Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Baseline Monitoring Documentation of Maritime Heritage Resources in the Wisconsin Shipwreck Coast National Marine Sanctuary

NOAA Maritime Archaeologist Performs a Site Condition Assessment over the Remains of vessel Niagara. Image by NOAA Office of National Marine Sanctuaries

Report of 2022 Field Operations

Madeline Roth, John Bright, and Russ Green

December 2022

Baseline Survey and Documentation of Maritime Heritage Resources in the Wisconsin Shipwreck Coast National Marine Sanctuary

Prepared By:

NOAA Office of National Marine Sanctuaries
1305 E/W Hwy
Silver Spring, MD 20910

December 2022

Recommended Citation:

Roth, Madeline, John Bright, and Russ Green
2022 Baseline Survey and Documentation of Maritime Heritage Resources in the Wisconsin Shipwreck Coast National Marine Sanctuary. Office of National Marine Sanctuaries, National Oceanic and Atmospheric Administration, Silver Spring, MD.

Executive Summary

In June 2022, a team from the Office of National Marine Sanctuaries (ONMS) conducted resource assessments of selected historic shipwrecks within NOAA's newly designated Wisconsin Shipwreck Coast National Marine Sanctuary (WSCNMS). The project's overarching goal was to better understand the current states of preservation at these sites, and obtain data needed to establish resource protection efforts such as long term monitoring and the installation of permanent mooring systems.

The team conducted multibeam sonar mapping of 13 sites and diver-led site assessments of 10 shipwreck sites. These "rapid" archaeological assessments used a strategic mix of photos, video footage, direct observations, and photogrammetric modeling. The assessments made during this project were focused in large part on determining the best location and tackle for permanent moorings. Sonar mapping was used to obtain precise coordinates of selected shipwreck sites and georectification of photogrammetric models. This position information is essential to the accurate placement of mooring buoy anchors adjacent to the sites.

Baseline data was entered into the newly created ONMS Maritime Anthropological Resource Information System (MARIS). Many of the sites were previously documented by the Wisconsin Historical Society and several are on the National Register of Historic Places. Consequently, this project was aimed at quickly getting a sense of the current state of preservation at selected sites to support the efforts described above.

In addition to site recording, project staff conducted extensive photo and video documentation to support sanctuary outreach, education, and marketing/branding efforts. This included the acquisition of footage to support virtual reality experiences. Footage of operations was collected for internal ONMS productions and an external Discover Wisconsin production. The project also hosted two educators through the Illinois Sea Grant program's teacher-at-sea experience. This immersive experience was designed to expose the educators to sanctuary research, and solicit feedback on products to support formal and informal educational efforts. Their participation also supported field activities and will be captured in an ONMS Stories from the Blue video.

Participants included Office of National Marine Sanctuary personnel from WSCNMS, Thunder Bay National Marine Sanctuary, the Maritime Heritage Program, and Communications and Engagement Division. Vessel support and marine operations were supported by NOAA's Great Lakes Environmental Research Lab.

Table of Contents

List of Figures

List of Tables

Acronyms

CCR	Closed-Circuit Rebreather
DAC	Data Acquisition Computer
DB	Database
GLERL	Great Lakes Environmental Research Laboratory
HRG	High resolution geophysical
IGLD 85	International Great Lakes Datum, 1985
IHO	International Hydrographic Organization
INS	Inertial Navigation System
LMFS	Lake Michigan Field Station
LWD	Low Water Datum
MARIS	Maritime Anthropological Resource Information System
MBES	Multibeam Echosounder
NAD	North American Datum
NAVD	North American Vertical Datum
NDP	NOAA Diving Program
NDSSM	NOAA Diving Standards and Safety Manual
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
OC	Open-Circuit
OIC	Operator-in-Charge
ONMS	Office of National Marine Sanctuaries
QC	Quality Control
R/V	Research Vessel
SBET	Smoothed Best Estimate of Trajectory
SV	Sound Velocity
SVP	Sound Velocity Profiler
SVS	Sound Velocity Sensor
TBNMS	Thunder Bay National Marine Sanctuary
TDS	Technical Diving Supervisor
UDS	Unit Diving Supervisor
UTC	Universal Time Coordinated
WSCNMS	Wisconsin Shipwreck Coast National Marine Sanctuary

Introduction

Designated in 2021, Wisconsin Shipwreck Coast National Marine Sanctuary (WSCNMS) provides stewardship for our nation's maritime heritage in Lake Michigan. Co-managed by NOAA and the state of Wisconsin, the sanctuary expands on the state's 30-year management of these historic sites, bringing new opportunities for research, resource protection, and education. In partnership with local communities, the sanctuary provides a national stage for promoting recreation and heritage tourism.

The 36 historic shipwreck sites within the sanctuary represent vessels that played a central role in building the nation between the 1830s and 1930s (Figure 1). Twenty-seven are listed on the National Register of Historic Places and research suggests that another 60 shipwrecks may yet to be discovered.

Figure 1. Map of known and suspected shipwrecks in Wisconsin Shipwreck Coast National Marine Sanctuary. Map by NOAA.

The aim of the 2022 fieldwork was to conduct baseline assessments on the condition and spatial distribution of select shipwreck sites within WSCNMS. From 8 to 16 June 2022, a team of researchers from the National Oceanic and Atmospheric Administration (NOAA) Office of National Marine Sanctuaries (ONMS) conducted multibeam sonar mapping of 13 sites and diver-led site recording of 10 shipwreck sites. Cumulatively, the sites were chosen because they are popular dive sites with publicly accessible coordinates. At present, 10-15 sites are slated for installation of an ONMS-sponsored mooring system in the spring of 2023. The assessments made during this project were focused in large part on determining the best location and tackle for permanent moorings.

In addition to site recording, project staff conducted extensive photo and video documentation to support sanctuary outreach, education, and marketing/branding efforts. Footage of operations was collected for internal ONMS productions and an external Discover Wisconsin production. The project also hosted two educators through the national Sea Grant program's teacher-at-sea experience. This immersive experience was designed to expose the educators to sanctuary research and solicit feedback on products to support formal and informal educational efforts. Their participation also supported field activities and was captured in an ONMS Stories from the Blue video.

Data generated during this fieldwork includes multibeam sonar acoustic files, photographs, video, photogrammetric models, site reports, and inventory files. These materials are curated by the WSCNMS, the ONMS Communications Team, and the ONMS Maritime Heritage Program (MHP). This report serves as the official record of field operations. For additional information or access to data, contact the project PI Russ Green at russ.green@noaa.gov.

Management History

Over the past 50 years, the significance of Lake Michigan shipwrecks has been increasingly recognized. Initially located via commercial fishing and avocational remote sensing, the assemblage of deeper-water (50 ft/17 m) shipwrecks in the current WSCNMS boast a high degree of structural and archaeological integrity. From the 1970s onwards, these sites attracted recreational and technical divers, resulting in several decades of enhanced exploration and understanding. Unfortunately, this period is also marked by opportunistic artifact removal and structural deterioration from looting activities (Meverden and Thomsen 2010; Thomsen and Zant 2016; Zant et al. 2017). With the passage of the Abandoned Shipwreck Act in 1987, the Wisconsin Historical Society's (WHS) Maritime Preservation and Archaeology Program was formed to manage and ultimately protect all abandoned historic shipwrecks located within state waters (Wisconsin Historical Society 2021).

The WHS Maritime Preservation Program has undertaken systematic field investigation and site documentation since its inception in 1988. Their management has resulted in the successful nomination of multiple shipwrecks to the National Register of Historic Places and an extensive collection of archaeological reports and public outreach materials. In 2014, local communities nominated the now-designated WSCNMS as a national marine sanctuary, in large part due to the extensive fieldwork and promotion of maritime heritage by the Wisconsin Historical Society.

Today, the State of Wisconsin remains an active co-manager in sanctuary operations. In addition, local museums including the Wisconsin Maritime Museum and the Roger Street Fishing Village offer non-divers a chance to experience and explore the state's shipwreck heritage.

ONMS Heritage Management and Resource Inventory

With the establishment of WSCNMS in 2021, ONMS became responsible for the identification, evaluation, and long-term preservation of underwater cultural heritage within the sanctuary boundary (16 USC § 1431 *et seq.*; 54 USC § 300320). Under both the National Historic Preservation Act (54 USC § 300320) and the National Marine Sanctuaries Act (16 USC § 1431 *et seq.*), ONMS has an obligation to manage maritime heritage resources through systematic monitoring and subsequent implementation of mitigation or stabilization activities (Roth 2021). A key component of this monitoring is the establishment of a baseline dataset which serves as a point of comparison for all future assessments.

The ONMS Maritime Heritage Program (MHP) developed the Maritime Anthropological Resource Information System (MARIS) database to serve as both the initial baseline inventory and monitoring system for underwater cultural heritage located in national marine sanctuaries. MARIS implementation is a key component of ONMS heritage management and, as such, became a project goal for 2022 field operations in WSCNMS.

Project Goals and Objectives

The goal of this project was to conduct preliminary documentation of shipwreck sites within recreational or technical diving depths for the purposes of site monitoring and installing permanent moorings for resource protection and to facilitate visitor use. To meet this overarching goal, several research objectives were outlined during initial project planning. These project objectives include:

- Perform condition assessments of sanctuary resources sites with a focus upon shipwreck locations that will receive permanent mooring buoy systems in spring 2023, by means of:
    - Direct diver observations recorded in-situ and transcribed as MARIS database entries
    - Photo and video recordings
    - Generation and interpretation of 3D photogrammetric models
    - Generation and interpretation of high resolution multibeam sonar data outputs for referencing and positioning
- Develop archives of photo and video footage (e.g. B-roll) to support sanctuary outreach, education, marketing/branding efforts, including:
    - Virtual reality/360° footage at selected wreck sites
    - Obtain B-roll for Discover Wisconsin production
- Catalog the results of site monitoring and documentation during implementation of the NOAA MHP MARIS database system

- Use geophysical outputs to determine positions for siting mooring buoy deployments at selected sites scheduled for Spring 2023
- Host two educators, onboard, for two days as part of a teacher-at-sea experience; capture the experience in a Stories from the Blue video.

Field Methods and Data Processing

Between 8 and 16 June 2022, a team of researchers from the ONMS conducted sanctuary-specific MARIS baseline [1]assessments of underwater cultural heritage resources located within WSCNMS. The project team consisted of staff from the WSCNMS, Thunder Bay National Marine Sanctuary (TBNMS), the NOAA Great Lakes Environmental Research Laboratory (GLERL), the ONMS MHP, and the ONMS Communications Division (Comms). A list of project participants and their role in field operations is presented in Table 1. All on-water operations–diving and geophysical mapping–were performed onboard NOAA vessel R5002 (R/V *Storm*). Selected sites were accessed via shore in the Rawley Point area adjacent to Two Rivers, WI.

Table 1. Project Participants in 2022 field operations.

Name	NOAA Office	Role
Matt McIntosh	Comms	Scientific Diver; Photography Lead
Kate Thompson	Comms	Scientific Diver; Production Supervisor; Photography Support
Nick Zachar	Comms	Scientific Diver; Videography Lead
Randy Gilmer	GLERL	R5002 Vessel Captain; Topside Diving Support
Joe Hoyt	MHP	Technical Diver; Photogrammetry Lead; MARIS Support
Madeline Roth	MHP	Scientific Diver; MARIS Lead
John Bright	TBNMS	Technical Diver; Sonar Survey Lead; Marine Operations Support; Dive Supervisor
Russ Green	WSCNMS	Technical Diver, Project PI; Photography Support

These methods aligned with tasks necessary to accomplish goals and objectives listed in the prior section. An overview of the project schedule and products produced arranged by individual shipwreck sites are presented in Table 2.

[1] The ONMS MARIS database uses a baseline-condition assessment model for long-term heritage monitoring. Throughout this document, the term “baseline” is used to denote the first assessment of the heritage resource conducted by ONMS personnel. It does not necessarily correspond to the first assessment of a heritage resource, either by professional archaeologists or avocational historians.

Table 2. Overview of project schedule and products generated for each shipwreck site. APN= Alpena, MI; CHX=Charlevoix, MI; PTS=Petoskey, MI; MARIS=Maritime Anthropological Resource Information System database entries; MBES=multibeam echosounder sonar survey data acquisition; VR=virtual reality video data acquisition.

Date	Activity	Site	Stills	Video	VR	MARIS	Photomodel	MBES
5-Jun	R5002 Transit	APN - CHX						
6-Jun	R5002 Transit	CHX - SHB						
7-Jun	Project Mob	SHB						
8-Jun	Dive Ops	Atlanta	X	X		X		
		Niagara	X	X	X	X	X	
9-Jun	Dive Ops	Hetty Taylor	X	X	X	X	X	
		Advance	X	X	X	X	X	
	Survey Ops	Hetty Taylor						X
		Advance						X
10-Jun	Dive Ops	Selah Chamberlain	X	X		X		
	Survey Ops	Walter B Allen						X
		Silver Lake						X
		Helvetia						X
		Selah Chamberlain						X
		Robert C. Pringle						X
11-Jun	Dive Ops	Northerner	X	X	X	X	X	
		Mahoning	X	X	X	X	X	
12-Jun	Survey Ops	Gallinipper						X
		Home						X
		Floretta						X
		Rouse Simmons						X
		Vernon						X
		Henry Gust						X
	Dive Ops	Continental	X	X				
13-Jun	Dive Ops	America	X	X		X	X	
		SC Baldwin	X	X		X		
14-Jun	Wx; Outreach							
15-Jun	Dive Ops	Selah Chamberlain	X	X			X	
	Survey Ops	Selah Chamberlain						X
	Outreach	Selah Chamberlain						
15-Jun	Snorkel Ops	LaSalle	X			X	X	
16-Jun	Project DeMob							
17-Jun	Wx; Maint							
18-Jun	R5002 Transit	SHB - PTS						
19-Jun	R5002 Transit	PTS - APN						

Multibeam Sonar Survey Data Acquisition

NOAA vessel R5002 is configured to support on-water research tasks which include geophysical survey. In addition to being a fit-to-purpose scientific diving platform, the vessel is likewise designed to deploy remote sensing instruments and acquire high resolution geophysical survey data. R5002 features a through-hull mounted multibeam echosounder (MBES) and sound velocity sensor (SVS) as well as a permanently installed inertial navigation system (INS) which provides position and motion data to all active survey devices. The vessel's cabin has an online survey workspace consisting of rack enclosures, desk space, and large mounted monitors. While diving operations are managed off the vessel's working deck, geophysical mapping is performed inside the vessel's cabin through a coordinated network of instrumentation, computers, and displays that enable a surveyor and vessel operator to navigate the vessel and acquire high resolution geophysical mapping data.

Prior to the start of site documentation efforts in WSCNMS, NOAA staff mobilized R5002 for geophysical mapping operations. Each year mapping instrumentation installed onboard R5002 must undergo procedures to calibrate, test, and/or verify proper operations. Likewise, software interfaces require updates which must be applied and tested thereafter. This process, referred to as the vessel's Mobilization and Calibration (MAC) was performed in Alpena, MI. Results from R5002's 2022 MAC procedures are outlined in a separate document provided in Appendix A.

R5002 arrived in WSCNMS with its mapping gear mobilized and ready for data collection. During vessel transit, all site locations were loaded into a navigation program and survey run lines were plotted to ensure data acquisition included the entire site location and surrounding lakebed area. Selected sites were those in water depths greater than 150 feet, however, a few locations in shallower depths were also incorporated into the mapping activities. General selection criteria were depth-based: shipwreck sites which could not be visited by NOAA divers during the project (i.e. those beyond the 150 foot depth limit of the NDSSM Light Decompression[2] guidelines) were instead documented with remote sensing surveys to ascertain detailed information about site location, depth, orientation, and geological conditions in the surrounding area. In a few instances, sites visited by divers were also surveyed using the techniques described herein. In such cases, positions for features derived from the sonar data

[2] The NOAA Diving Standards and Safety Manual (NDSSM) contains multiple tiers of technical diving operations, each requiring separate levels of authorization. Section 8.3 outlines policies for "Tech Lite" decompression diving. Here, requirements for vessel and in-water diving support are relaxed for divers who do not exceed a depth of 150 feet. While NOAA Divers at WSCNMS, TBNMS, and MHP are authorized for deeper technical diving activities and could have accessed additional shipwreck locations, implementation of those diving modes would have necessitated more extraneous vessel, in-water, and topside support requirements. This, in turn, would have diverted effort from site-documentation at additional sites. As a result, the project team elected to use remote sensing methods for documented sites below 150 feet water depth, and "Tech Lite" diving operations at 150 feet and shallower.

enable more precise georeferencing of photogrammetric modeling outputs produced from diver-collected imagery.

In both cases–shallow and deeper sites–data acquisition involved navigating the vessel to each site's reported location then completing a localized set of parallel survey run lines in that area. During sonar file recording, the online surveyor monitored the sonar display to ensure coverage of the entire shipwreck sites as well as the surrounding lakebed. Of all the sites selected for sonar survey, only one was not located at its reported location–*Floretta*-which necessitated an expanded survey plan to locate and document the site at a position roughly 300 meters away from its waypoint. Otherwise, site surveys were completed in less than an hour with each vessel quickly located near its expected position.

Recorded files were stored on an onboard computer during operations. Table 1 provides an inventory of each site mapped using R5002's sonar system. After each day of mapping, files were copied to a transfer drive and brought to the field office in Sheboygan, WI, where post processing and visualization tasks were initiated.

Multibeam Sonar Data Processing Workflow

Raw sonar and navigation files were copied from the data acquisition computer (DAC) onboard R5002 to a portable transfer drive. After each day's on-water operations, these copied files were brought to a field office in Sheboygan, WI, to be added to a project archive. Once the geophysical data archive was updated, a post-processing workflow was started to produce high-resolution sonar data outputs.

Specific details related to the processing workflows, file management tasks, and final data archive are provided in Appendix B and Appendix C accompanying this report. In general, the same procedures used to generate hydrographic data compliant with IHO S-44 standards were used for rendering WSCNMS site files. Though not encompassing large areas of lakebed, survey files from WSCNMS mapping operations were processed in such a way as to maximize their horizontal and vertical position accuracy and to improve gridded data resolution and thus optimize feature identification at each surveyed site.

Diving Operations

During project operations NOAA Divers completed a total of 22 archaeological monitoring dives on 10 shipwreck sites located in Lake Michigan off the Wisconsin coast (Figure 2). In addition, the Comms team conducted one additional dive on the shipwreck *Continental* (see Figure 1) to collect footage for video production. This site, however, was not assessed regarding its archaeological condition during the dive.

All NOAA diving operations followed protocols outlined by the NOAA Diving Standards and Safety Manual (NDSSM). TBNMS's Unit Diving Supervisor (UDS) served as the project's diving supervisor and oversaw compliance with all NOAA Diving Program (NDP) policies. Individual NOAA Divers and Divemastsers ran daily deck operations during multiple diving rotations performed at various sites throughout the project. Topside support coordinated these operations with the NOAA vessel Operator-in-Charge (OIC). All dives were conducted as OSHA-exempt scientific monitoring and documentation dives. During each dive, divers were individually tasked with completing photography, videography, monitoring, or support roles. These roles are discussed in further detail in the sections below.

Diving operations were conducted up to a maximum depth of 130 feet. Teams were split between open-circuit and closed-circuit diving modes. The open-circuit team practiced no-decompression diving while the closed-circuit rebreather (CCR) team utilized the NDSSM Tech Lite guidelines to perform decompression diving at depths not exceeding 150 feet. Divers were deployed in a live boating mode from R5002 (except during a handful of shore-dives off Rawley Point). Divers were supported by a topside Divemaster and deck hands, and all diving activities were recorded on NOAA Form (NF) 57-03-25. Each diving day opened with a pre-dive briefing and operational risk management assessment; each day's operations concluded with post-dive briefing and UDS review and close-out of the diving records. No safety incidents occurred during this project.

Figure 2. Heritage resources investigated for baseline MARIS assessment via diving during FY22 field operations.

MARIS Data Collection

Prior to dive operations, a site file was generated in the ONMS MARIS database for each heritage resource. While shipwreck sites are colloquially termed or known by their vessel names, MARIS also assigns every resource a site number differentiated by a four-letter sanctuary code. As such, sites in WSCNMS were assigned a 'WISC' prefix followed by a cardinal four-digit number. The pre-inventory focused on relevant historical information, National Register status, and past management history. During field operations, the condition of each resource was subsequently assessed by sanctuary staff. Resource threats and disturbances[3] were noted during the dive. Following all dives, project personnel discussed observed site conditions and impacts. This information was then recorded in the ONMS MARIS database. All impacts were assigned a temporal interval, if possible. In addition, ONMS archaeologists identified proposed

[3] A threat has the potential to impact a resource while a disturbance is negatively impacting a resource's aesthetic, archaeological, cultural, educational, historic, and/or recreational value(s).

management actions and updated relevant pre-inventory fields related to location and site environment.

Photography and Videography

The project acquired still and video imagery to support site assessments, establish baseline monitoring, create photogrammetric models, record film, virtual reality/360° and marketing efforts. Much of the video filming and still photography efforts were directed at capturing "b-roll" to be used in current and future WSCNMS and partner video, marketing, and educational productions. Project video footage has since been used in the production of a promotional sanctuary/community video produced by Discover Wisconsin. Virtual reality footage acquired during the project was collected for similar purposes, including educational efforts. An important project outcome was to create a pilot virtual reality piece that can be shared with educators and spark discussions and efforts aimed at incorporating this type of footage into the classroom, as well as for informal visor experiences.

The camera model used for underwater video was a RED DSMC2 Dragon-X. Footage was shot in resolutions varying from 4K-6K. The camera system used for underwater 360° capture was a Boxfish 360°. This system comprises three Z Cam E1 Micro 4/3 sensor cameras, each with a 185° circular fisheye lens. The camera records at a resolution of 5.7K, ideal for 360°/VR outreach products. Underwater photography was captured using a Canon 1DX Mk II DSLR.

Several camera models were utilized to collect still images used for photogrammetric modeling, site documentation, and outreach materials. These camera models included Nikon D4, D800, and D810 as well as a Canon 1DX. All three models are DSLR-type camera bodies. Various lens configurations were employed. Raw photogrammetric imagery was captured through rectilinear lenses. Site documentation imagery was captured with a combination of rectilinear and wide-angle lenses. Each camera system was also equipped with an artificial lighting system to compensate for low ambient light levels at underwater sites, especially in deeper areas.

Photogrammetry

As one of this project's objectives was the implementation of rapid assessment methods to provide baseline data on historic shipwreck site conditions, photogrammetric modeling was selected as the central methodology for capturing physical site details. While highly detailed photogrammetric models can be generated through focused, iterative acquisition and processing workflows, the project team elected to focus on a rapid, single-dive approach to the raw imager acquisition used to generate photogrammetric models. In other words, the team generally spent only one dive per shipwreck site collecting images for photogrammetric processing.

During this dive, one diver was tasked exclusively with site-wite imagery acquisition used only for photogrammetry. Another diver would collect additional still images around complex features or areas with high relief to be merged with the main imagery set acquired by the first diver. Although bottom times differed depending on the depth of the site, and thus more or less images could be collected, each dive resulted in several hundred individual still images. This acquisition method can be easily repeated. This will allow teams in the future to generate similar models for comparative analysis.

Photogrammetric models were generated for seven WSCNMS sites. A majority of raw photogrammetry images were captured with a Nikon D4 camera outfitted with a 15 mm Sigma fisheye lens. The camera system was housed in an Aquatica housing and 9.25-inch dome port. Two Inon Z4 strobe lights were connected to the system using hot shoe connections. Supplemental images were supplied by a Nikon D810 camera equipped with a 17-55mm Nikkor AF-S lens and two Ikelite 160 Substrobe lights.

All images were recorded in the Nikon native RAW format as .NEF files. These images were pre-processed before being introduced into the photogrammetric workflow. First, all .NEF files were converted to .XMP and .JPG formats via Adobe Camera RAW converter. Color corrections and white balance adjustments were also made in the Adobe program and applied as batch updates when possible. Once pre-processing was completed, photogrammetric modeling was initiated within Agisoft's Metashape Professional (v.1.7.2) software. A standardized workflow for modeling was utilized. This included steps for:

- uploading a series of images defined as one or more chunks
- aligning camera locations, generation of sparse point cloud
- generating a dense point cloud
- manual editing to remove incorrect or extraneous data in the dense point cloud
- generating a connected mesh surface was created from the dense point cloud
- generating texture for the mesh based on input imagery color values

Once this workflow was completed, 3D model files were exported from the Agisoft Metashape project. These were uploaded to the Wisconsin Shipwreck Coast NMS SketchFab account and are available for viewing, downloading, and embedding in digital content at https://sketchfab.com/wishipwreckcoast. Completed site models include:

- WISC-0022, Niagara
- WISC-0023, Northerner
- WISC-0008, America
- WISC-0027, Henry Gust (published in 2021)
- WISC-0005, LaSalle
- WISC-0016, Hetty Taylor
- WISC-0017, Advance
- WISC-0022, Mahoning

Processing work and organization of the data archive remain ongoing tasks at the time this report was issued. Additional processing steps will utilize available geophysical data to scale and reference individual models. Archival work will organize the raw and pre-processed imagery files.

Results of Investigations

Data processing workflows associated with geophysical survey data, photogrammetric modeling, and video production were initiated during field operations. Likewise, site observations recorded by divers were input into the MARIS database as the initial site entries within that repository. While these processes were started during WSCNMS site documentation operations, however, many required additional time following project demobilization to reach completion. Information derived from individual data sources was synthesized into geophysical outputs, visualized data products, and site condition metrics. These results are herein reported per categorical groupings.

Multibeam Sonar Data Results

After the completion of the data processing workflow described in Appendix B, fully processed multibeam sounding data was derived. This included cleaning raw soundings, vertically referencing all soundings to IGLD 85 LWD, and gridding bathymetry information at 1 meter resolution or higher when possible. WSCNMS sites were easily distinguished from the lakebed within processed data products.

Updated locations and depths for each WSCNMS site were derived from the processed data products and are reported in Table ##. Prior to these operations, site locations known to NOAA consisted of single sets of coordinates. In some cases, these coordinates were tens to hundreds of meters away from the actual site location. As a result, during operations the NOAA team relied heavily upon WHS site data records. Meanwhile, completion of sonar survey data acquisition and processing resulted in highly accurate bathymetric maps enabling identification of site features, extents, and depths. The NOAA team used this information to extrapolate multiple locations corresponding to site features of interest (see Table ##). Moreover, archiving of these results will enable future feature position as needed for follow-on research.

Gridded data was exported from the processing software as georeferenced imagery compatible with GIS data programs. Updated site positions were incorporated into an existing WSCNMS point feature class containing site locations. These position data were also added into the MARIS database records. Depths noted were vertically referenced to LWD. As a result, they represent water depth at a given location during periods of low lake levels. During project operations, Lake Michigan water level was .80 to .95 meters (2.6 to 3.1 feet) above the LWD benchmark. Observed depths during project operations, therefore, would be up to 1 meter deeper than those reduced to LWD. While planning future operations, current Lake Michigan water levels should be referenced to adjust expected water depths at a given site.

Table 3. Updated position information for WSCNMS sites derived from processed MBES survey data. Positions are reported in both UTM coordinates (WGS 84 UTM Zone 16N) and WGS 84 latitude and longitude. Depths are reported in meters relative to IGLD 85 LWD.

Site	Waypoint	Easting	Northing	Latitude	Longitude	Depth
WISC-0030 | Rouse Simmons	bow	466913.23	4902783.35	44.277543	-87.414624	48.5
	stern	466939.21	4902752.26	44.277265	-87.414296	
WISC-0036 | Vernon	SW extent	467015.79	4894336.18	44.201499	-87.412806	58.7
	NE extent	467052.28	4894368.68	44.201793	-87.412352	
WISC-0027 | Henry Gust	SW extent	460692.43	4888020.46	44.144326	-87.491470	20.9
	NE extent	460698.40	4888032.23	44.144432	-87.491396	
WISC-0028 | Home	bow	455574.20	4866319.67	43.948660	-87.553639	50.8
	stern	455583.02	4866343.18	43.948872	-87.553531	
WISC-0025 | Floretta	bow	457073.75	4866650.91	43.951731	-87.534979	52.9
	NE section	457111.01	4866672.23	43.951925	-87.534516	
	stern	457088.62	4866694.76	43.952127	-87.534797	
WISC-0026 | Gallinipper	bow	461112.23	4862331.90	43.913070	-87.484334	62.4
	stern	461097.15	4862358.47	43.913309	-87.484524	
WISC-0037 | Walter B Allen	E extent	451058.39	4853201.07	43.830264	-87.608708	49.5
	W extent	451016.81	4853203.83	43.830287	-87.609225	
WISC-0033 | Silver Lake	NW extent	453488.73	4850477.48	43.805900	-87.578246	58.4
	SE extent	453509.30	4850456.90	43.805716	-87.577988	
WISC-0014 | Helvetia	bow	451172.22	4848730.96	43.790026	-87.606885	47.4
	stern	451114.81	4848713.48	43.789865	-87.607597	
WISC-0015 | Selah Chamberlain	bow	447064.74	4846529.57	43.769924	-87.657716	22.4
	stern	447136.68	4846505.47	43.769712	-87.656820	
WISC-0016 | Hetty Taylor	bow	447226.36	4836710.68	43.681533	-87.654745	29.6
	stern	447201.19	4836700.59	43.681440	-87.655056	
WISC-0029 Robert C Pringle	bow	455278.90	4837722.60	43.691172	-87.554929	84.7
	stern	455287.73	4837755.72	43.691471	-87.554822	
WISC-0017 | Advance	bow	442232.87	4829019.19	43.611912	-87.715870	22.6
	stern	442197.37	4828999.66	43.611733	-87.716308	

WISC-0014 *Helvetia*

Mapping operations at WISC-0014 were completed on 10 June, 2022. A total of 3 sonar files were collected. These raw data were processed to render the image seen in Figure 3, from which position and depth data were derived reported in Table 3.

