification of individual SEACAT profilers, Rainier affixed a uniquely colored band of electrical tape around the housing at the top of each profiler. When assigned to a field unit in the plan of the day, the SEACAT profiler is simply referred to by color such as “green” or “black”.

All Rainier launches (2801 and 2802) are equipped with 24-volt electric winches attached to small swing-arm davits to deploy and recover CTD profilers while the vessel is at rest.

| | | |
|---------------------|---------------------------|--------------|
| <i>Manufacturer</i> | SEA-BIRD Electronics, INC | |
| <i>Model</i> | SBE 19 SEACAT | |
| <i>Inventory</i> | <i>Component</i> | CTD |
| | <i>Model Number</i> | 19-02 |
| | <i>Serial Number</i> | 192472 -0281 |
| | <i>Calibration</i> | 2021-11-26 |



Figure 12: A SEA-BIRD SEACAT SBE 19 profiler.

A.6.2.2 SEA-BIRD Electronics, INC SBE 19plus SEACAT

The SBE 19plus SEACAT profiler is designed to measure conductivity, temperature, and pressure in marine or fresh-water environments. The plastic housing of the profiler is rated for depths up to 600 meters (1950 feet). The 19plus runs continuously, sampling at four scans per second (4 Hz). Nine D-size alkaline batteries provide 60 hours operation in profiling mode. Eight Mbytes of FLASH RAM records 50 hours of conductivity, temperature, and pressure data while sampling at four scans per second.

To ease quick identification of individual SEACAT profilers, Rainier affixed a uniquely colored band of electrical tape around the housing at the top of each profiler. When assigned to a field unit in the plan of the day, the SEACAT profiler is simply referred to by color such as “green” or “black”.

All Rainier launches (2801 and 2802) are equipped with 24-volt electric winches attached to small swing-arm davits to deploy and recover CTD profilers while the vessel is at rest.

| | | | | | | |
|---------------------|---------------------------|------------|------------|------------|------------|------------|
| <i>Manufacturer</i> | SEA-BIRD Electronics, INC | | | | | |
| <i>Model</i> | SBE 19plus SEACAT | | | | | |
| <i>Inventory</i> | <i>Component</i> | CTD | CTD | CTD | CTD | CTD |
| | <i>Model Number</i> | 19plus | 19plus | 19plus | 19plus | 19plus v2 |
| | <i>Serial Number</i> | 4039 | 4114 | 4306 | 4343 | 7530 |
| | <i>Calibration</i> | 2021-11-30 | 2021-11-26 | 2021-11-30 | 2021-11-26 | 2021-11-30 |



Figure 13: A SEA-BIRD SBE 19plus SEACAT profiler.

A.6.3 Sound Speed Sensors

A.6.3.1 Reson Inc. SVP 70

The SVP 70 is a direct reading sound velocity probe with a sound transmission path of 125mm. The unit's housing is constructed of robust titanium that eases cleaning in environments with high levels of marine growth and is recommended for permanent installations. The SVP 70 is used on all MBES launches (2801 and 2802) in addition to two on Rainier, one for each sonar system. Since Rainier can only service her SVP 70s during a dry dock, two sensors mounted simultaneously also allow for some redundancy in the event that one fails.

Aboard Rainier, these two sensors are mounted in close proximity to the ship's multibeam transducers and provide real time surface sound speed values for refraction corrections. Yearly calibrations of these SVP 70s are not performed since the instrument can only be removed from the ship during a dry dock. The relative health of these sound speed sensors are monitored whenever the ship is collecting MBES data by comparing live sound speed values to MVP, CTD and/or XBT casts whenever they occur to guarantee correct operation. Additionally, the two SVP 70s mounted in Rainier's gondola may be read simultaneously at any time to ensure that correct real time surface sound speed values are being produced.

Aboard MBES launches, the SVP 70 sensor is mounted in close proximity to each launches' multibeam transducers and provides real time surface sound speed values for refraction corrections.

| | | | | |
|---------------------|---------------------|----------------------|----------------------------|----------------------------|
| <i>Manufacturer</i> | Reson Inc. | | | |
| <i>Model</i> | SVP 70 | | | |
| <i>Inventory</i> | <i>S221 Rainier</i> | <i>Component</i> | Surface sound speed sensor | Surface sound speed sensor |
| | | <i>Model Number</i> | SVP 70 | SVP 70 |
| | | <i>Serial Number</i> | unknown | unknown |
| | | <i>Calibration</i> | N/A | N/A |
| | <i>2801</i> | <i>Component</i> | Surface sound speed sensor | |
| | | <i>Model Number</i> | SVP 70 | |
| | | <i>Serial Number</i> | 0217007 | |
| | | <i>Calibration</i> | 2020-01-30 | |
| | <i>2802</i> | <i>Component</i> | Surface sound speed sensor | |
| | | <i>Model Number</i> | SVP 70 | |
| | | <i>Serial Number</i> | 0614179 | |
| | | <i>Calibration</i> | 2021-03-10 | |
| | <i>spares</i> | <i>Component</i> | Surface sound speed sensor | Surface sound speed sensor |
| | | <i>Model Number</i> | SVP 70 | SVP 70 |
| | | <i>Serial Number</i> | 3417109 | 2817018 |
| | | <i>Calibration</i> | 2018-03-05 | 2018-03-01 |

A.6.4 TSG Sensors

No TSG sensors were utilized for data acquisition.

A.6.5 Other Sound Speed Equipment

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

A.7 Computer Software

| <i>Manufacturer</i> | <i>Software Name</i> | <i>Version</i> | <i>Use</i> |
|-----------------------------------|--|--|--|
| CARIS | HIPS and SIPS (x64) | 11.4.6 | Processing |
| CARIS | BASE Editor (x64) | 5.5.2 | Processing |
| Applanix | POSPac MMS | 8.9 (8.9.8440.17433) | Processing |
| QPS | FM Geocoder Toolbox (FMGT) | 7.10.2 | Processing |
| NOAA (HSTB) | Pydro_22 | 22.1 r10370 (auto update ON) | Processing |
| HYPACK, Inc. | Hypack 2022 | 22.3.4.0 | Acquisition |
| Kongsberg Maritime AS | SIS | 4.3.2 | Acquisition (launches) |
| Kongsberg Maritime AS | SIS | 5.11.1 build data 2022-11-11 | Acquisition (ship) |
| Applanix Corporation | MV-POSView | 10.5 | Acquisition (on launch 2802) |
| Applanix Corporation | MV-POSView | 11.21 | Acquisition (on ship & launch 2801) |
| AML Oceanographic Ltd. ODIM | MVP Controller | 2.48 | Acquisition |
| Lockheed Martin Sippican, Inc. | WinMK21 {control software for MK-21 Data Acquisition System (DAQ), XBT interface} | 7.8.0 | Acquisition |

A.8 Bottom Sampling Equipment

A.8.1 Bottom Samplers

No bottom sampling equipment was utilized for data acquisition.

B. System Alignment and Accuracy

B.1 Vessel Offsets and Layback

B.1.1 Vessel Offsets

EM2040 (launches)

During system integration, HSTB personnel chose the system reference point and reference frame to be centered on and aligned with the EM2040 transmit transducer. While this complicates configuration, it brings the POS MV into the multibeam reference frame. Having the positioning system and the multibeam system in the same reference system eliminates the need for different CARIS HIPS HVF entries depending upon the vertical-control workflow (e.g. ellipsoid vs water-level control).

Full static surveys were not conducted for Rainier's Jensen multibeam launches when the EM2040 multibeam systems replaced the previous outdated MBES systems in 2017. Due to the relatively short baselines between the multibeam transducers, the POS MV IMU, and the POS MV antennas, new offsets were determined by combining the previous NGS spatial relationship survey, the engineering drawings of the echo sounder mount, and a few additional field measurements.

As part of the field measurements, the bolt holes for the sonar transducer mounting plate were measured inside the hull relative to the IMU. With this measurement and the engineering drawing of the mount, the transducer offsets from the attachment hole was calculated. All transducers are mounted in a "forward" convention, with the transmitter cable on the port side, receiver cable output towards the bow.

The offsets between the EM2040 transmit transducer and the POS MV sensors (IMU and antennas) were entered into the POS MV. The patch test values (the residual misalignment between the multibeam and attitude sensor) were also entered into the POS MV IMU to Reference Frame field. SIS contains only the offsets between the transmit transducer and the receiver and the location of the waterline. The GAMS calibration was re-run after the POS MV reference frame was rotated with the patch test values to align the antenna baseline in the new frame.

Because the POS and Kongsberg frame are explicitly collocated and aligned upfront, the CARIS HIPS HVF is relatively simple. All fields contain all zeros with "apply = No" with the exception of the SVP, TPU, Waterline, and Dynamic Draft fields. SVP1 has all zeros, but SVP2 has the same offsets between the transmit transducer and receive transducer as is entered in SIS ($X=-0.305$, $Y=-0.100$, $Z=-0.016$). The waterline is the same as the entry is in SIS with "apply = No."

EM 304 & EM2040 (ship)

During the 2022-2023 winter dry-dock Rainier had her Kongsberg EM710 system removed and replaced by two new systems, a Kongsberg EM2040 for relatively shallow waters and an EM304 for mid to deep waters. As part of the new installation a static vessel offset survey conducted by IMTEC in November and December of 2022. Representatives the Hydrographic Systems and Technology Branch (HSTB) transformed these static vessel offset values into an IMU centered and IMU-aligned frame.

During systems acceptance testing for the ship off of Hawaii in late February measured sonar linear were put into TX1 and RX1 of the SIS installation parameters. Additionally, Caris HVFs were created (one for each sonar system). Transmit transducer xyz offsets were entered under SVP1 and receive transducer offsets were entered into SVP2. Both transmit and receive transducer offsets were also entered in the TPU values (Offsets) of the HVF. The waterline value was set as 0.0 since the IMU is located close to the water line.

B.1.1.1 Vessel Offset Correctors

| | | | | |
|--------------------|--------------------------|--------------|--------------------|--------------------|
| <i>Vessel</i> | S221_EM304_2023 | | | |
| <i>Echosounder</i> | Kongsberg Simrad EM302 | | | |
| <i>Date</i> | 2023-02-01 | | | |
| <i>Offsets</i> | <i>MRU to Transducer</i> | | <i>Measurement</i> | <i>Uncertainty</i> |
| | | <i>x</i> | 1.718 meters | 0.020 meters |
| | | <i>y</i> | 4.459 meters | 0.020 meters |
| | | <i>z</i> | 4.712 meters | 0.020 meters |
| | | <i>x2</i> | 1.709 meters | N/A |
| | | <i>y2</i> | 7.845 meters | N/A |
| | | <i>z2</i> | 4.701 meters | N/A |
| | <i>Nav to Transducer</i> | <i>x</i> | 0.945 meters | 0.020 meters |
| | | <i>y</i> | 16.500 meters | 0.020 meters |
| | | <i>z</i> | 17.945 meters | 0.020 meters |
| | | <i>x2</i> | 0.936 meters | N/A |
| | | <i>y2</i> | 19.886 meters | N/A |
| | | <i>z2</i> | 17.934 meters | N/A |
| | <i>Transducer Roll</i> | <i>Roll</i> | -0.379 degrees | |
| | | <i>Roll2</i> | -0.315 degrees | |

| | | | | |
|--------------------|--|--------------|--------------------|--------------------|
| <i>Vessel</i> | S221_EM2040_2023 | | | |
| <i>Echosounder</i> | Kongsberg Simrad EM2040 300kHz 0.5x1_Normal Mode | | | |
| <i>Date</i> | 2023-02-01 | | | |
| <i>Offsets</i> | <i>MRU to Transducer</i> | | <i>Measurement</i> | <i>Uncertainty</i> |
| | | <i>x</i> | 0.659 meters | 0.020 meters |
| | | <i>y</i> | 6.912 meters | 0.020 meters |
| | | <i>z</i> | 4.708 meters | 0.020 meters |
| | | <i>x2</i> | 0.354 meters | N/A |
| | | <i>y2</i> | 6.911 meters | N/A |
| | | <i>z2</i> | 4.694 meters | N/A |
| | <i>Nav to Transducer</i> | <i>x</i> | -0.114 meters | 0.020 meters |
| | | <i>y</i> | 18.953 meters | 0.020 meters |
| | | <i>z</i> | 17.941 meters | 0.020 meters |
| | | <i>x2</i> | -0.419 meters | N/A |
| | | <i>y2</i> | 18.952 meters | N/A |
| | | <i>z2</i> | 17.927 meters | N/A |
| | <i>Transducer Roll</i> | <i>Roll</i> | -0.623 degrees | |
| | | <i>Roll2</i> | -0.623 degrees | |

| | | | | |
|--------------------|--|--------------|--------------------|--------------------|
| <i>Vessel</i> | 2801_EM2040 | | | |
| <i>Echosounder</i> | Kongsberg Simrad EM2040 300kHz 0.5x1_Normal Mode | | | |
| <i>Date</i> | 2021-03-19 | | | |
| <i>Offsets</i> | <i>MRU to Transducer</i> | | <i>Measurement</i> | <i>Uncertainty</i> |
| | | <i>x</i> | 0.203 meters | 0.010 meters |
| | | <i>y</i> | 0.136 meters | 0.010 meters |
| | | <i>z</i> | 0.535 meters | 0.010 meters |
| | | <i>x2</i> | -0.102 meters | N/A |
| | | <i>y2</i> | 0.036 meters | N/A |
| | | <i>z2</i> | 0.519 meters | N/A |
| | <i>Nav to Transducer</i> | <i>x</i> | 0.203 meters | 0.010 meters |
| | | <i>y</i> | 0.136 meters | 0.010 meters |
| | | <i>z</i> | 0.535 meters | 0.010 meters |
| | | <i>x2</i> | -0.102 meters | N/A |
| | | <i>y2</i> | 0.036 meters | N/A |
| | | <i>z2</i> | 0.519 meters | N/A |
| | <i>Transducer Roll</i> | <i>Roll</i> | 0.000 degrees | |
| | | <i>Roll2</i> | 0.000 degrees | |

| | | | | |
|--------------------|--|--------------|--------------------|--------------------|
| <i>Vessel</i> | 2802_EM2040 | | | |
| <i>Echosounder</i> | Kongsberg Simrad EM2040 300kHz 0.5x1_Normal Mode | | | |
| <i>Date</i> | 2023-03-15 | | | |
| <i>Offsets</i> | <i>MRU to Transducer</i> | | <i>Measurement</i> | <i>Uncertainty</i> |
| | | <i>x</i> | 0.193 meters | 0.010 meters |
| | | <i>y</i> | 0.137 meters | 0.010 meters |
| | | <i>z</i> | 0.537 meters | 0.010 meters |
| | | <i>x2</i> | -0.112 meters | N/A |
| | | <i>y2</i> | 0.037 meters | N/A |
| | | <i>z2</i> | 0.521 meters | N/A |
| | <i>Nav to Transducer</i> | <i>x</i> | 0.193 meters | 0.010 meters |
| | | <i>y</i> | 0.137 meters | 0.010 meters |
| | | <i>z</i> | 0.537 meters | 0.010 meters |
| | | <i>x2</i> | -0.112 meters | N/A |
| | | <i>y2</i> | 0.037 meters | N/A |
| | | <i>z2</i> | 0.521 meters | N/A |
| | <i>Transducer Roll</i> | <i>Roll</i> | 0.000 degrees | |
| | | <i>Roll2</i> | 0.000 degrees | |

B.1.2 Layback

No towfish data were collected for the 2023 field season.

