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Data Acquisition & Processing Report

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State(s): Washington

General Locality: Puget Sound

2021

CHIEF OF PARTY
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Date:

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Data Acquisition and Processing Report

NOAA Navigation Response Team - Seattle

Chief of Party: Patrick Faha LTJG/NOAA

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A. System Equipment and Software

A.1 Survey Vessels

A.1.1 NRT Seattle

<i>Vessel Name</i>	NRT Seattle	
<i>Hull Number</i>	S3006	
<i>Description</i>	Aluminum Hydrographic Survey Vessel	
<i>Dimensions</i>	<i>LOA</i>	34 ft
	<i>Beam</i>	8.5 ft
	<i>Max Draft</i>	1.5 ft
<i>Most Recent Full Static Survey</i>	<i>Date</i>	2018-04-10
	<i>Performed By</i>	Kevin Jordan, National Geodetic Survey, Field Operations Branch
<i>Most Recent Full Offset Verification</i>	<i>Date</i>	2018-04-10
	<i>Method</i>	The TOPCON GPT 3000 Series Theodolite was used to position all points on the launch, a SECO 25 mm Mini Prism System configured to have a zero mm offset was used as target sighting and distance measurements



Figure 1: NOAA NRT-Seattle S3006 in Puget Sound.

A.2 Echo Sounding Equipment

A.2.1 Multibeam Echosounders

A.2.1.1 Kongsberg EM2040C

S3006 is equipped with a hull-mounted Kongsberg EM2040C, whose frequency range is from 200 to 400 kHz with frequency selection in steps of 10 kHz, enabling the user to choose on the fly the best operating frequency for the application. The maximum depth range for a single head system in cold ocean water is 520 m at 200 kHz with a swath width up to 580 m. The angular coverage for 200 to 320 kHz is 130° with one sonar head, allowing coverage 4.3 times water depth. For frequencies above 320 kHz the angular coverage per head is gradually decreasing to 70° at 400 kHz. The nadir beam width is 1° x 1° at 400 kHz. The system has a maximum ping rate of 50 Hz with 400 soundings per ping.

For hydrographic survey collection, angular coverage within SIS is set to Auto, with beam spacing set to high definition equal distant, to obtain max swath width on any depth . Dual swath mode typically operates as "fixed" so the along ship angle between the transmit fans are equal to the along ship TX opening angle. The frequency of the EM2040C is typically set to 300 kHz for normal survey operations, and will shift to

400 kHz for shallow water data collection. Pulse type is changed by the operator to vary primarily between FM and very short CW depending on the depth of the water, to obtain maximum coverage available.

Components of the EM 2040C include a sonar head, a processing unit, and a hydrographic workstation. Motion sensor and positioning data from the POSMV system, with sound speed profile data being input to the EM 2040C via separate sound speed profiling equipment. All echo sounder electronics are contained in the sonar head which is interfaced to the processing unit via GBit Ethernet. The processing unit also supplies 48 VDC power via the same cable. Operator control, data quality inspection, and data storage is handled by the hydrographic workstation running SIS software.

Note- The Hydrographic Systems Technology Branch (HSTB) Sonar acceptance report for the 2040C utilized by the NRTs was never completed. The acceptance document included in the appendices of this report is what the team lead has been provided with. For questions, please contact HSTB and Chief, NRB.

<i>Manufacturer</i>	Kongsberg				
<i>Model</i>	EM2040C				
<i>Inventory</i>	S3006	<i>Component</i>	Sonar Head	Kongsberg TPU	Hydrographic Work Station
		<i>Model Number</i>	EM2040C	EM2040C	HWS MP8300
		<i>Serial Number</i>	1158	CZC3440R5X	CZC3410KSV
		<i>Frequency</i>	200-400kHz	N/A	N/A
		<i>Calibration</i>	2018-05-02	2018-08-03	2018-08-03
		<i>Accuracy Check</i>	2019-03-28	2019-03-28	2019-03-28



Figure 2: EM 2040C sonar head and processing unit

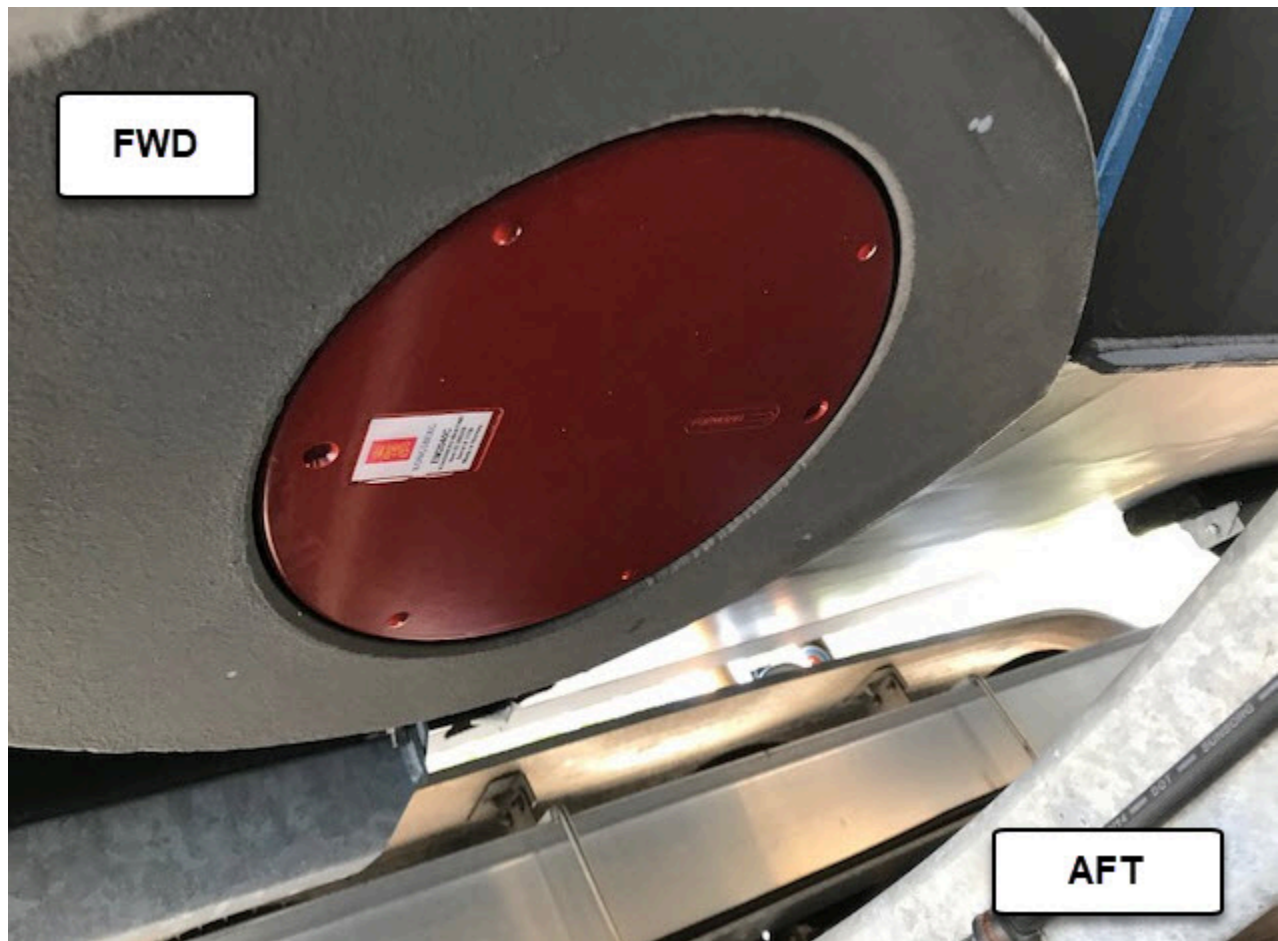


Figure 3: EM2040C mounted centerline on hull on the aft portion of S3006.

A.2.2 Single Beam Echosounders

No single beam echosounders were utilized for data acquisition.

A.2.3 Side Scan Sonars

A.2.3.1 EdgeTech 4125

The EdgeTech 4125 dual-frequency (400/900 kHz) side scan sonar system is a frequency modulated (FM), dual-frequency, side scan sonar that uses EdgeTech's proprietary Full Spectrum "chirp" technology to generate high-resolution side scan imagery. Frequencies are transmitted as linearly-swept, wide-band, high energy acoustic pulses, and the received echoes are processed into high signal-to-noise (SNR) images that can be directly displayed as shades of gray color on a computer monitor. Operating ranges are 150 m at 400 kHz and 75 m at 900 kHz. Horizontal beam widths are 0.46° at 400 kHz and 0.28° at 900 kHz. The vertical beam width is 50°. Across-track resolution is 2.3 cm at 400 kHz and 1.0 cm at 900 kHz.

Components of the 4125 system are a rugged stainless steel towfish and a rack-mounted topside processing unit. The towfish contains the sonar transducer arrays and the electronics required to transmit and receive the sonar signals; to receive the downlink commands from the topside processor; and to provide the uplink side scan data, sensor data, and status information to the topside processor. The rack mount interfaces with a user supplied computer over a 10/100BaseT Ethernet connection.

NRT-Seattle side scan sonar is mounted via a universal pole mount over the port side of the vessel.

<i>Manufacturer</i>	EdgeTech			
<i>Model</i>	4125			
<i>Inventory</i>	S3006	<i>Component</i>	Tow Fish	Edgetech Topside Processor
		<i>Model Number</i>	4125	4125
		<i>Serial Number</i>	40426	40261
		<i>Frequency</i>	400/900 kHz	N/A
		<i>Calibration</i>	N/A	N/A
		<i>Accuracy Check</i>	N/A	N/A



Figure 4: EdgeTech 4125 towfish

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

The lead line was build in accordance to the specifications in the 2014 Field Procedures Manual 1.5.3.1.1. The prepared lead line was soaked in salt water for 24 hours, and while wet, cotton coverings were working along the wire. The line was then dried under tension, and soaked again for another 24 hours. Meter markings are written on a leather strip to indicate the numerical value. Calibrated during HSSR annually and is 20m length with anchoring plate. Only used during HSSR verification. Lead line measurements can also be taken in locations that are too shallow for echosounders, to get least depths over shoals, dangers to navigation, or to perform multibeam checks.

The 2021 Lead Line calibration results are included in the appendices of this report. The field unit's lead line does not meet the 2020 HSSD offset values within 0.1M.

<i>Manufacturer</i>	NRT-Seattle		
<i>Model</i>	Custom		
<i>Inventory</i>	S3006	<i>Component</i>	Lead Line
		<i>Model Number</i>	N/A
		<i>Serial Number</i>	N/A
		<i>Calibration</i>	2021-04-22



Figure 5: NRT-Seattle's lead line, good for depths up to 20 meters.

A.3.3 Sounding Poles

No sounding poles were utilized for data acquisition.

A.3.4 Other Manual Sounding Equipment

No additional manual sounding equipment was utilized for data acquisition.

A.4 Horizontal and Vertical Control Equipment

A.4.1 Base Station Equipment

No base station equipment was utilized for data acquisition.

A.4.2 Rover Equipment

No rover equipment was utilized for data acquisition.

A.4.3 Water Level Gauges

No water level gauges were utilized for data acquisition.

A.4.4 Levels

No levels were utilized for data acquisition.

A.4.5 Other Horizontal and Vertical Control Equipment

No other equipment were utilized for data acquisition.

A.5 Positioning and Attitude Equipment

A.5.1 Positioning and Attitude Systems

A.5.1.1 Applanix POS MV V5

S3006 is equipped with the Applanix POS MV 320, V5. The POS MV V5 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.

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. When using differential correctors, the POS/MV generates positional data to an accuracy of 0.5-2 meters.