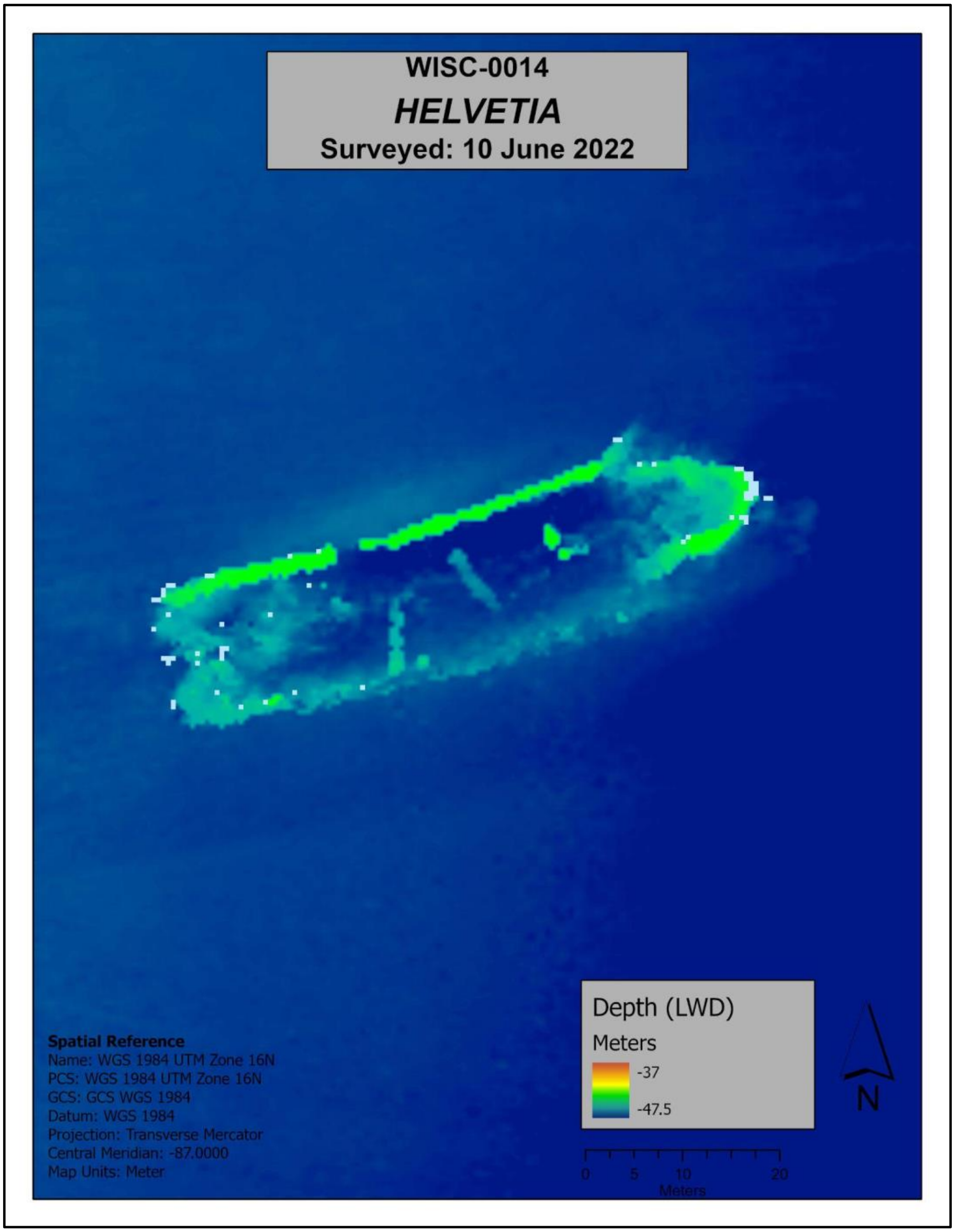


Figure 3. Processed multibeam sonar data from at the site of WISC-0014. Map by NOAA TBNMS.

WISC-0015 *Selah Chamberlain*

Mapping operations at WISC-0015 were completed on 10 and 15 June, 2022. A total of 8 sonar files were collected. These raw data were processed to render the image seen in Figure 4 and Figure 5, from which position and depth data were derived reported in Table 3.

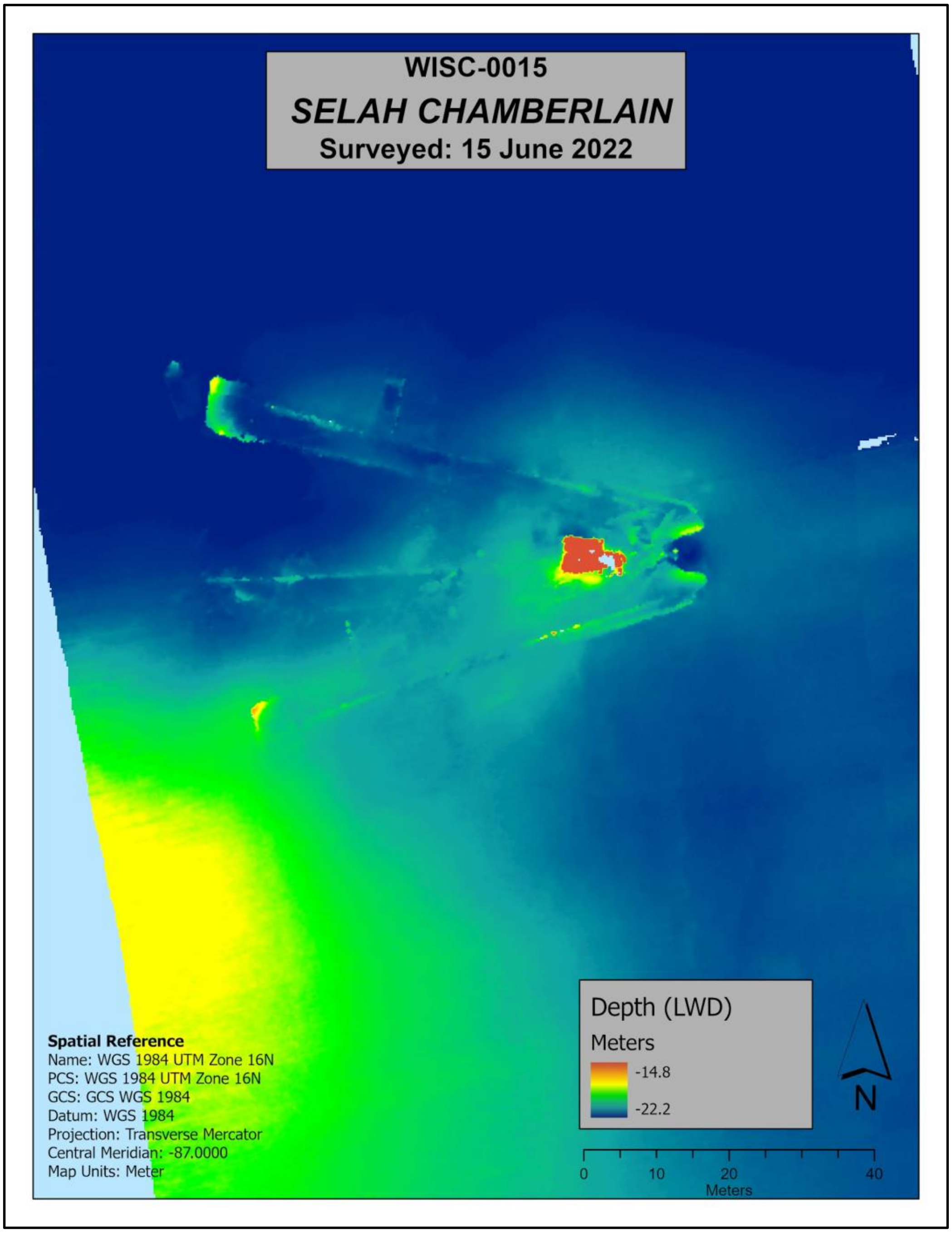
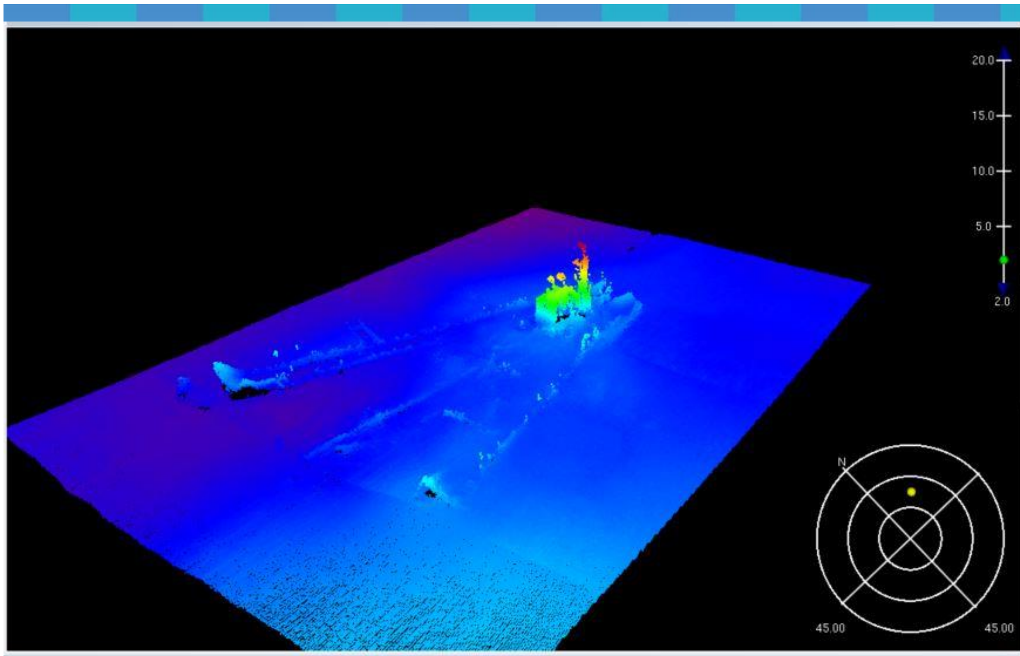


Figure 4. Processed multibeam sonar data from at the site of WISC-0015. Map by NOAA TBNMS.



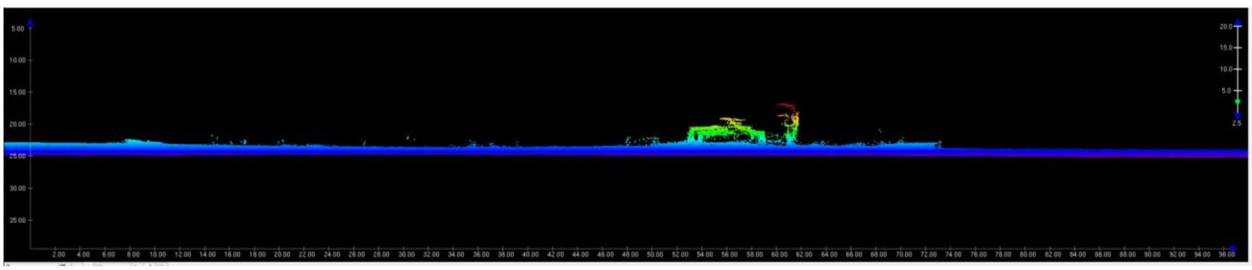


Figure 5. Processed multibeam sonar data from at the site of WISC-0015, showing perspective views. These are particularly helpful in planning for the deployment of permanent mooring systems. Image by NOAA TBNMS.

WISC-0016 *Hetty Taylor*

Mapping operations at WISC-0016 were completed on 9 June, 2022. A total of 3 sonar files were collected. These raw data were processed to render the image seen in Figure 6, from which position and depth data were derived reported in Table 3.

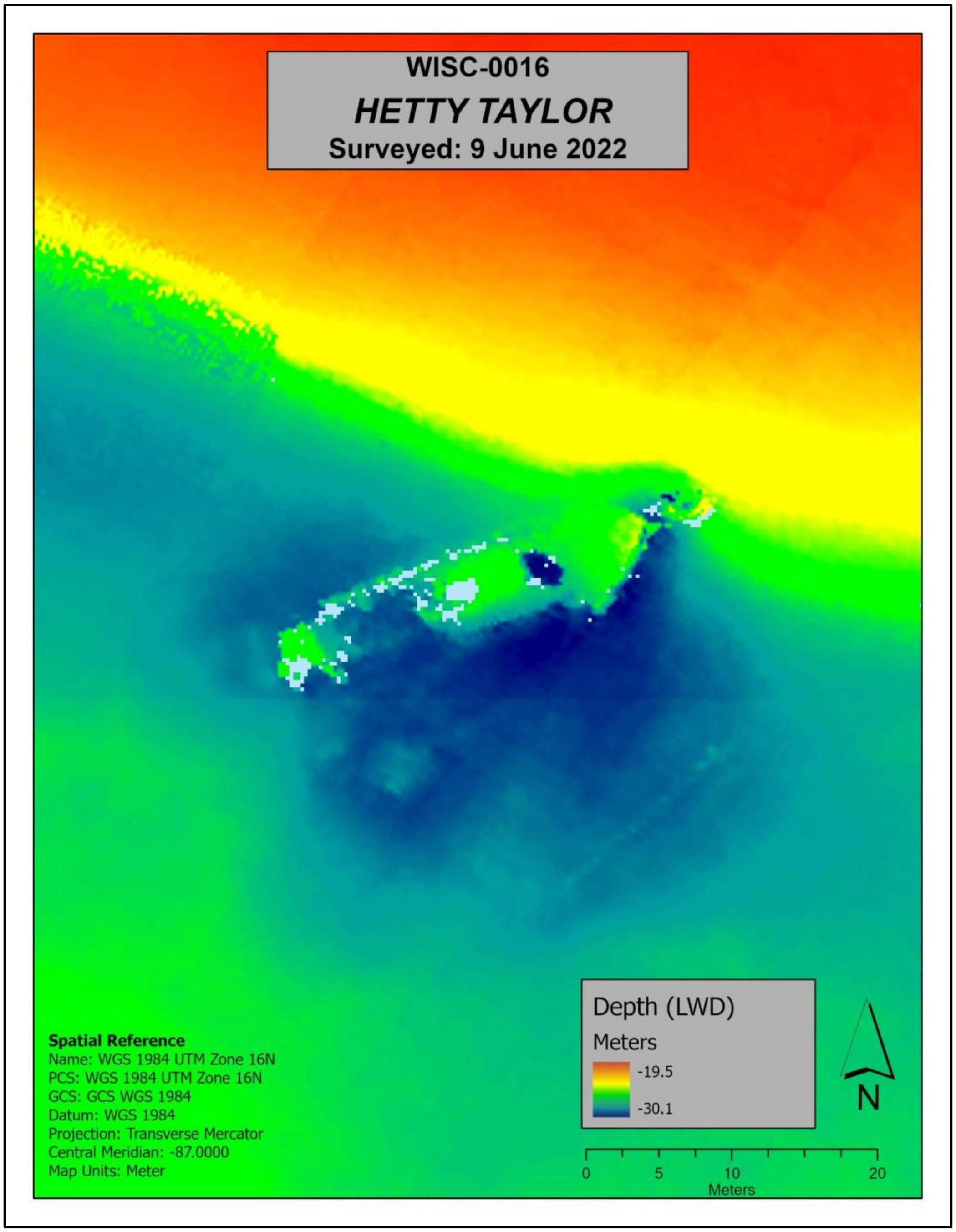


Figure 6. Processed multibeam sonar data from at the site of WISC-0016. Map by NOAA TBNMS.

WISC-0017 *Advance*

Mapping operations at WISC-0017 were completed on 9 June, 2022. A total of 3 sonar files were collected. These raw data were processed to render the image seen in Figure 7, from which position and depth data were derived reported in Table 3.

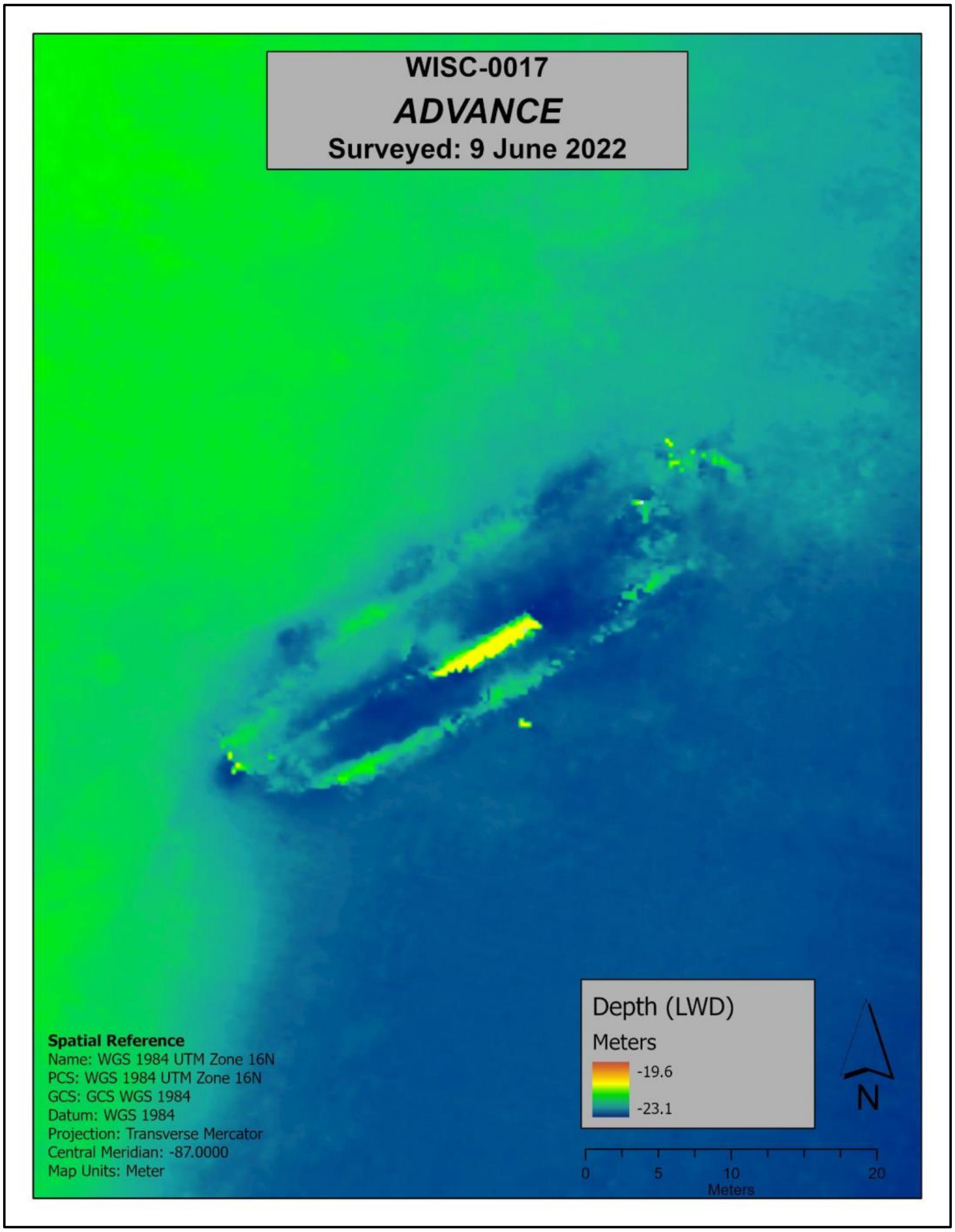


Figure 7. Processed multibeam sonar data from at the site of WISC-0017. Map by NOAA TBNMS.

WISC-0025 *Floretta*

Mapping operations at WISC-0025 were completed on 12 June, 2022. A total of 10 sonar files were collected. These raw data were processed to render the image seen in Figure 8, from which position and depth data were derived reported in Table 3.

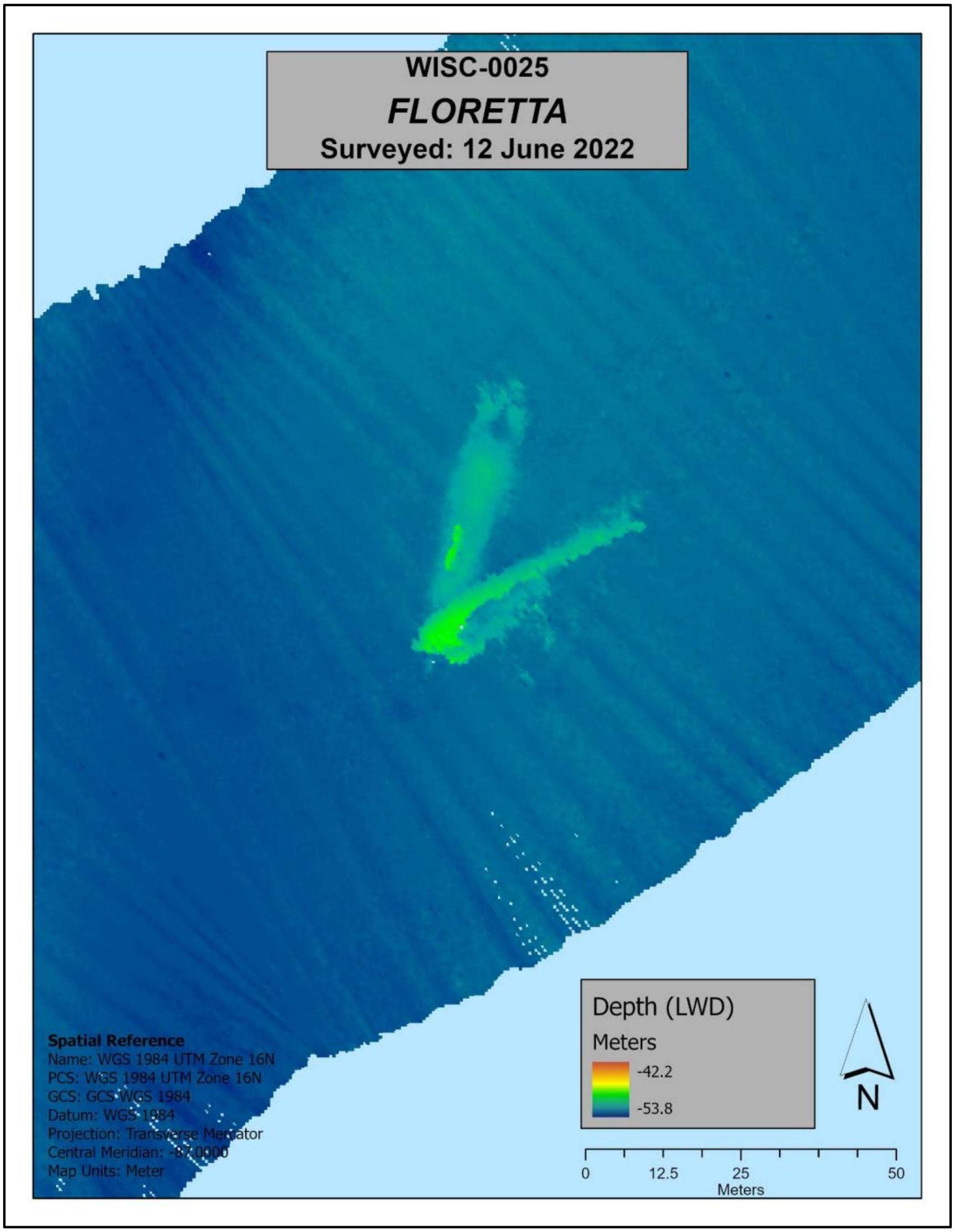


Figure 8. Processed multibeam sonar data from at the site of WISC-0025. Map by NOAA TBNMS.

WISC-0026 *Gallinipper*

Mapping operations at WISC-0026 were completed on 12 June, 2022. A total of 3 sonar files were collected. These raw data were processed to render the image seen in Figure 9, from which position and depth data were derived reported in Table 3.

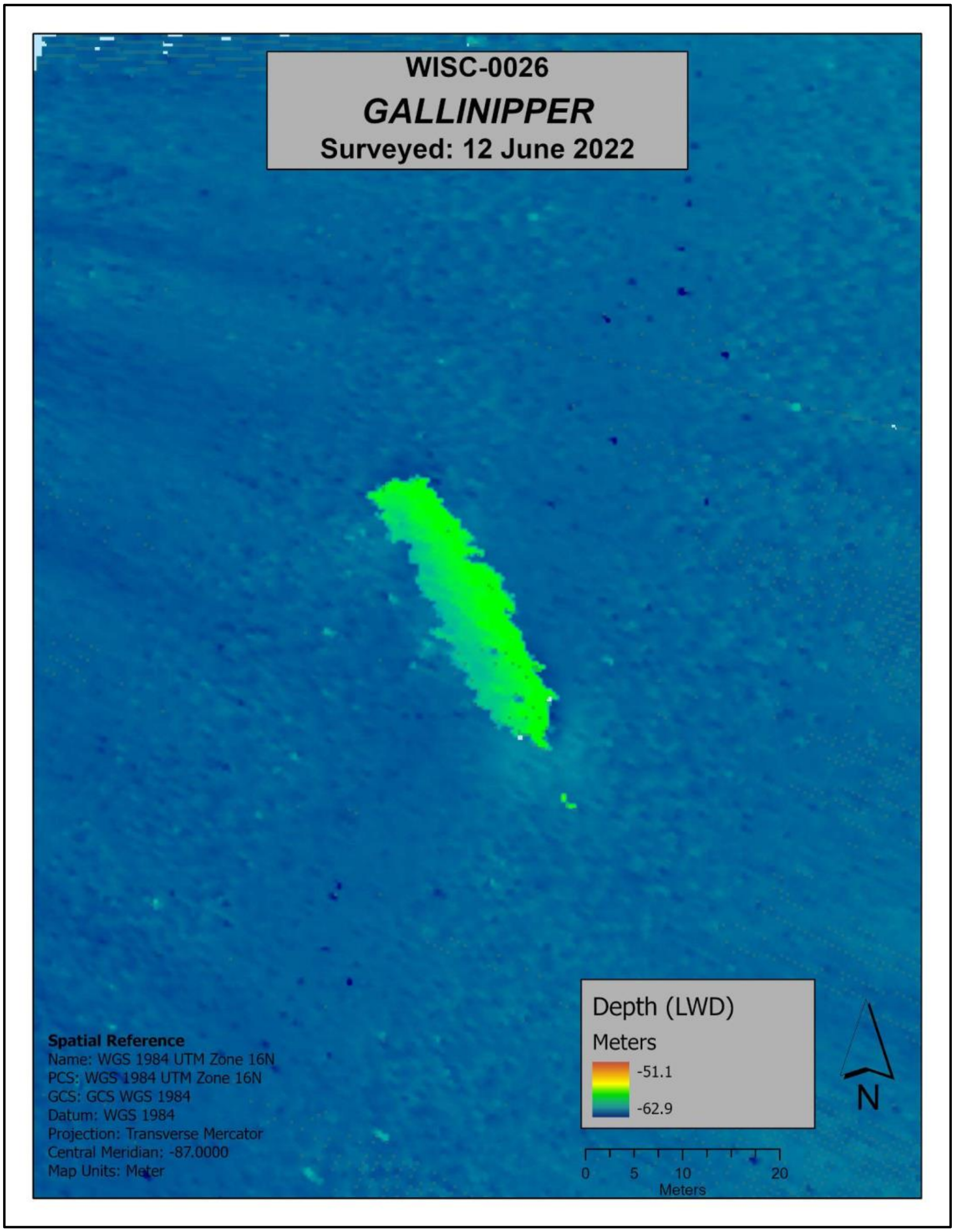


Figure 9. Processed multibeam sonar data from at the site of WISC-0026. Map by NOAA TBNMS.

WISC-0027 *Henry Gust*

Mapping operations at WISC-0027 were completed on 12 June, 2022. A total of 3 sonar files were collected. These raw data were processed to render the image seen in Figure 10, from which position and depth data were derived reported in Table 3.