Layback correctors were not applied.

B.2 Static and Dynamic Draft

B.2.1 Static Draft

All Rainier survey launches were constructed with integrated benchmarks that were later surveyed by the National Geodetic Survey, Geodetic Services Division Instrumentation & Methodologies Branch. For all launches two of these benchmarks are located on the outboard deck, both port and starboard, close to in-line with the IMU.

Historically the static draft values for all Rainier survey launches have been determined using the two benchmarks located on the port and starboard outboard deck. A carpenter's level is placed on these benchmarks and held level to the deck while either a steel tape or laser rangefinder is used to measure

directly to the surface of the water. At the same time the launch is kept level by observing the POS MV output and shifting personnel in the launch as required. Five measurements are taken for each benchmark. Both the port and starboard measurements differenced from the corresponding NGS benchmark to produce an individual waterline value for each launch.

Due to the late return of the launches after winter repairs, waterline measurements were not conducted prior to *Rainier*'s departure from her California drydock period. Windy weather in Hawaii also prevented waterline measurements while the launches were moored at the small boat pier in Pearl Harbor. A measurement to the "scum line" was collected in California while launch 2802 was up on blocks and out of the water compared well with the prior 2019 waterline. With the lack of any foreseeable opportunities to make waterline measurements in protected waters, the decision was made to retain the 2019 waterline values for the 2023 field season.

For *Rainier*, static draft is determined by direct measurement to the physical waterline. Waterline measurements are entered into SIS Installation Parameters for initial visualization in SIS. Ultimately the waterline value entered into the CARIS HVF is utilized in post processing instead of the draft entered into SIS.

For *Rainier*, multiple measurements (for averaging) are taken from port and starboard benchmarks to the actual waterline of the ship using either the Impulse 200 LR handheld laser or a fiberglass tape with the end weighted to combat any wind. These benchmarks, located on the top lip of the hull on "D" deck, were positioned using coordinate measurement data taken on the *Rainier* February 14 through February 19, 2014. Kongsberg conducted this ship sensor alignment & orthogonal coordinate survey through a subcontract with IMTEC while the ship was in a floating dry dock at Lake Union Drydock Company, Seattle, WA.

B.2.1.1 Static Draft Correctors

| <i>Vessel</i> | <i>Date</i> | <i>Loading</i> | <i>Static Draft</i> | |
|------------------|-------------|----------------|---------------------|--------------------|
| | | | <i>Measurement</i> | <i>Uncertainty</i> |
| S221_EM304_2023 | 2023-02-01 | 0.100 meters | 0.000 meters | 0.020 meters |
| S221_EM2040_2023 | 2023-02-01 | 0.100 meters | 0.000 meters | 0.030 meters |
| 2801_EM2040 | 2019-03-26 | 0.015 meters | -0.643 meters | 0.006 meters |
| 2802_EM2040 | 2019-03-28 | 0.015 meters | -0.632 meters | 0.006 meters |

B.2.2 Dynamic Draft

The purpose of the dynamic draft and settlement & squat measurements (DDSSM) is to correlate a vessel's speed through the water with the vertical rise/fall of the vessel's Inertial Navigation System (INS) reference point (typically chosen to be coincident with Inertial Measurement Unit, IMU). Since both *Rainier* and her launches lack a method of accurately logging speed through the water, the GNSS-based speed over ground (SOG) is used as a proxy. Consequently, the presence of currents introduce errors into the DDSSM that must be mitigated by careful planning of data acquisition methods. Ideally, this test would be conducted in an area with no current, chop, or swell.

Historically, Rainier has performed DDSSM using the ellipsoidally-referenced method in Lake Washington, which is free of tidal effects, currents, and significant wave action. After the move to Newport, Oregon, this was no longer an option. Experiments using the ellipsoidally-referenced method in both open waters of the Pacific Ocean and in the Yaquina River with daily currents up to 3 knots produced poor to unusable results. The best results are obtained by timing data acquisition to coincide with slack current but even these values were suspect.

Because of external factors, such as tide, current, wind, bottom depth, and method of measurement; dynamic draft measurements have been observed to vary insignificantly from year to year and between vessels of the same class. Since all launches found aboard the NOAA Ship Rainier and Fairweather are all of the same class (Jensen) with effectively the same hull design and characteristics we use a single dynamic draft table for all launches. By analyzing 27 dynamic draft measurements collected from 2010 to 2015 between eight vessels (2801-2808), a class specific dynamic draft table with statistically robust values was created. All of Rainier's Jensen survey launches use this single dynamic draft table for 2023 field season. See the report "FA_classHSL_DynamicDraft" attached to this document for more information. DDSSM for all Rainier Jensen launches were determined as described above and applied to these launches for the 2023 field season.

DDSSM for Rainier was determined on May 1, 2013 using the ellipsoidally-referenced method just outside of Birch Bay, Puget Sound, Washington. To reduce the effect of any potential current, reciprocal lines were run at each RPM step in order to get an average speed over ground for each RPM. This average speed was used to estimate the vessel's speed through the water.

Dynamic draft and vessel offsets corrector values are stored in the HIPS Vessel Files (HVF's). Survey platforms which mount more than one acquisition system or use sonar systems with multiple frequencies have a separate HVF associated with each individual acquisition method. Each of these HVF's contains sensor offset and dynamic draft correctors that pertain to this single acquisition system. Sensor offset and dynamic draft correctors were applied to bathymetric data in CARIS during post-processing.

B.2.2.1 Dynamic Draft Correctors

| <i>Vessel</i> | S221_EM304_2023 | | S221_EM2040_2023 | | 2801_EM2040 | | 2802_EM2040 | |
|----------------------|---------------------------|------------------------|---------------------------|------------------------|---------------------------|------------------------|---------------------------|------------------------|
| <i>Date</i> | 2023-02-01 | | 2023-02-01 | | 2015-05-09 | | 2015-04-13 | |
| <i>Dynamic Draft</i> | <i>Speed (m/s)</i> | <i>Draft (m)</i> | <i>Speed (m/s)</i> | <i>Draft (m)</i> | <i>Speed (m/s)</i> | <i>Draft (m)</i> | <i>Speed (m/s)</i> | <i>Draft (m)</i> |
| | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 0.50 | -0.01 | 0.50 | -0.01 | 0.50 | -0.01 | 0.50 | -0.01 |
| | 1.00 | -0.02 | 1.00 | -0.02 | 1.00 | -0.01 | 1.00 | -0.01 |
| | 1.50 | -0.01 | 1.50 | -0.01 | 1.50 | 0.00 | 1.50 | 0.00 |
| | 2.00 | 0.00 | 2.00 | 0.00 | 2.00 | 0.02 | 2.00 | 0.02 |
| | 2.50 | 0.01 | 2.50 | 0.01 | 2.50 | 0.03 | 2.50 | 0.03 |
| | 3.00 | 0.03 | 3.00 | 0.03 | 3.00 | 0.05 | 3.00 | 0.05 |
| | 3.50 | 0.05 | 3.50 | 0.05 | 3.50 | 0.05 | 3.50 | 0.05 |
| | 4.00 | 0.08 | 4.00 | 0.08 | 4.00 | 0.05 | 4.00 | 0.05 |
| | 4.50 | 0.10 | 4.50 | 0.10 | 4.50 | 0.03 | 4.50 | 0.03 |
| | 5.00 | 0.13 | 5.00 | 0.13 | 5.00 | 0.00 | 5.00 | 0.00 |
| | 5.50 | 0.15 | 5.50 | 0.15 | 5.50 | -0.05 | 5.50 | -0.05 |
| | 6.00 | 0.17 | 6.00 | 0.17 | 6.00 | -0.10 | 6.00 | -0.10 |
| | 6.50 | 0.19 | 6.50 | 0.19 | 6.50 | -0.14 | 6.50 | -0.14 |
| 7.00 | 0.21 | 7.00 | 0.21 | 7.00 | -0.20 | 7.00 | -0.20 | |
| <i>Uncertainty</i> | <i>Vessel Speed (m/s)</i> | <i>Delta Draft (m)</i> | <i>Vessel Speed (m/s)</i> | <i>Delta Draft (m)</i> | <i>Vessel Speed (m/s)</i> | <i>Delta Draft (m)</i> | <i>Vessel Speed (m/s)</i> | <i>Delta Draft (m)</i> |
| | 0.50 | 0.05 | 0.50 | 0.05 | 0.08 | 0.01 | 0.08 | 0.01 |

B.3 System Alignment

B.3.1 System Alignment Methods and Procedures

EM2040 (launches)

Patch testing was conducted for the two Jensen launches sailed with this year just outside the entrance channel to Pearl Harbor, Hawaii in early March as part of the HSRR. Patch test lines were planned in accordance with direction found in section 5.2.4.1 of the HSSD. Bias values were determined using the Caris patch test tool in the order of navigation timing error, pitch, roll, and finally heading (yaw). Each bias was independently determined by a number of testers and entered into an Excel spreadsheet when an average value was determined. From the spreadsheet, the angular bias in question was entered into the patch test tool

before determination of the next bias value. The final angular bias values were transferred to the POS MV once all tests were completed. Bias values in the POS MV have the opposite sign applied to accommodate rotating the IMU relative to the transducer rather than rotating the transducer relative to the IMU.

In their final state, CARIS HVF files and SIS attitude parameters for Kongsberg EM2040 multibeam sonar systems have the patch test values set to zero and all patch test values stored in the POS MV. Patch test values may be present in the HVF during Hydrographic System Readiness Review (HSRR) process when the patch test and reference surface are run on the same day. The reference surface can only be analyzed when the data has current patch test values applied. Since the patch test values are determined by a process which requires multiple rounds of processing carried out by different hydrographers to produce meaningful average values and standard deviations, final values may not be determined until days after the patch test and reference surface were collected. The only way to apply patch test values to the reference surface is to create backdated entries in the HVF. Once the final patch test values are determined, they are entered into the POS MV and zeroed out in the HVF. This entire process should take place prior to the collection of any sonar data for use in charting products.

A second patch test for launch 2801 (RA1) was conducted 5/24/2023 (DN144) just outside the entrance channel to Pearl Harbor, Hawaii using the same line plan as the initial patch tests collected for 2023 HSRR. This test was necessary since the proper offset values were not entered into SIS in the “new” acquisition station handed down from the ship’s EM710 system which was replaced during the winter. Although one day of launch data was collected with the errant SIS offset values, examination of both the reference surfaces generated for the HSRR and the single day of launch data using the erroneous SIS offsets exhibit no offsets or data artifacts when compared to “correct” overlapping data of launch 2802.

EM304 & EM2040 (ship)

During the 2022-2023 winter dry-dock *Rainier* had her Kongsberg EM710 system removed and replaced by two new systems, a Kongsberg EM2040 for relatively shallow waters and an EM304 for mid to deep waters. As part of the installation package representatives from both Kongsberg and HSTB visited the ship off of Hawaii in late February for systems acceptance testing. Measured sonar linear and angular offsets derived from a static vessel offset survey conducted by IMTEC in November and December of 2022 were entered into TX1 and RX1 of the SIS installation parameters. Residual angular patch test values found using Quincy software were entered into Attitude 1 of the SIS installation parameters and applied to the incoming attitude data stream. Additionally, Caris HVFs were created (one for each sonar system)

This method to handle the angular offsets of the vessel sonar differs from the previous EM710 system setup where residual alignment correctors for the ship were applied in the POS MV and measured installation alignment errors between the Tx and Rx applied in the acquisition software (SIS). This change in the method of configuration was in part chosen to avoid adjusting alignment correctors in the POS MV which would be both unwieldy when switching between sonar systems and require inconsistent and impractical HVF methodology to collect MBES data with both sonar systems simultaneously.

Once the sonar systems were accepted and the actual field season began *Rainier* personnel observed a distinct artifact in adjacent survey indicative of a “large” roll bias issue. Once the angular bias values entered into SIS were confirmed as correct, HSTB was contacted to help resolve the issue. Eventually the problem was traced to difference between SIS4 and SIS5. Version 4 of SIS applies all corrections to the

attitude stream before logging it into the RAW .all file. On the other hand SIS v5 (required for the new sonar systems) logs the raw attitude stream into the RAW .kml file, ignoring any angular correction values entered into the SIS installation parameters. The resolution to this problem was to sum the angular offsets of Attitude 1 with the Angular Offsets of the TX1 and RX1 respectively and place the results in SVP1 and SVP2 of the HVF. New Caris HVFs were created (one for each sonar system) reflecting this change and the issue was resolved. See “SIS 5 & CARIS Residual Angular Offset Issue & Fix” included in the appendices of this report for more information.