In addition to position, the 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) this data is 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 to an accuracy of 0.008° and heading data with an accuracy of 0.02° . Horizontal position is accurate to $\pm 8\text{mm} + 1\text{ppm} \times \text{baseline length}$ while vertical position is accurate to $\pm 15\text{mm} + 1\text{ppm} \times \text{baseline length}$. 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. Heading accuracy is monitored by the crew and survey operations are temporarily suspended in the event that the error exceeds 0.08° .

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.

The Heave Bandwidth filter is 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.

Position and Attitude data are recorded daily at 50Hz, and saved to a single file on a desktop hard drive.

<i>Manufacturer</i>	Applanix				
<i>Model</i>	POS MV V5				
<i>Inventory</i>	S3006	<i>Component</i>	IMU	PCS	GNSS Antenna
		<i>Model Number</i>	IMU 7	POS MV V5	Trimble GA530
		<i>Serial Number</i>	2404	5926	14817
		<i>Calibration</i>	2018-05-02	2018-08-03	2018-08-03



Figure 6: POS MV V5 system components: IMU, POS Computer System, and two GNSS antennas.



Figure 7: GNSS antennas set up on the forward cabin roof on S3006.

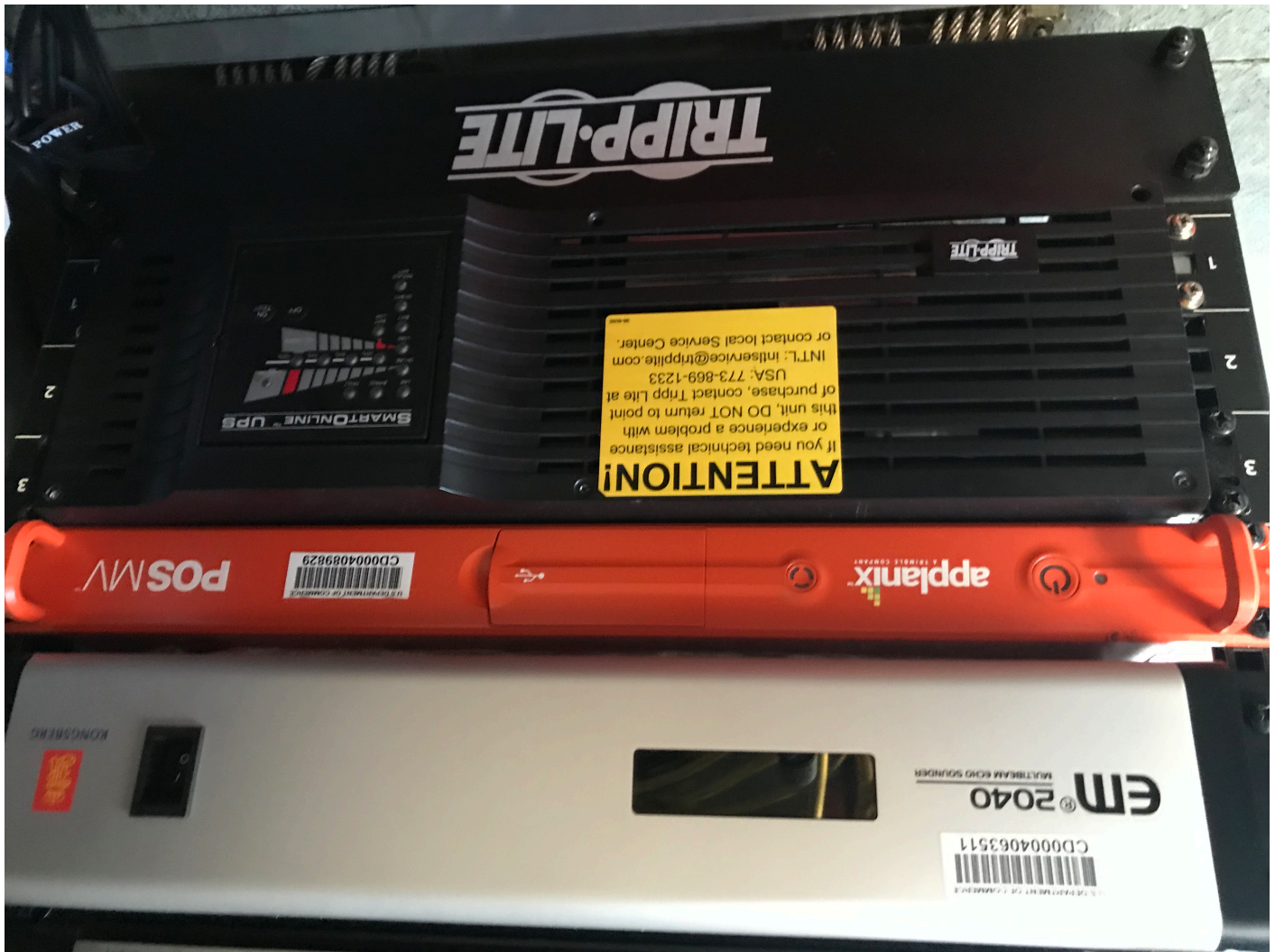


Figure 8: POS MV installed in the server rack on S3006.

A.5.2 DGPS

DGPS equipment was not utilized for data acquisition.

A.5.3 GPS

A.5.3.1 Simard GS70

Simrad Chart Plotter with associated GPS is used during acquisition in addition to hypack to assist driving for coverage.

<i>Manufacturer</i>	Simard		
<i>Model</i>	GS70		
<i>Inventory</i>	S3006	<i>Component</i>	GPS Smart Antenna
		<i>Model Number</i>	GS70
		<i>Serial Number</i>	072-2637-000
		<i>Calibration</i>	N/A

A.5.4 Laser Rangefinders

Laser rangefinders were not utilized for data acquisition.

A.5.5 Other Positioning and Attitude Equipment

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

A.6 Sound Speed Equipment

A.6.1 Moving Vessel Profilers

No moving vessel profilers were utilized for data acquisition.

A.6.2 CTD Profilers

A.6.2.1 Sontek CastAway-CTD

The CastAway-CTD is a small, rugged CTD designed for profiling to depths of up to 100m. The system achieves a 5 Hz response time, fine spatial resolution, and high accuracy, with sound speed measurements accurate within ± 0.15 m/s. It uses a six electrode flow through conductivity cell with zero external field coupled with a rapid response thermistor to attain high measurement accuracies. The instrument is simple to deploy, does not require a pump and is hydrodynamically designed to free fall rate of 1 m/s.

Each CastAway-CTD cast is referenced with both time and location using its built-in GPS receiver. Latitude and longitude are acquired both before and after each profile. Plots of conductivity, temperature, salinity and sound speed versus depth can be viewed immediately on the CastAway's integrated color LCD screen. Raw data is downloaded via Bluetooth to the launch acquisition computer for analysis and to export into SIS.

Castaway units are returned to Sontek annually for calibration. Castaway units are returned to Sontek annually for calibration, which ensures the conductivity and temperature flow cell is ready for use.

CastAway is powered by two AA batteries that are installed in a water tight compartment in the bottom of the housing unit. Batteries on the unit need to be changed about every three days. There is a large shackle zip tied to the bottom of the unit to ensure collection of the entire water column.

<i>Manufacturer</i>	Sontek	
<i>Model</i>	CastAway-CTD	
<i>Inventory</i>	<i>Component</i>	CTD
	<i>Model Number</i>	SonTek
	<i>Serial Number</i>	CC1433007
	<i>Calibration</i>	2021-05-04

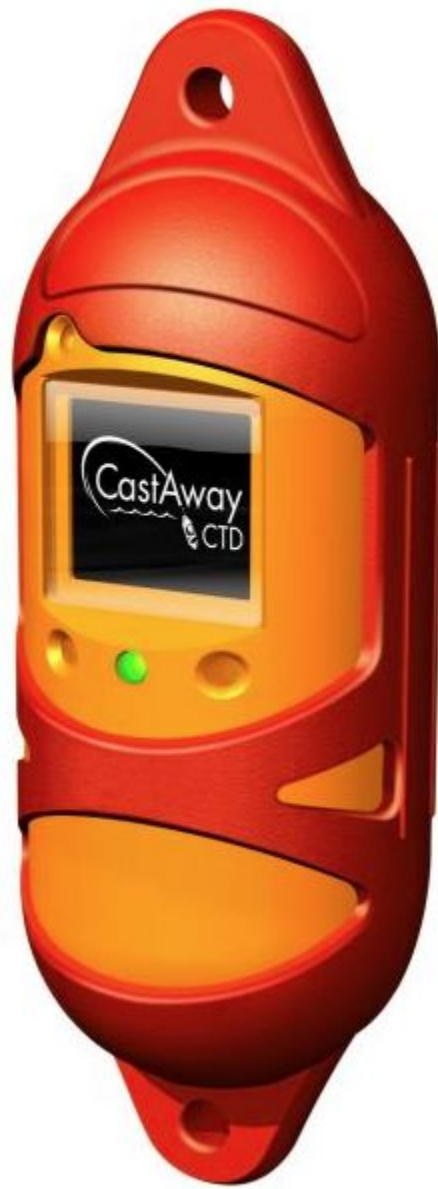


Figure 9: CastAway-CTD

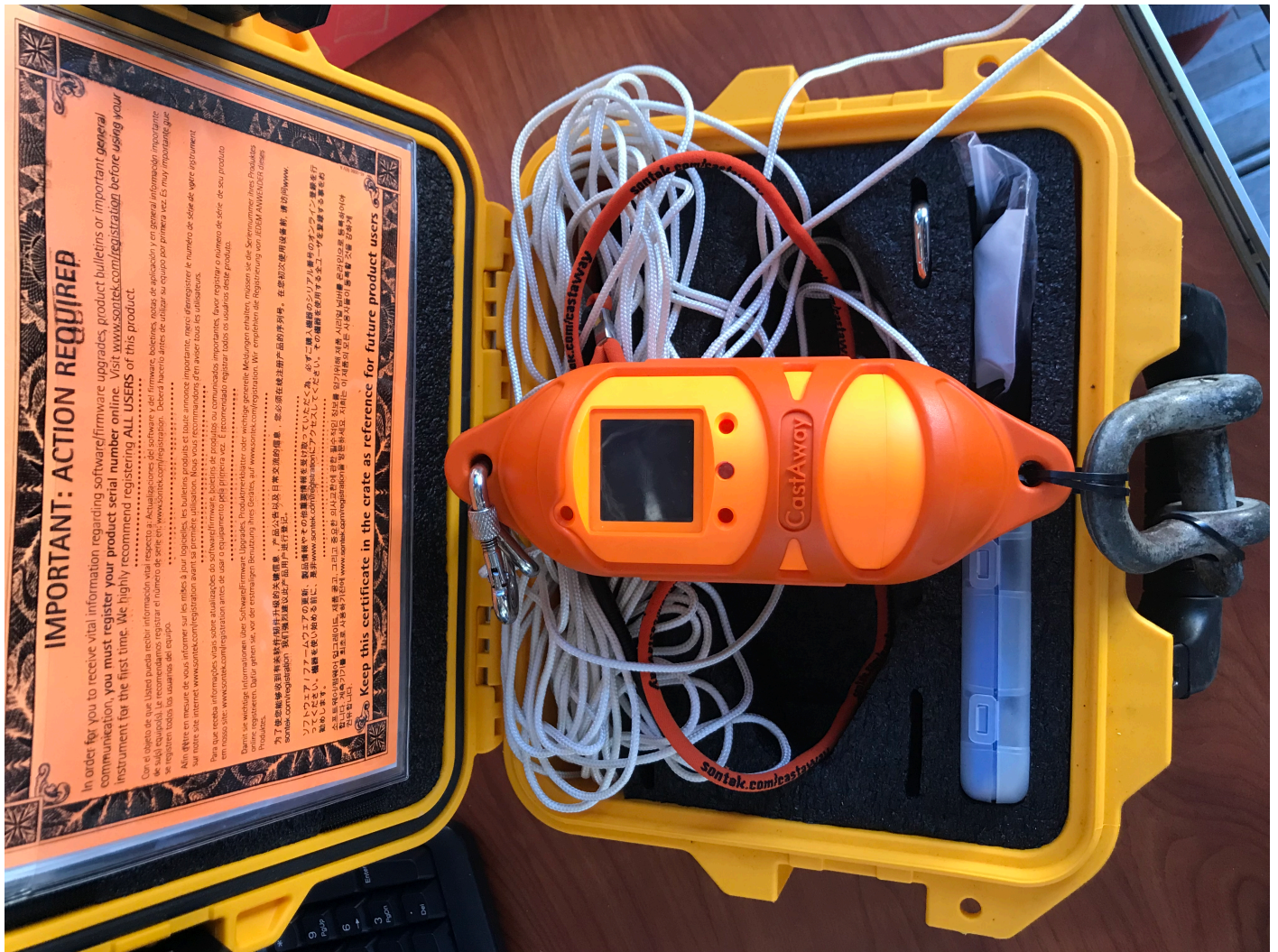


Figure 10: NRT-3's CastAway set up, featuring a large shackle zip tied to the bottom.