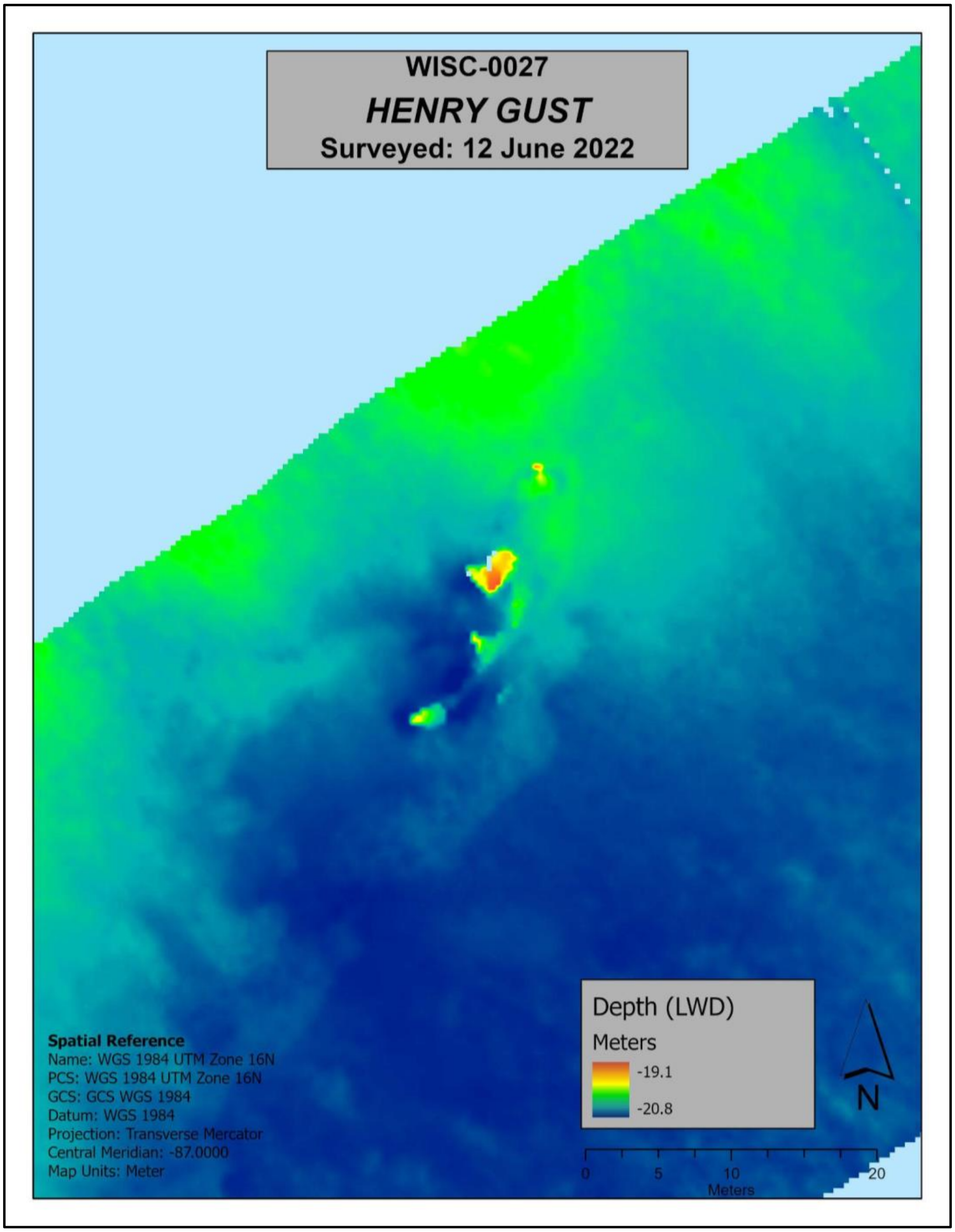


Figure 10. Processed multibeam sonar data from at the site of WISC-0027. Map by NOAA TBNMS.

WISC-0028 *Home*

Mapping operations at WISC-0028 were completed on 12 June, 2022. A total of 4 sonar files were collected. These raw data were processed to render the image seen in Figure 11, from which position and depth data were derived reported in Table 3.

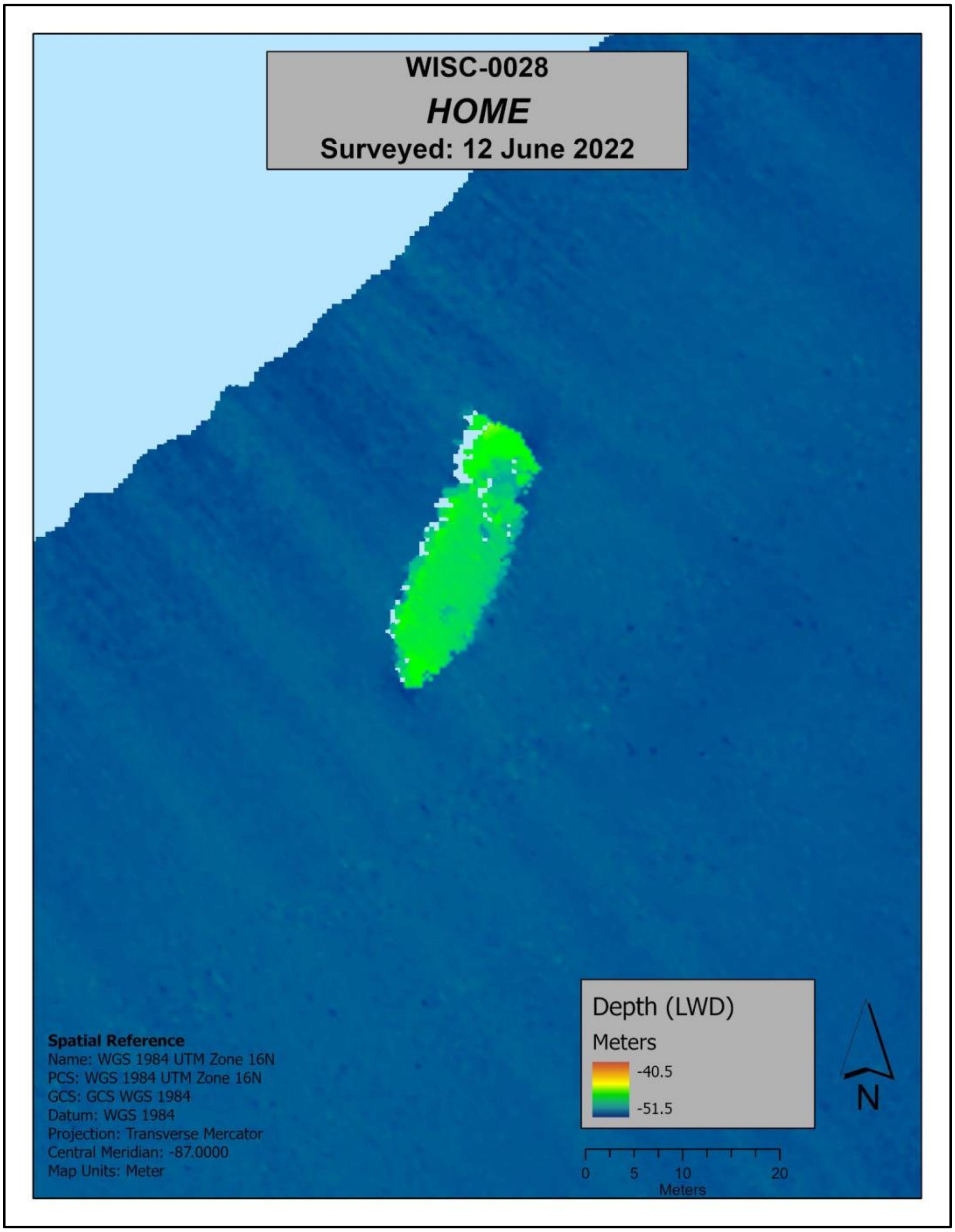


Figure 11. Processed multibeam sonar data from at the site of WISC-0028. Map by NOAA TBNMS.

WISC-0029 *Robert C Pringle*

Mapping operations at WISC-0029 were completed on 10 June, 2022. A total of 2 sonar files were collected. These raw data were processed to render the image seen in Figure 12, from which position and depth data were derived reported in Table 3.

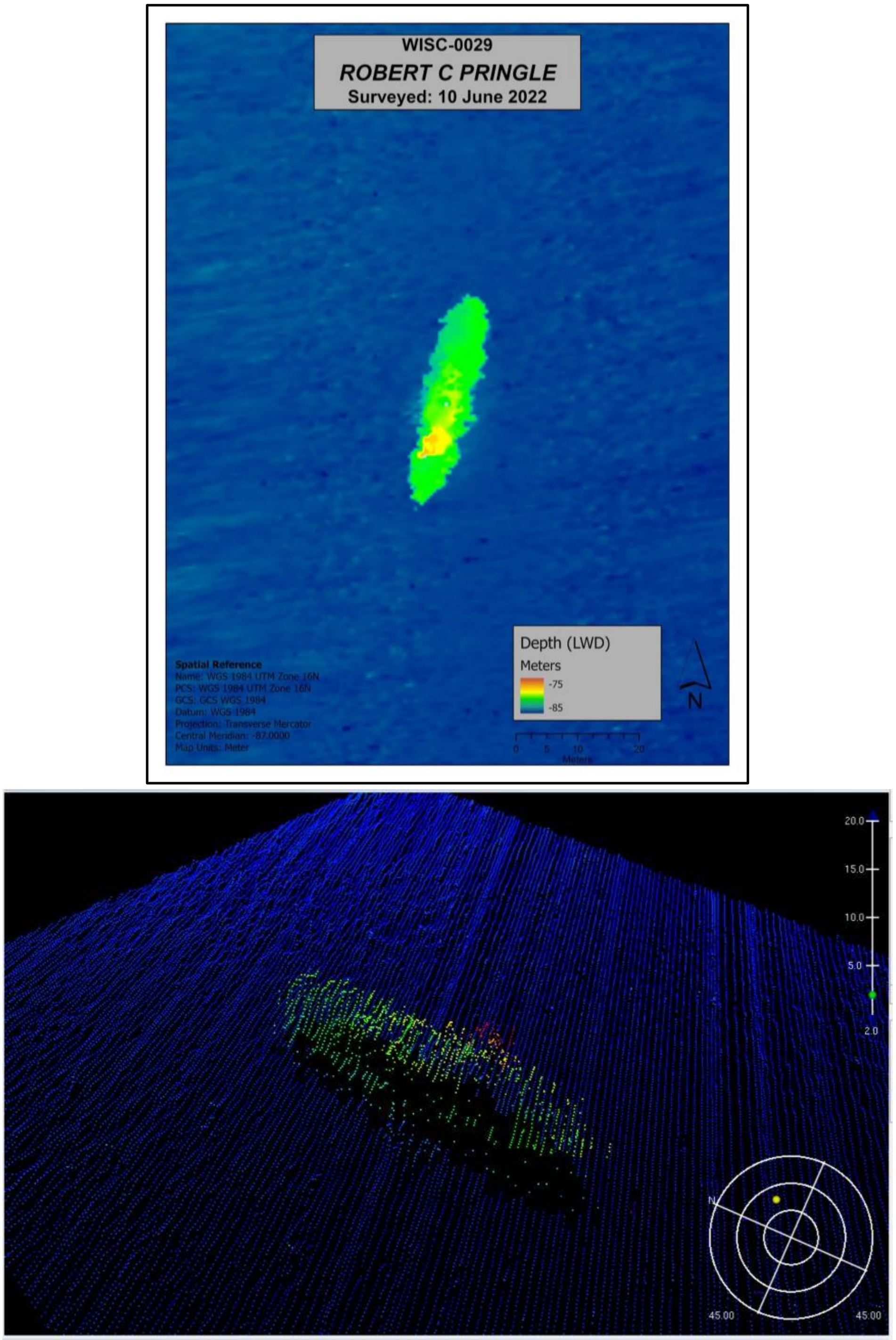


Figure 12. Processed multibeam sonar data from at the site of WISC-0029. Map by NOAA TBNMS.

WISC-0030 *Rouse Simmons*

Mapping operations at WISC-0030 were completed on 12 June, 2022. A total of 2 sonar files were collected. These raw data were processed to render the image seen in Figure 13, from which position and depth data were derived reported in Table 3.

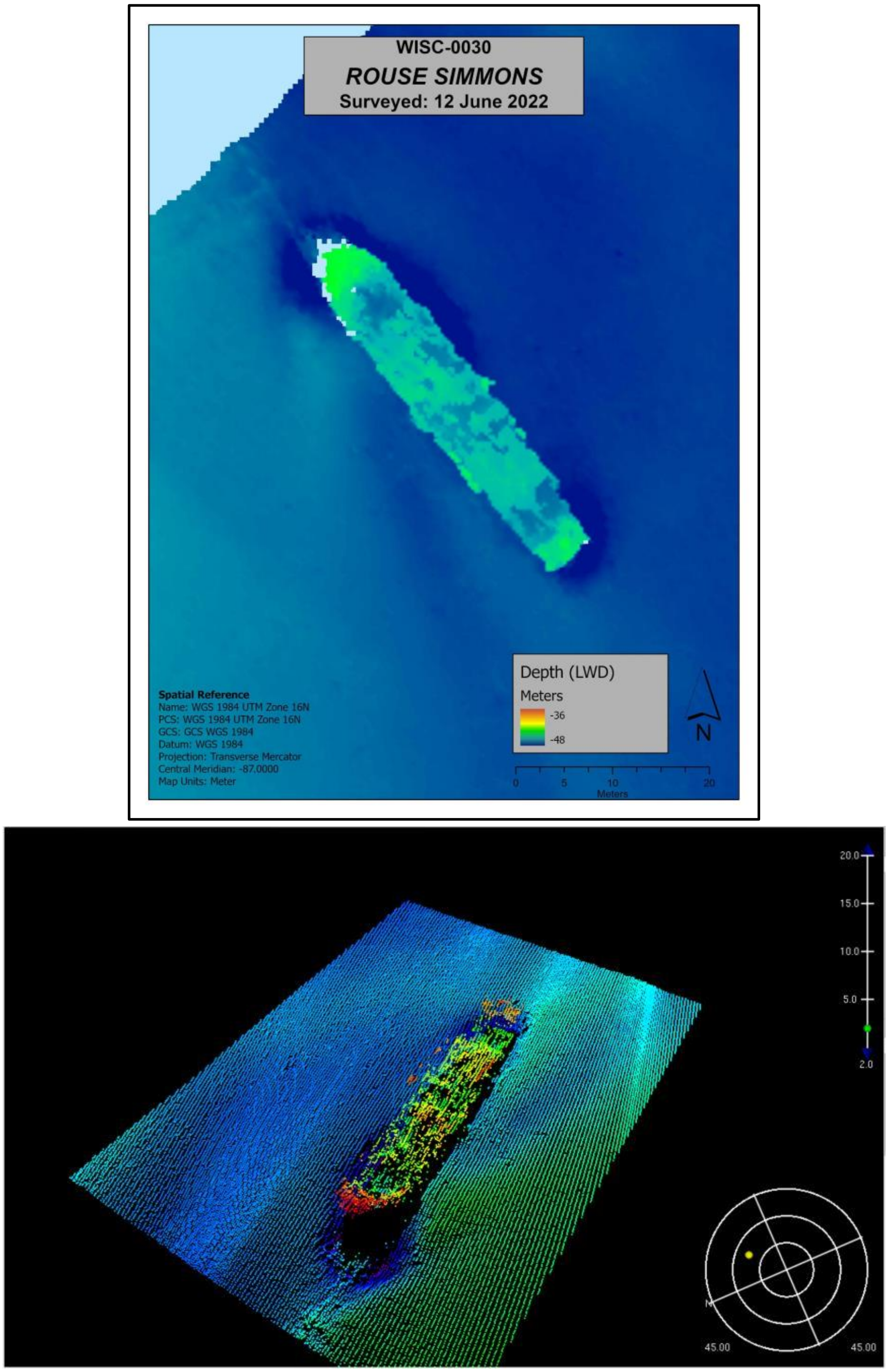


Figure 13 Processed multibeam sonar data from at the site of WISC-0030. Map by NOAA TBNMS.

WISC-0033 *Silver Lake*

Mapping operations at WISC-0033 were completed on 10 June, 2022. A total of 3 sonar files were collected. These raw data were processed to render the image seen in Figure 14, from which position and depth data were derived in reported Table 3.

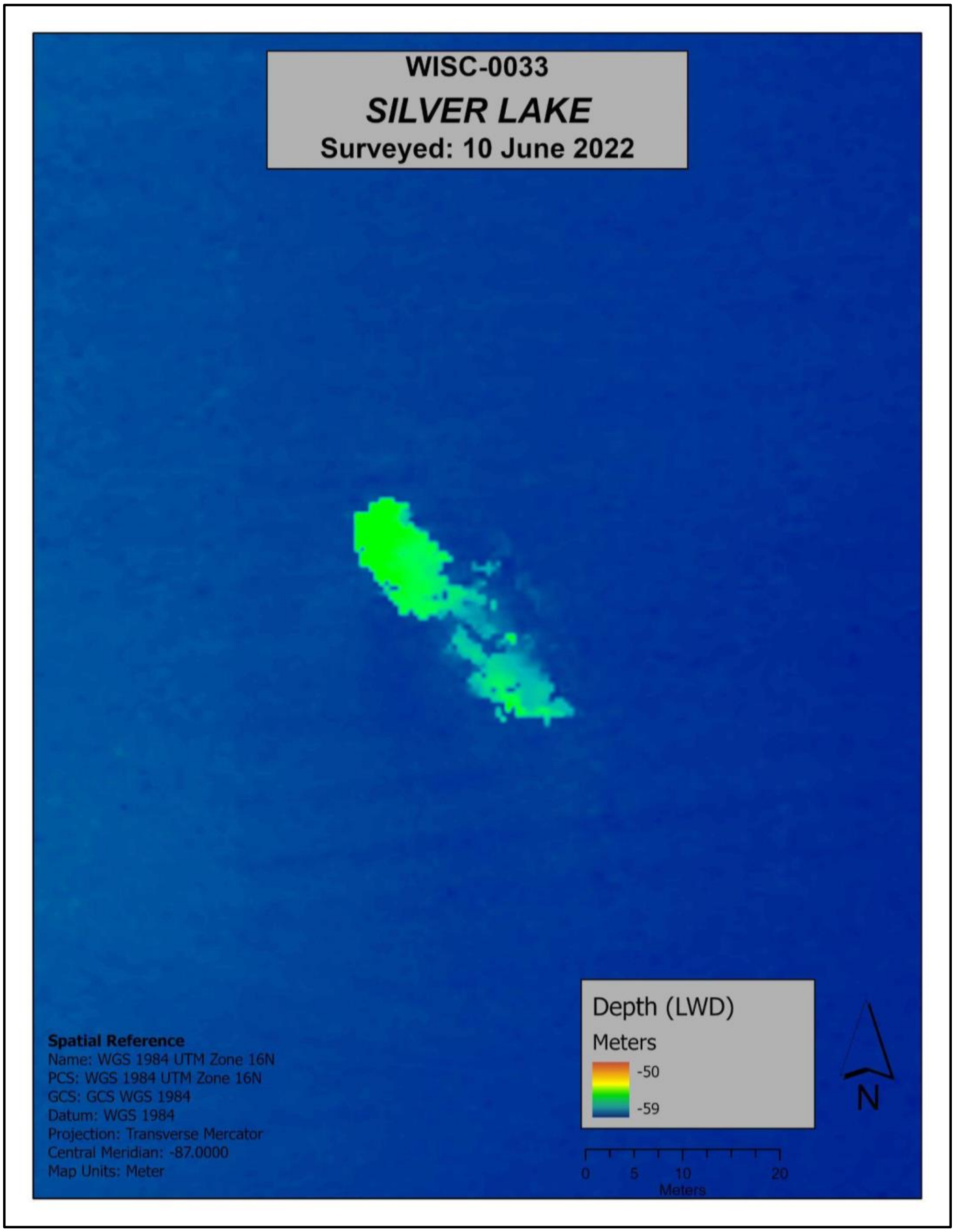


Figure 14. Processed multibeam sonar data from at the site of WISC-0033. Map by NOAA TBNMS.

WISC-0036 *Vernon*

Mapping operations at WISC-0036 were completed on 12 June, 2022. A total of 2 sonar files were collected. These raw data were processed to render the image seen in Figure 15, from which position and depth data were derived reported in Table 3.

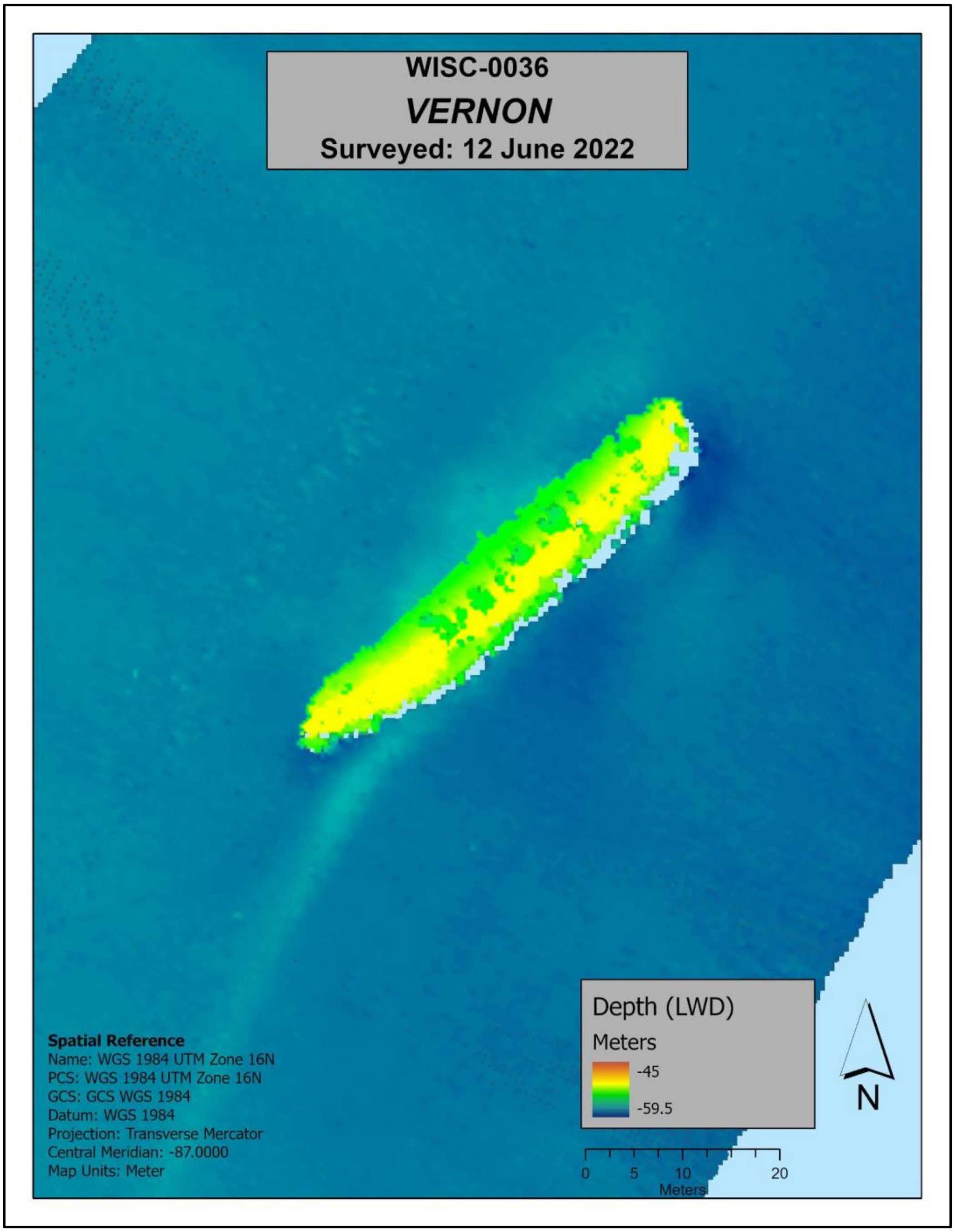


Figure 15. Processed multibeam sonar data from at the site of WISC-0036. Map by NOAA TBNMS.

WISC-0037 *Walter B Allen*

Mapping operations at WISC-0037 were completed on 10 June, 2022. A total of 3 sonar files were collected. These raw data were processed to render the image seen in Figure 16, from which position and depth data were derived reported in Table 3.

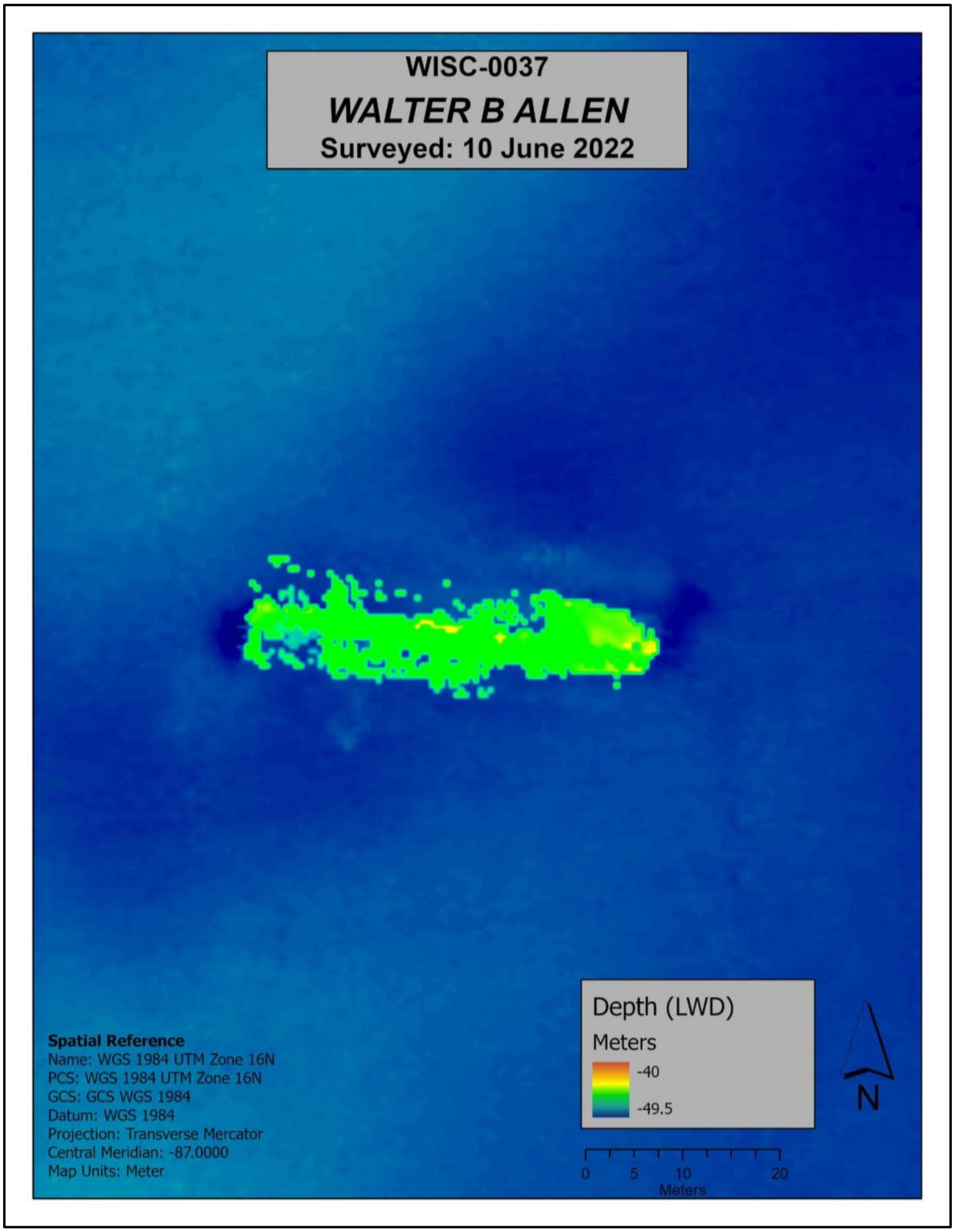


Figure 16. Processed multibeam sonar data from at the site of WISC-0037. Map by NOAA TBNMS.

Shipwreck Monitoring and Inventory

A complete MARIS site file has been generated for each of the 10 resources visited during field operations. In addition, the site files have been updated for the 12 resources that were surveyed via multibeam but not assessed during field operations. These resource files remain incomplete as they lack relevant condition and threats/disturbances data.

Baseline MARIS assessment reports were generated for the sites with completed MARIS site files. These baseline assessments are not necessarily the first archaeological assessment conducted at a resource site; instead, they are the initial assessment conducted post-designation of WSCNMS. These baseline reports were shared with the Wisconsin Historical Society as a project product. The summary of 2022 findings presented in MARIS is duplicated below.

WISC-0005 *LaSalle*

The canal schooner *LaSalle* was built by Parsons and Humble Shipyard in Tonawanda, New York. Designed for use with the inland canal systems, *LaSalle* served as a cargo carrier throughout the Great Lakes and their connected waterways. With a cargo of wheat destined for Buffalo, the vessel sailed into a storm. While off the coast of Rawley Point, the rudder slipped out of its position and the vessel drifted into shallow water and the notorious quicksands. Several vessels attempted to free *LaSalle* from the sandbar to no avail. Badly damaged, the canal schooner was stripped of materials and abandoned.