B.3.1.1 System Alignment Correctors

| | | | |
|---|-----------------------------------|------------------|--------------------|
| <i>Vessel</i> | S221_EM304_2023 | | |
| <i>Echosounder</i> | Kongsberg Simrad EM302 | | |
| <i>Date</i> | 2023-02-01 | | |
| <i>Patch Test Values</i> | | <i>Corrector</i> | <i>Uncertainty</i> |
| | <i>Transducer Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Navigation Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Pitch</i> | 0.000 degrees | 0.100 degrees |
| | <i>Roll</i> | 0.000 degrees | 0.100 degrees |
| | <i>Yaw</i> | 0.000 degrees | 0.150 degrees |
| | <i>Pitch Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Roll Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Yaw Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Heave Time Correction</i> | 0.000 seconds | 0.001 seconds |
| <i>Date</i> | 2023-02-01 | | |
| <i>Patch Test Values (Transducer 2)</i> | | <i>Corrector</i> | <i>Uncertainty</i> |
| | <i>Transducer Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Navigation Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Pitch</i> | 0.000 degrees | 0.100 degrees |
| | <i>Roll</i> | 0.000 degrees | 0.100 degrees |
| | <i>Yaw</i> | 0.000 degrees | 0.150 degrees |
| | <i>Pitch Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Roll Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Yaw Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Heave Time Correction</i> | 0.000 seconds | 0.001 seconds |

| | | | |
|---|--|------------------|--------------------|
| <i>Vessel</i> | S221_EM2040_2023 | | |
| <i>Echosounder</i> | Kongsberg Simrad EM2040 300kHz 0.5x1_Normal Mode | | |
| <i>Date</i> | 2023-02-01 | | |
| <i>Patch Test Values</i> | | <i>Corrector</i> | <i>Uncertainty</i> |
| | <i>Transducer Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Navigation Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Pitch</i> | 0.000 degrees | 0.100 degrees |
| | <i>Roll</i> | 0.000 degrees | 0.100 degrees |
| | <i>Yaw</i> | 0.000 degrees | 0.150 degrees |
| | <i>Pitch Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Roll Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Yaw Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Heave Time Correction</i> | 0.000 seconds | 0.001 seconds |
| <i>Date</i> | 2023-02-01 | | |
| <i>Patch Test Values (Transducer 2)</i> | | <i>Corrector</i> | <i>Uncertainty</i> |
| | <i>Transducer Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Navigation Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Pitch</i> | 0.000 degrees | 0.100 degrees |
| | <i>Roll</i> | 0.000 degrees | 0.100 degrees |
| | <i>Yaw</i> | 0.000 degrees | 0.150 degrees |
| | <i>Pitch Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Roll Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Yaw Time Correction</i> | 0.000 seconds | 0.001 seconds |
| | <i>Heave Time Correction</i> | 0.000 seconds | 0.001 seconds |

| | | | |
|--------------------------|--|------------------|--------------------|
| <i>Vessel</i> | 2801_EM2040 | | |
| <i>Echosounder</i> | Kongsberg Simrad EM2040 300kHz 0.5x1_Normal Mode | | |
| <i>Date</i> | 2023-05-25 | | |
| <i>Patch Test Values</i> | | <i>Corrector</i> | <i>Uncertainty</i> |
| | <i>Transducer Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Navigation Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Pitch</i> | 0.000 degrees | 0.155 degrees |
| | <i>Roll</i> | 0.000 degrees | 0.155 degrees |
| | <i>Yaw</i> | 0.000 degrees | 0.251 degrees |
| | <i>Pitch Time Correction</i> | 0.002 seconds | 0.005 seconds |
| | <i>Roll Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Yaw Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Heave Time Correction</i> | 0.000 seconds | 0.005 seconds |

| | | | |
|---|-----------------------------------|------------------|--------------------|
| <i>Date</i> | 2023-05-25 | | |
| <i>Patch Test Values (Transducer 2)</i> | | <i>Corrector</i> | <i>Uncertainty</i> |
| | <i>Transducer Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Navigation Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Pitch</i> | 0.000 degrees | 0.155 degrees |
| | <i>Roll</i> | 0.000 degrees | 0.155 degrees |
| | <i>Yaw</i> | 0.000 degrees | 0.251 degrees |
| | <i>Pitch Time Correction</i> | 0.002 seconds | 0.005 seconds |
| | <i>Roll Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Yaw Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Heave Time Correction</i> | 0.000 seconds | 0.005 seconds |

| | | | |
|---|--|------------------|--------------------|
| <i>Vessel</i> | 2802_EM2040 | | |
| <i>Echosounder</i> | Kongsberg Simrad EM2040 300kHz 0.5x1_Normal Mode | | |
| <i>Date</i> | 2023-03-08 | | |
| <i>Patch Test Values</i> | | <i>Corrector</i> | <i>Uncertainty</i> |
| | <i>Transducer Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Navigation Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Pitch</i> | 0.000 degrees | 0.155 degrees |
| | <i>Roll</i> | 0.000 degrees | 0.155 degrees |
| | <i>Yaw</i> | 0.000 degrees | 0.251 degrees |
| | <i>Pitch Time Correction</i> | 0.002 seconds | 0.005 seconds |
| | <i>Roll Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Yaw Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Heave Time Correction</i> | 0.000 seconds | 0.005 seconds |
| <i>Date</i> | 2023-03-08 | | |
| <i>Patch Test Values (Transducer 2)</i> | | <i>Corrector</i> | <i>Uncertainty</i> |
| | <i>Transducer Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Navigation Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Pitch</i> | 0.000 degrees | 0.155 degrees |
| | <i>Roll</i> | 0.000 degrees | 0.155 degrees |
| | <i>Yaw</i> | 0.000 degrees | 0.251 degrees |
| | <i>Pitch Time Correction</i> | 0.002 seconds | 0.005 seconds |
| | <i>Roll Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Yaw Time Correction</i> | 0.000 seconds | 0.005 seconds |
| | <i>Heave Time Correction</i> | 0.000 seconds | 0.005 seconds |

C. Data Acquisition and Processing

C.1 Bathymetry

C.1.1 Multibeam Echosounder

Data Acquisition Methods and Procedures

For both the Rainier's Kongsberg systems (EM2040 and EM304) and the launches Kongsberg EM2040 systems, multibeam data were monitored in real-time with the acquisition software, SIS (Seafloor Information System). Data were displayed using 2-D and 3-D data display windows in the real-time screen display.

For launch acquisition, real-time coverage tools are now exclusively used to assess MBES coverage in lieu of traditional pre-planned line files. During the planning stage, "bite sized" polygons were arranged to cover the parts of survey area shallow enough for the launch sonar on each assigned sheet. These polygons were devised to fall within a similar depth range band so that they could be acquired at the proper resolution to find holidays as they occurred in the field. Polygons were also shaped to optimize running with the contours and not against them. Polygons covering deeper areas were planned to be larger than those covering shoaler areas. In general, polygons were sized such that a launch could expect to complete 3 to 5 polygons per day.

Once the polygons were drawn using CARIS HIPS and SIPS or CARIS BASE Editor, they were exported as either S-57 (.000) files or shape files since Hysweep can handle both formats. Hysweep displays these polygons over the chart in addition to plotting the MBES swath coverage as it is collected. This display of the real-time swath coverage is based upon the matrix file, a polygon with user defined geographic bounds and resolution set up prior to data collection. The resolution of the matrix is selected to match depth range of the polygon currently being worked on. The launch coxswain uses this matrix display to adjust the line as it is driven so that the swath currently being collected overlaps the grid of previously collected data. By keeping a close eye on the matrix file during initial data collection, any holidays are immediately evident in the field and can easily be filled in. This method of data acquisition saves time in both the pre-planning stage as well as greatly reducing the need for filling holidays during the subsequent rounds of data acquisition. Traditional holiday lines, small polygons, or exported CARIS BASE surface GeoTIFFs may be used to direct data acquisition after post-processing in the event of any holidays found later in the data processing pipeline.

For ship acquisition, a blended solution including real-time coverage and bathymetric GeoTiffs from outside sources was used. Much of "shoaler" waters of project OPR-T382-RA-23 have previously been surveyed with MBES by various government and private entities interested in the geology and ocean research of the area. Using this data as a guide, Rainier surveyed from 120 meters out to the offshore sheet limits around islands and atolls leaving areas shoaler than 120 meters for the launches. The ship's EM304 is used in all water depths while the EM2040 is used simultaneously with the EM304 in waters shoaler than ~250m. Ship lines are run in either concentric rings or as an inward spiral "jellyroll" pattern with a ~20% overlap with the

adjacent line. In relatively deep areas where there is no danger of finding waters shoaler than 100 meters, Rainier prefers to run long lines parallel to seafloor contours to minimize time lost due to the number of course adjustments and turning about to run the next line. At all times during data acquisition, real-time coverage is used to prevent excessive overlap or holidays and a ~20% overlap with the adjacent line to is maintained. Due to unresolved computer interfacing issues, Rainier was forced to use the EM304 SIS realtime display instead of Hysweep for the realtime coverage display on the bridge; the ship's EM2040 was able to output coverage properly to Hysweep.

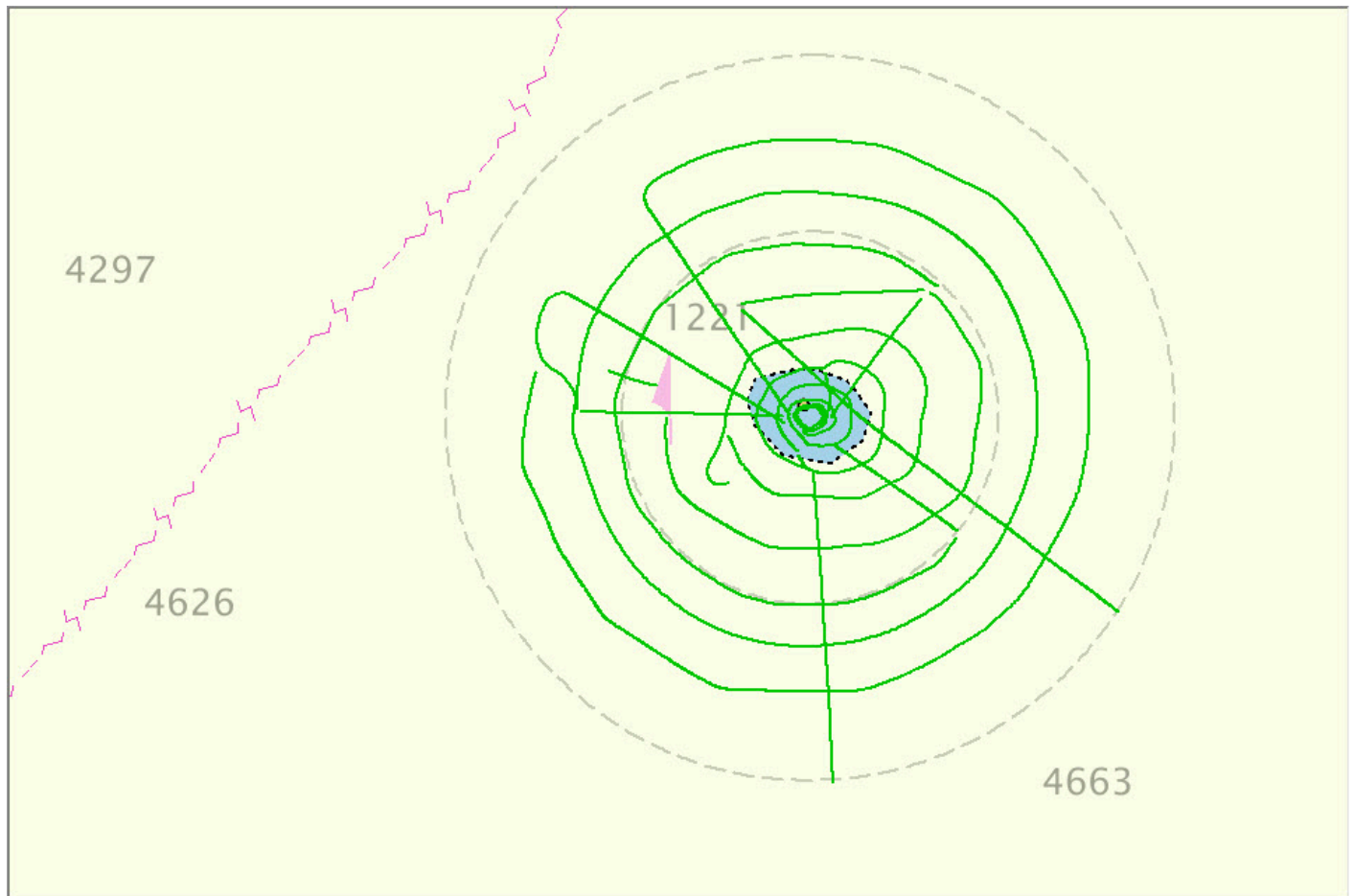


Figure 14: An example of ship EM304 lines run around Swains Island in a concentric ring pattern.

Data Processing Methods and Procedures

Following acquisition, multibeam sonar data were processed by using the Pydro tool “Charlene”. Charlene is a HSTB developed software utility that automates all of the tasks in-between raw data collection and a final daily product that occur each night. These steps are:

1. Moving raw data from the transfer drive to the ship’s network
2. Conversion of “raw” SIS data to the HDCS data format.
3. Import Sensor Data (delayed heave, SBET, RMS)

During typical night processing only delayed heave is configured to be imported by Charlene. SBET and RMS files are typically applied later after they are created and quality checks are complete.

4. Process Data (Georeference Bathymetry), HIPS 11 combines three processes (sound velocity corrections, TPU computations, and vertical datum transformations) in this step.