A.6.3 Sound Speed Sensors

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

The AML MicroX instrument with an SV-Xchange sensor-head provides surface sound speed data to the Kongsberg EM 2040C for beam forming and steering. The unit is configured to output an AML datagram to SIS.

The unit is mounted in a removable PVC pole that is inserted into a bracket on the transom between the two motors. Before surveying, the PVC pole is lowered into the bracket about 2' 6" below the waterline. The AML sensor is then lowered in the PVC piling and powered on from the 12 AC panel. When survey operations are complete the unit is powered off, removed from the PVC pipe and stored on the boat. The PVC pipe is then raised from the bracket for transiting.

<i>Manufacturer</i>	AML Oceanographic		
<i>Model</i>	Micro-X with SV-Xchange		
<i>Inventory</i>	S3006	<i>Component</i>	Sound Speed Sensor- Tip
		<i>Model Number</i>	Micro-X
		<i>Serial Number</i>	203521
		<i>Calibration</i>	2019-04-23



Figure 11: AML Micro-X SV probe



Figure 12: The PVC poles that are mounted inside a bracket on the transom that holds the AML sensor while surveying. The hole in the bottom of the tube allows for water flow over the sensor.

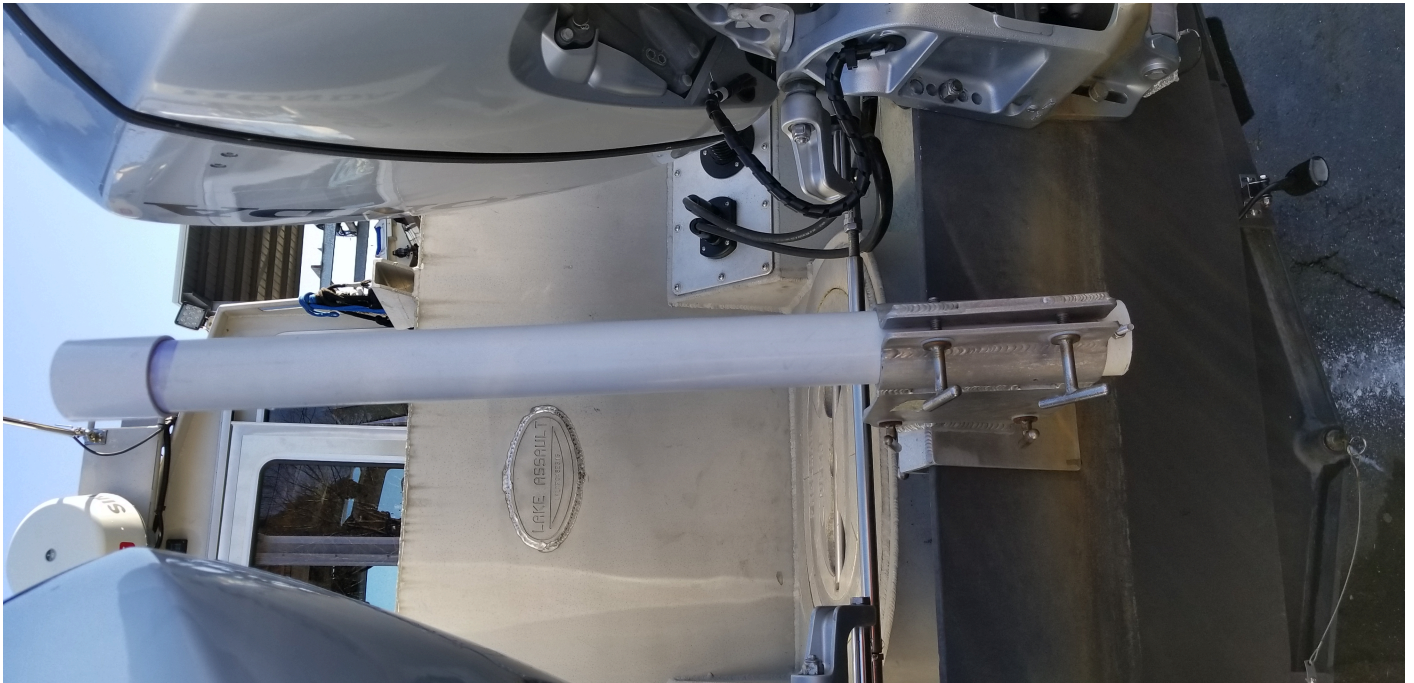


Figure 13: PVC pole mounted with a bracket to the stern of S3006



Figure 14: S3006's AML Micro-X SV probe.

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>
Teledyne Caris	Base Editor	5.4.5	Processing
Teledyne Caris	HIPS and SIPS	11.3.1	Processing
NOAA, Hydrographic Systems and Technology Branch (HSTB)	Pydro Explorer (ie: Charlene, QC tools 3, XmlDR, SHAM, transmission letter)	19.4 (r12060)	Processing
Xylem	Hypack / Hysweep	2018a	Acquisition
Applanix Corporation	MV- POS View	v10.5	Acquisition
Applanix Corporation	POSPAC MMS	8.6	Processing
Kongsberg	Seafloor Information System	4.3.2	Acquisition
EdgeTech	Discover 4125	40.0.0119	Acquisition
NOAA	Sound Speed Manager	2018.1.45	Acquisition and Processing
SonTek	CastAway CTD	1.5	Acquisition

A.8 Bottom Sampling Equipment

A.8.1 Bottom Samplers

A.8.1.1 Rickly Petite Ponar

The Rickly Petite Grab is a stainless steel Ponar type grab sampler, a commonly used sampler that is very versatile for all types of bottom sediments such as sand, gravel and clay. This modified self-tripping sampler features center hinged jaws and a spring loaded trigger pin that releases when the sampler makes impact with the bottom. The sampler's jaws are closed by the scissor action of the lever arms when the sampler is retrieved. On top of sample units chamber, cuts with slits have been made that are covered with neoprene rubber flaps to allow water to flow through for a controlled descent.

For deployment, a sturdy line is secured to the boat, and operator deploys the bottom sampler from the port side of the boat with the dive door open. Once the line goes slack, the operator tugs on the line three times to lift the bottom sampler from the bottom and drop it again. The bottom sampler is then hauled to the surface

and the sample inspected on the lid of a 5 gallon bucket and compared to sediment color and size cards. If no sample was obtained, the collection process is repeated twice more.



Figure 15: Rickly's Petite Ponar type grab sampler used on NRT-3.

B. System Alignment and Accuracy

B.1 Vessel Offsets and Layback

B.1.1 Vessel Offsets

Vessel offset correctors are the values used to describe the location of all hydrographic sensors in relation to a defined reference point. These values are needed to compute sensor lever arms required to correct for vessel orientation and ultimately produce the final geographic position for every sounding collected.

All offsets and associated uncertainties for NRT-Seattle were derived from full or partial surveys performed by NGS personnel. Images of the benchmarks used in the NGS survey are included in this report. Due to the lack of centerline bench marks on S3006, a 3rd bench mark was established on the stern and marked with an "X". The collected points were surveyed in an assumed coordinate system and needed to be translated the respective 0,0,0 reference point. The azimuth from CL 3 to CL 1 needed to be oriented to 0° 00' 00". Post Processing was performed using ForeSight DXM to produce the Coordinate Reports. The X Axis is Positive toward the Bow. The Y Axis is positive toward the Starboard side. The Z Axis is positive downward.

All offsets are tracked and updated as needed. The offsets for NRT-Seattle are measured with respect to the vessel's IMU, with the transmit transducer phase center is defined as the Reference Point (RP) for hull S3006; with the exception of the offsets between the primary GPS antenna and the IMU. The distance between primary antenna and IMU is entered into POSView, which then feeds position relative to the IMU to all integrated sonars. The patch test values were entered into the POS MV as well. SIS only contains the value associated with the location of the waterline.

The CARIS HIPS HVF is relatively simple, all field contain all zeros with "apply=no" with the exception of the TPU, Waterline and Dynamic Draft Field.

Transducer roll is -0.147000 degrees as entered in the HVF. When exporting the DAPR to PDF, the transducer roll value is rounded up to -0.15 degrees.

Offsets are applied to sidescan sonar data during the Recompute Towfish Navigation step.

Lever Arms & Mounting Angles

Lever Arms & Mounting Angles | Sensor Mounting | Tags, AutoStart

Ref. to IMU Target	IMU Frame w.r.t. Ref. Frame	Target to Sensing Centre	Resulting Lever Arm
X (m) 0.002	X (deg) 0.124	X (m) 0.005	X (m) 0.010
Y (m) 0.009	Y (deg) 1.577	Y (m) -0.006	Y (m) 0.003
Z (m) -0.393	Z (deg) 0.451	Z (m) 0.089	Z (m) -0.304

Ref. to Primary GNSS Lever Arm	Ref. to Vessel Lever Arm	Ref. to Centre of Rotation Lever Arm
X (m) 4.253	X (m) 0.000	X (m) 0.000
Y (m) -0.741	Y (m) 0.000	Y (m) 0.000
Z (m) -3.131	Z (m) 0.000	Z (m) 0.000

Notes: 1. Ref. = Reference
2. w.r.t. = With Respect To
3. Reference Frame and Vessel Frame are co-aligned