As documented by the Wisconsin Historical Society, the vessel sits in shallow water in the quicksands off Rawley Point (Thomsen and Zant 2016). The hull, measuring 140 ft. in length, remains largely intact (Thomsen and Zant 2016). The weather deck, Sampson post, and windlass knees were all noted in the 2016 initial documentation. While the vessel was thought to be stripped of materials, the rigging was found in the vessel's hull. Deadeyes and circular hearts are present on the site.

During the ONMS MARIS assessment conducted on 15 June 2022, it was noted that the site is currently covered by sand for the most part. Approximately 50 ft. of the upper hull is exposed. Fabric was observed during the assessment, although it remains unclear if it is historic or modern. Visibility was low, approximately 10 ft. Photographs were taken for photogrammetric modeling. In comparison with the 2015 site imagery, the hull has been largely reburied. This process was noted as an active disturbance with unknown impacts. No adverse threats were noted during assessment.

The site is slated to receive a permanent mooring system, after which an annual monitoring regime can be implemented. Mapping of site extents is recommended for comparison with 2015 site imagery. Continued threats/disturbances analysis is also recommended to understand environmental site processes.

WISC-0008 *America*

The canal schooner *America* was built by Archibald Muir at Port Huron, Michigan. The vessel was developed to transit through the Welland Canal system of locks. The vessel typically carried lumber and ice. While traveling through Lake Michigan with a cargo of iron ore, *America* crossed through a tow line of vessels under tow. The tow line ripped a hole in the hull of *America*, quickly sending the canal schooner to the bottom.

The canal schooner *America* was initially reported in 1977. The Wisconsin Historical Society conducted a preliminary non-invasive site investigation in 2012, recording extant site remains (Zant et al. 2017). As documented by the Wisconsin Historical Society, the hull is broken, however all structures and rigging are still present on site. The deck is totally collapsed, and both the port and starboard sides of the vessel have broken at the turn of the bilge (Zant et al. 2017). The centerboard trunk remains upright, along with the stem and stern posts. Scantlings are presented in the National Register nomination. Additional distinct site features include the samson post, windlass barrel, rudder, capstan, and deck artifacts including bitts (Zant et al. 2017). The center cargo hatch sits inverted on the lakebed adjacent to the main wreck site. The vessel's three masts are all located adjacent to the starboard side of the hull (Zant et al. 2017). Several artifacts have been recovered from the site; these are on display in the Wisconsin Maritime Museum and the Rogers Street Fishing Village.

The site was initially assessed by ONMS on 13 June 2022, including collection of photogrammetric and video data and diver observations to support the initial MARIS baseline assessment. Divers noted the site sits flush with the lakebed. Masts and rigging elements are disarticulate from the main wreckage and located in adjacent areas. The bow and stern have a higher vertical relief from the lakebed. No portable artifacts were observed during the dive. In addition, divers noted a large amount of older mooring line fouled near the vessel’s bow (Figure 17); these lines should be removed from the site as soon as reasonably possible once a permanent mooring system is deployed. After the installation of a recreational dive mooring system, the site will be monitored annually. Recommended actions include removing derelict materials and installing a mooring system to facilitate recreational use.

Figure 17. Bow area of *America* showing fouled polypropylene rope formerly used as mooring lines tied into the shipwreck. Image by NOAA.

The site was assigned an annual monitoring schedule in anticipation of installation of a recreational mooring system. Site recording was a recommended management step to supplement the existing photomosaic.

WISC-0015 *Selah Chamberlain*

The steam barge *Selah Chamberlain* was built by Quayle Martin at Cleveland, Ohio for use as a Great Lakes bulk carrier. Operating out of Cleveland, OH, the vessel transported coal, iron ore, and wheat between Buffalo, NY and Duluth, MN. While passing through Lake Michigan, *Selah Chamberlain* encountered foul weather and collided with another vessel. While attempting a run towards shore, *Selah Chamberlain* quickly took on water, sinking to the lakebed. Several salvage operations occurred, although none were successful.

A non-invasive site survey was conducted by the Wisconsin Historical Society and East Carolina University in 1996 and 1997. Subsequent site visits were conducted in 2004, 2008, 2012, and 2016 by a team from the Wisconsin Historical Society. As documented by the Wisconsin State Historical Society, the remains of *Selah Chamberlain* are in approximately 85 feet of water (Thomsen et al. 2019). The vessel is broken into three sections, with much of the lower hull present. The hull itself is splayed open. The fantail stern is located on site, split open to expose the boilers and engine. The steam machinery is the largest concentration of materials in-situ. The cast iron frame of the tandem engine rises close to twenty-five feet off the bottom, creating a unique display offering engineering details not seen on later engines (Thomsen et al. 2019). The deck, superstructure, cabins, and pilothouse are no longer present on site.

On 10 June 2022, a team from the NOAA Office of National Marine Sanctuaries visited the site to conduct a preliminary MARIS baseline assessment. The site was recorded with still and video. Given limited visibility, only a partial photogrammetric model could be created. The project team noted that remains display a significant encrustation of Dreissenid mussels. While some timbers lying prone on the lakebed show moderate encrustation, any upright hull and iron has been colonized. Features in the double boiler are moderately identifiable. In addition, the interior of the remaining hull structure has sunk into the sand. Framing elements are visible above the lakebed, with the steam engine being a prominent site feature. The rudder and drive shaft assembly are clearly identifiable. The bow was not visited during field operations.

The engine appears largely as described in past reports, with the notable addition of a derelict mooring buoy and 15-ft. chain that are entangled with the boiler assembly (Figure 18). No other obvious anthropogenic impacts were noted on site. Given the status of the existing mooring, it is strongly suggested that a new mooring buoy be installed adjacent to historic materials and the derelict system removed. The site was assigned an annual monitoring schedule due to anticipated installation of a recreational mooring system. Mapping of site extents is recommended to support archaeological site research. Continued threats/disturbances analysis is also recommended to understand impact of derelict mooring on site structure.

Figure 18. Braided line and chain tied to the engine of *Selah Chamberlain*; these lines were formerly used as part of a mooring buoy system but have since been abandoned. Image by NOAA.

WISC-0016 *Hetty Taylor*

The wooden schooner *Hetty Taylor* was built at Milwaukee for use in the Great Lakes trade. The vessel primarily carried lumber between various ports and Milwaukee. While passing through Lake Michigan, the vessel encountered a squall, capsizing five miles from shore. The vessel settled upright in 110 feet of water; the masts protruding above the lake's surface. A diver was hired to salvage the site shortly after. Multiple salvage efforts occurred, however they were all unsuccessful in re-floating the hull.

During the summer of 1996, avocational divers Robert and Charles Thom documented the site, assisted by the Wisconsin Historical Society. The Wisconsin Historical Society maintains a seasonal mooring at the wreck site. As documented by the Wisconsin State Historical Society, *Hetty Taylor* rests upright in 105 feet of water (Meverden and Jensen 2004). The hull demonstrates a moderate degree of structural integrity, although it is higher than comparable sanctuary sites at similar depths; the bow remains upright and largely intact. A windlass and anchor chain remain in-situ on the main deck. Several hatchways are present along with the centerboard trunk (Meverden and Jensen 2004). The port hull remains upright, intact from keel to rail. The starboard side of the vessel has collapsed, as has the stern. Visible stern elements are present, including the rudder.

The site was assessed by ONMS on 9 June 2022, using photogrammetric modeling and photography of site remains. All data were recorded in MARIS.

Site preservation appears largely as described in the National Register Nomination. The small wooden schooner sits on a slope—a berm of sediment has gathered on the port side of the vessel while the starboard side remains scoured out. The bow remains in-situ with the bowsprit intact. The forward hatch remains open, and fragments of cloth, fabric, or plastic were seen in the hold. The entire site truncates past the aft mast step, and large portions of the starboard side of the vessel have fallen away. The centerboard trunk sits at a 75-degree angle and is currently held up by the starboard main deck. The port main deck at the centerboard trunk is falling inward.

No seasonal mooring was identified on the surface; however, the mooring tackle was identified buried in sediment. A chain uplink connects to a subsurface buoy. The subsurface had a portion of chain attached but had not been connected to a topside buoy yet. The only additional anthropogenic impact noted was a small memorial placed off the starboard side of the vessel. Repair or a new installation of a permanent mooring system is recommended. Thorough reconnaissance of the site to determine the current presence and location of portable artifacts, should be done in tandem with a mooring installation.

The site was assigned an annual monitoring schedule due to anticipated installation of a recreational mooring system. Certain resource protection measures could be implemented as the site shows active human use and has a history of looting. In addition, continued threats/disturbances analysis is recommended given the current state of the centerboard and potential collapse of standing vessel features.

WISC-0017 *Advance*

The schooner *Advance* was built by James M. Jones at Milwaukee, WI. Serving as a cargo carrier, the vessel was passing through Lake Michigan when it began to leak. Capsizing south of Sheboygan, the captain and four of the crew drowned while attempting to reach shore in a yawl.

As documented by the Wisconsin Historical Society, the schooner is broken up, located at its loss location in approximately 80 feet of water (Wisconsin Sea Grant and Wisconsin Historical Society 2022a). The centerboard trunk is present; however, the hull is largely disarticulated to the lower portions of the vessel. Parts of the wreck embedded in sediment likely remain articulate.

The site was initially documented for entry into the MARIS database on 9 June 2022, using photogrammetric modeling and photography of site remains. The stern and stem posts still stand erect while the port and starboard sides of the vessel are lying flush with the lakebed. A windlass provides an area of interest, as does the upright centerboard trunk. Ceiling planking is visible and does not bear the same extent of Dreissenid mussel coverage as other areas on site. Several other features are proud of the lakebed, including a heavily encrusted stanchion post and several keelsons/large timbers. These timbers were wrapped with lines that were heavily encrusted. Further research is needed to determine which of these lines are modern or historic rigging. Additional evidence of human interaction is present—modern lines and ropes cover much of the site (Figure 19) as evidenced by their material and the inclusion of floats and jugs. Modern refuse was also present on the lakebed around the site (e.g., divers observed snack wrappers and food packing.

After a sanctuary mooring buoy is installed on site, non-historic lines should be removed from the site and an in-depth reconnaissance of the site should be conducted to determine current presence and location of portable artifacts. The site was assigned an annual monitoring schedule due to anticipated installation of a recreational mooring system. Continued threats and disturbances analysis is suggested given the presence of modern debris.

Figure 19. Examples of former mooring lines fouled around the site of *Advance*. Image by NOAA.

WISC-0019 *Atlanta*

Built by the Cleveland Dry Dock Company of Ohio, the steamer *Atlanta* was owned by the Goodrich Transit Company. The vessel transported packages and passengers between ports on Lake Michigan. While passing through the lake in early spring, a fire broke out in the hold of the vessel. The passengers and crew all made it off the burning ship, although one crew member did not survive the transit to a rescue vessel. *Atlanta* was towed into shallow water where it burned to the waterline. Following fourteen years of decay, the vessel salvage was awarded to Leathem & Smith Towing and Wrecking Company of Sturgeon Bay, WI. Much of the machinery—the target of the salvors—was found to be burned beyond use. The scotch boiler was found in working condition and returned to service. The remaining materials were sold for scrap.

The site has long been known to local communities, with salvage efforts first documented in 1920 but likely occurring at the time of wrecking. During the 2016 field season, students from East Carolina University visited the site, conducting an archaeological survey and non-disturbance documentation. As documented by the Wisconsin Historical Society, the remains of *Atlanta* are located in shallow water on a sandy bottom (Thomsen et al. 2018). The wreckage primarily consists of the lower hull, although vertical integrity rises above ten feet in certain locations. The hogging trusses and diagonal bracing are visible, as are remnants of plumbing and electrical wiring (Thomsen et al. 2018). The drive shaft and associated materials are also located in-situ. Portable artifacts have been noted, including enamelware, glassware, and small artifacts. Given the circumstances of the loss event, human remains are not expected on site.

The site was initially assessed for its MARIS baseline condition on 8 June 2022. Selected site photography was taken in addition to the MARIS baseline assessment. Due to shallow water, the NOAA vessel did not live boat over the shipwreck site. Average water depth surrounding the wreck site was 10-13 ft.

The site was colonized by a thick algal layer. No small portable artifacts were observed on site. Dreissenid mussels cover the majority of vertical structure and all associated iron ship construction features, regardless of orientation in the water column. A significant number of small fish schools were present on site. Anthropogenic impacts include a small amount of fishing line and several golf balls. Scouring is present around the stern of the vessel, creating a berm of sediment that at this time obscures the aft starboard side of the vessel. The hull interior is filled with a sediment of sand and shell hash. Iron truss framing appears similar to the extent recorded by the ECU field school, however, the vessel’s interior now has a large amount of sediment obscuring site features. Additional steam machinery is present on site.

The site was assigned an annual monitoring schedule due to anticipated installation of a recreational mooring system. Artifact analysis was recommended as portable artifacts have been identified on site in the past. In addition, continued threats/disturbances analysis is recommended as the site is likely impacted by storms and freeze/thaw cycles.

WISC-0021 *Niagara*

The steamer *Niagara* was built by Jacob Banta at Buffalo, NY. Owned by the New York & Erie Railway Company of Erie Pennsylvania, the side-wheel steamer carried both passengers and cargo throughout the Great Lake. Later serving the Collingwood Line, *Niagara* was considered one of the company's best steamers. While traveling south on Lake Michigan in 1856, the steamer caught fire, killing 60 of the 300 passengers on board.

As documented by the Wisconsin Historical Society, the remains of Niagara are located in 55 feet of water (Wisconsin Sea Grant and Wisconsin Historical Society 2022c). The stern and lower hull are present to just forward of the steam machinery. The hull sides have broken at the turn of the bilge and are lying flush on the lakebed. The central keelson and floor keelsons are extant, as is the steam engine, walking beam, and triple firebox boilers (Wisconsin Sea Grant and Wisconsin Historical Society 2022c). The vessel's two paddlewheels are also located on site. Given a review of past underwater imagery, the paddlewheels have lost a significant degree of preservation..

The site was assessed and entered into the MARIS database on on 8 June 2022. Two dive teams conducted photogrammetric modeling and selected site photography for the baseline assessment of the site. Video was collected for outreach while photographs were primarily collected for photogrammetric modeling.

The research team noted extensive evidence of Dreissenid mussel encrustation. The paddle wheel shafts are present; however, several portions of the site have lines or straps in place that may have been used by looters to access areas of interest. One strap with a rubber handle was visible on the walking beam of the engine (Figure 20). Portions of the keelsons are visible under the mussel layer and show construction features including fasteners and scarph joints.

A mooring buoy is present on the wreck site, consisting of a train wheel attached via chain uplink to subsurface and surface buoys. The dive team used the mooring assembly for entry and exit-- the buoy location was well placed for site access. No portable artifacts were visible; however, it was difficult to determine the condition of wreck material due to colonization by either algae or Dreissenid mussels. Large features on site (walking beam, paddle wheel shafts, boiler components) are aesthetically appealing, forming a concentrated area of interest for recreational divers. Remaining sections of hull and internal framing elements sit flush with the lakebed, creating limited relief. The site was assigned an annual monitoring schedule due to anticipated installation of a recreational mooring system.

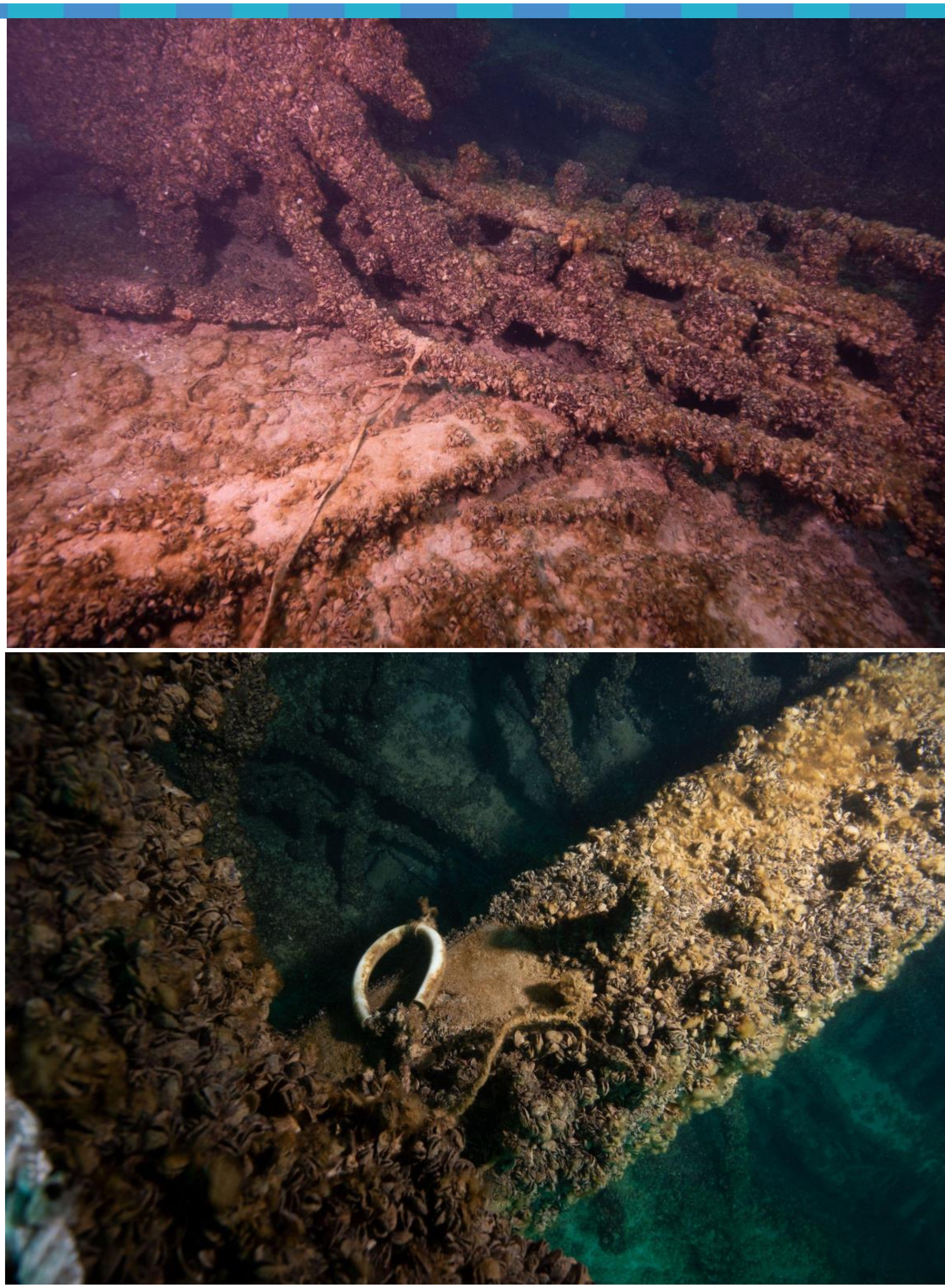


Figure 20. Lines tied to features along the site of *Niagara*. Image by NOAA.

WISC-0022 *Mahoning*

The wooden brig *Mahoning* was built at Cleveland, Ohio. The vessel primarily served as a bulk cargo carrier, transporting lumber between ports. While transiting Lake Michigan in November

1864, the vessel was caught in a storm and left stranded near the mouth of the Black River. Ca. 1865 salvage attempts resulted in the recovery of the vessel's steam pumps, anchor, chain, rigging, and blocks. The hull was brought under tow, however it capsized during transport. Reportedly, two lives were lost when the vessel was under tow.

As documented by the Wisconsin Historical Society, the vessel lies in 55 feet of water (Wisconsin Sea Grant and Wisconsin Historical Society 2022b). The hull is disarticulated, although the capstan, stock anchor, and dead eyes are all located on site. A boiler and steam pump are present at the wreck site (Wisconsin Sea Grant and Wisconsin Historical Society 2022b).

On 11 June 2022, the site was visited by a team from the NOAA Office of National Marine Sanctuaries for MARIS baseline documentation, collecting video footage and stills for photogrammetric modeling (Figure 21). While live boating, the dive teams used a locally maintained mooring for a decent/ascent line. Divers observed that a significant portion of the vessel is present in a disarticulated state. The recreational mooring buoy is affixed to the bow, which consists of the capstan, windlass, anchor chain, and an assemblage of timbers. The deck and port hull from the turn of the bilge to rail are splayed out in two sections that sit flush to the lakebed. The centerboard trunk is collapsed onto the hull. Towards the stern, the stern post is present. The rudder is disarticulate from the aft portion of the vessel. A lead scupper was observed affixed to a timber. A portion of concreted iron was also visible, possibly part of a scupper.

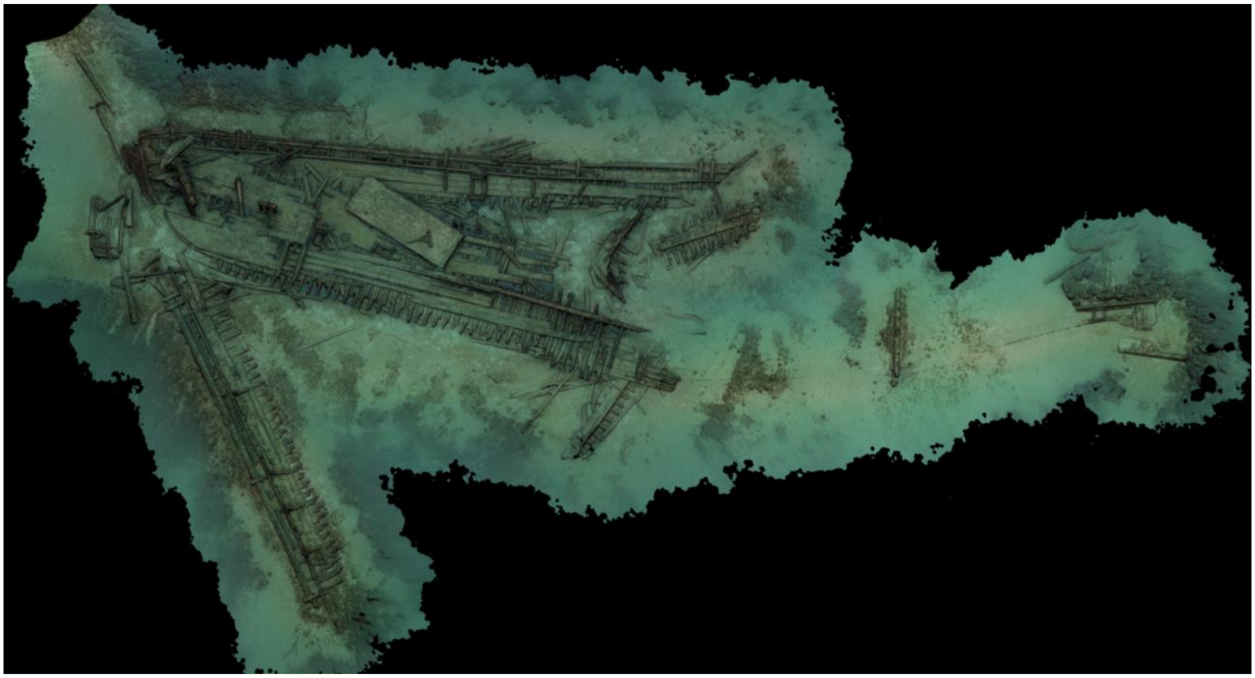


Figure 21. Orthomosaic export of the photogrammetric model generated at the *Mahoning* wreck site.

An annual monitoring interval was established due to the presence of a recreational mooring and shallow depth of site. The current mooring attached to the shipwreck (Figure 22) should be removed, and replaced with a permanent mooring adjacent to the site. In addition, remote sensing is recommended to assist with pinpointing a location for installation of a new mooring block. Continued threats and disturbances analysis recommended to assess impact of present mooring system.

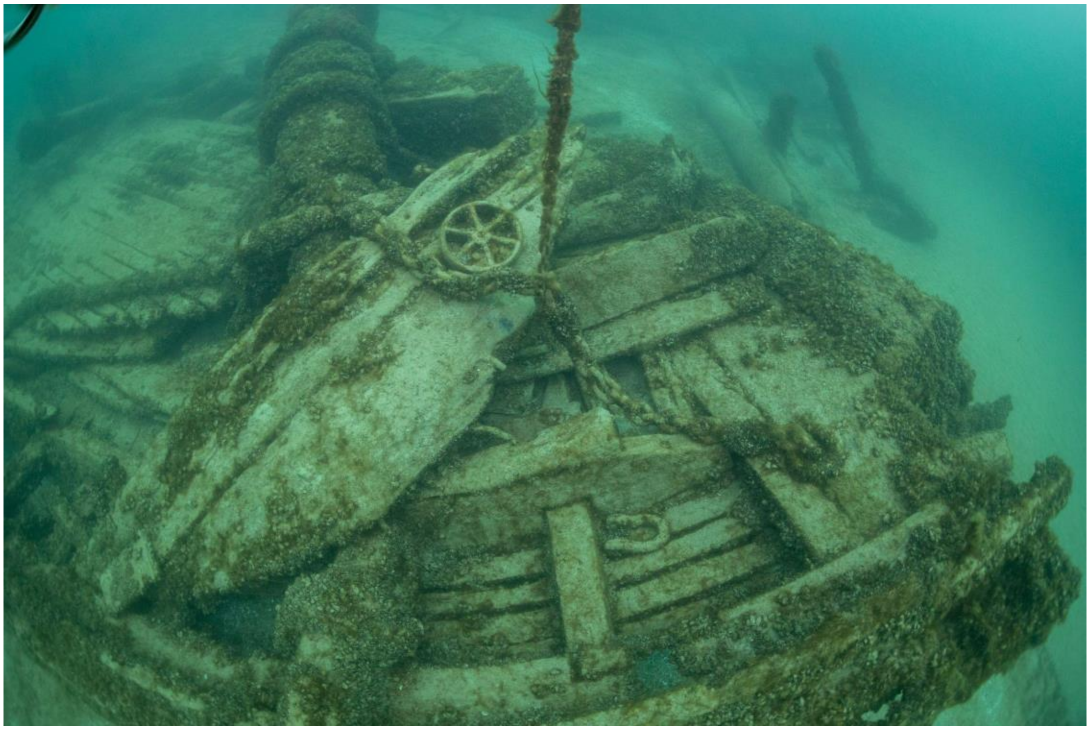


Figure 22. Bow area of *Mahoning* showing mooring chain (rising to the surface) tied into what is presumably historic chain on the wreck site. Image by NOAA.

WISC-0023 *Northerner*

The schooner *Northerner* was built by John Oades at Clayton, New York. The vessel served as a cargo carrier throughout the Great Lakes. While transiting Lake Michigan, *Northerner* began to sink while loading cordwood at Amsterdam, WI. Realizing the hull was leaking, the captain brought the hull into the Port Washington harbor where the deck cargo was unloaded. *Northerner* was put under tow for repairs in Milwaukee. While under tow, the hull filled with water and capsized. A cargo of cordwood is still present in the vessel's hold.

The vessel was initially identified via a rigging block removed by local diver Butch Klop in the 1970s. The Wisconsin State Historical Society conducted site reconnaissance in 2009 (Meverden and Thomsen 2010). As documented by the Wisconsin Historical Society, the hull of Northerner lies upright and intact in 140 feet of water (Meverden and Thomsen). The main mast remains upright and in-situ. The stern mast was removed by divers and is currently displayed in a local museum. The hold contains the cargo of cordwood, although the deck cargo was removed prior to sinking. Large artifacts present include the windlass, anchor chain, centerboard, bowsprit, and figurehead (Meverden and Thomsen 2010).

On 11 June 2022, ONMS conducted a preliminary MARIS assessment of the site, obtaining video, stills, and diver observations. In addition, the mooring maintained by volunteers on the site was assessed for its condition and placement. Overall the system was in good condition, however, the single train wheel anchor showed signs of dragging and may need to be replaced with a large deadweight system (Figure 23). The schooner today appears largely as described by the Wisconsin Historical Society. The hull is intact and features many opportunities to access the hold and the associated cargo. The bow, bowsprit, and caprail offer points of interest to the diver. While colonized by Dreissenid mussels, the site features many clearly distinguishable features. A complete photogrammetric model was generated from imagery collected at this site (Figure 24).

Figure 23. Installed mooring anchor (single train wheel) and chain at the *Northerner* site. Drag marks indicate that a more substantial mooring block is needed. Image by NOAA.

Figure 24. Photogrammetric model of *Northerner*.

The site was assigned an annual monitoring schedule due to anticipated installation of a recreational mooring system. Recommend continued threats/disturbances analysis as the vessel's structural integrity presents both enhanced research opportunities but also enhanced damage from threats.

WISC-0031 *S.C. Baldwin*

The steam barge *S.C. Baldwin* was built by Campbell, Owen, and Co. as an iron ore carrier for the Escanaba & Lake Michigan Transportation Company. Launched in 1871, the vessel transported ore from Escanaba, Michigan to Milwaukee, Wisconsin. Outfitted with a secondary deck after two seasons of work, the vessel was reportedly the first double decked steamer on the Great Lakes. Following several decades of service, the vessel was converted to a stone carrying barge in 1904. From 1905 to 1908, *S.C. Baldwin* carried limestone throughout Lake Michigan. While under tow in August of 1908, *S.C. Baldwin* began taking on water, capsizing in heavy seas. One crew member perished in the sinking, however their body was later recovered. As such, no human remains are present on site.