5. Optionally create a VR depth range or raster surface to check for density issues and holidays using QC tools.

Charlene uses the following options when CUBE surfaces are created:

- Surface Type – CUBE
- IHO S-44 Order – Order 1a
- Include status – check Accepted, Examined and Outstanding
- Disambiguation method - Density & Locale (this method selects the hypothesis that contains the greatest number of soundings and is consistent with neighboring nodes).
- Advanced Configuration – Grid-resolution thresholds are set as a function of depth range as described in the HSSD.
- The day number is included in the name of the "daily" fieldsheet (ex: H13733_DN105_VR.csar).

Once a "daily" fieldsheet is created, either manually or by using Charlene, preliminary data cleaning is performed daily using field sheet CUBE surface as a guide for "directed editing". Typically the night processing crew only cleans out the most blatant of fliers and blow-outs, leaving the final cleaning to the sheet manager. Depth, Standard Deviation, Hypothesis Strength and Hypothesis Count models derived from the boat-day surface are viewed with appropriate vertical exaggeration and a variety of sun illumination angles to highlight potential problem areas. Based on this analysis the most appropriate cleaning method is selected as follows:

- Subset Mode is the default tool selected due to its ability to quickly compare large numbers of soundings with adjacent or overlapping data for confirmation or rejection. Subset mode also excels with the assessment of possible features, disagreement between overlapping lines, and crossline comparison. Subset Mode can be used to visually enhance patterns and anomalies in CUBE surfaces.
- Swath Editor is more rarely utilized but can be useful for burst noise, multipath, and other "gross fliers" which are specific to a particular line or lines, and most easily removed in this mode. Additionally, when it was felt that the quality of the data was reduced due to environmental conditions such as rough seas or extreme variance in sound velocity, data were filtered on a line by line basis to a lesser swath width to ensure data quality.
- Both modes (but particularly Swath Editor) are used as a training aid to help novices learn how the various sonars operate, and provide feedback to the acquisition process.

With the advent of CUBE-based processing, it has become possible to adjust the final bathymetric surface directly by selecting the correct hypothesis to use. Although this method is available, it standard practice on Rainier to clean soundings in the traditional method until the CUBE algorithm selects the correct hypothesis.

Once all the data from all survey platforms is cleaned the “daily” field sheet CUBE surface is examined to ensure bottom coverage and plan additional lines or polygons to fill “holidays”. In addition “daily” field sheets are used to compare adjacent lines and crosslines, for systematic errors such as tide or sound velocity errors, sensor error, sonar errors (consistent bad beams), vessel configuration problems, and noise. Any irregular patterns or problems are reported immediately to the FOO and the Survey Manager so that remedies can be found and applied before more data are acquired.

Following directions spelled out in Hydrographic Surveys Technical Directive 2017-2, Variable Resolution (VR) grids are now the final surface deliverable. Due to both a lack of optimization for VR surfaces in CARIS and older processing machines, Rainier found it difficult to exclusively utilize VR grids as the sole product of night-processing, particularly in the larger more data intensive sheets, and instead a hybrid approach was used. For initial cleaning single resolution grids are often used while a separate VR surface is analyzed with Pydro QC Tools for density issues and holidays. Only later down the processing pipeline when most of the “bad data” has been cleaned out are VR surface solely used. These VR surfaces are analyzed with QC Tools for fliers during final cleaning in preparation for submission.

A coarse 4 meter resolution “Launch” BASE surface may also be maintained for use in the survey launches during data acquisition. The 4 meter resolution was selected to maintain smaller, easily transportable GeoTiff files.

- Naming convention is Hxxxxx_4m_DNxxx.
- The surface is created as a single resolution CUBE surface at 4 meter resolution.
- The CUBE surface is colored using a standardized custom Rainier generated CARIS Colour Range table.
- The color palette selected is intended to aid swift navigation over previously surveyed areas in addition to highlighting shallow areas.

On occasion a finer 1 meter resolution BASE surface may be created for use in the field when survey launches are expecting to work nearshore. The naming convention and custom CARIS Colour Range table used remain the same as the aforementioned coarse 4 meter surface.

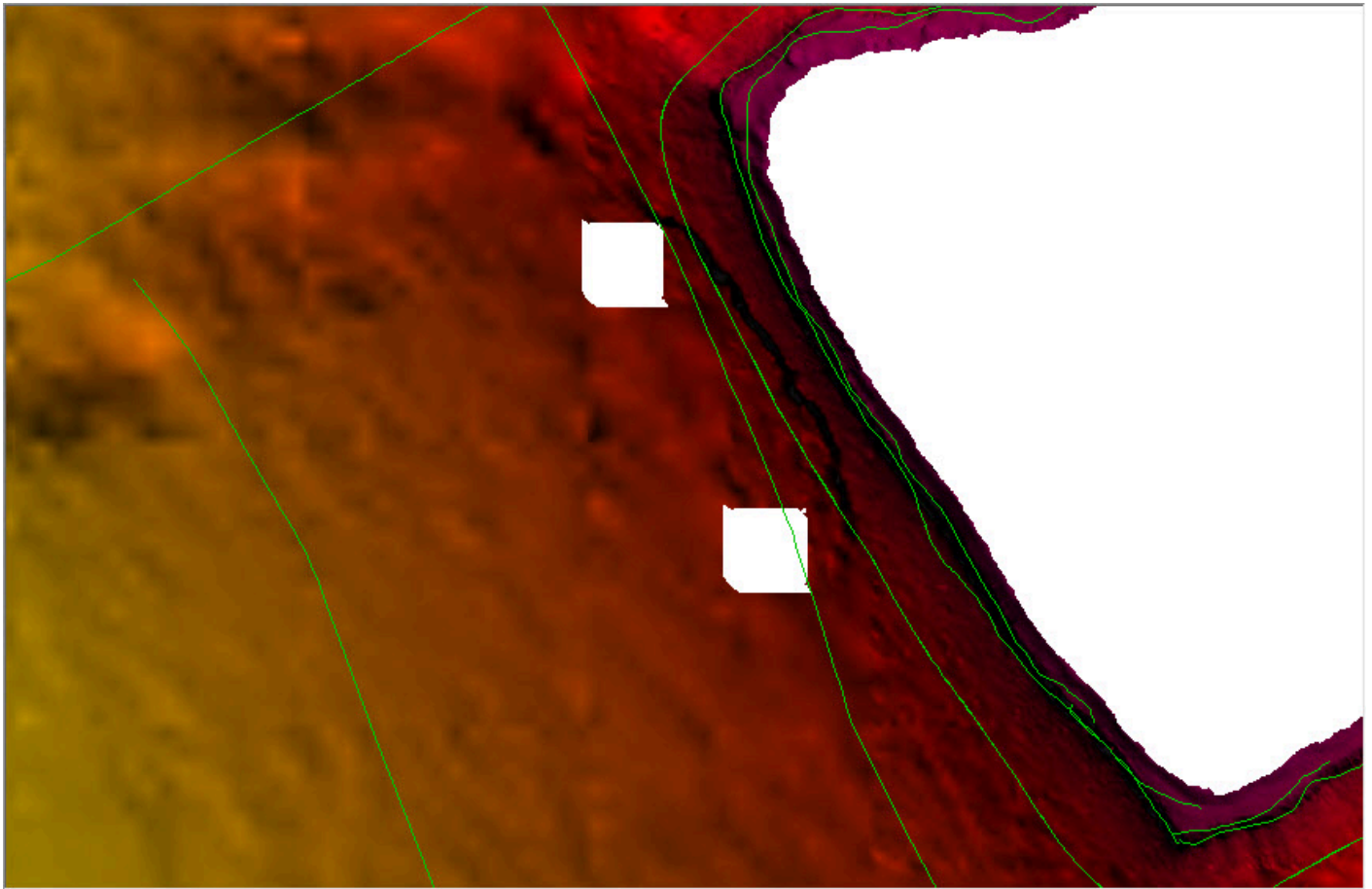


Figure 15: An example of "false" holidays created in a CSAR surface where no real data gaps exist. See section C.1.4.3 of this report for more information and mitigation techniques.

C.1.2 Single Beam Echosounder

Single beam echosounder bathymetry was not acquired.

C.1.3 Phase Measuring Bathymetric Sonar

Phase measuring bathymetric sonar bathymetry was not acquired.

C.1.4 Gridding and Surface Generation

C.1.4.1 Surface Generation Overview

Although the HSSD still contains provisions for single-resolution deliverables, Hydrographic Surveys Technical Directive 2017-2 expressed the desire that all NOAA field units should use variable resolution surfaces to the greatest extent possible in lieu of individual grids for each required depth/resolution band. Rainier submitted VR surfaces as the deliverable for all 2023 surveys.

For variable-resolution deliverables, the hydrographer creates two surfaces. First is a single surface for the entire hydrographic survey and second is a finalized version of this single surface with the option to honor designated soundings selected. VR surfaces submitted adhere to the following naming convention and use 'VR' for the 'units of resolution:

<Survey Registry Number>_<Sounding Type>_<Units of Resolution>_<Vertical Datum>

In spite of the fact that CARIS provides several options for the creation of VR surfaces, only surfaces using depth-based methods (with prescribed grid-resolution thresholds) or density-based estimation methods (using the Calder-Rice algorithm) are approved. In the case of a depth-based surface, object detection coverage and complete coverage surfaces each have a separate set of approved grid-resolution thresholds.

Although Rainier has experimented with both depth-based and density-based VR surfaces, depth-based surfaces became the preferred method and all VR surfaces submitted for the 2023 field season are of the depth-based variety. It has been Rainier's observations that a Calder-Rice density-based surface is ~7 times larger than a depth ranges surface covering the same area. This is likely because our sounding density and the resulting resolution of our VR surfaces is much higher than raster surfaces. Depth-based surfaces also appear superior in terms of processing time and ease of use in CARIS.

Since surveyed soundings acquired by Rainier routinely exceed 1000 meters and at times reach greater than 5000 meters for OPR-T382-RA-23, Rainier personnel often found it impossible to meet the density requirements for complete coverage multibeam at these great depths. HSSD 5.2.2.3 requires a variable resolution grid-resolution of 16 meters for complete coverage multibeam in the 160-320 meter depth range. The grid resolution for water depths greater than 320 meters is defined as 5% of the water depth but not to exceeding 32 meters resolution. Although discussions with HSD have indicated that an increase of grid-resolution with extreme depths was in the works, no such direction has been forthcoming. Therefore a request was made with Angelina Ponella (the Hydrographic Survey Project Manager for OPR-T382-RA-23) for permission to use 64 meter grids in survey depths greater than 1000 meters. Rainier personnel edited the NOAA_DepthRanges_CompleteCoverage_2023.txt supplied with Pydro to include a 64 meter grid-resolution for depths greater than 1000 meters and this modified depth ranges file was used to generate QC and submission surfaces. Documentation for this adjustment to the official specifications is included in the appendices of this report.

C.1.4.2 Depth Derivation

Final depth generation in the form of a scale dependent dataset of individual soundings created as the submission product has not been a part of Rainier's processing pipeline ever since CUBE surfaces became the final deliverable.

C.1.4.3 Surface Computation Algorithm

VR surfaces created aboard Rainier adhere to a set of recommended estimation parameters and mandatory population method parameters as documented in HSSD. Estimation method parameters for Depth-Based CARIS VR Surfaces deal with Range/Resolution values in addition to maximum and minimum grid size. Estimation method parameters for Density-Based CARIS VR Surfaces deal with estimation method (Calder-

Rice Density is required), finest cell resolution, in addition to maximum and minimum grid size. Population method parameters for all CARIS VR surfaces deals with horizontal and vertical uncertainty calculation methods, IHO order, and disambiguation method for a given surface in addition to the CUBE configuration parameters values.

After all correctors have been applied and verified as correct and all data cleaning is complete, a finalized BASE Surface is created as a final product. During the finalization process, Caris gives the user a choice in assigning an uncertainty value for each grid node based on either a) the computed uncertainty derived from a mix of a priori and real-time uncertainty estimates, b) the standard deviation of the soundings contributing to the depth solution, or c) the greater of the two values. Historically, and with an abundance of caution Rainier chose to apply the greater of the two values but new direction from the most recent FPM requires using either uncertainty or standard deviation.

For all finalized BASE surfaces submitted this field season, Rainier chose to use the computed uncertainty to assign an uncertainty value to each grid node. Rainier feels that grid node uncertainty is best represented based on survey equipment uncertainty values recorded in real time, uncertainty derived from analyzing the results of multiple years of system alignment and accuracy measurements, and post processed RMS values calculated from raw GBS base data processed against raw GPS rover files as opposed to a “simple” standard deviation value of the soundings contributing to the node.

CARIS VR Surface Holes:

Rainier has observed an issue in Caris where VR surfaces contain false holes which show up as square shaped holidays in areas with sufficient MBES data to produce a surface. The problem has been traced to inappropriate values being entered for the Maximum Grid Size option when creating a new variable resolution surface. Although 64 meters is recommended value for most NOAA surveys, in areas with either steep topography or extreme depths a Maximum Grid Size of 128 or even 256 meters may be required to get rid of the false holes. Any deviation from the recommended 64-meter Maximum Grid Size will be documented in the applicable descriptive report.

C.2 Imagery

C.2.1 Multibeam Backscatter Data

Data Acquisition Methods and Procedures

Backscatter data are collected by default with the EM304 and EM2040 on Rainier and the EM2040s on her launches.

Data Processing Methods and Procedures

Prior to the 2018 field season HSD issued a Technical Directive that tasked NOAA field units to create and submit processed multibeam acoustic backscatter data using QPS' Fledermaus Geocoder Tool Box (FMGT) software. Since current sonar systems are generally not calibrated, it is inadvisable to mosaic together backscatter from different vessels without explicitly accounting for the relative calibration differences between the systems. To this end, an inter-vessel backscatter calibration test was devised. A single line roughly 200 – 300 meters in length in an area with a flat, consistent surface, free of metal or debris was selected. For each launch the line was run in both directions at survey speed (8 – 10 kts), at every frequency (200, 300, 400 kHz), using every pulse length (SP, LP, FM) for a total of 16 lines per vessel (400 kHz does not have an FM pulse length). By comparing the backscatter across the swath over a flat and consistent seafloor, the backscatter offsets as a function of angle can be determined. Acquiring data on the calibration line in both directions helps to counter the impact of environmental noise.