Compute IMU w.r.t. Ref. Misalignment

Enable Bare IMU

Ok Close Apply View

Figure 16: Lever Arms and Mounting Angle values entered in POS MV for S3006



Figure 17: Benchmark location, port side aft on S3006



Figure 18: Benchmark location, starboard side aft on S3006



Figure 19: Benchmark location, centerline forward on S3006

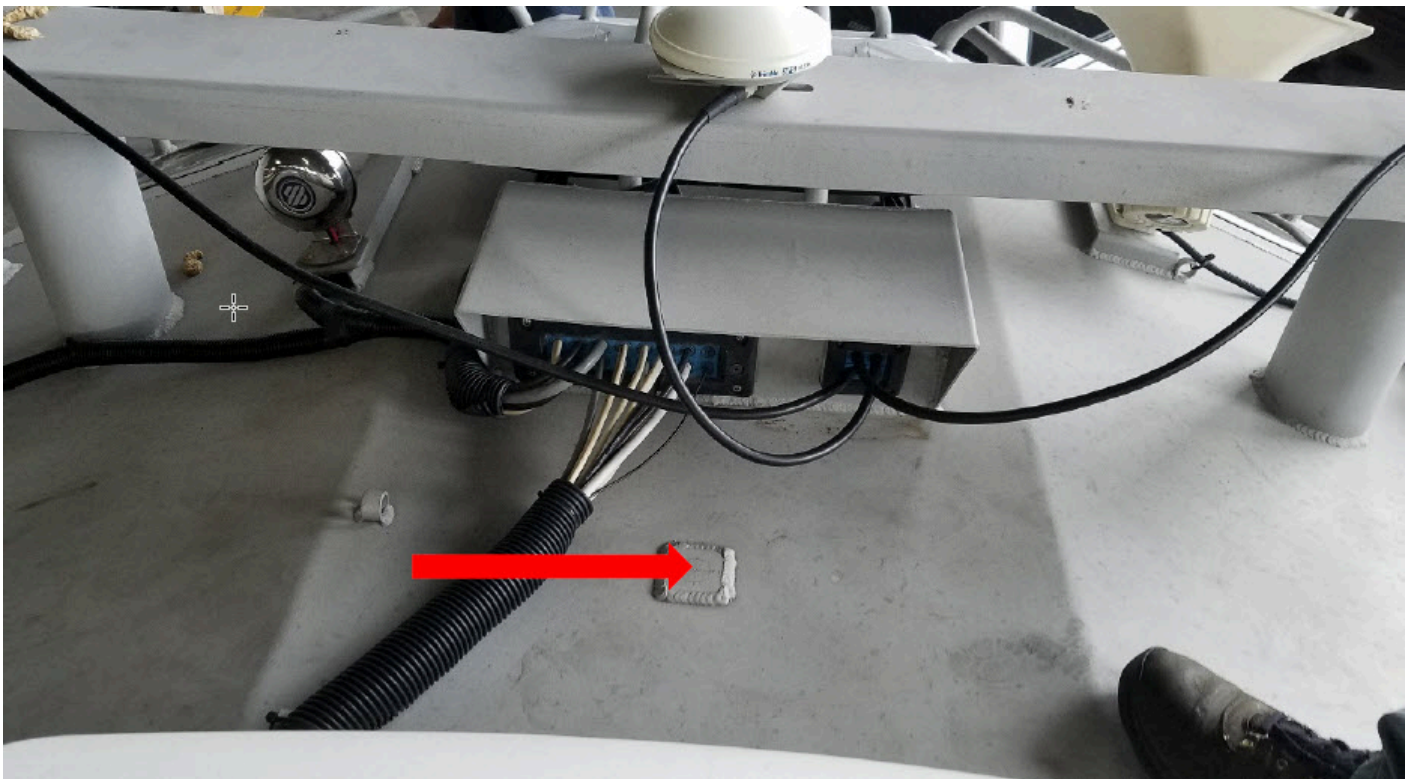


Figure 20: Benchmark location, centerline mid-ships on top of the house on S3006

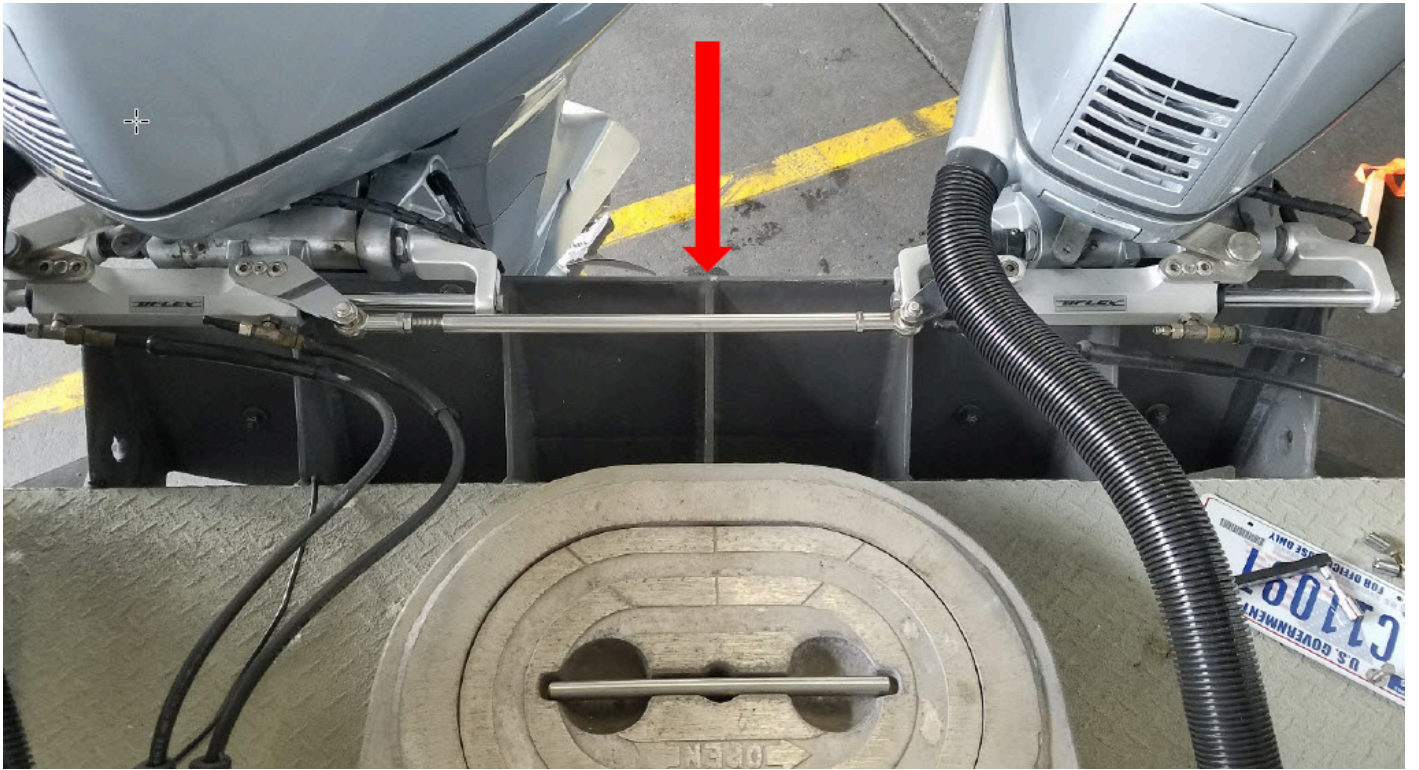


Figure 21: Added benchmark location, centerline aft on S3006



Figure 22: Enhanced image of added benchmark location, centerline aft on S3006

B.1.1.1 Vessel Offset Correctors

<i>Vessel</i>	NRTSEA_S3006_EM2040C			
<i>Echosounder</i>	Kongsberg EM2040C 300kHz Simrad EM2040C 300kHz			
<i>Date</i>	2021-04-20			
<i>Offsets</i>	<i>MRU to Transducer</i>		<i>Measurement</i>	<i>Uncertainty</i>
		<i>x</i>	-0.035 meters	0.010 meters
		<i>y</i>	-0.014 meters	0.010 meters
		<i>z</i>	0.434 meters	0.010 meters
	<i>Nav to Transducer</i>	<i>x</i>	0.741 meters	0.010 meters
		<i>y</i>	-4.325 meters	0.010 meters
		<i>z</i>	3.131 meters	0.010 meters
	<i>Transducer Roll</i>	<i>Roll</i>	0.000 degrees	

B.1.2 Layback

No towfish layback collected for this project.

Layback correctors were not applied.

B.2 Static and Dynamic Draft**B.2.1 Static Draft**

All static draft values are stored in the CARIS HVF as the waterline value. This value is measured during the annual HSRR and used for the entire field season, barring any significant equipment or loading changes. This value was measured using a level and steel tape during HSSR by NRT-Seattle in April 2021, and only measured once during the field season.

The static draft value is entered in Kongsberg SIS Installation Parameters window. The The Apply switch in the CARIS HVF is set to "No". If it is set to "Yes", the waterline value will be applied twice, once in SIS and again in Merge. If it is set to "yes", the waterline value will be applied twice, once in SIS and again when merging.

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>
NRTSEA_S3006_EM2040C	2021-04-20	0.015 meters	-0.555 meters	0.024 meters

B.2.2 Dynamic Draft

The field unit acquired dynamic draft survey line on S3006 in Lake Washington, Seattle, WA on March 29, 2021. While logging a POS file, one straight line was run north and south at 4, 6, 8, and 10 knots for approximately 2 1/2 minutes. The POS file was imported into POSpac and processed using Applanix RTX and GNSS Inertial Processor. Pydro's POSpac AutoQC was used to open the project to see the results by directing the program to the extract folder and HVF file. No tide file was needed due to collection in Lake Washington. The resulting Dynamic Draft tab shows a table that correlates speed with vessel draft, which can be input into the vessel file. A 4th order polynomial regression was determined from the test and outputs were used to calculate an average of values from 2021 and previous years. The average values were entered into the Caris HVF.