The site was re-located via sport fishermen in the 1970s. The site has since become a popular recreational dive given its relatively shallow depth. In the summer of 2015, staff and volunteers from the Wisconsin Historical Society conducted a targeted archaeological survey of site remains. As documented by the Wisconsin Historical Society, *S.C. Baldwin* rests on a sandy bottom in approximately 75 feet of water (Thomsen and Zant 2016). The stem post rises from the lakebed and the hull is presumed intact from the waterline to keel. Notably, deck features including the cargo hatches are located on site. Historic salvage events removed the deck works, rigging, and anchors (Thomsen and Zant 2016). As such, the stempost, keelson structure, stern, and stern decking retain a high degree of archaeological integrity on site. Scantlings are presented in both the research report and National Register nomination.

During the summer of 2021, an interdisciplinary team from NOAA ONMS and the University of Delaware conducted a targeted sidescan sonar survey of the site using an Iver3 Autonomous Underwater Vehicle. In addition, a photogrammetric model of the stempost was created. Low dive visibility prevented an in-depth survey of historic materials.

On 13 June 2022, ONMS collected still and video in support of an initial MARIS entry. No threats were noted during the FY22 baseline assessment, however fishing and anchoring were both noted as disturbances. Divers noted the stem post and associated timber assemblage remain a feature of interest on the site. Poor visibility prevented a full assessment of remains, however the stem post, stanchions, and portion of the port hull near the bow all retain a high degree of structural integrity. While colonized by Dreissenid mussels, the wooden hogging arch is still visible on the interior ceiling planking of the port forward hull. Much of the forward hull was covered with a layer of sand. Continued photo modeling is recommended as it would support better understanding of site sedimentation. Recommended management actions include additional site recording as only the bow was visited by divers. In addition, derelict line and marine debris should be removed from the site. The mooring system should be sited independently from historic materials and reinstalled. The site was assigned an annual visitation schedule due to its current use as a recreational dive site and the relative shallow depth.

Site Photography and Video Documentation

The various site documentation activities described in previous sections resulted in an extensive archive of photo and video files. These include raw and processed file types corresponding to the outputs from the imaging platforms utilized. Archived imagery files are described in Table 4.

Table 4. Summary of imagery archive resulting from project operations. **Organization and archiving of raw imagery files from the Nikon camera systems is ongoing. An additional memo related to these images and the photogrammetric models which resulted will be provided in follow-up reporting from the project team.

Platform	Number of Folders	Number of Files	Directory Size (bytes)
RED	418	1185	2,395,369,897,984
Insta360	8	46	105,949,167,616
GoPro	0	4	2,695,102,464
Boxfish	5	24	135,841,972,224
A7 II	29	646	47,303,622,656
1DX	9	2509	125,716,242,432

D800**	3	268	9,938,477,056
D810**	36	3320	125,243,006,976
D4**	0	0	0
DJI	5	73	10,953,826,304

Teacher-at-Sea Program

A month prior to the project, Sea Grant partners from Michigan and Illinois reached out to NOAA regarding the potential for educators to join a research cruise. Given that WSCNMS was designated less than a year ago, this represented an excellent opportunity for sanctuary and ONMS staff to interact directly with educators and provide them with impactful experiences that will translate well in the classroom. The team hosted two elementary school educators for 3 days, including 2 days on the RV *Storm*. This immersive experience provided the educators with a firsthand look at diving and sonar operations, as well as mission briefings, data processing, photomodel processing and more.

Feedback from the educators was very positive, but the experience was definitely a two-way exchange. The educators helped ONMS test the feasibility of future educator-at-sea experiences, and develop approaches that will ensure positive results in the classroom. WSCNMS looks forward to making this an annual part of its education program. A short ONMS-produced "Stories from the Blue" video will chronicle the teachers' experiences and help promote the program.

Discussion

This project constituted the first effort by the sanctuary to assess current conditions of its resources. The project benefits immensely from the detailed documentation of many sites by the Wisconsin Historical Society, which paves the way for meaningful follow-on, periodic assessments. An "assessment" of any cultural resource is nearly always a subjective undertaking, and further hampered by visibility and other factors on a given day. One of the goals of this project was to develop a framework and methodology for rapid assessments that can be deployed with consistency and repeated for ongoing monitoring. Products like photomodels, for example, can substantially reduce subjectivity. They are also relatively easy to create and repeat- in short a very efficient way to monitor a large collection of shipwreck sites over time.

Video and images can be used for monitoring as well, but more care must be taken to ensure consistency and repeatability over time. Focusing on specific areas of a shipwreck over time, for example, is a more effective use of these tools, than trying to capture an entire site at periodic intervals. Diver observations should be considered in a similar way- two divers looking at the same feature or swimming the same transect across a shipwreck will likely report different observations. In short, these methods must be used in a targeted way to be effective long term monitoring techniques. One outcome of this project was to evaluate these methods, refine them, and develop a sustained monitoring program that is both practical and effective.

The MARIS database baseline and condition report criteria offer initial frameworks for evaluating and articulating the condition of sanctuary resources. The site condition evaluation below is based on these.

Resource Condition and Threats/Disturbances Trends

The ONMS MARIS database framework uses current resource condition and observable threats and disturbances to quantify and qualify anthropogenic and natural impacts to archaeological resources and appropriate management actions. A threat is categorized as a negative impact with the potential to occur while a disturbance is a negative impact that is presently active.

The 10 fully-inventoried resources were assigned an overall condition of 'Good' or 'Good/Fair,' indicating that resources either showed no signs of active disturbances (Good) or minimal disturbances (Good/Fair). Only two resources were assigned a 'Good/Fair' condition, both due to the recreational moorings that are currently fixed to historic materials.

In addition to disturbances, multiple cultural threats[4] were observed across the majority of resources (Table 5). Seven of ten sites showed evidence of human impacts, including derelict lines (5/10 sites), marine debris (4/10 sites), or tools associated with modern salvage events (2/10 sites). In many cases, salvage is known to have impacted historic vessel structure or site assemblages. As ONMS does not have comparative monitoring data sets, however, the impact of past salvage events to current site condition could not be determined unless there were tangible remnants of salvage activities.

Table 5. Cultural threats identified during FY22 resource condition assessment. Threat absence or presence is indicated by 0 or 1, respectively. Resource structural integrity and presence of a mooring are included for comparison.

Site	Recreational Mooring	Structural Integrity	Human Impacts	Derelict Lines	Modern Looting or Salvage	Marine Debris
Atlanta	0	Fair	1	0	0	1
Niagara	1	Fair	1	1	1	0
Hetty Taylor	1	Good	1	0	1	1
Advance	0	Fair	1	1	0	1
Selah Chamberlain	1	Good	0	1	0	0

[4] While observed, the majority of anthropogenic impacts were identified as threats because their impact to resource value or significance is not quantified.

Northerner	1	Excellent	0	0	0	0
Mahoning	1	Good	1	0	0	0
S.C. Baldwin	1	Poor	1	1	0	1
America	1	Fair	1	1	0	0
LaSalle	0	Fair	0	0	0	0
Total	7	N/A	7	5	2	4

Additionally, generalized environmental threats were identified including sediment movement (3/10 sites), storm surge (2/10 sites), and seasonal freeze/thaw cycling (1/10 sites). As environmental trends were determined using past data collected by the Wisconsin Historical Society, comparison of similar variables was limited. Subsequent condition assessments are likely to yield a better understanding of environmental threats and disturbances as comparative data is collected.

Monitoring Schedule and Proposed Management Actions

Each of the 10 sites was placed on an annual condition assessment cycle as all are located within recreational dive depths. Many of the resources demonstrate observable human impacts and currently sustain some level of dive or visitor activity. As such, each resource has been identified as a good candidate for an ONMS-implemented mooring system.

General proposed management actions include enhanced assessment of threats and disturbances, additional site mapping, analysis of material culture, and enhanced site protection. Resource specific management actions are outlined in Table 6.

Table 6. Recommended management actions for resources inventoried during FY22 field operations

Resource	Recommended Management Action(s)
Atlanta	Material culture analysis was recommended as portable artifacts have been identified on site in the past. In addition, continued threats/disturbances analysis is recommended as site is likely impacted by storms and freeze/thaw cycles.
Niagara	Recommend continued threats/disturbances analysis to assess impact of past looting events to structural stability.
Hetty Taylor	Protection was identified as a management action as the site shows active human use and has a history of looting. In addition, continued threats/disturbances analysis is recommended given the current state of the centerboard and potential collapse of standing vessel features.
Advance	Historical research, site recording, and mapping were identified as management actions that would support a better understanding of the vessel's historic context. Continued threats and disturbances analysis is suggested given the presence of modern debris.
Selah Chamberlain	Mapping of site extents is recommended to support site research. Continued threats/disturbances analysis is also recommended to understand impact of derelict mooring on site structure.
Northerner	Recommend continued threats/disturbances analysis as the vessel's structural integrity presents both enhanced research opportunities but also enhanced damage from threats.
Mahoning	Historical analysis, mapping, site recording, and material culture analysis are recommended due to site features observed while diving and to increase knowledge of the vessel's historic context. In addition, remote sensing is recommended to assist with installation of a new mooring. Continued threats and disturbances analysis recommended to assess impact of present mooring system.

S.C. Baldwin	Recommended management actions include additional site recording as only the bow was visited by divers. In addition, recommend removing derelict line and marine debris from the site and re-installing a mooring system that is sited independently from historic materials.
America	Protection was identified as a management action as derelict line on site has the potential to foul vessel propellers and subsequently damage historic materials. Site recording was also recommended to supplement existing photomosaic .
LaSalle	Mapping of site extents is recommended for comparison with 2013 site imagery. Continued threats/disturbances analysis is also recommended to understand environmental site processes.

As marine debris and derelict lines or mooring systems were present at 7 of 10 sites, an overarching management action for sanctuary staff is to conduct targeted marine debris removal. All debris and lines were portable, suggesting that removal could be conducted by hand. As two of the recreational mooring systems are tied directly onto historic structures, a secondary management action is the installation of entire mooring systems at new locations on site. Photogrammetric site models were created for 8 of 10 sites, establishing a three-dimensional record of resource materials at their 2022 locations. Subsequent photo models of sites should be collected annually to identify changes in spatial patterning of materials. Additional opportunistic models (i.e. post storm events and seasonal change) are also recommended, especially for resources located in nearshore shallow water environments.

Conclusions and Recommendations

This project consisted of a combined multibeam remote sensing survey and diver-led inventory of underwater cultural heritage within the WSCNMS. The survey work supports on-going sanctuary research and outreach efforts. Imagery, collected at eleven shipwreck sites, further supports public education and offers an opportunity for non-diving members of the public to experience maritime heritage resources.

In addressing the research aims, the project team has conducted ten condition assessments on heritage resources located within WSCNMS. These condition assessments were supported by photographs, video recordings, 360º footage, and photogrammetric models. In addition, 3-dimensional sonar data was collected at 13 shipwreck sites. This data not only records site height and surrounding bathymetry, but will support future installation of ONMS-sponsored mooring buoys.

Photographs and video recordings were also used to capture B-roll footage of on-water operations, the surrounding community, and constituents that support the National Marine Sanctuary System. This footage will be used to continue WSCNMS and ONMS outreach, education, and marketing/branding efforts. At present, the footage is currently being used to generate 2 documentary-style films (Stories from the Blue) and will be used to produce many videos into the future. These films highlight not only the place, but also the people dedicating their work to protecting these special places for future generations and to encourage expanded stewardship of the nation’s fragile and awe-inspiring marine and Great Lakes resources. The 360° footage will also be used to develop virtual reality experiences that allow the public to visit and experience the shipwrecks of WSCNMS from anywhere in the world.

Opportunities for Continued Geophysical Exploration

High resolution geophysical (HRG) tools offer an array of technologies available to support exploration, characterization, and documentation of submerged cultural heritage sites. These tools support the rapid assessments of the type implemented in the current project, and offer exceptional quality in terms of the precision and accuracy of their data products in terms of geospatial positioning and resolution. Common HRG methods would include side scan sonar, multibeam sonar, sub-bottom sonar, and marine magnetometer sensors. Utilization of these technologies would allow researchers to ascertain detailed information on site positioning (including precise positioning on individual features resolved within the HRG data), site orientation, depths and heights of bottom, three-dimensional shape and volume, extent and disposition of buried materials, and categorization of surrounding benthic materials.

In the current project, HRG results were used as a positioning source to mark, reference, and locate features of individual sites during photogrammetric data processing. When available, similar HRG datasets can be used to repeat this process on existing or future photogrammetric data products. This type of cross-utilization will enable more powerful digital analytic tools to be used when describing site formation processes at cultural resources sites within WSCNMS.

Several sites documented in the current study, furthermore, contained expansive areas of site structure buried beneath the lakebed. These included WISC-0005 and WISC-0015, as well as anecdotal accounts of buried cultural resources throughout the Rawley Point area northeast of Two Rivers. Full characterization of these sites, as well as exploration and discovery of additional cultural materials in this area, would be greatly aided through HRG surveys. In particular marine magnetic surveys as well as sub-bottom sonar mapping.

Meanwhile, additional exploration is needed within areas of WSCNMS. While most of the WSCNMS geography has been mapped using common hydrographic survey methods, work is still needed to characterize targets, classify benthic habitats, and implement additional geophysical tools to map sub-surface features or collect focused, high resolution datasets over targeted areas and sites. These datasets will be critical for site management and resource protection efforts, and support actionable field operations (e.g. buoy deployments) and education/outreach efforts (e.g. VR tours and web-based products).

Fortunately for site managersHRG tools are being integrated into an increasing number of platform types and deployment modes. This will expand future possibilities for using these tools WSCNMS. Platforms include crewed surface vessels, as well as uncrewed platforms deployed above, on, and below the water's surface. Likewise, sensors, interfaces, and softwares are becoming increasingly intuitive and user-friendly. Numerous operations will be available and existing tools in use by NOAA and their partners will continue to offer valuable applications for cultural resource research and protection efforts.

Opportunities for Targeted Archaeological Site Research

Of the inventoried sites, three stand out as good candidates for continued archaeological research: *Mahoning* (1847), *Northerner* (1851), and *LaSalle* (1874). The relatively workable depth of *Mahoning* (17 meters/55 ft), combined with its early site history and extent of various materials, makes it an excellent candidate for targeted site mapping. While the Dreissenid mussel encrustation has colonized some site materials, construction features are still visible in timbers. The overall extent of materials suggests a large portion of the wreck is still present on site. As the site has not been mapped by the Wisconsin State Historical Society, additional research may support a National Register nomination or enhanced historical context of the site. The two-dimensional nature of the site further enhances mapping of features that are otherwise less accessible.

Northerner presents an incredible opportunity for recreational divers to experience a site with a high degree of both archaeological and structural integrity. As the cargo is visible and accessible, the site presents an opportunity to conduct three-dimensional recording of interior spaces, including arrangement of cargo and stowage. Given the site's depth (38m/125 ft.), any work would require technical diving. While the site has been previously recorded, enhanced mapping of interior spaces may shed new light on the vessel's historical context.

Finally, the *LaSalle* presents an opportunity for invasive archaeological excavation. As the site is often buried, there is a strong likelihood that sub-sediment features retain a high degree of archaeological and structural integrity. The relative site depth (3-5 m/10-15 ft.) and annual change in sediment patterns suggests the site would be quickly reburied, a necessary component for successful stabilization post-excavation. Targeted sediment removal would likely enhance understanding of the resource and provide additional information on the vessel's construction.

Mooring Buoy Deployment Preparation

Of the 21 sites visited by the NOAA team, mooring buoy systems were observed at 10 locations. These included sites with installed surface buoys as well as those with rigging and tackle noted underwater which appeared derelict or out of service. Of the sites surveyed with multibeam sonar, furthermore, surface floats were observed at 2 locations. Mooring gear may be present at some (or all) of the other surveyed site locations even though surface tackle was not present. Table 7 summarizes observations pertaining to mooring buoy status at each site visited by the NOAA team. At locations documented with sonar, absence of a surface buoy was not assumed to mean absence of mooring buoy tackle at a given location. Instead, those sites were listed as "Unknown" since mooring equipment may be attached to the site but not visible from the surface.

WSCNMS intends to deploy independent mooring buoy systems at sites throughout the management area. Observations of mooring buoy status at sites visited during 2022 are a key planning milestone ahead of developing a buoy deployment plan for future operations. Likewise, lessons learned from mooring buoy deployments at similar sites and depths in TBNMS are necessary for effective planning. The combination of these two inputs should inform WSCNMS buoy deployment preparations for the upcoming field season.

Key to all mooring systems at TBNMS is their independent anchor devices; none are attached directly to historic shipwreck sites. Instead, a variety of deadweight anchors are utilized including train wheels, concrete blocks, and rock boxes. These anchors are positioned near their assigned shipwreck sites to facilitate diving operations, yet they do not connect to any portion of the resource itself. Individual anchors are selected appropriate to the size of vessel which may visit the site. In shallow water (i.e., less than 10 ft) where smaller boats will travel, single train wheels, concrete blocks, and rock boxes are utilized. In deeper water where larger vessels can access sites, doubled train wheels are utilized.

RECOMMENDATION: WSCNMS should employ independent mooring systems.

- Sites with existing independent moorings (e.g., WISC-0016, WISC-0021, WISC-0023) should replace tackle and components as needed.
- Sites which anchor directly to the resource should be decommissioned and removed after an independent mooring is established.
- Sites without any mooring system should have new independent moorings established.

Table 7. Aggregated observations related to mooring buoy equipment at sites visited by NOAA researchers between June 8-17, 2022. * indicates surface buoy type being a fit-to-purpose mooring float.

Site	Mooring Gear Present	Surface Buoy* Present	Anchor Types
WISC-001 Continental	NO	NO	N/A
WISC-0005 LaSalle	NO	NO	N/A
WISC-0008 America	YES	NO	Unknown
WISC-0014 Helvetia	Unknown	NO	Unknown
WISC-0015 Selah Chamberlain	YES	NO	Site
WISC-0016 Hetty Taylor	YES	YES*	Screw Augers
WISC-0017 Advance	YES	NO	Site
WISC-0019 Atlanta	NO	NO	N/A
WISC-0021 Niagara	YES	YES*	Trainwheel
WISC-0022 Mahoning	YES	YES*	Site
WISC-0023 Northerner	YES	YES*	Trainwheel
WISC-0025 Floretta	Unknown	NO	Unknown
WISC-0026 Gallinipper	YES	YES	Unknown
WISC-0027 Henry Gust	Unknown	NO	Unknown
WISC-0028 Home	Unknown	NO	Unknown
WISC-0029 RC Pringle	Unknown	NO	Unknown
WISC-0030 Rouse Simmons	YES	YES	Unknown
WISC-0031 SC Baldwin	YES	YES*	Site
WISC-0033 Silver Lake	Unknown	NO	Unknown

WISC-0036 Vernon	Unknown	NO	Unknown
WISC-0037 WB Allen	Unknown	NO	Unknown

TBNMS has successfully deployed many of its mooring systems from a surface vessel. In this mode, the mooring is completely assembled at the surface and lowered into place via a slip-line and crane. Clear access from the surface to the lakebed are essential for a safe and effective deployment. In water depths less than 100 feet, divers can assist by placing marker buoys to assist with buoy anchor positioning. Beyond these depths, an ROV can be deployed during the mooring installation to verify proper placement and situation of the tackle. In either case–deep or shallow–any existing mooring tackle at a site poses a risk to the safe navigation of the surface vessel and/or risks fouling of the marker line, ROV tether, or new mooring tackle.

RECOMMENDATION: WSCNMS should consider removal of extant mooring tackle prior to the installation of new moorings to include:

- Clearing of any surface tackle and lines which may pose a risk to navigation of the surface vessel
- Removal of in-water tackle which may pose a risk of fouling with the new mooring or equipment used to aide the placement of the new mooring system
- Removal of any attachments to resource sites

Lastly, successful performance of the above installation method requires effective operational planning. High resolution geophysical site data should be referenced when selecting buoy locations and determining water depths. Surface vessels should be capable of holding station for prolonged periods of time; vessels with dynamic positioning are optimal for the task. Subsea positioning and real time surface vessel navigation are critical for safely delivering a large buoy anchor to the lakebed near resource locations.

RECOMMENDATION: WSCNMS should incorporate existing or delivered geophysical site data when planning the location for buoy anchor positions.

RECOMMENDATION: WSCNMS should incorporate technological tools such as ROV, USBL positioning, and vessels with dynamic positioning capability, in their mooring buoy deployment operational planning.

Works Cited

Meverden, Keith, and John Jensen
2004 *Hetty Taylor National Register Nomination*. Prepared for the National Register of Historic Places, National Park Service, Department of the Interior, Washington, DC. Submitted by the Wisconsin Historical Society, Madison.

Meverden, Keith; and Tamara L. Thomsen
2010 *Small Boats on a Big Lake: Underwater Archaeological Investigations of Wisconsin's Trading Fleet 2007-2009*. State Archaeology and Maritime Preservation Technical Report Series #10-001. Wisconsin Historical Society, Madison.

Roth, Madeline
2021 Monitoring and Management of Tangible Maritime Heritage Resources. *Maritime Heritage Program Policy Guidance, Maritime Heritage Program, Office of National Marine Sanctuaries. National Oceanic and Atmospheric Administration, Department of Commerce*. Silver Spring, MD.

Thomsen, Tamara, Paul Rechner, Mackenzie Stout, and Chad Gulseth
2014 *With Waves in Their Wake: Underwater Archaeological Investigations from the 2013 Field Season.* State Archaeology and Maritime Preservation Technical Report Series #14-002. Wisconsin Historical Society.

Thomsen, Tamara and Caitlin N. Zant
2016 *Fast Sailers & Quick Sands: Underwater Archaeological Investigations from the 2015 Field Season.* State Archaeology and Maritime Preservation Technical Report Series #16-001, Wisconsin Historical Society, Madison.

Thomsen, Tamara L., Caitlin N. Zant, and Victoria L. Kiefer
2018 *"A" is for Archaeology: Underwater Archaeological Investigations from the 2016 and 2017 Field Seasons.* State Archaeology and Maritime Preservation Technical Report Series #18-001. Wisconsin Historical Society, Madison.

Thomsen, Tamara L., Caitlin N. Zant, and Victoria L. Kiefer
2019 *Storms and Strandings, Collisions and Cold: Shipwreck Surveys of the 2018 Field Season.* State Archaeology and Maritime Preservation Technical Report Series #19-001. Wisconsin Historical Society, Madison.

Watzin, Mary C., Arthur B. Cohn, and Bryan P. Emerson

2001 *Zebra Mussels, Shipwrecks and the Environment: Final Report*. University of Vermont School of Natural Resources, Lake Champlain Maritime Museum, Vergennes, VT.

Wisconsin Historical Society
2021 About the Maritime Preservation Program. Maritime Preservation Program, Wisconsin Historical Society, Madison <https://www.wisconsinhistory.org/Records/Article/CS4070>. Accessed 28 June 2022.

Wisconsin Sea Grant and Wisconsin Historical Society
2022a Advance (1853-1885). Wisconsin Shipwrecks, Wisconsin Historical Society, Madison <wisconshipwrecks.org/Vessel/Details/11?region=Index>. Accessed 28 June 2022.

Wisconsin Sea Grant and Wisconsin Historical Society
2022b Mahoning (1847). Wisconsin Shipwrecks, Wisconsin Historical Society, Madison <wisconshipwrecks.org/Vessel/Details/405?region=Index>. Accessed 29 June 2022.

Wisconsin Sea Grant and Wisconsin Historical Society
2022c Niagara (1845). Wisconsin Shipwrecks, Wisconsin Historical Society, Madison <wisconshipwrecks.org/Vessel/Details/455?region=Index>. Accessed 28 June 2022.

Zant, Caitlin N., Tamara L. Thomsen, and Tori Kiefer
2017 *Sailing Canallers: A Great Lakes Regional Context.* State Archaeology and Maritime Preservation Technical Report Series #17-003, Wisconsin Historical Society, Madison.

Mobilization and Calibration Report

NOAA Vessel R5002

R/V *Storm*

September 2022

Prepared by:

Thunder Bay National Marine Sanctuary
Office of National Marine Sanctuaries
500 West Fletcher St
Alpena, MI 49707

Mobilization and Calibration Report
NOAA Vessel R5002: R/V *Storm*

DOCUMENT NO. TBNMS-202201-R5002-MAC-VER02

Version	Date	Description	Prepared by:	Reviewed by:	Approved by:
01	05/31/2022	Vessel MAC report	JB	CO	JB
02	9/23/2022	Updated for vertical reference information	JB	JB	JB

TABLE OF CONTENTS

APPENDICES

APPENDIX A | GNSS STATIC TEST AND QC REPORT

APPENDIX B | SENSOR CALIBRATION CERTIFICATES

APPENDIX C | NOAA R5002 SPATIAL RELATIONSHIP SURVEY REPORT

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

CP	Control Point
CRP	Common Reference Point
DAC	Data Acquisition Computer
DB	Database
EVT	Equipment Verification Test
GAMS	GNSS Aided Measurement System
GLERL	Great Lakes Environmental Research Laboratory
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IMU	Inertial Measurement Unit
IHO	International Hydrographic Organization
INS	Inertial Navigation System
ITRF	International Terrestrial Reference Frame
LMFS	Lake Michigan Field Station
MBES	Multibeam Echosounder
MRU	Motion Reference Unit
NAD	North American Datum
NAVD	North American Vertical Datum
NAS	Network Attached Storage
NGS	National Geodetic Survey
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
OPUS	Online Positioning User Service
POS MV	(Trade mark) Position and Orientation System for Marine Vessels
PPS	Pulse Per Second
QC	Quality Control
RMS	Root Mean Square

RTK	Real Time Kinematic
R/V	Research Vessel
Rx	Receive
SBET	Smoothed Best Estimate of Trajectory
SIS	Seafloor Information System
SN	Serial Number
SV	Sound Velocity
SVP	Sound Velocity Profiler
SVS	Sound Velocity Sensor
TBNMS	Thunder Bay National Marine Sanctuary
Tx	Transmit
TPU	Total Propagated Uncertainty
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator
VRS	Virtual Reference Station
WGS	World Geodetic Systems
WSCNMS	Wisconsin Shipwreck Coast National Marine Sanctuary

1. | INTRODUCTION

This document outlines the tests and procedures performed during the mobilization and calibration (MAC) trials of survey equipment on board National Oceanic and Atmospheric Administration (NOAA) vessel R5002, also known as R/V *Storm* (Figure 1), in preparation for undertaking geophysical and hydrographic mapping activities during the 2022 summer field season. These mapping tasks involve surveys within the newly created Wisconsin Shipwreck Coast National Marine Sanctuary (WSCNMS) as well as opportunistic operations in the Thunder Bay National Marine Sanctuary (TBNMS) and elsewhere in the Great Lakes region.

R5002 is a multipurpose marine science platform owned and operated by NOAA's Great Lakes Environmental Research Laboratory (GLERL). Its homeport is Alpena, MI at the Thunder Bay Shores Marina. During the period between 27 April and 25 May, field operations personnel from TBNMS and GLERL re-installed and integrated the components of a multibeam echosounder (MBES) and inertial navigation system (INS). These components are removed and re-installed annually, corresponding to the R5002's winter storage schedule. As a part of this integration process, all of the survey equipment onboard R5002 was subject to setup, testing, calibration, and verification procedures. Underway testing of this equipment occurred on 21 May. Following completion of MAC procedures, the vessel is scheduled to commence geophysical surveys within WSCNMS on 8 June, 2022.

Figure 1.Starboard-side view of NOAA Vessel R5002 at the Thunder Bay Shores Marina in Alpena, MI. Mobilization and calibration procedures for the 2022 field season took place throughout May 2022 with on water testing operations occurring 21 May 2022.

EQUIPMENT LIST

A list of equipment and components relevant to planned 2022 geophysical and hydrographic mapping activities are presented in Table 1.

Table 1. Integrated geophysical and hydrographic survey equipment onboard R5002.

EQUIPMENT	DESCRIPTION
Primary Positioning System	Applanix POS MV V4. Operated via Applanix MV POS View (v4.3.5.0)
Primary Inertial Navigation System	Applanix POS MV V4. Operated via Applanix MV POS View (v4.3.5.0)
Online Survey Navigation	HYPACK and HYSWEEP (HYPACK v2020)
Multibeam Echosounder (MBES)	Kongsberg Maritime EM2040C; Operated via Kongsberg Maritime Seafloor Information System (SIS) software (v4.3.2)
Surface Sound Velocity Sensor (SVS)	Valeport Mini SVS; deployed adjacent to MBES head on vessel port side.
Water column Sound Velocity Profiler (SVP)	SonTek CastAway CTD
Navigation Post-Processing	Applanix POSPac Mobile Mapping Suite (v8.7)
Sonar Data Post-Processing	CARIS HIPS and SIPS (v11.4)

SCOPE OF WORK

All MAC test items reported herein were conducted between the period 27 April and 25 May on an opportunistic basis by TBNMS and GLERL personnel; this basis being to complete the various MAC tasks onboard R5002 between other TBNMS field operations running concurrently. This included in-person mobilization activities as well as post-processing and assessment of calibration data. Performance of individual tasks utilized methods agreed to by a combined NOAA GLERL and TBNMS field team, consistent with industry standard procedures for the testing and verification of geophysical survey equipment. Ultimately, it is the goal of survey operations onboard R5002 to delivery bathymetry and backscatter data consistent with NOAA and International Hydrographic Organization (IHO) standards.