Relative calibration offsets for each vessel is determined by using commercial software (QPS FMGT) to create mosaics of each survey line. A cross-correlation analysis of the mosaic histograms reveals distinct decibel differences for each vessel, frequency, and pulse length. These offsets values are then used to normalize between common acquisition modes in post-processing, allowing for a more visually consistent mosaic and consistent backscatter data across multiple platforms. The backscatter range head bias values (in dB) were determined for each individual vessel during HSRR using a HSTB supplied excel spreadsheet.

Rainier processes multibeam backscatter to create GSF files and generate backscatter mosaics using QPS FMGT software. The Generic Sensor Files (GSF) created by FMGT contains the backscatter data from Kongsberg .ALL raw data combined with the processed bathymetry located in the HDCS files. Rainier processed and submitted GSF files and backscatter mosaics (one mosaic per frequency for each survey sheet) as part of the regular data submission package.

Following acquisition, backscatter data is processed by using the program FM Geocoder Toolbox (FMGT) and following these steps:

- 1) A new project is created for each sheet and each vessel and each sonar frequency. Thus one sheet can have multiple projects, one (or more) for each launch and possibly one more for the Rainier.
- 2) Vessel parameters are set. Vessel parameters allow the hydrographer to set configurations for each launch, frequency, and pulse length, in order to calibrate slight differences in decibel levels. This results in a smoother, less patchwork appearance of backscatter mosaics between each launch and frequency/pulse length. Parameter values may be determined by running a calibration line in the same direction with each possible combination of vessel, frequency, and pulse length. Rainier collects backscatter calibration yearly as part of the HSRR.
- 3) Utilizing inter-boat intensity offsets, lines are combined into single-frequency, multi-boat mosaics. Therefore, if multiple boats had worked in both 200kHz and 300kHz on a single sheet, 2 mosaics are created; one for each frequency.
- 4) When creating a mosaic for submission, any crosslines not needed in the mosaic are deselected. Export type is set as grayscale GeoTIFF. Initial guidance at the beginning of the field season recommended

no more than 35 MB per mosaic in an attempt to keep the file sizes low to allow for easier distribution through the website and other public forums. Multibeam backscatter mosaics follow the naming convention as described in the HSSD; <Survey registry number>_<Sounding Type>_<Units of resolution>_<vessel>_<frequency>_<xofx> where sounding type is 'MBAB' for multibeam echo sounder acoustic backscatter.

C.2.2 Side Scan Sonar

Side scan sonar imagery was not acquired.

C.2.3 Phase Measuring Bathymetric Sonar

Phase measuring bathymetric sonar imagery was not acquired.

C.3 Horizontal and Vertical Control

C.3.1 Horizontal Control

C.3.1.1 GNSS Base Station Data

GNSS base station data was not acquired.

C.3.1.2 DGPS Data

Data Acquisition Methods and Procedures

The POS MV are optionally configured to receive correctors from the Wide Area Augmentation System (WAAS). The WAAS is a Satellite Based Augmentation System (SBAS) for North America, developed by the Federal Aviation Administration and the Department of Transportation as an aid to air navigation. Usable by any WAAS-enabled GPS receiver, WAAS corrects for GPS signal errors caused by ionospheric disturbances, timing and satellite orbit errors, and it provides vital integrity information regarding the health of each GPS satellite. While WASS was available in Hawaii where most of the HSRR and acceptance testing of Rainier's new sonar systems occurred, no WASS reference stations are located in range of project OPR-T382-RA-23.

WAAS consists of multiple widely-spaced Wide Area Reference Stations (WRS) sites that monitor GPS satellite data. The WRS locations are precisely surveyed so that any errors in the received GPS signals can be detected. Two master stations, located on either coast, collect data from the reference stations via a terrestrial communications network and create a GPS correction message. This correction accounts for GPS satellite orbit and clock drift plus signal delays caused by the atmosphere and ionosphere. The corrected differential message is then broadcast through geostationary satellites with a fixed position over the equator. The information is compatible with the basic GPS signal structure, which means any WAAS-enabled GPS receiver can read the signal.

The WAAS specification requires it to provide a position accuracy of 7.6 meters (25 ft) or better (for both horizontal and vertical measurements), at least 95% of the time. Actual performance measurements of the system at specific locations have shown it typically provides better than 1.0 meter horizontally and 1.5 meters vertically throughout most of the contiguous United States and large parts of Canada and Alaska. In more remote regions of Alaska, values range could be slightly higher. WAAS performance analysis in Honolulu found a position accuracy of 7.03 meters horizontally 95% of the time. All POS MV systems in use on Rainier and her survey launches are configured to receive WAAS correctors.

Data Processing Methods and Procedures

All WAAS are applied in real time, no post-processing of individual DGPS correctors occurs in Rainier's processing pipeline.

C.3.2 Vertical Control

C.3.2.1 Water Level Data

Data Acquisition Methods and Procedures

The project instruction for OPR-T382-RA-23 required deployment of a tide buoy in one of a list of several recommended locations. Rainier chose to deploy the buoy in the vicinity of Ofu Island in American Samoa. The location was chosen primarily due to its central location and the ship's plan to spend the majority of her time in the American Samoa region. The buoy was deployed in ~85 feet of water in an area with a sandy bottom in the southern bight of Ofu Island.

Data Processing Methods and Procedures

No shipboard processing or data download was required for the tide buoy for the buoy Rainier deployed in the vicinity of Ofu Island in American Samoa. The buoy was built with remote download of data in mind and all of the tidal data collected by the buoy during deployment was downloaded by CO-OPS via satellite.

C.3.2.2 Optical Level Data

Optical level data was not acquired.

C.4 Vessel Positioning

Data Acquisition Methods and Procedures

All real time position and attitude data are acquired using POSView and post processed using POSpac MMS.

POS MV .000 files are collected by Rainier and her launches daily, beginning at least five minutes before the collection of bathymetric data and ending at least five minutes after the conclusion of bathymetric data collection. When conducting 24 hours operations, the POS file is usually broken up into 1 hour long pieces to facilitate processing and prevent potential data loss. Logging is started by opening the MV-POSView window and selecting “Ethernet Realtime...” from the Logging menu. In the Ethernet Realtime Output Control window only the following message groups are selected:

For Rainier & MBES launches; 1-5, 9, 10, 99, 110, 112, 10001, 10007, 10008, 10009, 10011 and 10012

The Output Control rate is also set to ‘50Hz’.

For typical Rainier survey areas in the Pacific, UTC midnight often falls in the middle of the survey day. This can cause issues with both acquisition planning and file management Rainier and her launches must always break POS logging at the end of the GPS week (UTC midnight on the Saturday/Sunday transition) where it is important to not log through UTC midnight since the processing software cannot properly handle this transition. For survey launches, if UTC midnight occurs on any other day of the week the POS logging continues through UTC midnight and only breaks at the end of the survey day. In the case where Rainier is conducting 24hr operations, POS is logged for the entire 24hr UTC day with the POS automatically creating a new file every hour allowing for uninterrupted operations. POS MV .000 files corresponding with MBES .all files are then applied in post-processing.

Data Processing Methods and Procedures

Rainier utilizes post processed methods for the horizontal positioning of bathymetric data. The exact method selected is based upon the availability, or lack thereof, of Continually Operating Reference Stations (CORS) near the project area. The four methods available in order of preference are 1) PP-RTX, 2) Smart Base, 3) Single Base, and finally 4) Precise Point Positioning (PPP). For all 2023 surveys, Post-Processed Real Time Extended (PP-RTX) was exclusively used to post-process positioning data and is the only method that will be described in more detail here.

PP-RTX:

Post-Processed Real Time Extended (PP-RTX) is the Trimble CenterPoint RTX positioning solution which combines the methodology of PPP with advanced ambiguity resolution technology to produce cm level accuracies without the need for local reference stations. PP-RTX is used when CORS stations are unavailable and a shore-side reference station would be difficult or impossible to install due to topography,

distance from shore, or land use restrictions. RTX positioning has been shown to produce excellent results and is on its way to supplanting Smart Base and Single Base as the preferred processing method.

Smoothed Best Estimate of Trajectory (SBET) files and associated Root Mean Square (RMS) files are calculated using the Applanix Position and Orientation System Post-Processing Package Mobile Mapping Suite (POSPac MMS) software. All SBET/RMS files are created in POSPac MMS using the “Post Processed Real Time Extended” (PP-RTX) aided-inertial processing mode that uses both terrestrial based reference station data combined with wide-area coverage GNSS satellite corrections to generate precise orbit, clock, and observation biases for satellites on a global scale. These corrections are accessed by POSPac MMS 8.1 via internet access to a Trimble network to provide centimeter level positioning corrections which are then applied by RTX to ship and survey launch POS files. No locally installed GPS base stations or CORS station data are used to generate PP-RTX mode SBET/RMS files.

PP-RTX Processing Methodology:

- 1) Open POSPac MMS 8.9.x or higher.
- 2) Create a New Project by clicking New Project on the Project tab.
- 3) Open the .000 POS file(s) found in the appropriate raw data folder and wait for the ephemerides to download.
- 4) Click on “Trimble PP-RTX” button to generate PP-RTX.
- 5) Click the Gold Star “GNSS-Inertial Processor” button, verify the processing mode is set to In-Fusion PP-RTX, and click the Fast Forward icon to perform all processing.
- 6) Click Display Plots and look for spikes or use the AutoQC tool for POSPac SBET Quality Control.
- 7) Once SBET quality is confirmed to be of sufficient quality to proceed, export the project with a File Format of “Custom Smooth Bet”. This will export a custom SBET in NAD83.
- 8) Copy the SBET and RMS files to the appropriate folder on the processed sheet directory. Rename the export_ YYYY_DDD_VSSL_A.out file to the following format: YYYY_DDD_VSSL_A_SBET.out and the smrmmsg_ YYYY_DDD_VSSL_A.out file to the following format: YYYY_DDD_VSSL_A_RMS.out.

PP-RTX processing may also be achieved in one easy step using Charlene as either a standalone process or part of the MBES data transfer and processing. In the event the ship is logging simultaneous EM304 and EM2040, a single SBET and RMS file is shared between them.

C.5 Sound Speed

C.5.1 Sound Speed Profiles

Data Acquisition Methods and Procedures

Rainier launches use Sea-Bird SEACAT conductivity, temperature, and depth profilers (CTD) to acquire sound speed data. Rainier uses the Rolls-Royce Moving Vessel Profiler (MVP200) and/or the Lockheed Martin Sippican Inc. Deep Blue XBT to acquire sound speed data.

The Sea-Bird SEACAT conductivity, temperature, and depth profiler (CTD):

All of Rainier's Jensen survey launches (2801 and 2802) are equipped with 24-volt electric winches attached to small swing-arm davits. These davits are used to deploy and recover Sea-Bird SEACAT profilers while the vessel is at rest. The rate at which the spool deploys line may be adjusted with friction washers controlled by a knob or T-handle located on the side of the winch spool. On rare occasions Rainier may utilize her oceanographic winch when collecting Sea-Bird SEACAT profiles.

Casts are conducted at least once every 4 hours to align with application procedures in HIPS and SIPS. Casts are also conducted when moving to a different survey area, or when conditions evolve (such as a change in weather, tide, or current), so as to warrant additional sound velocity profiles. The launch crew also monitors the real-time display of the Reson SVP 70 for changes of 2 m/s or greater in the surface sound velocity indicative of the need for a new cast.

Sound Speed Manager software is used for both setting up and processing data from Sea-Bird SEACAT instruments. Prior to deployment the SEACAT voltage is checked. The SBE 19plus should have a minimum of 9.5 volts and the SBE 19 should have a minimum of 7 volts. In the event of lower voltage readings, the instrument batteries are changed.

The site selected for a CTD cast should be in the deepest portion of the area expected to be surveyed within four hours and that can provide a representative profile. Before the instrument is placed in the water, the Hydrographer must ensure that the plastic tube covering the sensors has been removed. When conducting SEACAT casts with the SBE 19, the 3-2-1 rule of thumb is followed. The instrument should be turned on and allowed to sit on deck for 3 minutes while the sensors settle and form baseline. The instrument is then set to soak just below the surface for 2 minutes. Finally the instrument is lowered at a rate of 1 meter/second.

When conducting SEACAT casts with the SBE 19plus, the instrument should be lowered and held just below the water's surface for about 1 minute to allow air to escape the salinity cell. After soaking the instrument, it should be lowered at a rate of 1 meter/second through the water column. In areas where lenses of fresh water or other complex sound speed variation near the surface are suspected, the instrument should be lowered slowly (in some cases, much less than 1 meter/second) through the first 5-10 meters of water in order to accurately sample the sound speed. After this initial decent, the instrument should proceed to drop at a rate of 1 meter/second.

The Rolls-Royce Moving Vessel Profiler (MVP200):

The Moving Vessel Profiler (MVP) is an automated winch system that deploys a fish containing a sound speed sensor by free fall. The fish is towed behind the survey vessel in a ready position that is marked by messengers attached to the tow cable. Ideally at survey speeds the fish is “flying” just above the depth of the sonar transducers. The specified depth deployed is selected by specifying a distance off the bottom (typically 10 meters). Once at the depth limit, the winch freefall is automatically stopped and the drag forces on the fish cause it to rise toward the surface due to the ship's forward motion. The cable slack is then pulled in by the winch back to the towing position. In the event of a particularly deep survey area or prior to the entire survey system being brought on-line, the

MVP fish can be manually deployed while the ship is at rest using the hand-operated control box located on the winch. This method ensures that the maximum possible depth is obtained since the cable is deployed vertically. If necessary, during processing of later casts, the deep end of such a stationary cast can be tacked on to the end of shallower casts obtained while the ship is moving. The MVP fish can either be user-deployed or deployed automatically by the computer at a user defined time interval. Rainier employs the user-deployed method due to the danger of an automatic deployment taking place during a turn. Casts with the MVP are taken as often as every 15 minutes. This high frequency is due to the ease of collecting casts while losing no survey time stopping for a SEACAT cast. Frequent sound speed casts also better define the sound speed variation over the larger horizontal distances covered by the ship since long, straight lines are preferable to minimize turns while the MVP is deployed.