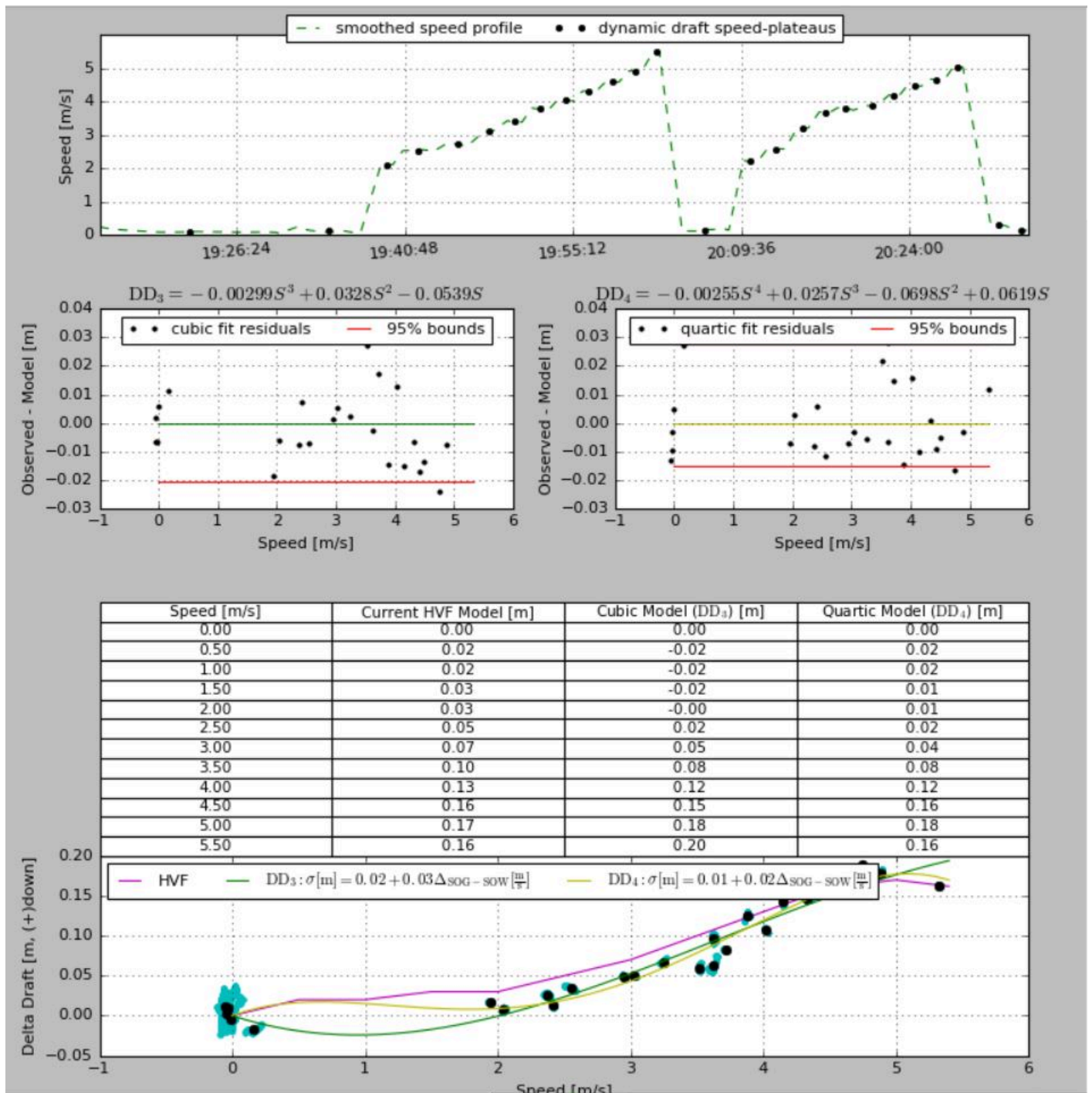


Figure 23: Dynamic Draft analysis from POSPac AutoQC

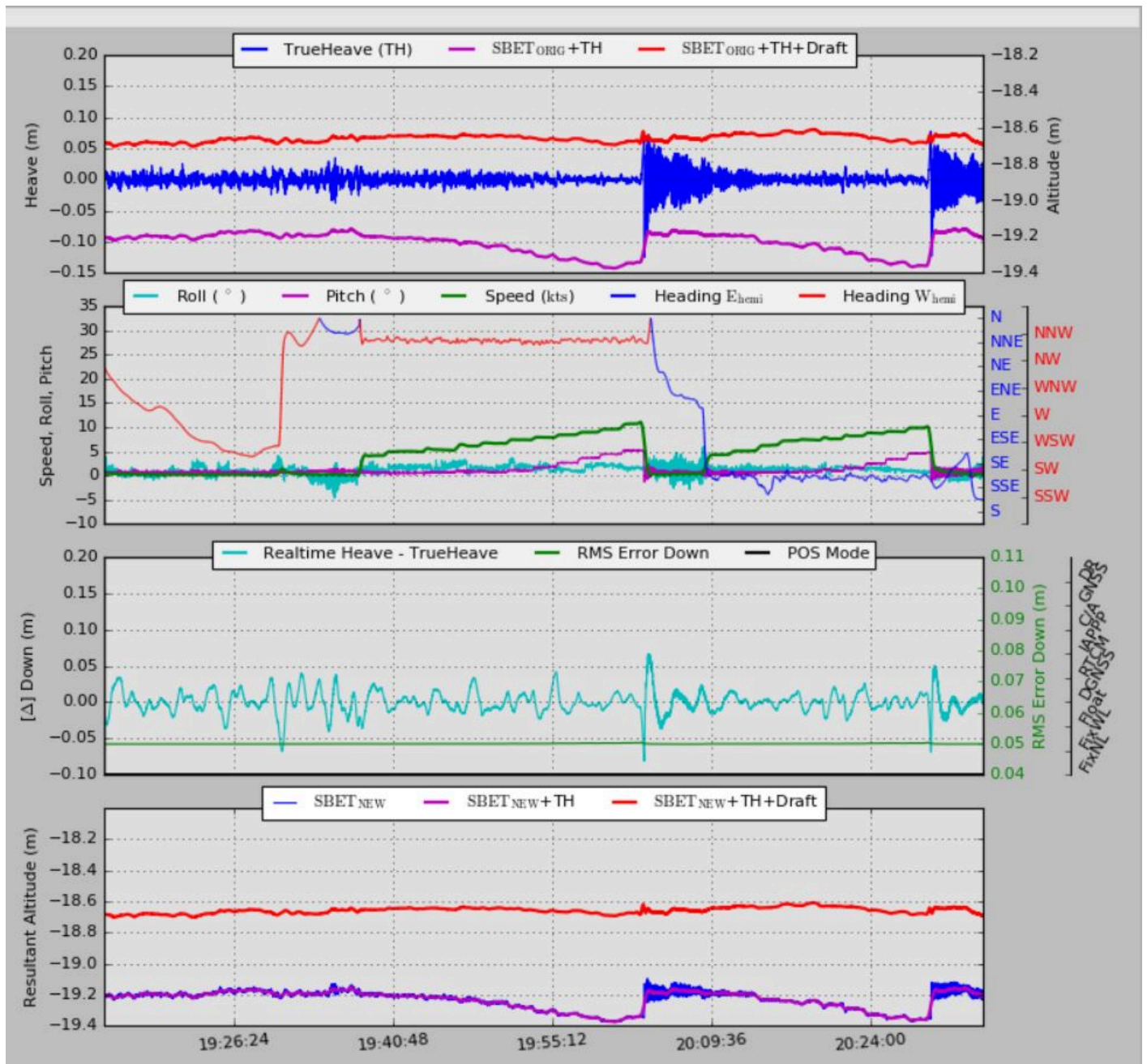


Figure 24: POSpac AutoQC Results from ERDMM line processed

B.2.2.1 Dynamic Draft Correctors

<i>Vessel</i>	NRTSEA_S3006_EM2040C	
<i>Date</i>	2021-04-20	
<i>Dynamic Draft</i>	<i>Speed (m/s)</i>	<i>Draft (m)</i>
	0.00	0.00
	0.50	0.01
	1.00	0.01
	1.50	0.01
	2.00	0.02
	2.50	0.04
	3.00	0.06
	3.50	0.09
	4.00	0.12
	4.50	0.15
	5.00	0.16
<i>Uncertainty</i>	<i>Vessel Speed (m/s)</i>	<i>Delta Draft (m)</i>
	0.05	0.03

B.3 System Alignment

B.3.1 System Alignment Methods and Procedures

NRT-Seattle conducted MBES calibration tests to verify the angular offsets between IMU orientation and the transducer orientation on March 30, 2021 as part of HSRR with both team members from NRT-3 and the HSTB West Coast Representative in Shilshole Bay. The procedure used follows the outline in section 1.5.5. of the 2021 Field Procedures Manual. Alignment between components are measured using patch test methods that result in rotational differences between the IMU and the sonar transceiver face along the x-, y-, and z-axes (Pitch, roll, and yaw). Timing bias was assumed to be zero. Pitch and yaw bias was determined using a target on the sea floor. And finally, roll bias was determined using the standard flat bottom method.

Patch test values were derived for each value after the applicable test in CARIS by three people, with the results averaged. These values were then entered into SIS before performing the next test. Once all tests were completed, the values were transferred to the POS MV. Data was converted in CARIS HIPS using a HVF file with heave, pitch, roll and timing values set to zero. True heave, water levels, the most recent dynamic draft, and sound velocity profiles were applied and the data merged before cleaning via Swath Editor. Biases were determined using the CARIS HIPS Calibration tool. Bias values were determined in the following order; pitch, roll, and finally yaw.

B.3.1.1 System Alignment Correctors

<i>Vessel</i>	NRTSEA_S3006_EM2040C		
<i>Echosounder</i>	Kongsberg EM2040C 300kHz Simrad EM2040C 300kHz		
<i>Date</i>	2018-04-11		
<i>Patch Test Values</i>		<i>Corrector</i>	<i>Uncertainty</i>
	<i>Transducer Time Correction</i>	0.000 seconds	0.010 seconds
	<i>Navigation Time Correction</i>	0.035 seconds	0.010 seconds
	<i>Pitch</i>	0.000 degrees	0.045 degrees
	<i>Roll</i>	0.000 degrees	0.045 degrees
	<i>Yaw</i>	0.000 degrees	0.148 degrees
	<i>Pitch Time Correction</i>	0.000 seconds	0.010 seconds
	<i>Roll Time Correction</i>	0.000 seconds	0.010 seconds
	<i>Yaw Time Correction</i>	0.000 seconds	0.010 seconds
	<i>Heave Time Correction</i>	0.000 seconds	0.010 seconds

C. Data Acquisition and Processing

C.1 Bathymetry

C.1.1 Multibeam Echosounder

Data Acquisition Methods and Procedures

Multibeam data from the EM 2040C on S3006 are monitored in real-time with the acquisition software, SIS (Seafloor Information System). Data are displayed using 2-D and 3-D data display windows in the real-time screen display. Mainscheme data are acquired using either planned lines, or an adaptive line steering approach whereby the coxswain views a real-time coverage map in Hysweep and accordingly adjusts line steering to ensure assigned coverage requirements are met. Additionally, vessel speed is adjusted as necessary, and in accordance with the NOS Hydrographic Surveys Specifications and Deliverables and Draft Standing Project Instructions, to ensure the required along-track coverage for object detection. NRT-3 typically does not change SIS settings from auto, but in some cases the range scale, gain, and pulse width parameters are adjusted; adjustable filtering and cleaning are not employed on S3006.

Data Processing Methods and Procedures

Following acquisition, multibeam sonar data were processed either using CARIS HIPS and SIPS manually or by using the automated Pydro Explorer application, Charlene, to perform the same steps. The standard data processing steps are as follows:

1. Convert raw Kongsberg (.all) data to the HDCS data format
2. Load delayed heave
3. Load and apply sound velocity corrections
4. Load SBET and RMS corrections
5. Compute GPS tide to transform data from the ellipsoid to the tidal datum using a VDatum separation model
6. Merge data to apply position attitude, and dynamic draft correctors to bathymetry and compute the corrected depth of each sounding
7. Compute Total Propagated Uncertainty (TPU)
8. Create CUBE grid(s) encompassing survey area
9. Data quality control and analysis

The following options are selected when CUBE surfaces were 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 also consistent with neighboring nodes).
- Advanced Configuration – Dependent upon the surface resolution (Object detection v. complete coverage)

Preliminary data cleaning is performed daily. Typically, the reviewer only cleans out the most blatant of fliers and blowouts, leaving the final cleaning to a later date when all data is consolidated. 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 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.

Once all the data is cleaned, the CUBE surfaces are examined to ensure complete coverage and to plan additional lines or polygons to fill "holidays."

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

Surfaces are generated in CARIS using the CUBE gridding method utilizing the settings mentioned in Data Processing Methods and Procedures. Resolution is determined by the Project Instructions and the HSSD. When creating Variable Resolution (VR) surfaces, the estimation method used is "Ranges".

C.1.4.2 Depth Derivation

Chart-datum depths are derived using tidal models provided to the field unit, usually in the form of a VDatum separation model that corrects for height disagreements between the acquisition datum (Ellipsoidal) and chart datum (Tidal). Anomalous data (fliers) may corrupt gridded depth estimates and draw gridded depth nodes away from reliable soundings. Flier Finder within QC Tools is used to help identify such anomalous soundings for the hydrographer to clean, or reject, from the submitted sounding dataset.

C.1.4.3 Surface Computation Algorithm

The disambiguation method used is always Density and Locale. The settings used for Capture Distance Scale, Horizontal Error Scale, and Capture Distance Minimum are those listed in the HSD (previously HTD 2017-2). After creation, CUBE surfaces go through a quality control process. During this process, the Depth, Uncertainty, Standard Deviation, and Density child layers are examined for compliance with NOAA specifications. After the surfaces pass quality control, they are finalized. Uncertainty values for finalized surface come from the greater of either Uncertainty, or Standard Deviation.

The advanced options configuration is manipulated to create VR surfaces. Estimation methods parameters for Density-Based CARIS VR Surfaces have the estimation method: "Ranges" , with the range/resolution file to NOAA_DepthRanges_ObjectDetection_2017.txt, in addition to maximum and minimum grid size. The NOAA Office of Coast Survey (OCS) has created and provide a customized CUBE parameters file (CubeParams_NOAA.xml) with new CUBE parameters that are required for each grid resolution. When creating CUBE surfaces, the user is provide an option to select parameter configuration based on the surface resolution re4quired for the survey, which optimizes the performance of the CUBE algorithm. The population parameters for CARIS VR surfaces is CUBE, with the IHO Order selected and set to "S44 Order 1a", and the CUBE Configuration is "NOAA_VR" for a given surface.

C.2 Imagery

C.2.1 Multibeam Backscatter Data

Data Acquisition Methods and Procedures

MBES backscatter data are logged via SIS and are included in the MBES files (.all format) by default. The acoustic backscatter strength of the bottom is calibrated in our factory, and have a typical accuracy of ± 1 dB. However, this value may be offset from zero to serve as a correction factor, for example if there is a change with the age of the system, or if data from two different systems are merged and there is a systematic offset between the two systems. These offset values are kept at zero unless otherwise documented.