Tasks performed during this period of work are outlined below. TBNMS field personnel included one surveyor; GLERL personnel included a single vessel captain. All alongside tasks were performed at the Thunder Bay Shores Marina in Alpena, MI. These tasks included instrument installation, hardware interconnect, and wet testing. The on-water sites used for calibrating and testing the installed INS, MBES, and SV included an open water area in Thunder Bay used for the GNSS aided measurement system (GAMS) calibration and a benthic feature on the southern edge of Thunder Bay Island used for a residual bias test (patch test) and sample survey area. All on-water testing took place on 21 May 2022.

NOTE: Dimensional control of vessel offsets and local survey tie-ins were not performed during these MAC procedures. Instead, instrument offsets and survey parameters from prior field operations were utilized.

Specific tasks undertaken during the mobilization and calibration activities are summarized as follows:

- **Network Communications**
    - Verify device interconnect, data distribution within vessel workstation comprised of Data Acquisition Computer (DAC) and Kongsberg Maritime SIS workstation [Alongside]
- **Vessel Positioning; Completed for Primary and Secondary Systems**

- Static global navigation satellite system (GNSS) health check [Alongside]
  - Heading validation [Alongside]
  - GNSS aided measurement system (GAMS) calibration, conducted 3x [Calibration Site]
- **Multibeam Echosounder (MBES)**
  - Patch test [Calibration Site]
  - Sample survey [Calibration Site]
  - Noise test [Alongside; Calibration Site]
- **Sound Velocity Profiler, Completed for Primary and Secondary Systems**
  - Verify calibration certificate [Alongside]
  - Comparison between SVP and MBES SVS [Calibration Site]
  - Check interface between SVP/DAC/SIS workstations [Alongside; Calibration Site]

2. | DATUMS

The geodetic datum parameters used during the mobilization project onboard R5002 are presented in Table 2, Table 3, Table 4, and Table 5. Note that these settings were input into the HYPACK/HYSWEEP navigation project settings (Figure 2) as the installed POS MV INS system uses the WGS 84 datum as a reference (Figure 3). This navigation information is distributed to all other online components of the survey system.

Table 2 Geodetic parameters used during acquisition for R5002[1].

Horizontal datum: ITRF 2014 (EPSG: 7789)	
Datum	International Terrestrial Reference Frame 2014 (ITRF 2014)
Ellipsoid	Geodetic Reference System 1980 (GRS 1980)
Prime Meridian	Greenwich (EPSG:8901)
Semi-major axis	6 378 137.000 m
Semi-minor axis	6 356 752.314 m
Inverse Flattening (1/f)	298.257222101
Unit	meter
Horizontal datum: WGS 84 (EPSG:4326)	
Datum	World Geodetic System 1984 (EPSG:6326)
Ellipsoid	World Geodetic System 1984 (EPSG:7030)
Prime Meridian	Greenwich (EPSG:8901)
Semi-major axis	6 378 137.000 m
Semi-minor axis	6 356 752.314 m
Inverse Flattening (1/f)	298.257222101
Unit	meter

[1] The NOAA GLERL and TBNMS team treat the ITRF 2014 realization to be equivalent to WGS 84 (see QPS Notes on ITRF 2014)

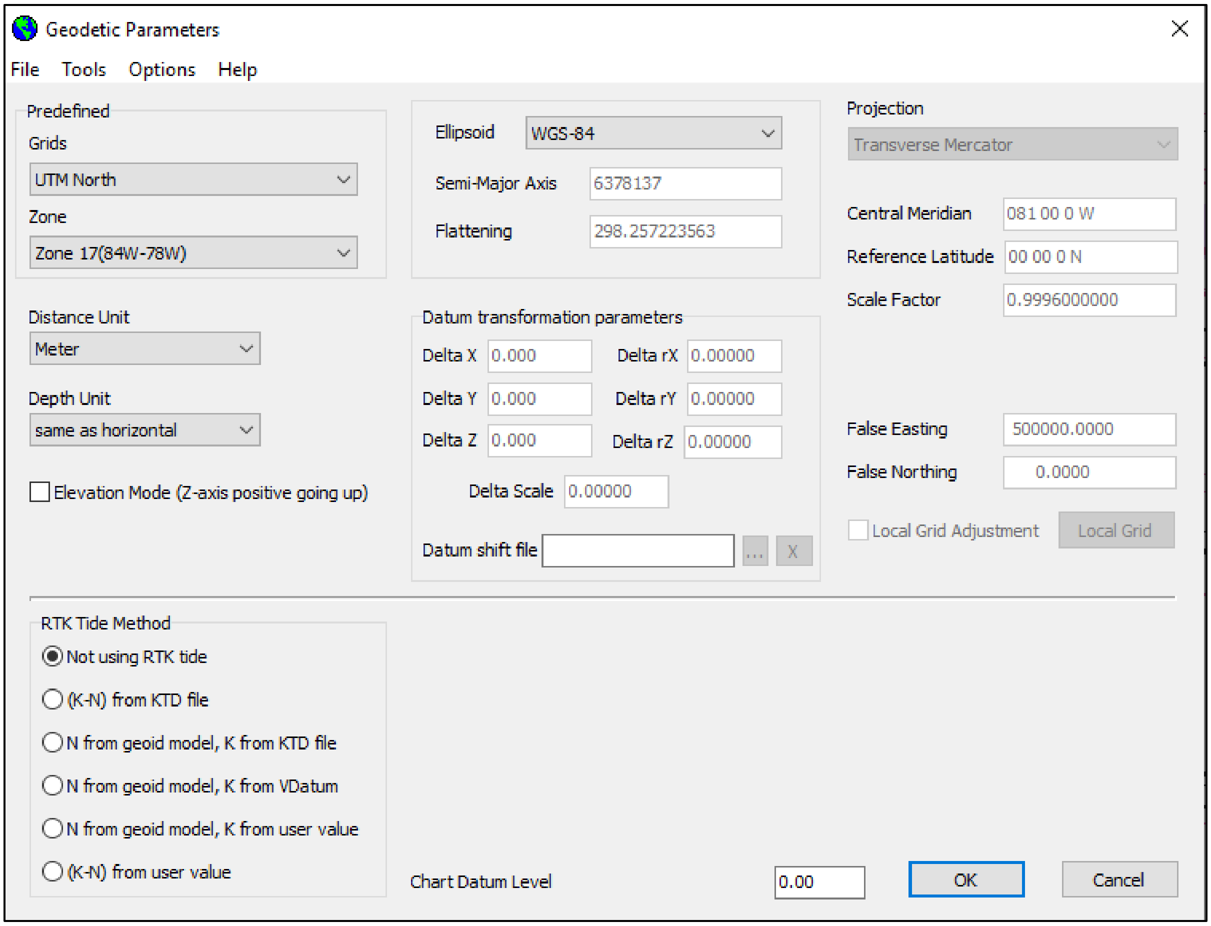
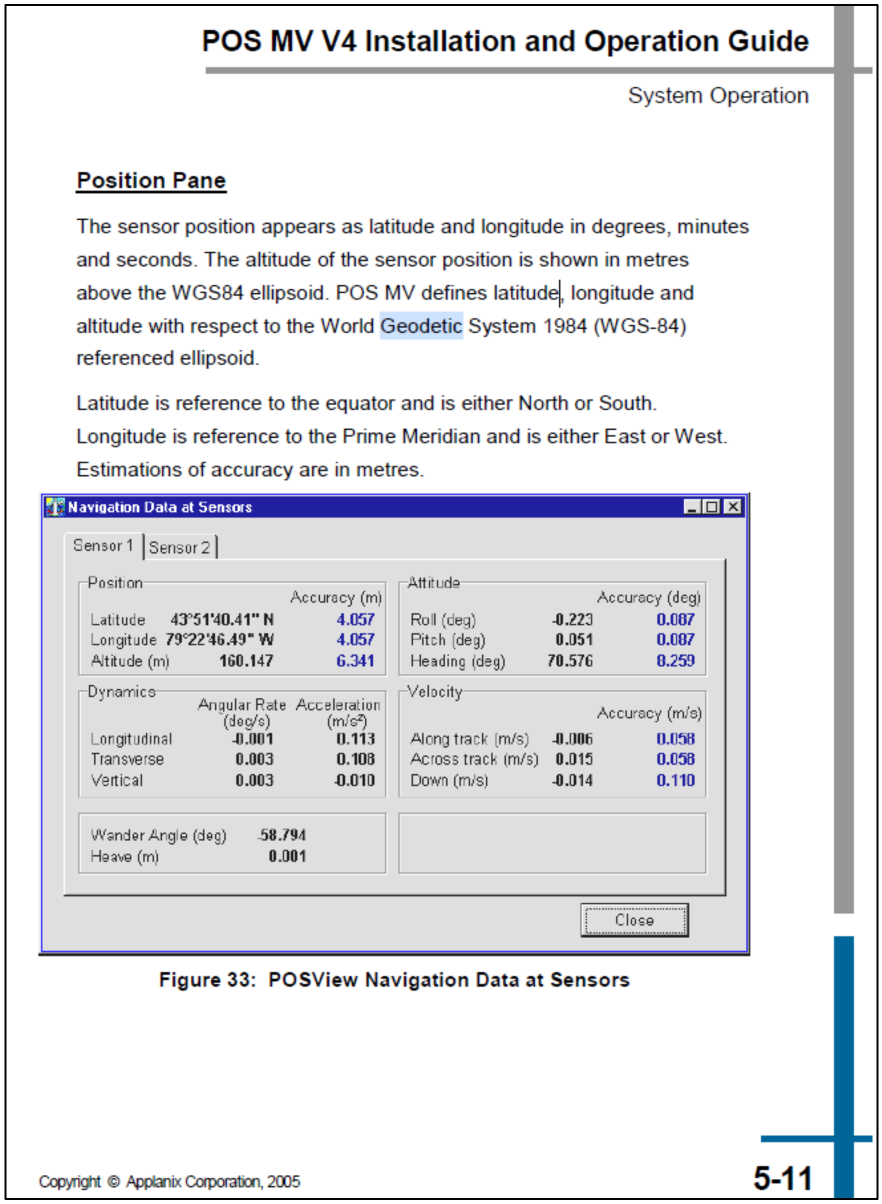


Figure 2. Programmed geodetic parameters input into R5002's HYPACK/HYSWEEP Navigation project settings.



POS MV V4 Installation and Operation Guide

System Operation

Position Pane

The sensor position appears as latitude and longitude in degrees, minutes and seconds. The altitude of the sensor position is shown in metres above the WGS84 ellipsoid. POS MV defines latitude, longitude and altitude with respect to the World Geodetic System 1984 (WGS-84) referenced ellipsoid.

Latitude is reference to the equator and is either North or South. Longitude is reference to the Prime Meridian and is either East or West. Estimations of accuracy are in metres.

Figure 33: POSView Navigation Data at Sensors

Copyright © Applanix Corporation, 2005

5-11

Figure 3. Verification of POS MV navigation parameters.

Table 3 Transformation parameters, if needed, to convert WGS 84 to NAD 83.

DATUM SHIFT FROM ITRF 2014/WGS 84 TO NAD 83 (right-handed convention for rotation- COORDINATE FRAME ROTATION*)	
Parameters	**Epoch 2020**
Shift dX (m)	1.01160000
Shift dY (m)	-1.91711000
Shift dZ (m)	-0.55737000
Rotation rX (“)	0.02744808
Rotation rY (“)	-0.00799467

DATUM SHIFT FROM ITRF 2014/WGS 84 TO NAD 83 (right-handed convention for rotation- COORDINATE FRAME ROTATION*)	
Rotation rZ (“)	0.01041876
Scale Factor (ppm)	-0.00063119

Table 4 Projection parameters for WGS 84 based UTM projection in zone 17N.

Projection Parameters: WGS 84 UTM Zone 17N (EPSG: 32617)	
Projection	UTM
Zone	17 N
Central Meridian	81° 00’ 00’’ W
Latitude origin	00° 00’ 00’’ N
False Northing	0 m
False Easting	500 000 m
Central Scale Factor	0.9996
Units	Meter

Table 5 Vertical reference parameters.

Vertical Reference Parameters	
Vertical Datum	North American Vertical Datum 1988 (NAVD 88)
Vertical Reference	IGLD 85

International Great Lakes Datum (IGLD 85)[2]: Mean water level at Rimouski/Pointe-au-Pere, Quebec, on the Gulf of St. Lawrence over the period 1970 through 1988, from which geopotential elevations (geopotential differences) throughout the Great Lakes region are measured. The term is often used to mean the entire system of geopotential elevations rather than just the referenced water level.

North American Vertical Datum of 1988 (NAVD 88): A fixed reference for elevations determined by geodetic leveling. The datum was derived from a general adjustment of the first-order terrestrial leveling nets of the United States, Canada, and Mexico. In the adjustment, only the height of the primary tidal bench mark, referenced to the International Great Lakes Datum of 1985 (IGLD 1985) local mean sea level height value, at Father Point, Rimouski, Quebec, Canada was held fixed, thus providing a minimum constraint. NAVD 1988 and IGLD 1985 are not identical. NAVD 1988 bench mark values are given in Helmert orthometric height units while IGLD 1985 values are in dynamic heights. See International Great Lakes Datum of 1985, National Geodetic Vertical Datum of 1929, and geopotential difference.

TIME DATUM

Coordinated Universal Time (UTC) is used on all survey systems onboard R5002. The synchronization of the vessel's INS and MBES systems is governed by the Pulse Per Second (PPS) issued by the Applanix POS MV system. Likewise, timing to the HYPACK/HYSWEEP navigation program and Kongsberg SIS MBES operating system are also governed by time messages from the POS MV. All displays, workstations, overlays, and logbooks are therefore annotated in UTC.

[2] NOAA NGS: Equivalence of IGLD85 and NAVD88

3. | DIMENSIONAL CONTROL

During mobilization of R5002 sensor offset measurements and dimensional control surveys were not performed on the vessel to verify locations of installed geophysical instruments and deck equipment. Finalized sensor offsets from prior surveys were instead utilized.

In addition to the normal sonar calibration tasks, sample bathymetric data was collected, processed, and reviewed specifically to assess any residual errors indicating mounting, offset, and alignment issues resulting from utilization of previous offset values. These results are presented and discussed in Section 5 Multibeam Sonar Calibration.

Dates and Location of Survey:

- 27 April – 17 May 2022: **Device Interconnect and Testing**. Thunder Bay Shores Marina, Alpena, MI.
- 21 May 2022: **GAMS Calibration**. Offshore, Lake Huron.
- 21 May 2022: **MBES Calibration and Verification**. Offshore, Lake Huron.
- 25 May 2022: **GNSS Static Tests, Waterline Verification**. Thunder Bay Shores Marina, Alpena, MI.
- 25 May 2022: **MBES Noise Check.** Thunder Bay Shores Marina, Alpena, MI.

R5002*'s* established vessel reference frame uses the primary motion reference unit (MRU) phase center as the common reference point (CRP) and the vessel's longitudinal and transverse axes as angular references, as shown in Figure 4. Previous dimensional control surveys generated measurements to establish the relative offsets between the MBES mount and GNSS antenna locations relative to the vessel's CRP. These included the relative offsets of the following instruments:

- Primary and secondary GNSS antennas, located on mounting arm over pilothouse.
- Primary IMU mount. Located on a dedicated shelf inside the vessel's forward storage hold. Placement oriented along vessel's centerline, slightly above waterline.
- Kongsberg Maritime EM2040C MBES Sensor mounting point and acoustic center (AC).

Figure 4. R5002's common reference point for sensor offsets is established at the marked phase center of the inertial navigation system motion reference unit component as shown by the marker on the top of the device.

A report of the prior sensor offset survey is provided in Appendix C of this document. This survey was conducted by a field team from NOAA's National Ocean Service, National Geodetic Survey Field Operations Branch in April of 2010 preceeding the installation of survey equipment onboard R5002. Throughout the intervening years as new sensors are installed or mounting points are modified or relocated, these offsets were updated accordingly and captured in various project-specific documents.

Currently used sensor offset values were maintained from those implemented in the 2019 and 2020 field seasons. These established offset measurements are presented in Table 6. Measurement convention used during the sensor offset survey is as follows:

- All measurement in meters
- Positive X-Axis is forward
- Positive Y-Axis is towards starboard
- Positive Z-Axis is upward
- Positive Pitch is bow upward
- Positive Roll is starboard down
- Positive Heading (Yaw) Rotation is clockwise WRT vessel centerline in plan view

Table 6. R5002 sensor installation offsets used during 2022 field operations.

Reference Item	X (forward) meters	Y (starboard) meters	Z (down) meters
IMU (vessel CRP)	0.00	0.00	0.00
MBES_AC	1.005	-0.873	1.815
GNSS_ANT_PRI	1.229	-0.916	-3.338
GNSS_ANT_SEC	1.223	1.374	-3.295

LOCAL SURVEY CONTROL

A dedicated sensor offset survey and geodetic survey control were not performed during the MAC process for NOAA vessel R5002 during the 2022 field season. As stated earlier, offsets and settings from prior projects, verified through QA/QC of associated field data, were carried over to the current suite of navigation and sonar equipment. Geodetic parameters described in Section 2 were maintained.

A static GNSS file was logged to produce the Diagnostic QC report mentioned in a following section. Data from this file was also used to develop a waterline comparison between recorded Lake Huron water level (preliminary water level data at the time this report was issued) versus the orthometric height of the vessel's CRP.

UPDATE ISSUED 23 SEPTEMBER, 2022

This comparison is presented in Table 7. A variance of .228 m was determined between the orthometric height of the CRP (corrected for the vessel's waterline) and actual Lake Huron water level. Lake Huron water levels were determined from averaged values reported at NOAA Tide Station 9075065 during the time period of INS file logging. Lake level values were compared against a water level computed from the GNSS height of the logged INS data during the static test. In particular, a vertical shift from the logged ellipsoidal height was applied to account for the conversion from the real time ellipsoidal reference to and IGLD85 orthometric system. The magnitude of this shift was determined via a point-specific conversion obtained through NOAA's online VDatum Vertical Datum Transformation App (Figure 5). The averaged location and ellipsoidal height from the post-processed INS files were input into the VDatum App as shown. Derived IGLD85 height of the CPR was adjusted per the measured waterline amount (-0.60 m) to generated an INS-computed lake level which was differenced with the water level reported at NOAA tide station 9075056.

Table 7. Water level elevation comparison between actual Lake Huron water level height, as provided by NOAA water level gauge 9075065 (preliminary) for 25 May and the orthometric-corrected post-processed POSPac navigation files (SBET) recorded between 1254 and 1326 UTC on the same day.

Vertical Reference	Height (IGLD85) meters	Description
Lake Huron Water Level (averaged)	176.715	NOAA Tide Station 9075065
Applanix POSPac SBET height (averaged)	176.943	INS computed height after applied 37.545 m separation value to convert from ellipsoidal height and orthometric height as well as vertical shift between the CRP and measured waterline level (-0.60 m).
Variance	**0.228**	**Difference between actual Lake Huron elevation and vessel-computed water level elevation.**

Additional vertical referencing observations were made on 3 September by comparion of bathymetric data acquired onboard NOAA vessel R5002 with two separate datasets collected in a similar area. At the request of Foth Infrastructure & Environment, LLC, NOAA collected bathmetric data along the LaFarge navigation channel and shipping fairway outside Alpena, Michigan, on 10 August, 2022. Processed bathymetric data was provided on 1 September. Surveyors from Foth Infrastructure & Environment, LLC compared data results from R5002 with two datasets from the same area. One was collected by the US Army Corps of Engineers (USACE) and another from JF Brennan, a private survey operator. While data from the USACE and JF Brennan aligned well, data from R5002 was shifted nearly 2 m (6-7ft) shallower along several cross sections (Figure 6, R5002 data in blue). All three datasets were referenced using the IGLD85 LWD.

In response to these results, calibration data from NOAA vessel's R5002 and R2802 (which were collected at the same site) were likewise compared. Results from this comparison showed data from R5002 0.9 m shallower than data from R2802 (Figure 7) despite both being referenced to the IGLD 85 LWD.

As a result of these comparisons, vertically referenced bathymetric data from R5002 should be considered unreliable and unable to meet IHO specifications for vertical accuracy. The 0.228 m variance between computed and acutal lake level indicate improper spatial referencing between the vessel's primary GNSS antenna and CRP. Varitions between processed R5002 data and co-located datasets obtained from R2802 and third parties indicates there may be additonal sensor offset inaccuracies between the CRP and MBES tracking point. Based on these observations, R5002 should undergo a full, updated sesnor offset survey. This finding also resutled from the 2021 MAC report (see *TBNMS-202102-R5002-MAC-DRAFT-VER01*, 16-17).

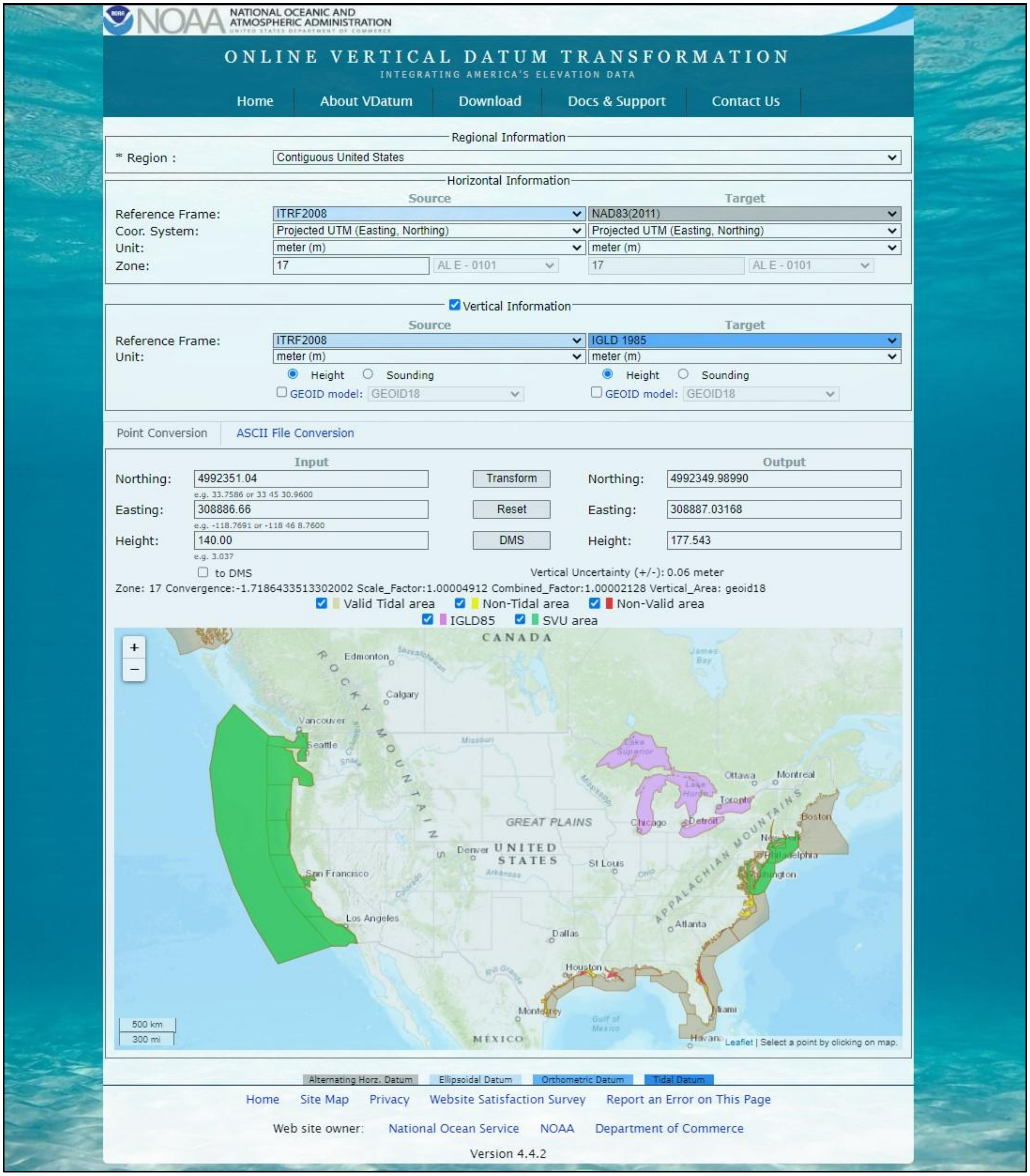


Figure 5. Vertical datum conversion output using input parameters from R5002 INS computed location and ellipsoidal height during static GNSS testing on 25 May. Input data was averaged Northing, Easting, and ellipsoidal height from the vessel's POSMV device. These values were converted from the ITRF2000 (WGS 84 equivalent) frame to orthometric height in an IGLD 85 reference frame at a date of 2022.0.

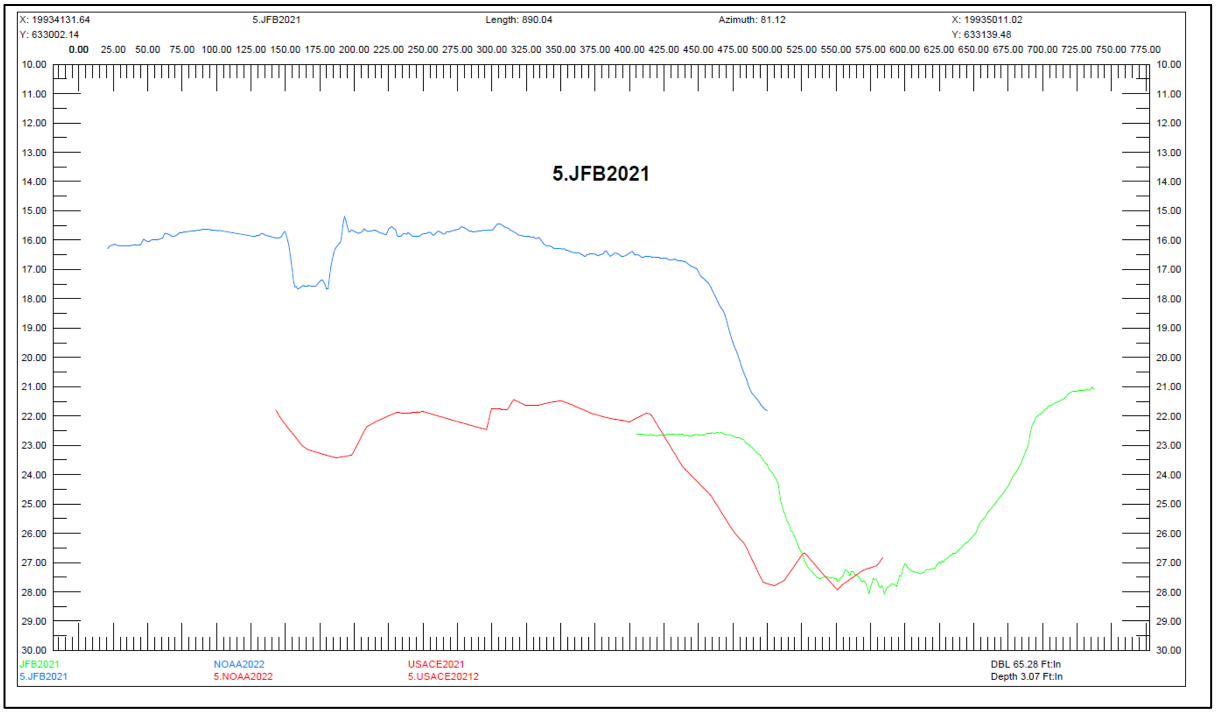


Figure 6. Comparison of R5002 data (blue) compared with data from USACE (red) and JF Brennen (green) showing a 6-7 ft discrepancy between the R5002 data and other cross sections.

Figure 7. Comparison of calibration data from R2802 and R5002 showing a 0.9 m discrepancy between the datasets despite both being referenced to IGLD85 LWD.

POSITION AND ORIENTATION SYSTEM FOR MARINE VESSELS (POS MV) INTEGRATION

Sensor offsets and rotations documented between the navigation and motion tracking components of the vessel's Applanix Position and Orientation System for Marine Vessels (POS MV) V4 Inertial Navigation System (INS) were input as installation and setup parameters. These quantities were entered via the Applanix MV POS View (v4.3.5.0) software interface on the data acquisition computer (DAC) workstation. This system utilized a Tate/Bryant coordinate reference schema, illustrated in Figure 8. It is important to note that this coordinate system varies from the measurement conventions utilized by the HYPACK online navigation program.