The Lockheed Martin Sippican Inc. Deep Blue XBT:

For project areas that include depths greater than the maximum range of the MVP (~235 meters underway, ~600 meters stationary), Rainier was provided with the XBT probes and launcher that include enough wire to cast a maximum depth of 760 meters. This depth exceeds the maximum depth of casts possible from the ship with her current winch setup. XBTs have the additional advantage of being deployable while the ship is underway. XBT probes are also convenient to deploy at nighttime if the MVP has been pulled out of the water for a long transit at speed and the personnel needed to re-deploy are asleep.

Casts from this system are created and downloaded in Sippican/Lockheed software and then processed in Velocipy and Sound Speed Manager.

As with CTDs, XBT casts are conducted at least every 4 hours to align with application procedures in HIPS and SIPS. Casts were also conducted when moving to a different survey area, or when conditions evolve (such as a change in weather, tide, or current), would warrant additional sound velocity profiles. The survey also monitors the real-time display of the Reson SVP 70 for changes of 2 m/s or greater in the surface sound velocity indicative of the need for a new cast.

Data Processing Methods and Procedures

Downloading and processing of sound speed data is performed using Velocipy, a part of the HSTB supplied Pydro program suite. Both raw and processed files are archived and submitted to the hydrographic branch as part of the sheet submission package.

For Seacat CTD:

- After a cast, the SBE Seacat is connected to the download computer with a serial cable.
- After starting Velocipy, “File/ Download from SBE” is selected from the dropdown menu. A window showing available casts is then displayed with checkboxes to select cast(s) for download.
- After download the user is then required to enter cast metadata. Empty slots for Project, Survey, NOAA Unit, Instrument, Username, Process Date, Draft, and Latitude and Longitude are given.
- After entering metadata, the sound velocity graph is viewable by clicking on the SV tab in the Metadata window. The user can change the sound speed/depth units (X and Y buttons), zoom in (Magnifier tool), and take a look/edit cast points (+ button). Additional tabs display the Temperature and Table view.
- Casts are exported into CARIS SVP format files by selecting File/Export Selected Profiles. A File Export Settings window will pop up, allowing the user to point to the CARIS/ SVP folder and if necessary append the current cast. After clicking OK, the Log Window should read ‘exported sound speed profile successfully’.
- To prepare for the next cast, SEACAT PreCast Setup is selected to clear all memory and initialize the profiler for the next cast.

For MVP:

- For the MVP, casts are typically processed as a group at the end of the day or survey watch.
- After starting Velocipy, “File/ Load Profiles” is selected from the dropdown menu. Navigate to the s12 file produced by the MVP and select file/s to process.
- After the files load, the user is then required to enter cast metadata. Empty slots for Project, Survey, NOAA Unit, Instrument, Username, Process Date, and Draft are given. Unlike the Seacat CTD, Latitude and Longitude are already populated.
- After entering metadata, the sound velocity graph is viewable by clicking on the SV tab in the Metadata window. The user can change the sound speed/depth units (X and Y buttons), zoom in (Magnifier tool), and take a look/edit cast points (+ button). Additional tabs display the Temperature, Salinity and Table view.
- Casts are exported into CARIS SVP format files by selecting “File/Export Selected Profiles”. A File Export Settings window will pop up, allowing the user to point to the CARIS/ SVP folder and if necessary append the current cast. After clicking OK, the Log Window should read ‘exported sound speed profile successfully’.

For XBT:

- Open Sound Speed Manager and use the input data button to open that XBT cast.
- Next if your XBT cast hit the seafloor you will need to remove the data from after that event. Use the remove data button and right click and drag a box over the temperature data after the XBT hit the seafloor.
- To add a salinity to the XBT cast use the retrieve salinity button. This will grab a salinity profile for the XBT location from the world ocean atlas.
- Extend the cast using the extend profile button.
- Optionally set the XBT cast as a reference cast using the "ref" button. Later when the MVP cast are imported to sound speed manager this will be used as the reference to extend the cast.
- Save the XBT cast using the export data button.

C.5.2 Surface Sound Speed

Data Acquisition Methods and Procedures

Surface sound speed values are measured by a SVP 70 on Rainier and on all Jensen survey launches. These sound speed values are applied in real-time to all MBES systems to provide refraction corrections to flat-faced transducers and are used in active beam steering.

Data Processing Methods and Procedures

Surface sound speed data are not independently processed.

C.6 Uncertainty

C.6.1 Total Propagated Uncertainty Computation Methods

Rainier's primary bathymetric data review and quality control tool are the CARIS CUBE (Combined Uncertainty and Bathymetry Estimator) BASE surfaces as implemented in CARIS HIPS. The CUBE algorithm generates a surface consisting of multiple hypotheses that represent the possible depths at any given position. The BASE surface is a grid of estimation nodes where depth values are computed based on the horizontal and vertical uncertainty of each contributing sounding as follows:

- Soundings with a low vertical uncertainty are given more influence than soundings with high vertical uncertainty.
- Soundings with a low horizontal uncertainty are given more influence than soundings with a high horizontal uncertainty.
- Soundings close to the node are given a greater weight than soundings further away from the node.

As soundings are propagated to a node, a hypothesis representing a possible depth value is developed for the node. If a sounding's value is not significantly different from the previous sounding then the same or modified hypothesis is used. If the value does change significantly, a new hypothesis is created. A node can contain more than one hypothesis. As node-to-node hypotheses are combined into multiple surfaces through methodical processing, a final surface that is the best representation of the bathymetry is created.

Any individual sounding's uncertainty, or Total Propagated Uncertainty (TPU), is derived from the assumed uncertainty in the echosounder measurement itself, as well as the contributing correctors from sound speed, water levels, position, and attitude. TPU values for tide and sound velocity must be entered for each vessel during TPU computation, unless using TCARI, where uncertainty is added directly to survey lines by Pydro.

- Tide values measured uncertainty value was used for projects with tidal vertical control and the error values ranged from 0.01 to 0.05 meters dependent upon the accuracy of the tide gauges used and the duration of their deployment. Under current guidance there is a requirement to acquire survey data vertically referenced to the ellipsoid, rendering this uncertainty value pointless. Rainier uses a value of 0.0 since this value is no longer applicable.
- Tide values zoning uncertainty value once referred to the Tide Component Error Estimation, the tidal error contribution to the total survey error budget is that included the estimated gauge measurement error, tidal datum computation error, and tidal zoning error. With the advent of surveys vertically referenced to the ellipsoid this value is now filled with the separation uncertainty of the VDATUM model. The actual uncertainty value can be found in either the Vertical Control Requirements section of the Project Instructions or in the metadata associated with the VDATUM model supplied.
- Measured sound speed value error ranges from 0.5 to 4 m/s, dependent on temporal/spatial variability. Although the FPM recommends a value of 4 m/s when one cast is taken every 4-hours, Rainier experience in the field indicates that a value of 3.0 m/s better models this error. If the ship measures sound speed with the MVP, a value of 1.0 m/s is used due to the higher sampling frequency. In cases where XBT casts are used on a sheet, the recommended value of 4.0 m/s is used.
- Surface sound speed value is dependent on the manufacturer specifications of the unit utilized to measure surface SV values for refraction corrections to flat-faced transducers. The Reson SVP 70 fixed-mount sound velocity probe is affixed to all Rainier MBES launches to provide correctors for the flat faced EM2040. A redundant pair of Reson SVP 70s are mounted in Rainier's MBES gondola to provide correctors for the ship's EM304 and EM2040. The Reson SVP 70 velocity probe has a published accuracy of 0.05 m/s.
- When a sheet has the requirement to acquire survey data vertically referenced to the ellipsoid, and converted to MLLW using VDatum, the separation uncertainty value replaces the tide zoning value in the calculation of TPU. The separation uncertainty value is included in the Vertical Control Requirements section of the Project Instructions. If a PMVD – now known as ERTDM (ellipsoidally-referenced tidal datum model) is used, the one-sigma modeled uncertainty for the ERTDM is either included with the ERTDM in the project files, or included in the ERTDM email from HSTB.

All other error estimates are read from the Hydrographic Vessel File (HVF) and Device Model file. The HVF contains all offsets and system biases for the survey vessel and its systems, as well as error estimates for latency, sensor offset measurements, attitude and navigation measurements, and draft measurements. In addition, the HVF specifies which type of sonar system the vessel is using, referencing the appropriate entry from the Device Model file.

In addition to the usual a priori estimates of uncertainty, some real-time and post-processed uncertainty sources were also incorporated into the depth estimates of Rainier surveys. Real-time uncertainties from the Kongsberg EM2040 and Kongsberg EM304 were recorded and applied in post-processing. Applanix TrueHeave files are recorded on all survey vessels, which include an estimate of the heave uncertainty, and are applied during post-processing. Finally, the post-processed uncertainties associated with navigation and GPS Height applied in CARIS HIPS via an SBET RMS file generated in POSPac.

TPU Calculation Methods

There are two places in CARIS where the user directly defines uncertainty values for use in CARIS to calculate TPU values, in the HVF and the direct input of SV and tide values during the TPU computation.

Source of TPU Values: Launches

Commonly reported ranges of TPU values for all motion, navigation position and timing values are found in HSSD 5.2.3.6. All timing values were set to 0.005 seconds as outlined for setups with Ethernet connections and precise timing. All offset values were chosen to be 0.010 meters based on the accuracy provided by professional surveys. Vessel speed uncertainty was defined as 0.03 m/s plus an average value (assumed to be 0.05 m/s) for currents for a total of 0.08 m/s.

Historically a single Loading TPU value (in meters) for the Caris HVF and used by all Jensen survey launches was determined annually by finding the difference between the maximum waterline measurement and the minimum waterline measurement between the 4 launches. In 2021 Rainier made the decision to analyze the historic record and come up with a single "Jensen representative value". This single, all-time loading value was determined by averaging together the Loading TPU values determined annually between the years 2012 to 2021. The resulting value is used for both of the Jensen launches that Rainier sailed with in 2023.

Historically the Draft TPU value (in meters) for the Caris HVF was determined yearly for each individual launch by measuring the waterline multiple times for both the starboard and port side of each launch, determine StdDev for each side, and keeping the highest value as Draft Uncertainty. In 2021 Rainier made the decision to analyze the historic record and come up with a single "Jensen representative value". This single, all-time draft value was determined by averaging together individual Draft TPU values determined annually for each launch between the years 2012 to 2021. The resulting value is used for both of the Jensen launches that Rainier sailed with in 2023.

Vessel delta draft is set at 0.010 meters in the Caris HVF, a value which falls within the range recommended in HSSD 5.2.3.6.

In the past Roll/Pitch and Yaw uncertainty were determined individually for each launch on an annual basis by using a number of testers to separately determine the pitch, roll, and yaw angular bias correctors. For each bias the standard deviation was also determined. The MRU Align StdDev Roll/Pitch value entered into the Caris HVF was calculated by finding the square root of the roll standard deviation squared plus the pitch standard deviation squared. The MRU Align StdDev gyro value entered into the Caris HVF was simply the yaw standard deviation.

In 2021 Rainier made the decision to analyze the historic record and come up with a single "Jensen representative value" for both roll/pitch and yaw standard deviation. Each launch's annual pitch, roll, and yaw standard deviation values were found for each year between 2012 to 2021 and weighed by the number of testers (a roll StdDev with 8 testers had twice the influence of a roll StdDev with 4 testers), These weighted standard deviation values were then averaged using data from all 4 Jensen launches, to obtain a "Jensen representative value" for each of the three angular biases. For all Jensen launches carried by Rainier in 2023, the MRU Align StdDev Roll/Pitch entered into the Caris HVF is the square root of the "Jensen representative" roll standard deviation squared plus the "Jensen representative" pitch standard deviation

squared. The MRU Align StdDev gyro entered into the Caris HVF is simply the "Jensen representative" yaw standard deviation.

Source of TPU Values: Ship

As part of the installation for Rainier's new sonar systems, a field support liaison from the Hydrographic Systems & Technology Branch created new HVFs with the TPU values populated. Motion, navigation, and timing sensor uncertainties, were all set within the commonly reported ranges of TPU values found in HSSD 5.2.3.6.

C.6.2 Uncertainty Components

C.6.2.1 A Priori Uncertainty

| <i>Vessel</i> | | S221_EM304_2023 | S221_EM2040_2023 | 2801_EM2040 | 2802_EM2040 |
|--------------------------|--------------|-----------------|------------------|--------------|--------------|
| <i>Motion Sensor</i> | <i>Gyro</i> | 0.02 degrees | 0.02 degrees | 0.02 degrees | 0.02 degrees |
| | <i>Heave</i> | 5.00% | 5.00% | 5.00% | 5.00% |
| | | 0.05 meters | 0.05 meters | 0.05 meters | 0.05 meters |
| | <i>Roll</i> | 0.02 degrees | 0.02 degrees | 0.02 degrees | 0.02 degrees |
| | <i>Pitch</i> | 0.02 degrees | 0.02 degrees | 0.02 degrees | 0.02 degrees |
| <i>Navigation Sensor</i> | | 1.00 meters | 0.50 meters | 1.00 meters | 1.00 meters |

C.6.2.2 Real-Time Uncertainty

| <i>Vessel</i> | <i>Description</i> |
|-------------------------|---|
| <i>All MBES systems</i> | As previously discussed in this section, some real-time uncertainty values are incorporated into the depth estimates of Rainier surveys by way of post-processing. Real-time uncertainties from the Kongsberg EM2040 and Kongsberg EM304 are recorded and applied in post-processing. Applanix TrueHeave files are recorded on all survey vessels, which include an estimate of the heave uncertainty, and are applied during post-processing. Finally, the post-processed uncertainties associated with vessel GPS height and navigation are applied in CARIS HIPS via an SBET RMS file generated in POSPac. |

C.7 Shoreline and Feature Data

Data Acquisition Methods and Procedures

Prior to shoreline verification the sheet manager prepares boat sheets, page sized chartlets with features color coded by assignment flag and/or source. Multiple boatsheets covering different sections of a sheet may be created. The scale each boatsheet is determined by the legibility of the features; enough room must be left to annotate each assigned feature by hand. Annotation of features is done in near real time and includes information such as observed time and height, photo number, and remarks. Sheet limits, final feature files, and charts must also be pre-loaded on the acquisition computer.