The absorption coefficient depends upon depth, water temperature, salinity and frequency. A correct value is important with respect to the validity of the bottom backscatter data measured by the system.

Users may also adjust the normal incidence sector [Angle from nadir (deg)] which defines the angle at which the bottom backscatter can be assumed not to be affected by the strong increase at normal incidence. For seabed imaging, it is important to adjust this angle so that a minimum of angle dependent amplitude variation is seen. The value for this parameter is kept at 15 degrees unless otherwise documented.

Data Processing Methods and Procedures

All NOAA Field units with the exceptions of NRB are required to process multibeam backscatter for creation of GSF files and generating backscatter mosaics using QPS FMGT software.

If the NRT's were to process backscatter, the following acquisition, backscatter data is processed by using the program FM Geocoder Toolbox (FMGT) and following the subsequent steps:

- A new project is created for each sheet and each vessel and each sonar frequency. Metadata within the .all files ensures that sonar-specific characteristics are captured during mosaic processing.

- Vessel parameters are set, and allow the hydrographer to set configuration for each frequency and pulse length in order to calibrate slight differences in decibel levels. This produces a smoother, less patchwork appearance of backscatter mosaics between each frequency and 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.

- Lines are imported into FM GT. One mosaic is created per boat and frequency (200kHz and 400kHz), meaning two mosaics are created, one for each frequency.

- Create a mosaic. Any crosslines not needed in the mosaic are deselected. Mosaic gridding resolution is set to ensure resulting TIF backscatter mosaic files do not exceed 200MB to keep the program from crashing. The product is exported as gray scale GeoTIFF.

C.2.2 Side Scan Sonar

Data Acquisition Methods and Procedures

Side scan imagery data is collected utilizing a pole mounted Edgetech 4125, typically operated on a 50 to 100 meter range scale. 900kHz and 400kHz data is logged, though normally only the high frequency data is processed. The 400kHz data is processed and used where it is warranted to have better data quality than the 900kHz.

NRT-Seattle uses Edgetech's Discover 1 program to monitor the quality of real-time imagery and to log raw side scan files in .JSD format while acquiring side scan data from the pole mounted system.....

Data Processing Methods and Procedures

There are no offsets applied through Discover 1; navigation and heading are calculated from ship's navigation recorded in the POS .000 file. The raw .JSD files are converted using NOAA's Hydrographic Systems Technology Branch Pydro Explorer v. 19 automated data processing tool, Charlene. this program takes takes the Caris HVF with tow point X and Y offset values in relation from the reference point (multibeam transducer), the Z value is from the waterline to the side scan. The process is the same steps as if manually converting the data in Caris HIPS and SIPS.

1. Convert Raw data- the raw .JSD files are converted to Caris processed data format. During this process towfish positioning is determined through the Edgetech 4125's altitude
- 2 Recompute towfish navigation- Towfish navigation is developed from data collected, using ship's navigation (POS .000 file), towfish altitude, and layback. Layback is calculated from the towpoint that is recorded in the Caris HVF; towfish gyro is used for direction.
3. Create Beam Pattern- build .BBP file through averaging the intensities and angles from across the data set. These averages are then applied to "Create Mosaic" to produce more consistent images
4. Create Mosaic- generate a SIPS mosaic utilizing the beam pattern, transmit and receiver gain, and the time varied gain (TVG) corrections.

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.

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 between 2 and 6 meters horizontally.

Data Processing Methods and Procedures

DGPS data are processed within the POS/MV system in real time, and included within the .000 file. Typically, the DGPS data are superseded by the more accurate, post-processed SBET files created from POSpac, or superseded by the use of Precise Point Positioning when available.

C.3.2 Vertical Control

C.3.2.1 Water Level Data

Data Acquisition Methods and Procedures

Water level data was not acquired.

Data Processing Methods and Procedures

Water level correctors are typically applied to hydrographic data by one of two methods;

- 1) discrete zones by way of a CO-OPS supplied zone definition file (.zdf)
- 2) TCARI, the Tidal Constituent And Residual Interpolator by way of a CO-OPS supplied TCARI grid file (.tc).

Depending on vertical control requirements, CO-OPS may require the installation of subordinate tide gauge(s) in the project area. If subordinate tide gauge(s) are used, station packages are sent to CO-OPS following installation, performance of bracketing levels, and removal as required by Section 4.6.1 of NOAA HSSD. For the 2019 field season, NRT3 was not required to install any tide gauges.

NRB utilizes SEP models for the majority of survey requirements. If the team needed to request tides from CO-OPS upon completion of a sheet, Pydro is used to generate a request for final tides which includes a times of hydrography abstract and mid/mif tracklines. This request is submitted via email to Final.Tides@NOAA.gov with the project number and sheet number in the subject line of the email. Once CO-OPS receives this request, a review of the times of hydrography, final tracklines, and six-minute water level data from all applicable water level gauges is conducted.

After this review if there are no issues, CO-OPS will send a notice indicating that the tidal zoning scheme (.zdf or .tc) sent with the project instructions has been approved for final zoning. If there are discrepancies, CO-OPS will make the appropriate adjustments and forward a revised tidal zoning scheme to the ship for final processing.

DISCRETE ZONES

For daily processing, soundings are reduced to Mean Lower-Low Water (MLLW) using predicted water levels files supplied with the project instructions. The predicted water level data are applied to the survey depths in CARIS using height ratio and time correctors from a preliminary CO-OPS provided zone definition file. No real-time tide or water level corrections of soundings took place in during data acquisition.

After the conclusion of data acquisition, CO-OPS will either accept preliminary zoning as the final zoning or supply a revised zoning file. Verified six-minute water level data is downloaded for the operating station(s) providing water level reducers for the project as listed in section 1.3.1 of the Water Level Instructions. Once all required water levels are downloaded, they are loaded from the main menu in CARIS HIPS, Process > Load Tide... and the zdf file is selected.

TCARI

To reduce soundings to Mean Lower-Low Water (MLLW), the TCARI grid file sent from CO-OPS is loaded into Pydro. Once in Pydro the TCARI grid may be examined along with the list of tide stations that affect it. TCARI utilizes all tide stations in the project area (historical and currently operating) for harmonic constants and datums. Only those stations selected in the residual column are used for residuals. Residuals are the difference between observed water levels and predicted water levels due to non-tidal components such as meteorological effects. The TCARI Project Instructions sent for each project list the stations required for residuals that must be downloaded from the CO-OPS website.

For initial daily processing, soundings were reduced to Mean Lower-Low Water (MLLW) using predicted water levels from the preliminary TCARI file supplied with the project instructions. Applying tides with the TCARI file by itself without loading any water level data simply applies predicted tides without any of the residual correctors that observed water levels would provide.

After the conclusion of data acquisition, verified six-minute water level data for operating stations supplying residuals as listed in section 1.3.6 of the Water Level Instructions are downloaded on the MLLW datum in meters and UTC. TCARI tides are loaded and applied directly to CARIS HDCS data using Pydro. Once all required water levels are downloaded, they are loaded from the main menu bar, Tides > Load WL Data. Tide reducers are generated for HDCS bathymetry from the main tool bar, Tides > CARIS TCARI Tide > Load TCARI Tide in HIPS PVDLs. At this time HDCS data is selected by project, vessel, and day with individual lines selected with the Descend/Confirm button. TCARI then creates new “Tide”, “TideLineSegments”, and “TideTmIDX” files for each line of bathymetry. Once TCARI created the new tide files, the lines were re-merged in CARIS to force the changes to take effect.

TCARI automatically calculates the error associated with water level interpolation. This error is incorporated into the residual/harmonic solutions and included in the Total Propagated Uncertainty (TPU) for the survey. Although the uncertainty values input into TCARI model are 2-sigma, Pydro automatically supplies 1-sigma values to CARIS when computing uncertainty.

ERS ERZT Separation Model and GPS tides

For the 2019 field season, NRT3 had the requirement to vertically reference survey data to the ellipsoid. This is achieved through the use of either a VDATUM or ERZT separation model.

C.3.2.2 Optical Level Data

Optical level data was not acquired.

C.4 Vessel Positioning

Data Acquisition Methods and Procedures

NRT3 utilizes Post Processed Kinematic (PPK) 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 three methods available in order of preference are 1) Smart Base, 2) Single Base, and finally 3) Precise Point Positioning (PPP).

Smart Base:

Smart Base is the preferred method when a minimum of four (six recommended) CORS stations are available for selection near the project area. In situations with a maximum baseline of 70 km, an optimal horizontal accuracy of 3-10 cm should be achieved.

Applanix POSPac software is used to produce a Smoothed Best Estimate of Trajectory (SBET) file. The SBET file consists of GPS position and attitude data corrected and integrated with inertial measurements and reference station correctors, exported into WGS84. The SBET is created using the Applanix proprietary “SmartBase” algorithm, which generates a Virtual Reference Station (VRS) on site from a network of established reference stations surrounding the project area, generally the Continually Operating Reference Station (CORS) network. Reference station data is downloaded with the POSPac MMS download tool and usually available within 24 hours. These SBET navigation and attitude files are applied to all lines in CARIS and supersede initial positioning and attitude data. For further details on the CORS network stations utilized in addition to processing methodology, refer to the HVCR of the appropriate project.

Single Base:

The Single Base solution of processing SBETs requires the input of attitude data acquired by the POS/MV in addition to simultaneously collected base station data. Vessel kinematic data is post-processed using Applanix POSPac processing software, POSGNSS processing software and Single Base processing methods. These SBET navigation and attitude files are applied to all lines in CARIS and supersede initial positioning and attitude data. Further details on the CORS station(s) and/or NRT3-installed GPS base station(s) utilized in addition to processing methodology would be included in the HVCR of the appropriate project.

Precise Point Positioning:

Precise Point Positioning (PPP) is used as a last resort when Smart Base or Single Base is not available. This occurs when NRT3 conducts survey operations far enough offshore that it is physically impossible to install a shore base station within the recommended 20km radius. Precise Point Positioning may also be used to cover data gaps and/or outages in data from a CORS station or a NRT3-installed base station. When PPP is chosen, an optimal horizontal accuracy of 10-50 cm should be achieved.

Data Processing Methods and Procedures

POSPac creates SBET (smoothed best estimate trajectory) files by post-processing the POSPac .000, GNSS and base station data. SBETs are ingested by CARIS, along with the original POSPac .000 file, to provide high accuracy positioning data to collected bathymetry.

The favored method of processing raw POS MV data requires input from nearby semipermanent shore stations. POSPac has two options for handling shore stations, Single Baseline and SmartBase processing. SmartBase processing is the preferred method, when an eligible network of installed base stations are available. For the SmartBase method, an optimal network consists of six to eight reference stations evenly distributed around the surveyed area and separated by 50 to 70 km. A minimum of four stations are required for Applanix SmartBase processing.

For the single base station method, the primary-reference baseline separation must be less than 20 km at the start and end of the mission and can occasionally grow to 100 km during the mission. For the single base station method, the primary-reference baseline separation must be less than 20 km at the start and end of the mission and can occasionally grow to 100 km during the mission. For the SmartBase method, an optimal network consists of six to eight reference stations evenly distributed around the surveyed area and separated by 50 to 70 km. A minimum of four stations are required for Applanix SmartBase processing. This information is utilized by Charlene for SBET and RMS processing.