The Tate/Bryant measurement convention is described as follows:

- Positive X-Axis is forward
- Positive Y-Axis is towards starboard
- Positive Z-Axis is ***downward***
- Positive Heading (Yaw) Rotation clockwise WRT vessel centerline in plan view
- Positive Pitch Rotation is bow upward
- Positive Roll Rotation is starboard down

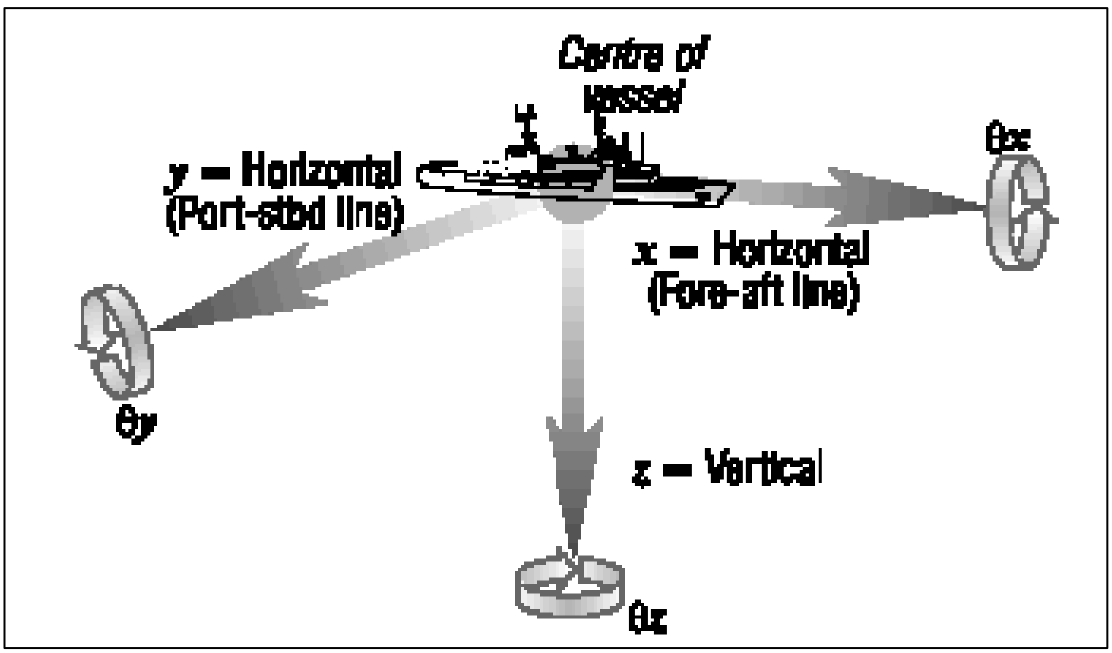


Figure 8. Frames of reference for the Applanix POS MV INS system, per Applanix POS MV Installation and Operation Guide.

The POS MV V4 system consisted of two GNSS antennas, an inertial measurement unit (IMU), and processing computer. One antenna is the primary position node while the secondary antenna is used for heading and motion computations. Both GNSS antennas onboard R5002 are mounted on a custom-fabricated spreader bar fixed atop the vessel's cabin. The primary antenna was mounted on the vessel's port side, with the secondary antenna mounted on the starboard side as shown in Figure 9. No auxiliary or differential GNSS correction were supplied to R5002*'s* INS system during the 2022 season.

Figure 9. View of POS MV's GNSS antennas installed on R5002 from bow looking aft.

The POS MV system's IMU is mounted to the top of shelf inside R5002*'s* forward storage hold. This area is below the main cabin deck and is secured behind the hold's access ladder, shown in Figure 10. Placement of the IMU was adjusted to rest upon the vessel's fore/aft centerline, as determined during the 2010 vessel survey (see Appendix C). Offsets between the CRP at the IMU and the primary GNSS antenna were confirmed in the POS MV interface program. These are presented in Figure 11. Table 7 presents static GNSS data relating Lake Huron water level to the recoded position of R5002*'s* CRP while stationary alongside. Note the IMU is situated above the vessel's waterline.

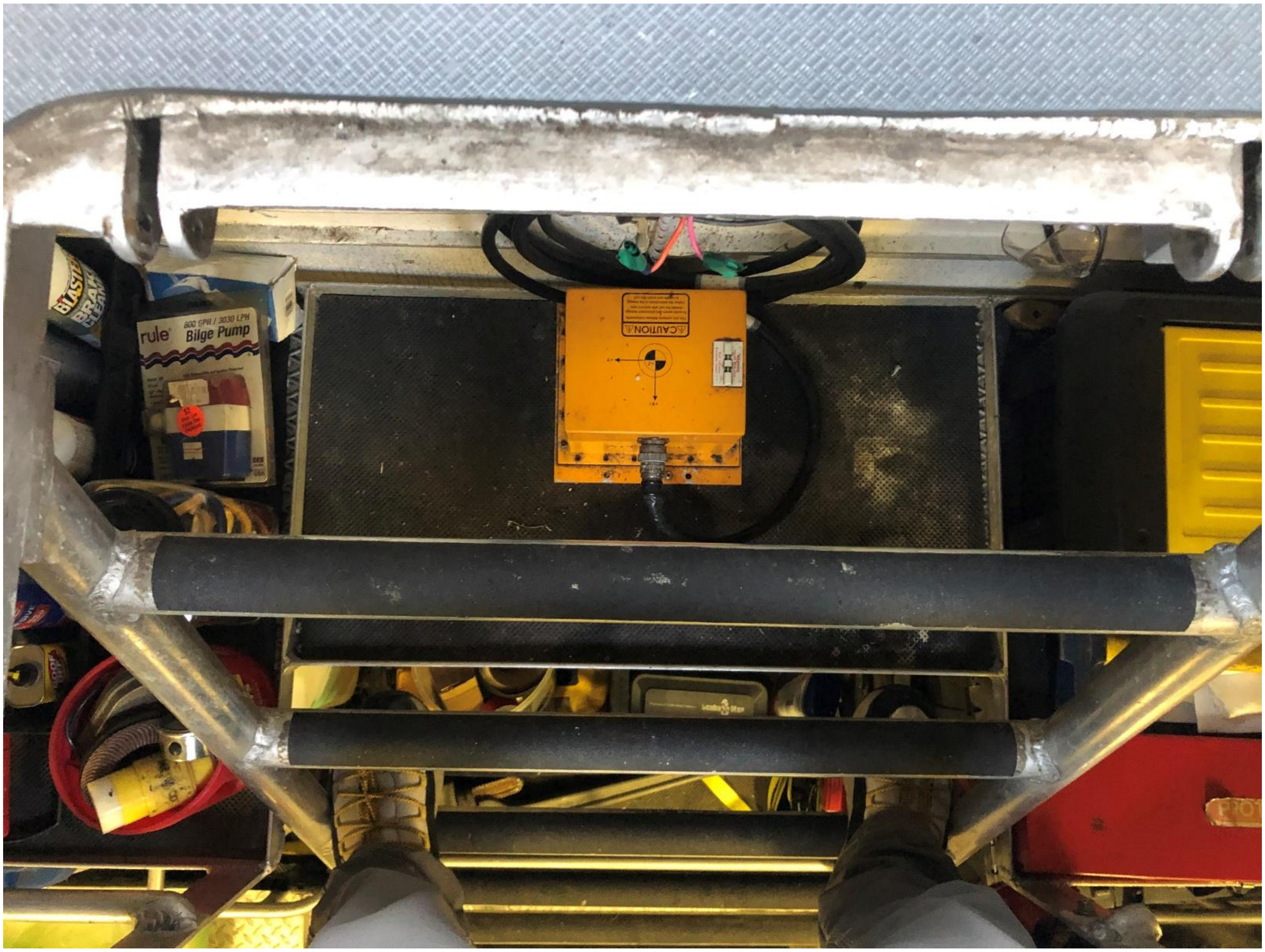


Figure 10. The POS MV IMU mounted to the top shelf in R5002's forward storage hold area.

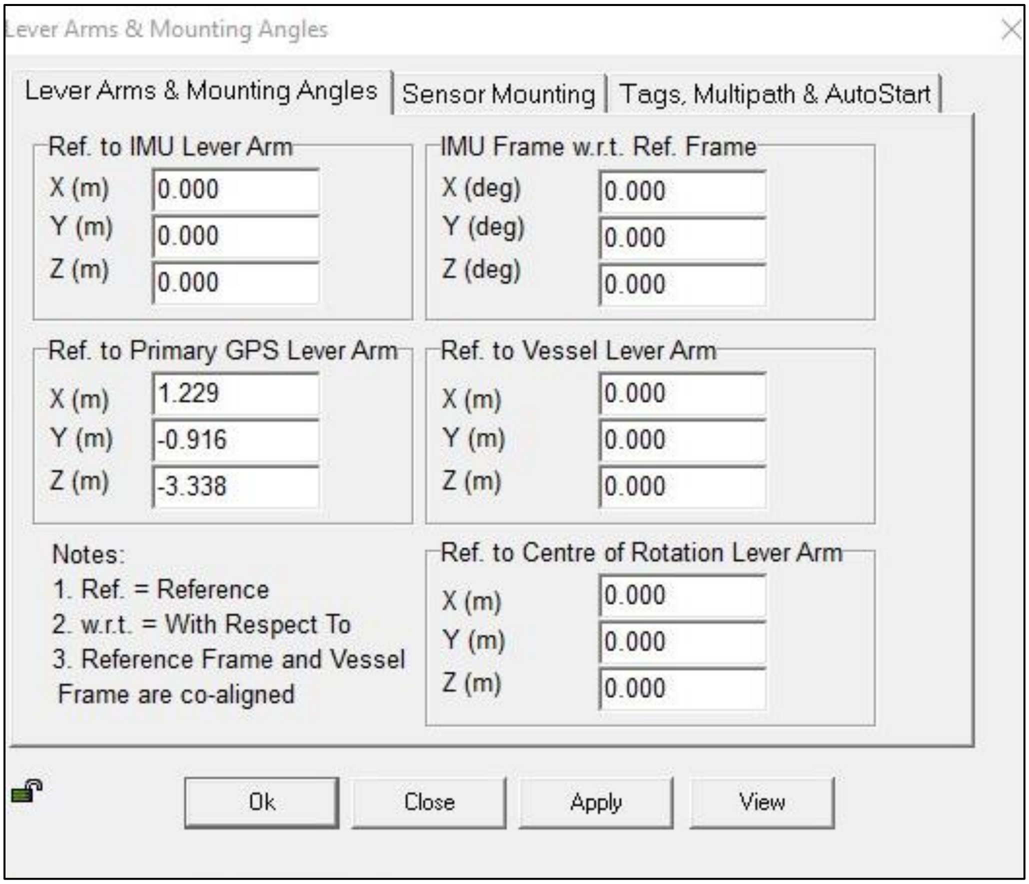


Figure 11. Programmed installation parameters in the vessel's MV POS View software interface. The offsets to the primary GNSS antenna, mounted on the port side of the vessel's wheelhouse, are shown as the offsets between reference to primary GPS lever arm.

KONGSBERG MARITIME EM2040C MULTIBEAM ECHOSOUNDER INTEGRATION

Offsets between R5002*'s* CRP and the phase center of the Kongsberg Maritime EM2040C multibeam echosounder (MBES) combined transmit (Tx) and receiver (Rx) array were determined during the 2014 field season. Specifically, measurements were taken to account for the position of the MBES mounting flange relative to the CRP, then from the mounting point to the instrument's acoustic center. The measurement convention in use by the Kongsberg seafloor information systems (SIS) software interface follows the same Tate/Bryant system in use by the Applanix program, described as follows (Figure 12):

- Positive X-Axis is forward
- Positive Y-Axis is towards starboard
- Positive Z-Axis is ***downward***
- Positive Heading (Yaw) Rotation clockwise WRT vessel centerline in plan view
- Positive Pitch Rotation is bow upward
- Positive Roll Rotation is starboard down

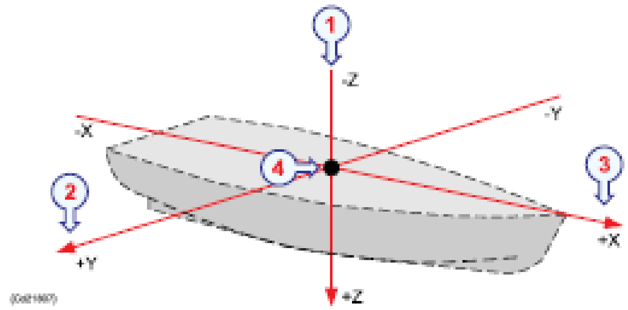
Figure 11 Kongsberg Maritime vessel coordinate system definition

1 *Downward (Z-axis)*

2 *Starboard (Y-azis)*

3 *Forward (X-axis)*

4 *Reference point (origo)*



Kongsberg Maritime definition of orientation

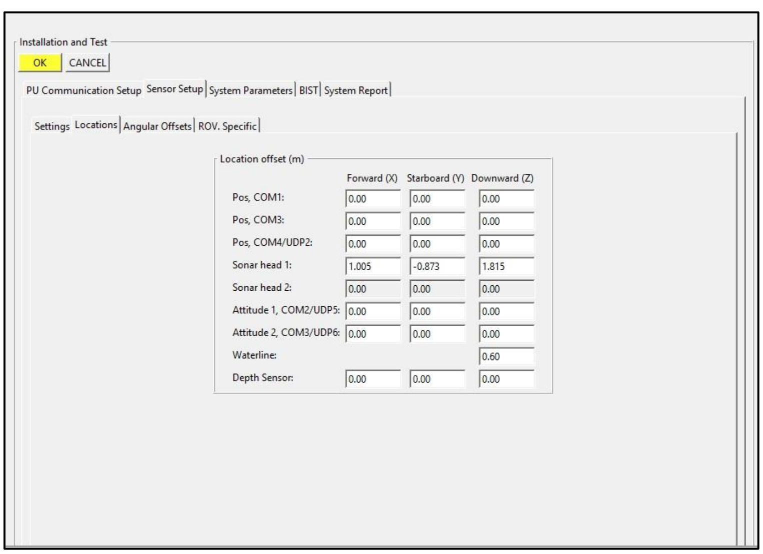
- Roll is positive when starboard side is low
- Pitch is positive when bow is high
- Yaw is positive clockwise
- Heave is positive up

Figure 12. Frames of reference for the Kongsberg SIS software system, per the Kongsberg Maritime EM2040C Installation Manual.

Measured offsets to the MBES acoustic center are presented in Table 8. Figure 13 shows the location of the EM2040C acoustic center, as provided by the manufacturer's documentation. Additionally, echosounder dimensions are provided in Figure 14. The acoustic center point is marked on the device and is considered level with the bottom profile plane of the MBES head.

Table 8 XYZ offsets between the Kongsberg Maritime EM2040C MBES head and the vessel CRP. These offsets are programmed into the SIS interface to correctly position sounding data in real time (bottom).

Instrument	Instrument Phase Center	X offset (fwd)	Y offset (stb)	Z offset (up)
Kongsberg Maritime EM2040C	MBES_AC	1.005	-0.873	1.815



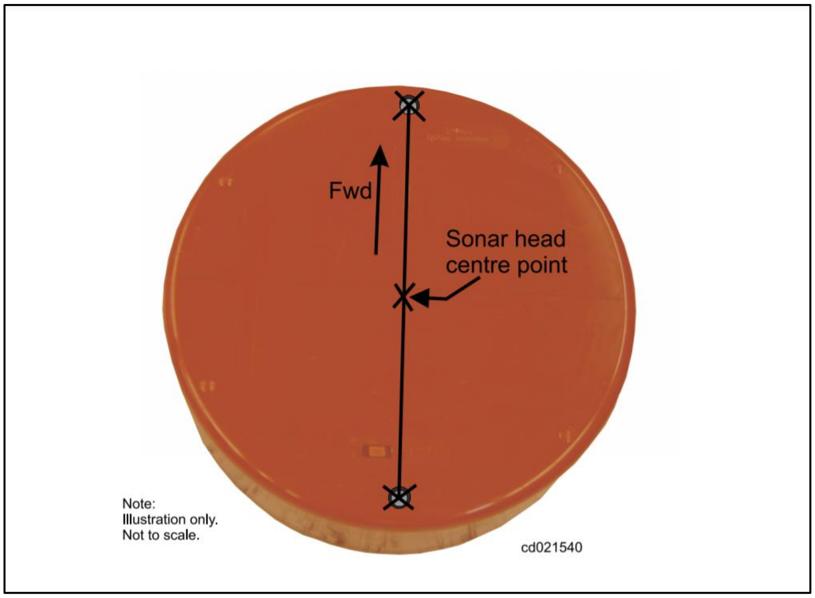


Figure 13. Location of Kongsberg Maritime EM2040C acoustic center. Image from Kongsberg Maritime EM2040C Installation Manual.

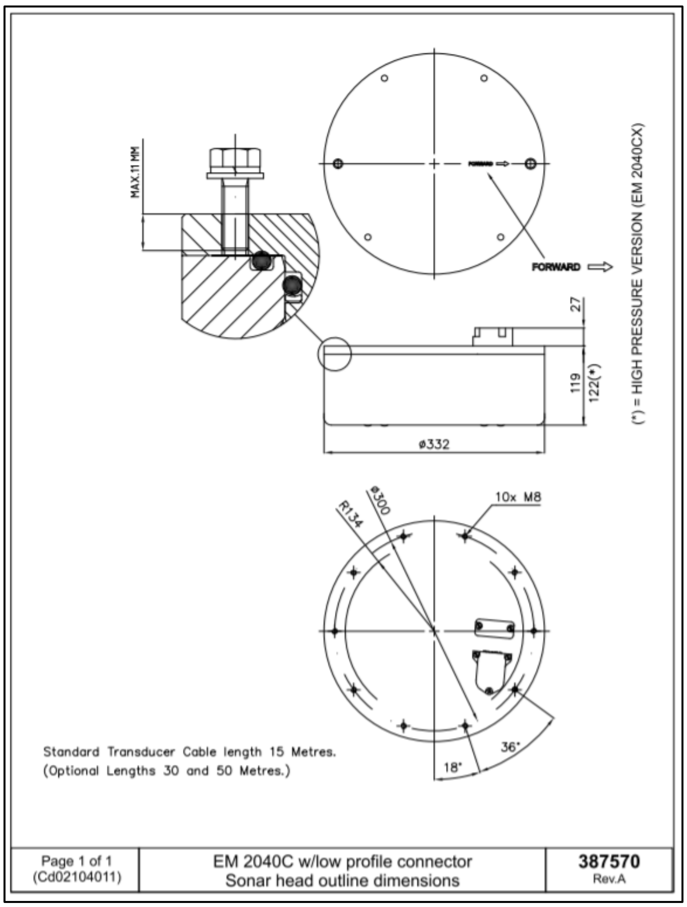


Figure 14. Dimensions of the EM2040C MBES sonar head. Figure from Kongsberg Maritime EM2040C Installation Manual.

R5002*'s* EM204C MBES is deployed through a transducer well located on the vessel's port side, forward of the IMU mount but in the same vessel compartment. Figure 15 shows the configuration of the transducer well with access via a hatch on the main cabin deck as well as the MBES cable pass-through bulkhead and sound velocity sensor (SVS) mounting tube adjacent to the MBES mount. When deployed, the water tight cover on the transducer well allows the vessel to operate normally. However, the SVS must be recovered during high-speed transit to prevent damage to the AML Oceanographic SVS device, as a result, the SVS mount features a PVC-sleeve inside the well to facilitate quick deployment and recover though the vessel's hull.

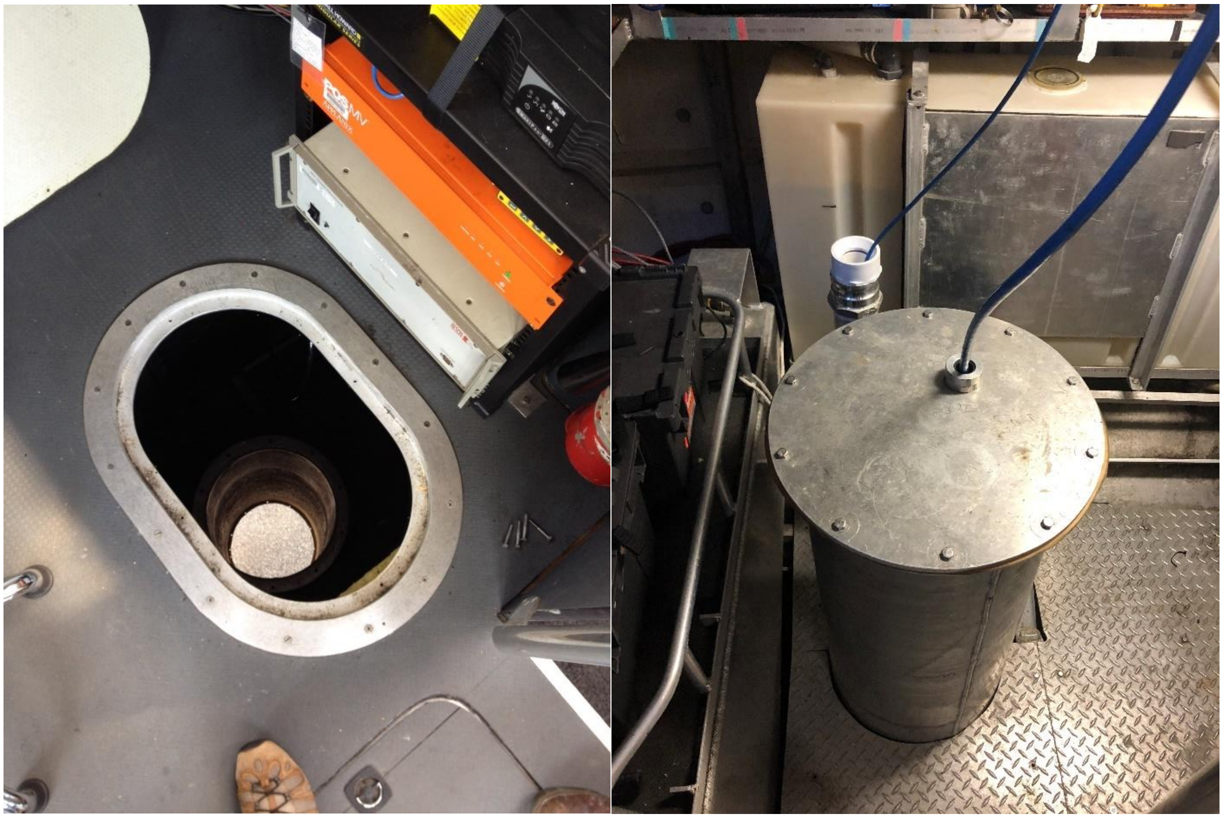


Figure 15. Access to the MBES transducer well as seen from the access hatch in the main cabin deck floor (left) photographed in 2014. Installed MBES and SVS (right) with transducer cover secured photographed during the 2022 MAC. During transit the MBES remains deployed, however, the SVS device is recovered.

The MBES unit is fixed to a custom mounting flange designed to orient the sonar level with R5002*'s* natural trim in the water. Figure 16 shows the mounting flange and pole which are lowered into the transducer well allowing the MBES unit to extend beneath R5002*'s* hull (Figure 17). While this design was intended to level with MBES and vessel planes, results from the MBES residual bias test (Section 5) revealed several degrees offset in each mounting angle direction. Apparent mounting misalignment between the two planes is likely due to two factors: the transducer well not set relative to the vessel's natural trim in the water, or, of greater magnitude, shifting of the vessel with changes in the vessel's equipment and tankage since the 2014 sonar installation procedure.

R5002 was re-powered in 2020. Newly installed motors may have shifted weight inside the vessel and altered its trim since the 2014 season. Also, R5002 has fore and aft fuel tanks each of 350-gallon capacity. In addition to the fuel tankage, the vessel also has two 75-gallon potable water tanks in the forward compartment; one on the port side and another on the starboard side. There are also black and grey water tanks (each also 75 gallons) situated in the forward compartment on the port and starboard sides. Water tankage was planned to counterbalance the vessel's installed crane and associated hydraulic oil reservoir (50-gallon capacity) on the vessel's stern, starboard side. Normal operation of the vessel entails variations in the capacity of all water and fuel tanks. While the crane and hydraulic reservoir remain static, fluctuations in the fuel and water levels onboard the vessel may cause variations in the vessel's trim. As such, attempts should be made to maintain consistent levels in all such tanks during survey operations.

During the 2022 season MAC, the fore and aft fuel tanks each contained approximately 250 gallons of fuel. Both black and grey water tanks were empty. Likewise, the starboard freshwater tank was empty while the port freshwater tank was filled to 2/3 level and marked with a date and time.

In future operations it may be useful to establish vessel tankage procedures to maintain consistency during survey operations. Likewise, re-survey of the vessel to update the 2010 and 2014 installation values may be useful as well, especially since the vessel was re-powered and any relevant configuration changes since 2010 and 2014 were undocumented.

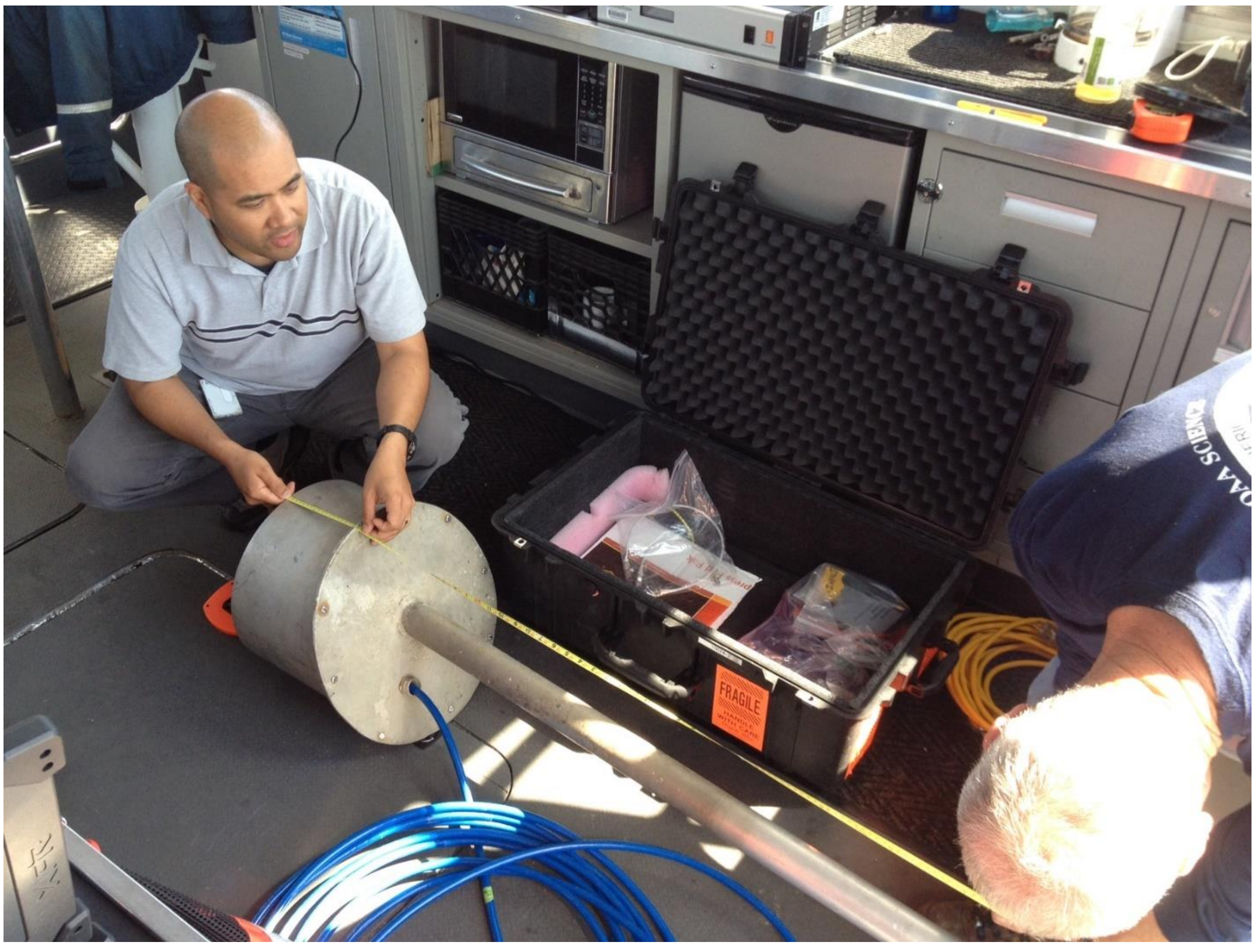


Figure 16. Reference measured between the MBES transducer phase center and the top of the mounting flange which secures the unit inside the transducer well. Image from 2014 sonar installation.

Figure 17. Deployment of the Kongsberg Maritime EM2040C MBES unit in the port transducer well on R5002. Image from 2014 sonar installation.