Under ideal circumstances shoreline verification is conducted during daylight periods near predicted MLLW tides of +0.5 meters or less. A line is run along the shore approximating the position of the Navigational Area Limit Line (NALL). Breakers on a fringing coral reef often dictates the position of the NALL. In the absence of direction to the contrary, the NALL was the furthest offshore of the following:

All sheets with exception of sheet 5:

- The 10 meter depth contour at MLLW.

Sheet 5, Pago Pago Harbor:

- The 3.5 meter depth contour at MLLW.
- A line seaward of the MHW line by the ground distance equivalent to 0.8mm at the scale of the largest scale raster chart of the area.

This definition of the NALL is subject to modification by the Project Instructions, Chief of Party (Commanding Officer), or the Hydrographer-In-Charge of the survey launch based on field observations. Some likely additional reasons for modifying the position of the NALL included:

- Sea conditions such as kelp or breakers in which it is unsafe to approach the shore to the specified distance or depth.
- Regular use of waters inshore of this limit by vessels navigating with NOAA nautical chart products. (This does not include skiffs or other very small craft navigating with local knowledge.)

As the approximate NALL line is run along the shore, the hydrographer both annotates the shoreline reference document and scans the area for features to be addressed. All features with CARIS Notebook custom attribute "asgnmt" populated with 'Assigned' and offshore of the NALL are fully investigated. 'Assigned' features inshore of the NALL are verified or DP'd for height if exposed but survey vessels do not navigate inshore of the NALL to either disprove or investigate potential submerged 'Assigned' features. Features are addressed in the following manner:

Offshore of the NALL:

- A feature found within 2mm at survey scale of the composite source position has its height/depth determined.
- A feature outside 2mm at survey scale of the composite source position has its field position revised in addition to a heights/depth determination.
- Features with any linear dimension greater than 1mm at survey scale are treated as an area and delineated.

- New features not in the Composite Source file.
- Maritime boundary points and other features specifically identified for investigation.

Inshore of the NALL:

- Assigned maritime boundary points only if they are safe to approach.
- Navigationally significant features that:
 - Are sufficiently prominent to provide a visual aid to navigation (landmarks). Note that rocks awash are almost never landmarks, but distinctive islets or other features visible at MHW can be useful for visual navigation.
 - Are within a ground unit distance equivalent to 0.8mm at the scale of the largest scale chart of the area. Common examples of these features include foul areas and large reef/ledge structures.
 - Are man-made permanent features connected to the natural shoreline (such as piers and other mooring facilities) larger than the resolution specified for the survey. Seasonal features will be evaluated by the Command.
 - Are man-made permanent features disconnected from the shoreline, such as stakes, pilings, and platforms, regardless of size.

Navigationally Significant features were defined as the following:

Small, private mooring facilities (piers and buoys) suitable for pleasure craft are not generally considered navigationally significant. Areas with a high density of mooring buoys for these vessels are delineated, but the features themselves not individually positioned.

Terminology used for field annotation of the shoreline reference document during shoreline verification is as follows:

"Noted"

The existence of a feature and its characteristics are confirmed from a distance, and its position appears to be correct within the scale of the chart or source.

- Appropriate for features inshore of the limit of hydrography and not navigationally significant, significant features that require no further investigation, or features unsafe to approach to verify position within survey scale.
- Noted features are annotated on the shoreline reference document but carried no further forward in the processing pipeline.

"Verified"

The feature's position and characteristics are acquired and recorded by directly occupying the site, or by applying a range and bearing offset to a known position. Positioning is generally by DGPS methods.

- Appropriate for navigationally significant features inshore of the limits of hydrography. Also, appropriate for existing features that do not require a height (VALSOU or HEIGHT attribute).

"DP for Height"

The feature's source position is correct, but height (VALSOU or HEIGHT attribute) is either unknown or incorrect. This position does not supersede that of the source data, so it is only necessary to approach the feature as closely as required to accurately estimate the height.

- Appropriate for source features found within 2mm at survey scale, but with incorrect or missing height or depth data.

"New"

The feature's position and attributes (including height) are acquired and recorded by directly occupying the site, or by applying a range and bearing offset to a known position. Positioning is generally by DGPS methods.

- Appropriate for items offshore of the NALL that are not present in the Composite Source.
- Items inshore of the NALL that are navigationally significant and are not present in source data.

"Not Seen"

The feature was present in source data but was not visually observed in the field. Full disproval search (see below) was not conducted.

- Appropriate for features above MHW, the absence of which can be proven visually from a distance.
- Source features inshore of the limit of hydrography that are not observed, but whose presence on or absence from the survey will not affect safe navigation.
- Any feature from source that was not seen, but for which full disproval search (see below) is impractical or unsafe.

"Disproved"

The feature is present in source data, but was not located after a full search. "Full Search" means MBES, SBES, SSS, and/or Detached Position coverage of the area that conclusively shows that the item is not located at the position given to the accuracy and scale of the source document.

The primary purpose of detached positions (DPs) is to verify and define shoreline features (ex: rocks, reefs ledges, piles), disprove charted features, position navigational aids and landmarks (ex: buoys, beacons, lights), and mark positions of bottom samples. Point features are captured in the field as height attributed targets in HYPACK.

The survey vessel's track may also be used to delineate area features, such as reefs, ledges, or foul areas. Where it is safe to approach these features to within the specified horizontal accuracy requirement, this method can produce a more accurate and efficient representation of large features than would be provided by multiple DPs on the extents.

A vessel's track may also be used to position point features. Typically while driving a buffer-line around the feature in question, the shoreline vessel will loop back around and drive straight towards the feature and approach as close as is safely possible, often with the nose of the skiff nearly touching the feature. It is then elementary to position the feature based on the pointing "arrow" that the track-line creates.

Rainier entered into the 2023 field season with the realization that shoreline operations would be quite different than that seen in a typical Alaska survey. Due to the dive operations simultaneously being carried out with survey operations deck space was at a premium and the usual shoreline skiffs were left in Oregon in favor of a dive compressor and re-compression chamber. In addition the 10 meter NALL enforced on all but one sheet greatly reduced the number of near-shore features that required investigation. Finally since the location and timing of launch operation was dictated by dive boat operations, no time was devoted to dedicated shoreline buffer lines during predicted MLLW tides, rather shoreline verification was conducted whenever a launch was near the inshore limit irregardless of tide level.

Rainier processes all features to have their heights reduced to MLLW by way of the ellipse. For all non MBES features that have not been reduced to MLLW, post-processing to MLLW by way of the ellipse is accomplished using the NOAA created program SHAM (SHoreline Attribution Machine) which requires a file of georeferenced time-tagged feature height observations and a POS MV file. The POS MV file does not necessarily have to be collected on the same platform that feature are observed from as long as logged POS data is concurrent with skiff shoreline acquisition. Examination of separation model slopes has shown that any launch running on the same sheet can provide adequate vertical positioning.

Data Processing Methods and Procedures

Following a day of shoreline verification, the HIC makes digital copies of the notes recorded on the paper boat sheets. In addition, any digital photos taken and the trackline hob file are archived in the appropriate folders of the sheet directory. Field annotations are transferred from the boat sheet into the appropriate S57 attribute fields. Digital photos are also linked to the corresponding feature.

Due to time constraints, a lack of trained coxswains, and an apparent lack of need, Rainier personnel decided against installing and calibrating the Velodyne LiDAR system on launch RA2. Due to this, Rainier entered the 2023 field season with only one method to reduce the heights of features to MLLW by way of the ellipse:

- Collect height and position data the traditional manner from a survey launch and deriving heights by eye or using sounding poles or lead lines. Final reduction to MLLW is accomplished with SHAM using position data from the survey launch POS MV, feature height collected manually, and ellipsoidal height from the post-processed SBET.

For features collected in the traditional way, the processing procedure the end of the day is as follows:

- Ensure that the POS MV .000 file of the launch providing vertical control has been processed using POSpac, and a valid SBET been created.
- At bare minimum, the “obstim” and “obsdpt” attributes of all features needing heights reduced to MLLW by way of the ellipse must be correctly attributed using time and height information hand annotated on the boat sheet. The “obstim” attribute is needed to sync the time that the “obsdpt” was recorded with the SBET, and hence an ellipsoidal height value. Optionally, if photos are linked using the "images" attribute, they will be renamed according to HTD 2018 guidance.
- In Pydro start SHAM, (the SHoreline Attribution Machine)
 - Select Traditional, ERS and NAD83.
 - Point to the .000 (s57) created in the previous steps.
 - Point to SBET file
 - Point to images folder (optionally) to have all photos renamed according to HTD 2018 guidance
 - Select PMVD and point to appropriate separation files (MLLW & MHW) in CSAR format
 - Enter a Waterline value of the vessel supplying the SBET file
 - Attribute sheet, vessel and last date of acquisition (if known)
 - Click on the “Start” button

- SHAM processes the provided information and produces a new, fully attributed .000 (s57) file with feature heights computed.

For surveys where limited shoreline verification was performed, DPs and/or CARIS VBES/MBES CUBE surfaces were used to help define kelp and foul areas. Any new line features were digitized in the HXXXXX_FFF.hob file. If an area feature required modification, a copy of the feature was edited to reflect the current survey and characterized as "new" while the original feature was flagged as "delete". When objects were added or modified as "new", the SORDAT and SORIND fields were updated. All features flagged as "delete" always maintain their original SORDAT and SORIND.

De-confliction of the composite source shoreline was conducted only on items specifically addressed in the field while conducting shoreline verification. As a general rule, nearly all features inshore of the NALL line are not investigated. All conflicting composite source features that are not addressed in the field were left unedited in the final features file HOB.

Composite source features offshore of the NALL which were DPed for height were also de-conflicted if multiple shoreline features were present representing the same item. The source item most closely representing the actual feature was flagged "Primary" and "retain" or "update" if edited for height while the other extraneous features were flagged "Secondary" and "delete" with a comment "removed due to deconfliction". In the event that a DP was taken to reposition an incorrectly charted feature, all of the composite source features in the wrong position were "Secondary" and "delete".

Primary and secondary flagged features are correlated using the NOAA custom attributes prkyid (Primary Key ID) and dbkyid (Database Key ID). The primary feature has its dbkyid populated with a unique number and any secondary features selected to be linked has its prkyid updated with the same number. The unique number assigned is typically the CARIS Feature Object ID (FOID).

On occasions when the conditions are right, a MBES launch may end up surveying close to the inshore survey limits and end up collecting a significant number of soundings inshore of the NALL. Any additional soundings collected inshore of the NALL were processed as follows:

- "Good" seafloor is not rejected anywhere. Any bad soundings are cleaned out to make the surface represent the seafloor, but there is no cut-off of soundings shoaler than the 3.5-meter or 0-meter curves. Negative soundings are fine so long as they accurately represent the bottom.
- No launch is to go inside the NALL line trying for the 0-meter curve, or developing items that are found outside the survey limits (i.e. NALL line)
- For cultural features (pilings, piers, buoys and buoy chains, etc.) that are above MLLW (i.e. negative sounding) AND on the CSF HOB layer, all soundings on the cultural item are deleted. This technique will prevent the BASE surface from being pulled up for features already charted above MLLW in the HOB file.
- For cultural features that are below MLLW, the shoalest sounding is designated (which the BASE surface will honor) AND the feature is included on the field verified HOB file.

- For cultural features that are above MLLW and are not on the field verified HOB file, the least depth is flagged as "outstanding," but not included in the BASE surface and all other data on the object is rejected. In this case, the "outstanding" sounding is used as a basis for creating a new feature in the field verified HOB, but it will not affect the BASE surface. This is accomplished by using the option in BASE surface creation to not include outstanding soundings. Alternatively, in the case of area-type cultural features, all depths may be temporarily retained and the resultant DTM used to digitize the feature. Once digitization is complete, all soundings on the cultural item are deleted.
- Rocks and reefs are treated as "seafloor." No data is rejected on rocks, reefs or ledges, even above MLLW. The primary method of getting heights on rocks will remain laser heights using LiDAR, but if a least depth of a rock is obtained with MBES, it will be designated and the height/depth will be used as the VALSOU in the FFF HOB. As previously stated, launches will not go inshore of the NALL line trying to get these data, but it will not be discarded if they are obtained. In cases where the echosounder data does not get the least depth, the soundings obtained will be left in the surface and a DP (or previously acquired comp source data) will be used for the feature.

Following acquisition, digital photos are renamed with a unique ID and moved into the "Multimedia" folder. Prior to final survey submission, all images associated with the Final Feature File are renamed using the Pydro program "Rename FFF Images" which renames all of the FFF images to conform with HTD 2018-5 (Feature Image File Naming Convention).

S-57 Attribution

With the advent of custom CARIS support files supplied by OCS, feature flags previously available only in Pydro are now supported in CARIS HIPS/SIPS, Bathy DataBase, and Plot Composer. All feature flagging can now be accomplished in CARIS HIPS/SIPS while Pydro is used for generating reports and performing QC.

Features are selected for investigation by HSD OPS based on distance from MHW. Project Instructions and the HSSD require that "All Composite Source File (CSF) features with the NOAA extended attribute 'asgmt' populated with 'Assigned' shall be addressed and included in the FFF."