- Smart Base Processing

- 1) Open Applanix POSPac™ Mobile Mapping Suite and set up the project
- 2) Load the Applanix .000 file (recorded on the launch)
- 3) Select the "Find Base Stations" option which will generate a list of nearby CORS stations and then click on the "Smart Select" button.
- 4) POSPac will need the Internet to access and download the base station data it finds as the best option to import. It will need a minimum of 4 stations as well as adequate ephemeris data to continue. This process is done automatically.
- 5) Once the base stations and ephemeris data have been downloaded, the Raw Data Check-In window will appear automatically, click OK. Once you click OK, POSPac will create a triangulated network of all the base stations it has chosen for processing.
- 6) Next run the SmartBase Quality Check. POSPac will run the quality check to see if the data downloaded is good enough for processing and generate a Results Summary. If the data is inferior, it will recommend to Re-run the SmartBase Quality Check processor or that there is not enough adequate data to continue.
- 7) Due to the remote locations Rainier surveys, sometimes there is not an optimal amount of data available. Occasionally you have to override the system and see if the SBET generated is up to spec. This is done by running the Applanix SmartBase processor.
- 8) Once the Applanix SmartBase processor has finished, the outline of the triangulated network will be highlighted in yellow. This means that you are ready for processing and that the appropriate base stations have been designated and set.

- Batch Processing -- Batch processing allows processing of multiple POS/MV .000 files from multiple vessels on a once per day per survey sheet basis.
- POSPac SBET Quality Control -- Once the POSPac project has completed processing successfully, quality control of the SBETs (Smoothed Best Estimated Trajectories) is performed.
- Exporting Custom SBET -- Once the QC is complete and the processing log updated, the next step is to export a custom SBET in NAD83.

- Single Base Station Processing

- 1) Open Applanix POSPac™ Mobile Mapping Suite and set up the project
- 2) Load the Applanix .000 file (recorded on the launch)
- 3) Load the satellite data logged by the base station (the .YYo file that corresponds to the day number being processed).
- 4) Once the coordinate manager window opens, the true ITRF coordinates from the OPUS report is input. The same ITRF coordinates are used throughout the project and are checked against "new" OPUS solutions to maintain consistency.
- 5) Both the SBET (in ITRF format) and smrmsg error data files are created.

For both a Single Base or Smart Base solution, SBETs are applied in CARIS by loading both the SBET files and error data files in smrmsg format. For every SBET file generated during single base station processing there is an associated smrmsg file.

- 1) Process --> Load Attitude/Navigation data... Load the WGS84 SBET files. Import data for Navigation, Gyro, Pitch, Roll, and GPS Height are all selected for survey launches. Only Navigation and GPS Height are selected for the ship.

2) Process --> Load Error data... Load the smrmsg error data file. Import data for Position RMS, Roll RMS, Pitch RMS, and Gyro RMS are selected for survey launches. Vertical RMS is not selected since HIPS will default to using the trueheave RMS values. Only Position RMS is selected for the ship.

In the event that no base station falls within the 20km limit as is often the case with offshore sheets, and a Precise Point Positioning (PPP) solution utilizing precise ephemeris data is used, SBET and RMS are loaded as follows.

1) Process --> Load Attitude/Navigation data... Load the custom SBET files (WGS84). Import data for Navigation and GPS Height are selected for survey launches and the ship.

2) Process --> Load Error data... Load the smrmsg error data file. Import data for just the Position RMS, is selected for survey launches and the ship. Vertical RMS is not selected since HIPS will default to using the trueheave RMS values for the launches.

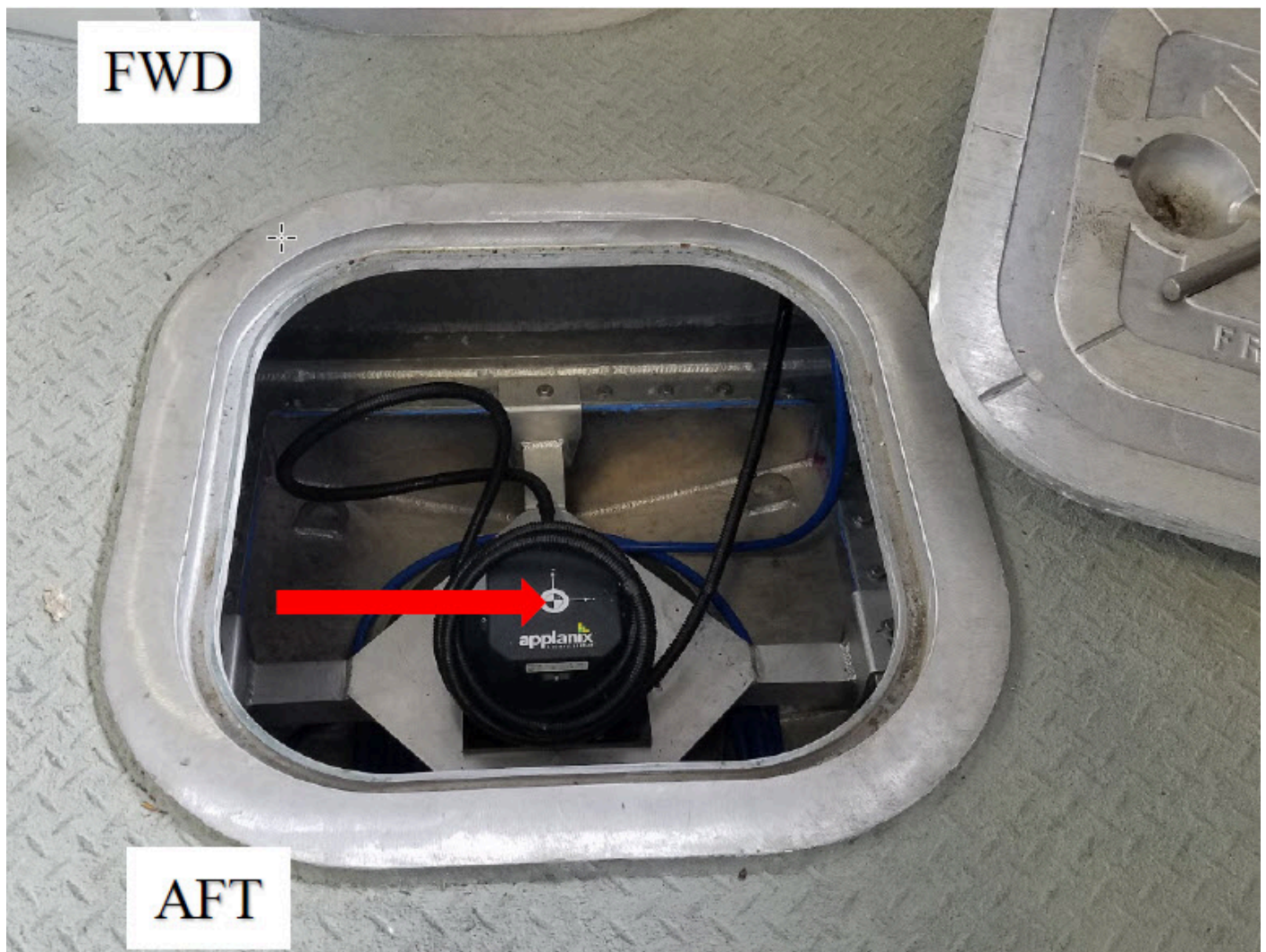


Figure 25: S3006 IMU orientation on the aft deck of S3006.

C.5 Sound Speed

C.5.1 Sound Speed Profiles

Data Acquisition Methods and Procedures

Sound velocity profiles are acquired with the SonTek CastAway-CTD. Upon start up, the CastAway takes several minutes to acquire a starting GPS location. Icons at the bottom of the LCD (plus the status LED) show the quality of the GPS location data. The number of satellites being tracked is also displayed. The CTD is manually prompted to start logging, and then lowered to just below the water surface where the instrument is kept at the water surface for approximately 10 seconds. This allows the CTD sensors to stabilize to the surface water conditions. The CTD is allowed to free fall (it's engineered to free fall at a rate of 1m/s), after which it is brought back to the surface by hand at a rate of approximately 1m/s. The CTD is then manually prompted to stop logging. Casts are transferred from the CTD to the NRT3 acquisition computer via blue tooth connection.

Casts are taken approximately every 4 hours or when there is a noticeable change in the environment or survey area as prescribed by the 2014 FPM. SIS monitors changes in the surface sound speed compared to the value obtained with the last cast in real-time. The "SV Profile" and "SV Used" numerical displays were highlighted in yellow if the difference is greater than 3 m/s and red for a difference greater than 5 m/s. Realtime surface sound speed is also monitored and additional casts are taken when there is a change in sound speed over 2 m/s.

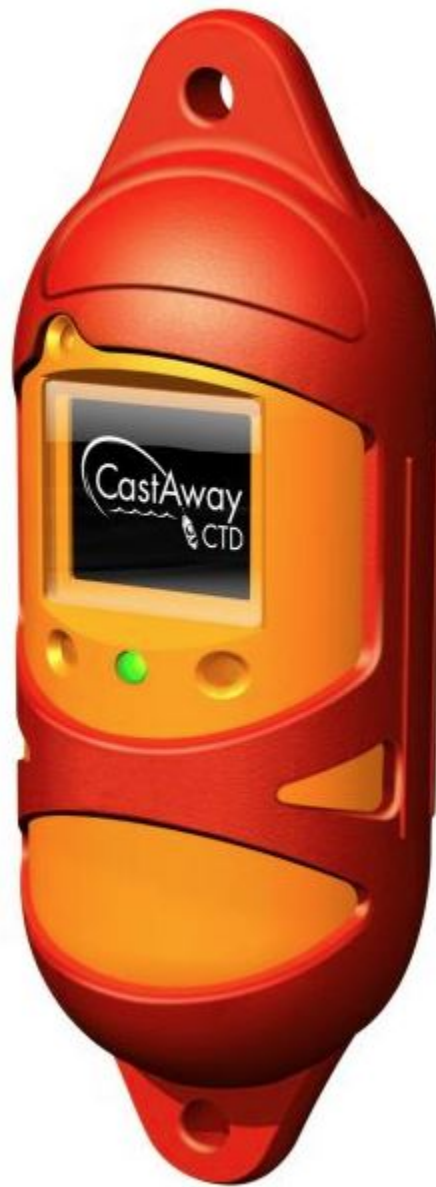


Figure 26: Sontek Castaway-CTD

Data Processing Methods and Procedures

Downloading and processing of sound speed data is performed using Sound Speed Manager, part of the HSTB-supplied Pydro program suite. Sound speed values are calculated using the UNESCO equation (Fofonoff and Millard, 1983). Processed profiles are sent to SIS for realtime beam control. In addition, both raw and processed CTD files are archived and submitted to the hydrographic branch as part of the sheet submission package.

All sound velocity profiles for CARIS are concatenated into a vessel-wide or sheet-wide files in order of ascending time and date. These concatenated file(s) are applied to all HDCS data acquired with "Nearest in distance within time (4 Hours)" selected under the "Profile selection Method".

C.5.2 Surface Sound Speed

Data Acquisition Methods and Procedures

Surface sound speed is recorded by the AML-X sound speed probe, mounted at the aft of S3006. The probe is able to be placed within an adjustable PVC shaft that can be lifted as needed to facilitate transit speeds or lowered to facilitate sound speed measurements. The probe turns on with a switch on the coxswain power console, and begins broadcasting sound speed values within seconds. The sound speed observations are broadcast at 1Hz directly to SIS, which uses the values for beam steering and gain adjustments.

Data Processing Methods and Procedures

Sound speed measurements are not processed by the user, and all measurements are used by SIS to automatically adjust sonar beam steering settings.

C.6 Uncertainty

C.6.1 Total Propagated Uncertainty Computation Methods

The hydrographer directly defines uncertainty values for CARIS to calculate TPU values, in the HVF and the direct input of SV and tide values during TPU computation.

All MRU alignment values are derived from the patch test. The gyro value is taken directly from the standard deviation of the yaw values. Pitch/roll value is combined as one in the HVF and is computed as the square root of pitch standard deviation squared plus roll standard deviation squared. '

Uncertainty values associated with VDatum models are provided in the project instructions. The field unit checks the uncertainty value provided in the project instructions with the associated VDatum text file (XXXXXX_sheets_exysep.txt.log) under the VDatum Vertical Area-Weighted SEP Uncertainty.

C.6.2 Uncertainty Components

C.6.2.1 A Priori Uncertainty

<i>Vessel</i>		S3006_EM2040C	NRTSEA_S3006_EM2040C
<i>Motion Sensor</i>	<i>Gyro</i>	0.02 degrees	0.02 degrees
	<i>Heave</i>	5.00%	5.00%
		0.05 meters	0.02 meters
	<i>Roll</i>	0.02 degrees	0.02 degrees
	<i>Pitch</i>	0.02 degrees	0.02 degrees
<i>Navigation Sensor</i>		1.00 meters	1.00 meters

C.6.2.2 Real-Time Uncertainty

<i>Vessel</i>	<i>Description</i>
S3006	Some real-time uncertainty values are incorporated into the depth estimates of NRT-3 surveys by way of post-processing. Real-time uncertainties from the Kongsberg EM2040 and Kongsberg EM710 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 roll, pitch, gyro 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

Source shoreline data is typically supplied by NRB Project Manager in a single Composite Source File (CSF) in S-57 format. The CSF is delivered with the project instructions and is to be used as the shoreline data for the field. The CSF is compiled from available source shoreline files (i.e. ENC, geographic cells, LIDAR, RNC, and Prior Surveys) into a single file in an S-57 .000 format. Additionally, a Project Reference file (PRF) is supplied containing sheet limits, maritime boundary points, and recommended bottom sample locations.

Shoreline verification is performed using several different methods depending on the nature of the feature. Under water features are verified or disproved using MBES and/or SSS. All features with the custom attribute "asgnmt" populated with 'Assigned' and offshore of the Navigational Area Limit Line (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. Above water features such as piers and pilings are verified using Hypack detached positions during daylight periods near predicted MLLW tides. A line is run along the shore approximating the position of the NALL.

The definition of the NALL is subject to modification by the Project Instructions, Chief of Party, and the team as a whole. 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.

Features are examined in accordance with with limited verification guidelines in the FPM. In the field, CARIS HIPS and SIPS is used to modify the assigned features during a low tide window that in convenient with the project working times. The features are exported to a .hob file, and the hydrographer attributes the existing features as they are investigated and scans the area for new features to be addressed. Images of new or existing features are taken with a cell phone camera, and emailed to the Chief of Party for future renaming and attachment. Hypack is utilize as a visualization tool for the coxswain, and the .hob feature file is uploaded to the coxswain display. The time of observation is recorded either in the .hob file, in a camera image time, or on a nearby piece of paper.

Features are addressed in the following manner for offshore the NALL:

- The height/depth of a feature found within 2mm at survey scale of the composite source position
- A feature outside 2mm at survey scale of the composite source position has its field position revised in addition to a height/depth determination
- Features with any linear dimension greater than 1mm at survey scale are treated as an area and delineated
- New features not identified 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 safe to approach
- Navigationally significant features, defined below.

Navigationally Significant features are defined as the following:

- All features within the limits of safe navigation (i.e. offshore the NALL)

Features inshore of the NALL which:

- Are sufficiently prominent to provide a visual aid to navigation (landmarks). Rocks awash are almost never considered landmarks, but distinctive islets or other features visible at MHW can be useful for visual navigation
- Significantly (a ground unit distance equivalent to 0.8mm at the scale of the largest scale chart of the area) deflect this limit. Common examples include foul areas and ledges
- 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 as they arise
- Man-made permanent features disconnected from the shoreline, such as stakes, pilings, and platforms regardless of size.

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

Data Processing Methods and Procedures

Features are generally documented and given S-57 attribution in real time. To increase efficiency, the boat crew may forgo S-57 attribution in the field and take thorough notes either digital using screen shots or on paper for later attribution. In the following days of shoreline verification, the HXXXXX_Final_Feature_File.hob used on the vessel, any digital photos taken, and the boat's trackline are then used to place and attribute features properly in the working project directory.

S-57 Attribution:

With the advent of custom CARIS support files supplied by OCS, Bathy DataBASE now supports feature flags previously available only in Pydro. All feature flagging can now be accomplished in BDB while Pydro is used for generating reports and performing QC. Features are selected for investigation by NRB OPS based on distance from MHW. Project Instructions require that "All features with attribute asgmt populated with 'Assigned' shall be verified even if they are inshore of NALL."

NRT-3 will not venture inshore of the NALL for investigation of assigned 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 it is visible. If the features is not evident while investigating 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 and SIPS are also brought into BDB 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 confirm to direction located within both the 2019 HHSD 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 BDB includes "descp" with a drop-down menu which is edited to reflect the hydrographer recommendations as follows:

- descp - 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".
- descp - 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 newly proposed feature is characterized as "new", while the original feature was flagged as "delete".
- 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.

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” sea floor is not rejected anywhere. Any bad soundings are cleaned out to make the surface represent the sea floor, but there is no cut-off of soundings shoaler than the 4-meter or 0-meter curves. Negative soundings are fine so long as they accurately represent the bottom.
- S3006 will not 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, buoy's 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 on 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 maybe 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 "sea floor." No data is rejected on rocks, reefs or ledges, even above MLLW. The primary method of getting heights on rocks will remain "leveling" (aka eyeballing) during traditional shoreline, 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 CSF 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 named utilizing the "Rename FFF Images per HTD" tool in Pydro explorer HTD 2018-4 and are located in the "multimedia" folder in the 2019 submission structure.

C.8 Bottom Sample Data

Data Acquisition Methods and Procedures

The clam shell style bottom sampler is set for deployment by placing the attached pin between the hinge. The device is allowed to free fall to the bottom and upon contact the line is jerked up sharply to snap the jaws shut. Bottom material is transferred from the clam shell into a plastic bucket and examined for type, color, texture and photographed. To determine size and color, the bottom sample is then compared with the color card and sediment grid referred to in HTD 2018-1.

Data Processing Methods and Procedures

NRB Operations provides the field unit with a number of recommended bottom sample locations included in the Project Reference File (PRF), encoded as S-57 SPRINGS. In the event that no sample is obtained after three attempts, the sample site's NATSUR is characterized as "unknown". Observations are recorded into a Google drive spreadsheet, that is then referenced in the office to update the .hob file. Bottom sample images are named in accordance with HTD 2018-4 HXXXXXX_SBDARE_YYMMDDThhmmss.jpg.



Figure 27: An example of the bottom sample from Portland, OR area.

C.9 Other Data

Data Acquisition Methods and Procedures

No additional data were acquired.

Data Processing Methods and Procedures

NRT-3 utilizes Charlene as part of the daily processing pipeline, 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. Charlene allows the user to:

1. Perform verification of raw data

2. Build deliverable directory structure
3. Transfer and verify raw data
4. Process MBES and SSS data with CARIS Batch Processor
5. Generate SBETs with POSpac Batch
6. Use NOAA tools like AutoQC, QCTools and TCARI

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. In less than 20m of water, any feature where the most probable accurate sounding is shoaler than the CUBE surface by greater than one half the allowable error under IHO S-44 Order 1 is considered inadequately captured by the CUBE surface. In greater than 20m of water, this allowable error is expanded to the full Order 1 error allowance at that depth. By the criteria above, if a sounding is eligible for designation it is not necessarily implied that a sounding must be designated. 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.

Prior to creating a finalized BASE surface collection, the hydrographer must systematically review significant feature least depths to ensure they are accurately portrayed by the BASE surface. A specific least depth sounding is preferred over the weighted mean-depth calculation for the associated BASE surface grid node, the sounding will be flagged as designated. The designated flag can be applied in either HIPS or Pydro. If a sounding is made Designated in one software, this flag will carry through to the other application. Designated soundings shall be selected in accordance with section 5.2.1 and 5.2.2 of the HSSD.

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 sea floor 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”.

As discussed in the Specifications and Deliverables section 5.2.1.2, the hydrographer should use discretion in designating soundings on features.

D.1.3 Holiday Identification

NRT-3 makes an active effort to identify and address potential holidays throughout acquisition. Holiday line plans are typically developed to address data gaps as mainscheme acquisition progresses, rather than at the end of mainscheme operations.

QC Tools 3 included as part of Pydro XL contains the tool “Detect holidays” which now largely automates the identification of holidays in bathymetry data sets. A user selected grid is scanned, and any empty grid nodes (“holes”) surrounded by populated nodes are identified. Holidays in VR grids are flagged according to the specifications found in the 2019 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. NRT-3 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 3 included as part of Pydro Explorer 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:

- The Depth layer plotted as a distribution (entitled “Depth Distribution”), the Density layer is plotted as a distribution (entitled “Object Detection Coverage”).
- The Density layer plotted as a distribution (entitled “Object Detection Coverage”).

- Density plotted against the corresponding Depth of the node (entitled “Node Depth vs. Sounding Density”).
- TVU QC plotted as a distribution (entitled “Uncertainty Standards”).
- TVU QC plotted against the corresponding Depth of the node (entitled “Node Depth vs. TVU QC”).
- Only for Variable Resolution grids, a histogram with the percentage of nodes at the prescribed resolution is created. This histogram can be used to evaluate whether “95% of all surface nodes have a resolution equal to or smaller than the coarsest allowable resolution for the node depth” as required by 2019 HSSD.

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.

ERS tide zoning uncertainty is unique to the separation model in use.

- Tide values measured uncertainty value error ranges from 0.01m to 0.05 m dependent upon the accuracy of the tide gauges used and the duration of their deployment. NRT3 utilizes the Tide Component Error Estimation section of the Hydrographic Survey Project Instructions now includes the estimated gauge measurement error in addition to the tidal datum computation error and tidal zoning error.
- Tide values zoning is unique for each project area and typically provided in Appendix II of the Hydrographic Survey Project Instructions, Water Level Instructions. In section 1.3.1.1 of the Water Level Instructions, Tide Component Error Estimation, the tidal error contribution to the total survey error budget is provided at the 95% confidence level, and includes the estimated gauge measurement error, tidal datum computation error, and tidal zoning error. Since this tidal error value is given for two sigma, the value must be divided by 1.96 before it can be entered into CARIS (which expects a one sigma value). If TCARI grids are assigned to the project area, this value is set at 0.0 since TCARI automatically calculates the error associated with water level interpolation and incorporates it into the residual/harmonic solutions.
- Measured sound speed value error ranges from 0.5 to 4 m/s, dependent on temporal/spatial variability. FPM recommends a value of 4 m/s when 1 cast is taken every 4-hours.
- 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. 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. The HVF specifies which type of sonar system the vessel is using, referencing the appropriate entry from the Device Model file.

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 is utilized for junction comparison analysis in the similar manner to crossline to mainscheme analysis.

D.1.5.3 Platform to Platform

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

This was S3006's first survey project since coming online, comparison surfaces between Rainier Launch 2903 and S3006 were completed in Portland, OR and were found to be in agreement.

D.2 Imagery data Integrity and Quality Management

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

E. Approval Sheet

As Chief of Party, I acknowledge that all of the information contained in this report is complete and accurate to the best of my knowledge.

Survey adequacy is provide in the individual survey Descriptive Reports.

Approver Name	Approver Title	Date	Signature
Patrick Faha	Chief of Party	11/02/2021	

List of Appendices:

<i>Mandatory Report</i>	<i>File</i>
<i>Vessel Wiring Diagram</i>	NRT3 Wiring Diagram.pdf
<i>Sound Speed Sensor Calibration</i>	Castaway_calibration_exp_10.2020.pdf 2021 AML calibration_03232021111808.pdf
<i>Vessel Offset</i>	NRT_S3006_2018_NGS_Survey.pdf
<i>Position and Attitude Sensor Calibration</i>	2021_HSRR_documentation_spreadsheet.pdf
<i>Echosounder Confidence Check</i>	2021_HSRR_documentation_spreadsheet.pdf
<i>Echosounder Acceptance Trial Results</i>	NRT1_2040c_acceptance_1.0.pdf

<i>Additional Report</i>	<i>File</i>
<i>Lead Line Calibration Report</i>	2021_HSRR_documentation_spreadsheet.pdf