No Rainier launches will venture inshore of the NALL, even for assigned investigation items, if there is a question of safety or potential equipment damage. If the feature in question is exposed, time and height attributes are assigned while driving past. If the feature is not evident while driving along the NALL during shoreline verification, a remark of "inshore of NALL not investigated" is made with a recommendation of "Retain as charted".

Feature attribution is completed for all 'Assigned' and any newly discovered items. Unassigned features are left untouched.

Submerged features, such as wrecks and submerged piles designated in CARIS HIPS are also brought into the shoreline HOB file for attribution.

All features marked as "primary" are edited to have their object/attribute instances describe each feature as completely as possible. Object attributes assigned to each feature conform to direction located within both

the current HSSD and the CARIS “IHO S-57/ENC Object and Attribute Catalogue”. S-57 attribution is not required for those features flagged as "secondary" nor for unassigned features.

NOAA specific attribution in the shoreline HOB file includes “descr” with a drop-down menu which is edited to reflect the hydrographer recommendations as follows:

- descrp - new -- A new feature is identified during survey operations. The hydrographer recommends adding the feature to the chart. Also, in cases in which the geographic position of an existing point feature is modified; the newly proposed feature is characterized as "new", while the original feature is flagged as "delete".
- descrp - update -- The feature was found to be portrayed incorrectly on the chart. Update is also used in the case where the feature was found to be attributed incorrectly or insufficiently and is modified to reflect the additional or corrected attribution. Also, for cases in which the geographic extents/position of an existing line feature are modified; the newly proposed feature is characterized as "update".
- descrp - delete -- The feature is disproved using approved search methods and guidelines. The hydrographer recommends removing it from the chart. Also, for cases in which the geographic position of an existing point object is modified; the original feature is flagged as "delete" and the newly proposed position of the feature is characterized as "new".
- descrp - retain -- The feature is found during survey operations to be positioned correctly and no additional attribution was required. The hydrographer recommends retaining the feature as charted.
- descrp – not addressed -- The feature is not investigated during shoreline acquisition, typically because it is either inshore of the NALL or unsafe to approach. The hydrographer recommends retaining the feature as charted.

Features described as "new" and "update" are updated with the SORIND/SORDAT attribution of the current survey.

Features described as "delete", "retain", and "not addressed" have their SORIND/SORDAT attribution remain unchanged.

C.8 Bottom Sample Data

Bottom sample data was not acquired.

C.9 Other Data

Data Acquisition Methods and Procedures

The project instructions for OPR-T382-RA-23 required Rainier to collect water column data concurrently with bathymetric and backscatter data for areas deeper than 200 meters. To meet this requirement water

column data collection was enabled for the ships EM304 system which was used to collect bathymetry in waters greater the ~120 meters. This water column data is saved in the SIS standard .kmwcd format and submitted as part of the standard sheet data submission package. At no point did Rainier process any of this water column data.

Data Processing Methods and Procedures

Initial data processing at the end of each survey day is the responsibility of the night processing team, or launch crew if no night processing team is assigned. In the event of 24-hr ship operations, the survey watch may act as the night processing team. The night processing Team is typically composed of two crew members, one with at least a year's experience, and one junior member in training. Daily processing produces a preliminary product in which all gross data problems have been identified and/or removed, and thus can be used by the survey team to plan the next day's operations. The night processors complete a data pass down log to inform the survey manager and FOO of any notable features, dangers, or systematic problems in the day's data.

In consultation with the sheet manager, the night processing team may be assigned to processing and QC checks of POSPac data. The sheet manager ensures SBETs are properly applying to the survey after post acquisition tasks are complete.

Relatively new to the night processing pipeline is Charlene, an automated night processing and data transfer tool developed by NOAA's Office of Coast Survey in early 2017. Night processing includes all of those tasks in between raw data collection and a final daily product that occur each night on our hydrographic vessels. Charlene was adopted as the official processing method for all Rainier hydrographic surveys.

Charlene allows the user to:

1. Perform verification of raw data
2. Build transfer drive and deliverable directory structure
3. Transfer and verify raw data
4. Process MBES with the CARIS Batch Processor
5. Generate SBETs with POSPac Batch
6. Apply said SBETs to the processed MBES data
7. Use NOAA tools like AutoQC, QCTools and Sham

D. Data Quality Management

D.1 Bathymetric Data Integrity and Quality Management

D.1.1 Directed Editing

Any CUBE surface created in CARIS includes a number of child layers (uncertainty, hypothesis count, hypothesis strength and standard deviation to name a few) in addition to the depth layer. Through the process of “directed editing” an experienced hydrographer may be able to review and/or edit problematic data not obviously evident by looking the depth layer alone.

Directed editing involves an overview examination of the depth layer in addition to the available child layers to find problems with the data. The hydrographer then jumps to the trouble spots and makes any necessary edits. This processing method makes the assumption that if the surface “looks good” then the underlying data is also good. If a “good” area is examined in subset mode, noise may be present but the CUBE algorithm is doing its job and preventing the surface from being affected. While good at spotting bursts of noise and other data quality issues, directed editing can have issues with finding single sounding fliers that may show up as only a single pixel if at all.

Problem spots in the child layers may be exaggerated by manipulating the colour file in addition to the min/max range. In addition to finding fliers, child layers can also be useful for seeing areas of noisy data not seen in the depth surface due to CUBE doing its job. In addition child layers may cause objects with high hypothesis counts or standard deviation such as wrecks to be easier to spot.

D.1.2 Designated Sounding Selection

On occasion, the resolution of the CUBE surface may not be sufficient to capture the high point of a feature. The hydrographer may designate soundings that are not incorporated in the gridded surface, although they are not required (HSSD). In general, sounding designation solely to adjust the surface is frowned upon and rarely used. Rather, sounding designation is used only when those soundings are of critical importance, such as in the case of Dangers to Navigation (DTONs).

An exception to this reluctance to designate sounding occurs in the case of point features. Although missed shoal points may occur on irregular shoals or rock pinnacles, man-made features such as piles and wrecks are of particular concern. These features have very slender high points that extend far above the surrounding seafloor as well as the CUBE surface. If a feature has been deemed worthy of inclusion in the final feature file (FFF) and has been ensonified by a MBES system, the shoalest point is flagged “designated” in CARIS. This designated sounding both eases the import of the feature in question into the FFF and ensures that the exact height and position of the feature is honored in the finalized VR surface to be submitted. During the “finalization” process, the CUBE surface is forced to honor all soundings which have been flagged “designated”.

D.1.3 Holiday Identification

QC Tools included as part of Pydro 22 contains the tool “Detect holidays” which now largely automates the identification of holidays in bathymetry data sets. To begin holiday finder, the user selects a grid and survey type (object detection or full coverage). Any empty grid nodes (“holes”) surrounded by populated nodes are identified. Holidays in VR grids are flagged according to the specifications found in the current NOAA NOS Hydrographic Survey Specifications and Deliverables.

The results of “Detect holidays” are output in a number of different file formats for ease of use regardless of the program used for data analysis. Rainier typically uses the S57 (.000) file that can be opened up in CARIS directly over the surface in question for further analysis.

D.1.4 Uncertainty Assessment

QC Tools included as part of Pydro 22 contains the tool “Grid QA” which now largely automates the computation of grid statistics to ensure compliance to uncertainty and density requirements. The Depth, Uncertainty, Density (if available), and a computed Total Vertical Uncertainty (TVU) QC layer (optional) are used to compute particular statistics shown as a series of plots. The TVU QC is either given to the program in the grid input, or calculated on-the-fly. It is determined by a ratio of uncertainty to allowable error per NOAA and IHO specification.

Grid QA outputs the following plots:

- Histogram of depth; The percentage of nodes per depth group vs depth (entitled “Depth Distribution”).
- Histogram of density; The percentage of nodes per density group vs soundings per node (entitled “Data Density”).
- Histogram of TVU QC; The percentage of nodes per uncertainty group vs node uncertainty as a fraction of allowable IHO TVU (entitled “Uncertainty Standards - NOAA HSSD”).
- Histogram of % resolution (VR-surfaces only); The percentage of nodes per resolution group vs node resolution as a fraction allowable (entitled “Resolution Requirements - Full Coverage” or "Resolution Requirements - Object Detection").

Optional plots include:

- Plot depth vs density; Depth vs soundings per node (entitled “Node Depth vs. Sounding Density”).
- Plot depth vs TVU QC; Depth vs node uncertainty as a fraction of allowable IHO TVU (entitled “Node Depth vs. TVU QC”).

These plots once generated are analyzed for compliance with the applicable specifications and may be included in a sheet’s Descriptive Report as proof of compliance.

D.1.5 Surface Difference Review

D.1.5.1 Crossline to Mainscheme

Pydro now includes the tool “Compare Grids” which now largely automates the comparison of co-located bathymetry data sets. This tool analyzes the difference between two gridded Depth/Elevation layers in CSAR/BAG format. The CSARs and/or BAGs input may be any combination of variable resolution or raster grids. Output consists of two CSAR grids and three plot files containing summary statistics. One of the CSAR output files contains the simple depth differences in a Diff layer. The other CSAR grid contains the layer fracAllowError, the fraction of the IHO-allowable error. As a quality control (QC) measure, cross-lines with a linear nautical total of at least 4% of mainscheme multibeam lines were run on each survey. Then a CUBE surface was created using strictly the main scheme lines, while a second surface was created using only the crosslines. The differences between these two surfaces are then analyzed using the “Compare Grids” tool. Summary statistics generated using “Compare Grids” are incorporated within the Descriptive Report for each survey.

D.1.5.2 Junctions

The Pydro tool “Compare Grids” described above can just as easily be used for junction comparisons as it is for cross-line analysis.

D.1.5.3 Platform to Platform

No platform to platform comparison is typically conducted as part of the standard sheet processing work flow.

D.2 Imagery data Integrity and Quality Management

D.2.1 Coverage Assessment

Side Scan Sonar:

No SSS data were collected for this project.

Backscatter:

Backscatter is processed using Fledermaus FM Geocoder Toolbox (FMGT) and the resulting mosaics examined to ensure they processed correctly. No re-acquisition for backscatter holidays or other issues was conducted.

D.2.2 Contact Selection Methodology

No SSS data were collected for any projects this field season and therefore no contacts were selected.

E. Approval Sheet

As Chief of Party, I have ensured that standard field surveying and processing procedures were followed during the 2023 field season. All operations were conducted in accordance with the Office of Coast Survey Field Procedures Manual (2020 edition), NOS Hydrographic Surveys Specifications and Deliverables (March 2022 edition), and all Hydrographic Technical Directives issued through the dates of data acquisition. All departures from these standard practices are described in this Data Acquisition and Processing Report and/or the relevant Descriptive Reports. I acknowledge that all of the information contained in this report is complete and accurate to the best of my knowledge.

Individual survey data for project OPR-T382-RA-23 meets or exceeds requirements as set forth in the NOS Hydrographic Surveys Specifications and Deliverables, Field Procedures Manual, Letter Instructions, and all HSD Technical Directives. These data are adequate to supersede charted data in their common areas. All surveys for project OPR-T382-RA-23 are complete and no additional work is required with the exception of deficiencies noted in in the applicable Descriptive Report.

| Approver Name | Approver Title | Date | Signature |
|----------------------------------|--------------------------|-------------|------------------|
| Héctor L. Casanova, CAPT/NOAA | Commanding Officer | 08/07/2023 | |
| James B. Jacobson | Chief Survey Technician | 08/07/2023 | |
| Garrison L. Grant, LT/NOAA | Field Operations Officer | 08/07/2023 | |

List of Appendices:

| <i>Mandatory Report</i> | <i>File</i> |
|---|---|
| <i>Vessel Wiring Diagram</i> | 2801 (RA-4) Wiring Diagram.pdf 2802 (RA-5) Wiring Diagram.pdf 2023_S221_Wiring_Diagram.pdf |
| <i>Sound Speed Sensor Calibration</i> | SBE 19 C0281 29Nov21.pdf SBE 19 P0281 29Nov21.pdf SBE 19 T0281 29Nov21.pdf SBE 19plus C4039 30Nov21.pdf SBE 19plus P4039 30Nov21.pdf SBE 19plus T4039 30Nov21.pdf SBE 19plus C4114 29Nov21.pdf SBE 19plus P4114 29Nov21.pdf SBE 19plus T4114 29Nov21.pdf SBE 19plus C4306 30Nov21.pdf SBE 19plus P4306 30Nov21.pdf SBE 19plus P4306 30Nov21.pdf SBE 19plus C4343 29Nov21.pdf SBE 19plus P4343 29Nov21.pdf SBE 19plus T4343 29Nov21.pdf SBE 19plus V2 C7530 30Nov21.pdf SBE 19plus V2 P7530 30Nov21.pdf SBE 19plus V2 T7530 30Nov21.pdf 2023 calibration SV70 0217007.pdf 2023 calibration SV70 0614179.pdf 2018 calibration SV70 2817018.pdf 2018 calibration SV70 3417109.pdf 2023 calibration AML 7510.pdf 2023 calibration AML 7511.pdf AML 008565.pdf AML calibration 008614.pdf |
| <i>Vessel Offset</i> | 2023 launch offset spreadsheet.pdf |
| <i>Position and Attitude Sensor Calibration</i> | 2023_POS-MV Calibration.pdf |
| <i>Echosounder Confidence Check</i> | 2023 Reference Surfaces - with_Patch2.pdf |
| <i>Echosounder Acceptance Trial Results</i> | 2017 Rainier_Launch_EM2040_Acceptance.pdf RA_2023_EM304_EM2040_AcceptanceReport_Version_0.1.pdf |

| <i>Additional Report</i> | <i>File</i> |
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| <i>Caris range file 6m extension</i> | NOAA eMail - 64m Grids.pdf |

| <i>Additional Report</i> | <i>File</i> |
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| <i>SIS 5 & CARIS Residual Angular Offset Issue & Fix</i> | CARIS Residual Angular Offset Investigation & Solution.pdf |
| <i>2023 Patch Tests Results</i> | 2023_Patch Tests.pdf |