4. | NAVIGATION, HEADING, AND MOTION SYSTEM

IMU FRAME AND VESSEL REFERENCE FRAME

All sensor offsets were derived and reported as relative measurements to the vessel CRP defined as X=0.000, Y=0.000, and Z=0.000 at the center top plate of Applanix POS MV IMU. All sensor offset measurements use this location as a CRP (see Table 6). Project geodetic parameters for horizontal and vertical reference datum used were presented in Section 2. The reference frames and measurement conventions utilized by the POS MV controller and Kongsberg Maritime SIS controller were presented in their respective sections in Section 3. One additional reference frame was in use onboard the vessel during MAC procedures: the HYPACK/HYSWEEP program used for online navigation and file logging. The measurement convention used by HYPACK data acquisition system Figure 18 and is described as follows:

• Positive X-Axis is towards starboard
• Positive Y-Axis is forward
• Positive Z-Axis is ***downward from static waterline***
• Positive Heading (Yaw) Rotation clockwise WRT vessel centerline in plan view
• Positive Pitch Rotation is bow upward
• Positive Roll Rotation is port upward/starboard downward

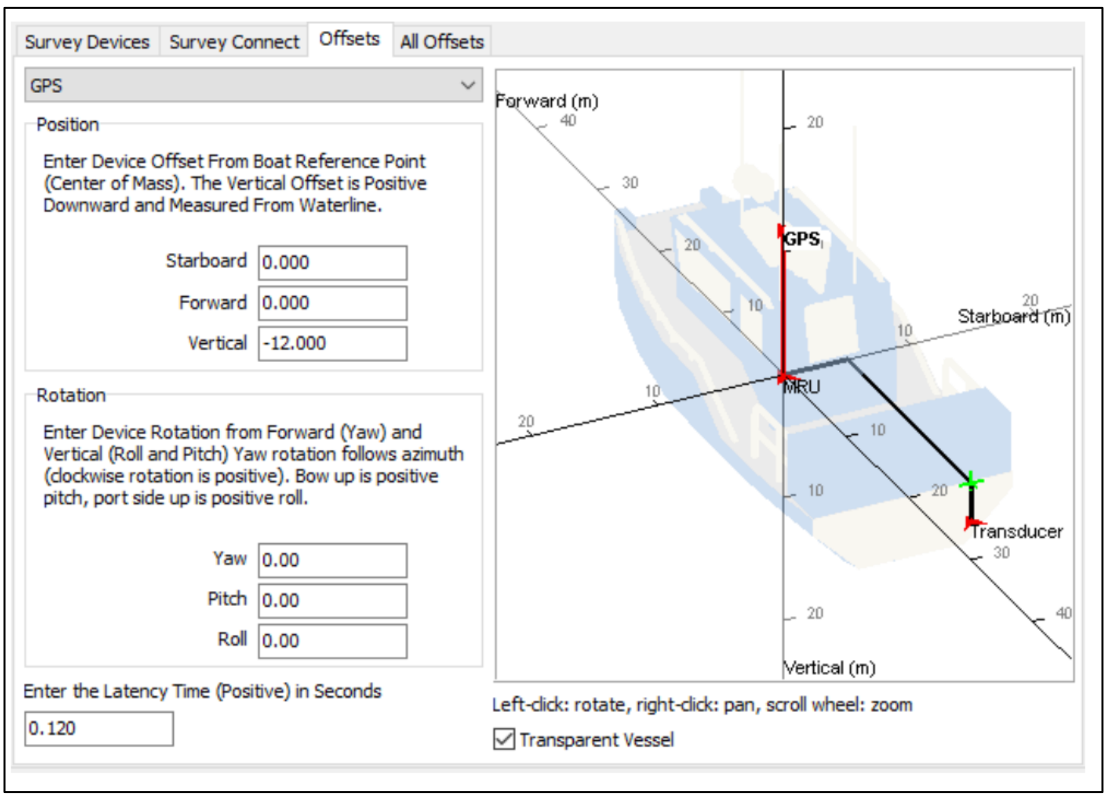
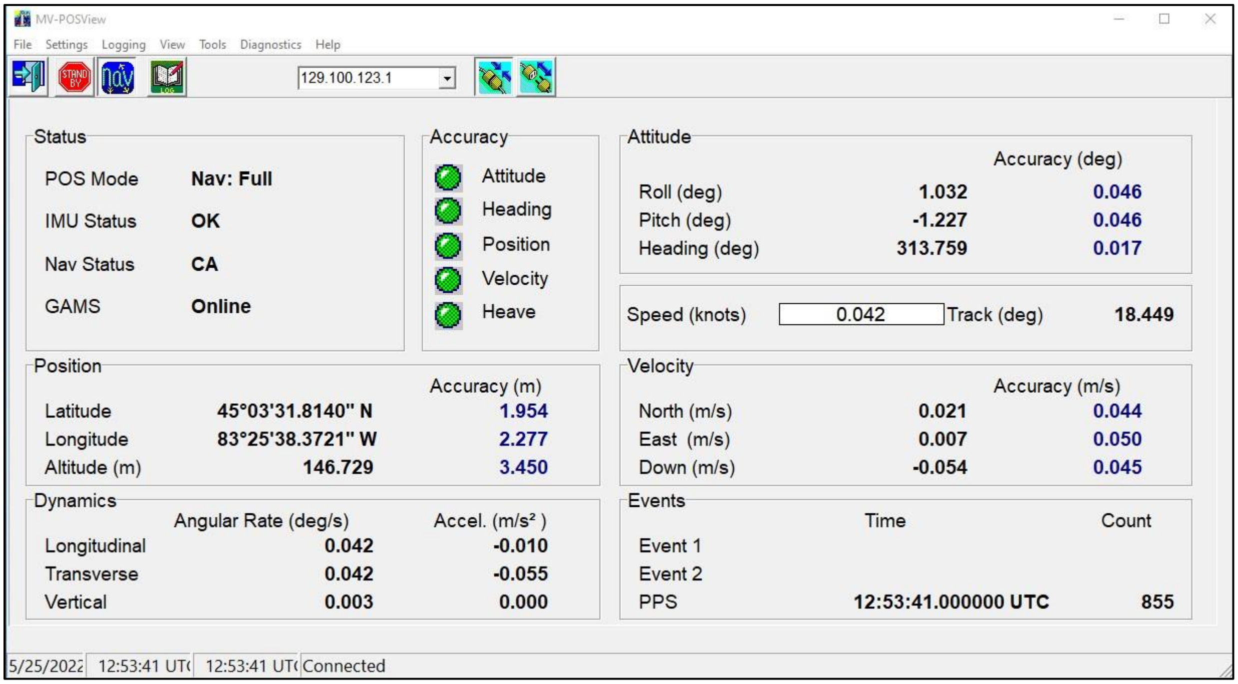


Figure 18. Measurement convention used in the HYPACK/HYSWEEP program.

Normal operating status of the POS MV system once all installation parameters were applied is shown in Figure 19. Operating status of the Kongsberg SIS program is also shown, with position and motion received from the POS MV in real time.



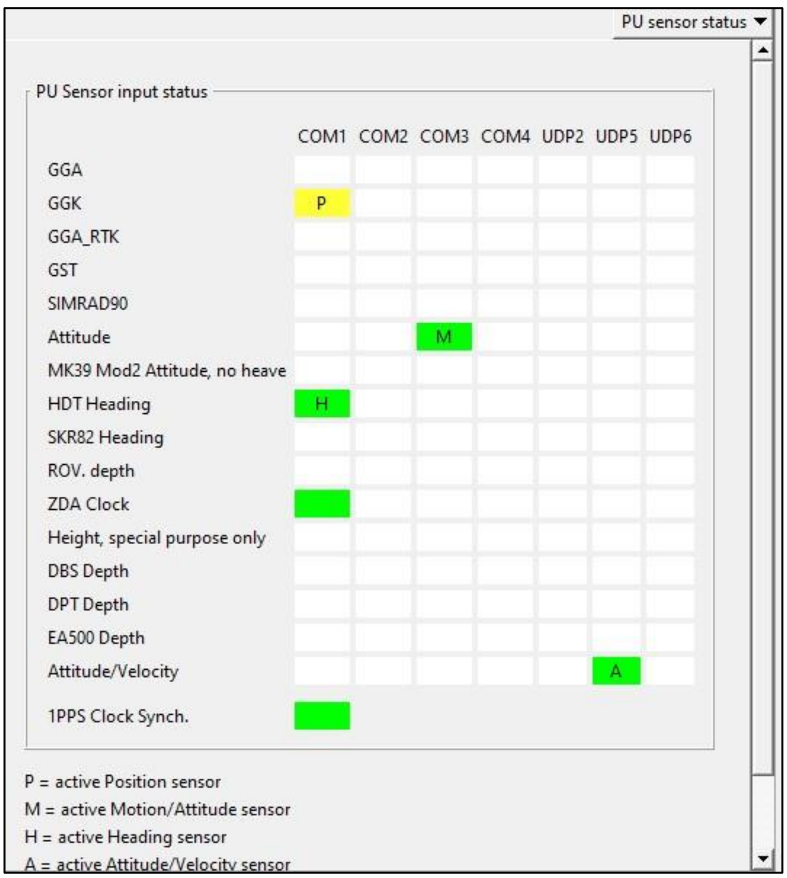


Figure 19. Control interfaces of the Applanix POS MV (top) and SIS (bottom) showing normal operating status following calibrations. Position and motion data from the Applanix INS were broadcast over the vessel workgroup and received by the SIS program to adjust properly adjust real time MBES data.

GNSS AZIMUTH MEASUREMENT SUBSYSTEM (GAMS) CALIBRATION

On 21 May 2022, a series of three GAMS calibrations were performed underway in Lake Huron in the vicinity of Thunder Bay Island, outside the marked navigation area. Summaries of parameter setup and results of these tests are presented in Table 9. The procedure used was the standard Applanix GNSS Azimuth Measurement Subsystem calibration performed three times, consecutively. These results were averaged and resulting values applied as the GAMS Parameter Setup 9 (Figure 20).

Table 9. Completed GAMS calibration values over three calibration events, averaged. Applied GAMS parameters used in the POS MV setup are provided in the final column.

R5002 POS MV V4						
Baseline Vector	**CAL 1**	**CAL 2**	**CAL 3**	**AVG**	**St. Dev**	**GAMS Parameter Setup**
X	0.001	-0.023	-0.012	-0.011	0.012	**-0.011**
Y	2.285	2.287	2.292	2.288	0.004	**2.288**
Z	-0.046	-0.038	-0.032	-0.032	0.007	**-0.038**

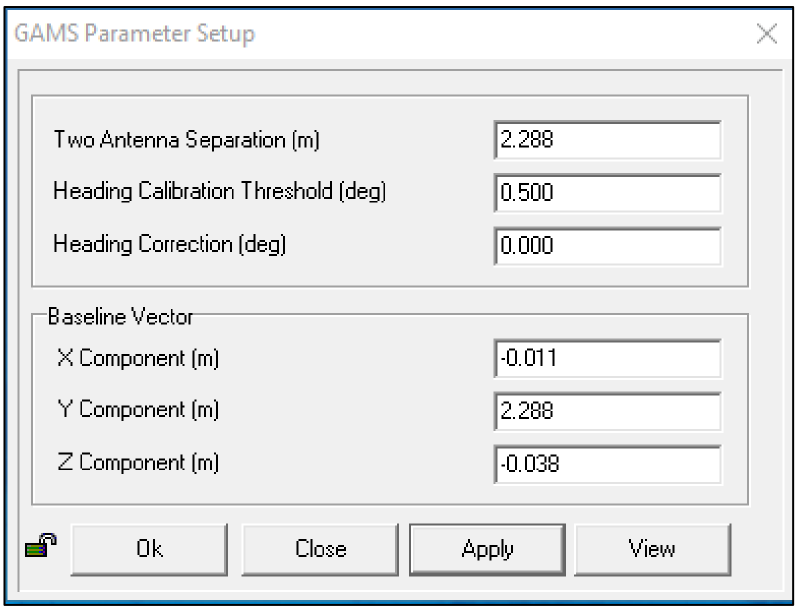


Figure 20. Applied GAMS Parameters input following conduct of three GAMS calibrations onboard R5002.

GNSS STATIC VERIFICATION

A static verification of the installed Applanix POS MV V4 INS system was performed by logging a 30-minute Applanix POSPac file on 25 May 2022 while the vessel was alongside the dock. This file, R5002_2022_05_25.000, was input into the Applanix Mobile Mapping Suite (MMS) for post-processing prior to the generation of an Applanix Diagnostic QC report. A full copy of this automatically generated report is included as Appendix A to this document.

Review of computed root mean square (RMS) error for horizontal and vertical position were 0.072 m and 0.073 m, respectively. The file recorded for the static test (R5002_2022_05_25.000) was collected after the GAMS calibration was completed.

5. | MULTIBEAM SONAR CALIBRATION

All underway MBES calibration tests were performed on 21 May 2022. These tests took place at a calibration site situated off the southern end of Thunder Bay Island, approximately 10 nm SE of Alpena, MI. Here, an MBES noise test, residual bias test, and sample survey were conducted. Data collected during these operations were processed to provide the results below.

While underway during MBES testing and calibration, raw data incoming from the EM2040C system showed no evidence acoustic cross-talk with any of R5002*'s* installed echosounders. Normal vessel operations did not appear to introduce any noise to the EM2040C MBES system while operating at 300 kHz. R5002 utilizes a depth sounder as part of its onboard Furuno navigation and electronics equipment. This device operates at a frequency of 165 kHz. While alongside, the depth sounder and EM2040C were energized and pinging. All frequency settings of the EM2040C, from 200 to 400 kHz, were checked for indications of noise or interference from the Furuno device; none were detected.

MBES CALIBRATION SITE

R5002*'s* EM2040C MBES calibration was performed at a site shown in Figure 21. This area included a section of flat-bottom area of Lake Huron averaging 18 m water depth used for the roll component of the MBES patch test. Also in this area was a sloping benthic feature utilized for the pitch, yaw (heading), and timing error tests, as well as a nearby shipwreck used as part of a sample survey. During these operations a single sound velocity cast was collected. Post-processing of the INS navigation data, combined with the MBES and SVP data, allowed for derivation of updated patch test values and assessment of survey data alignment.

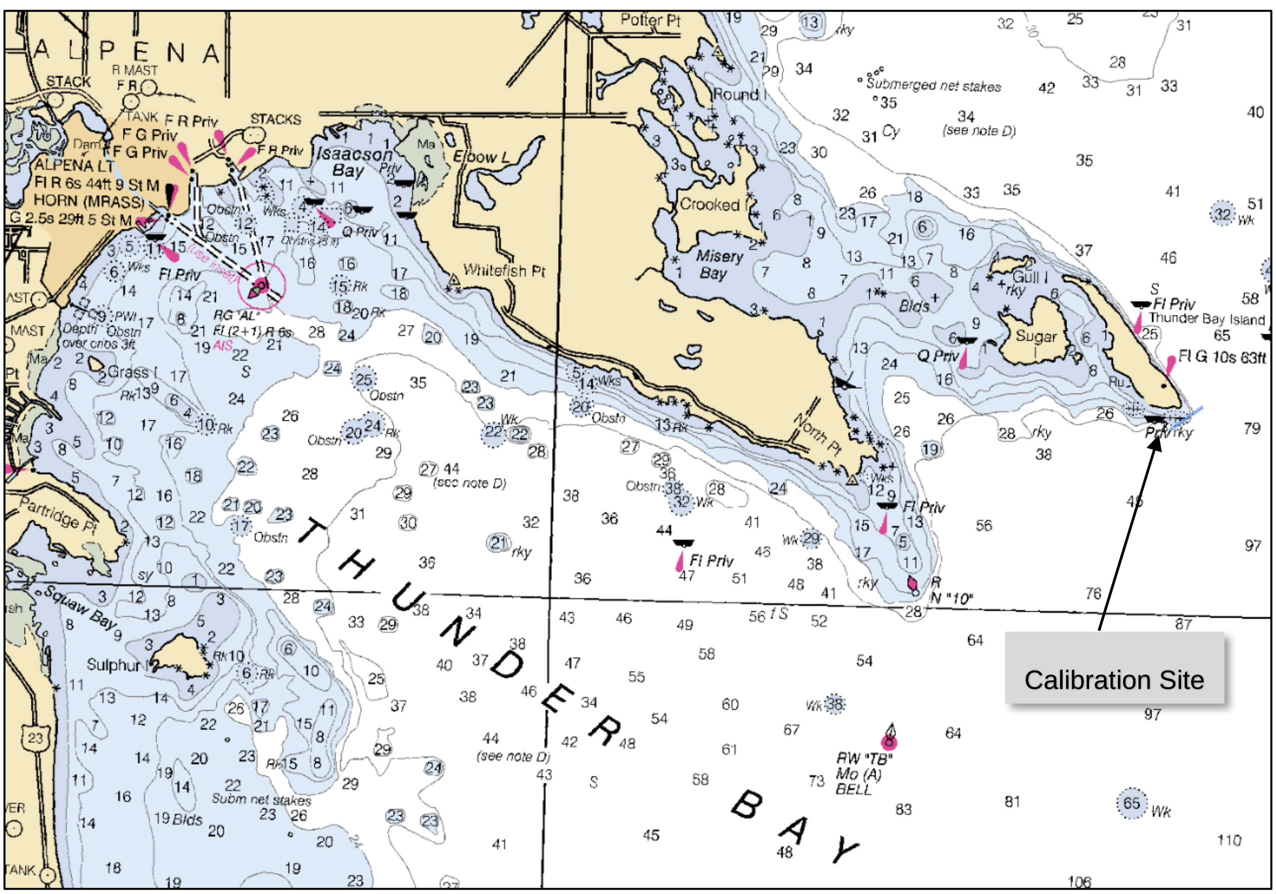


Figure 21. Location of the calibration site off the southern end of Thunder Bay Island used for underway testing of survey equipment onboard R5002, 21 May 2022.

MBES RESIDUAL BIAS TEST

Results from the MBES residual bias test (patch test) performed on 21 May are shown in Table 10. During the test sonar data was recorded with the Kongsberg Maritime SIS program (.ALL files) while navigation files from the Applanix POS MV were also recorded (.000 POSPac files). Offsets between the vessel CRP and MBES were programmed into the Kongsberg SIS interface. The HYPACK/HYSWEEP program was used for online navigation. Sound velocity casts were collected at the start of data acquisition. MBES data was imported into CARIS HIPS for post-processing and correction. Sound velocity files were applied as corrections. A post-processed smoothed best estimate of trajectory (SBET) was exported from the Applanix Mobile Mapping Suite to the CARIS project to improve navigation and motion reference information. Once all these corrections were applied, the patch test utility within CARIS was initiated to determine mounting angle offsets.

Table 10. Kongsberg Maritime EM2040C residual bias (patch) test results from 21 May 2022.

	Heading	**Roll**	**Pitch**	**latency (s)**
Final Settings	-4.280 °	2.950 °	6.100 °	0.00

The roll test was performed at the calibration site a single survey line plotted in a flat area of Lake Huron, shown in Figure 22, with the remaining tests performed on a sloping geological feature off the terminus of Thunder Bay Island as also indicated in Figure 22.

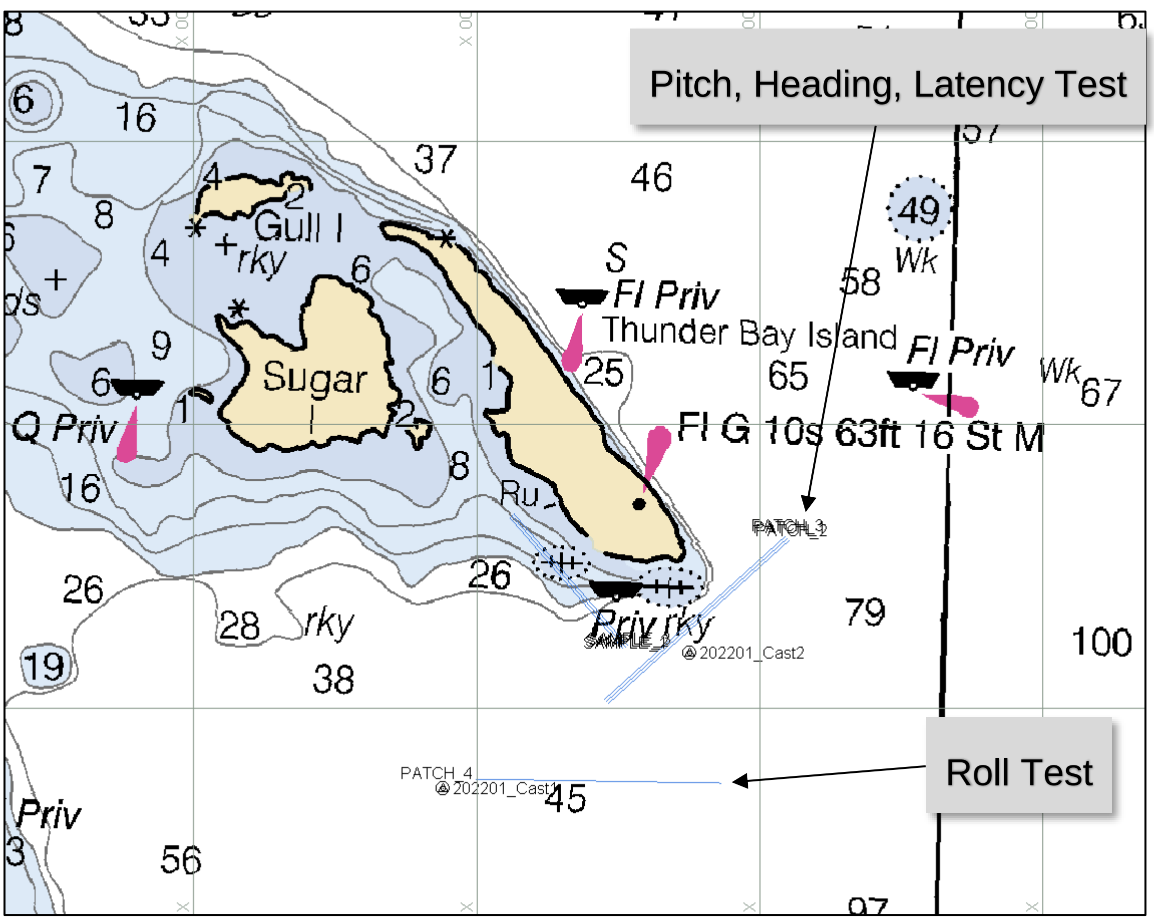


Figure 22. Residual Bias Test run lines used for 21 May 2022 Patch Test onboard R5002.

LATENCY TEST

For position latency determination, a survey line was set over a well-defined bottom feature where depths change from 20 m to 16 m in a short distance. The run line was plotted perpendicular with the rising slope of this feature, per the representation in Figure 23. Two run lines were recorded over this survey line, both in the same direction. One occurred at half of the online survey speed (~3 knots) and the other at normal online survey speed (~6 knots). Any latency offset would appear as a feature position offset (or contour shift for a slope) along track between the processed data sets. Figure 24 shows the plotted run lines in the CARIS post-processing patch test utility. No along track offset in target position was seen and no latency adjustments were required. Figure 25 shows line profiles before and after the latency calibration was applied.

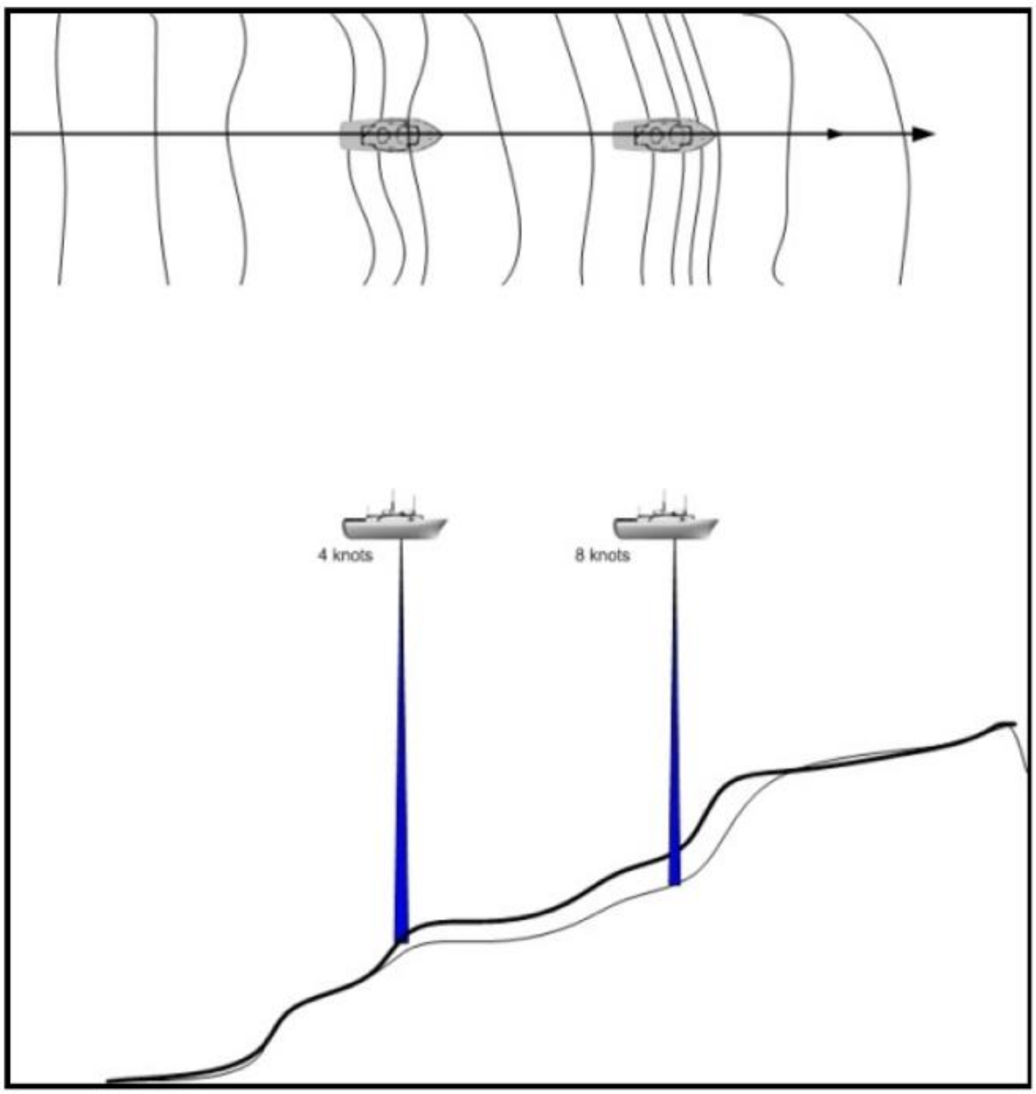


Figure 23. Latency data collection method. Image source: R2Sonic MBES Manual.

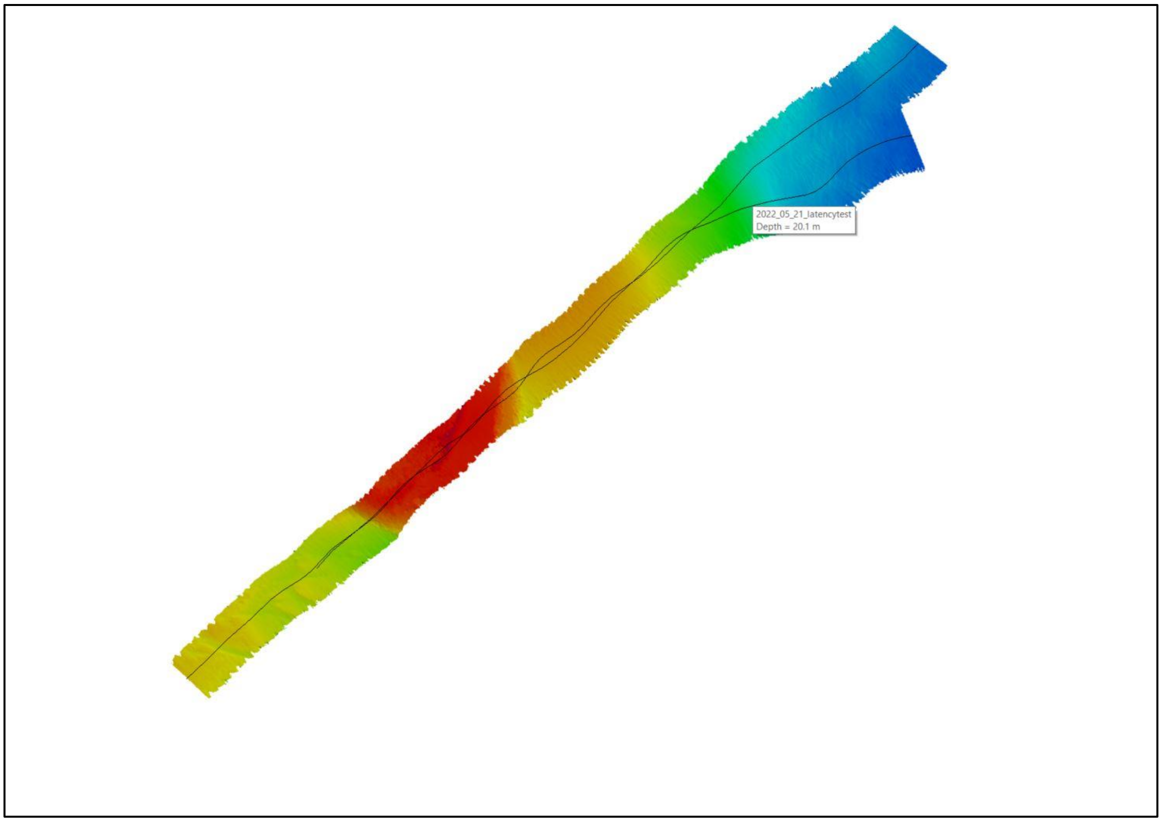


Figure 24. Survey run lines and cross section used for MBES latency calibration.

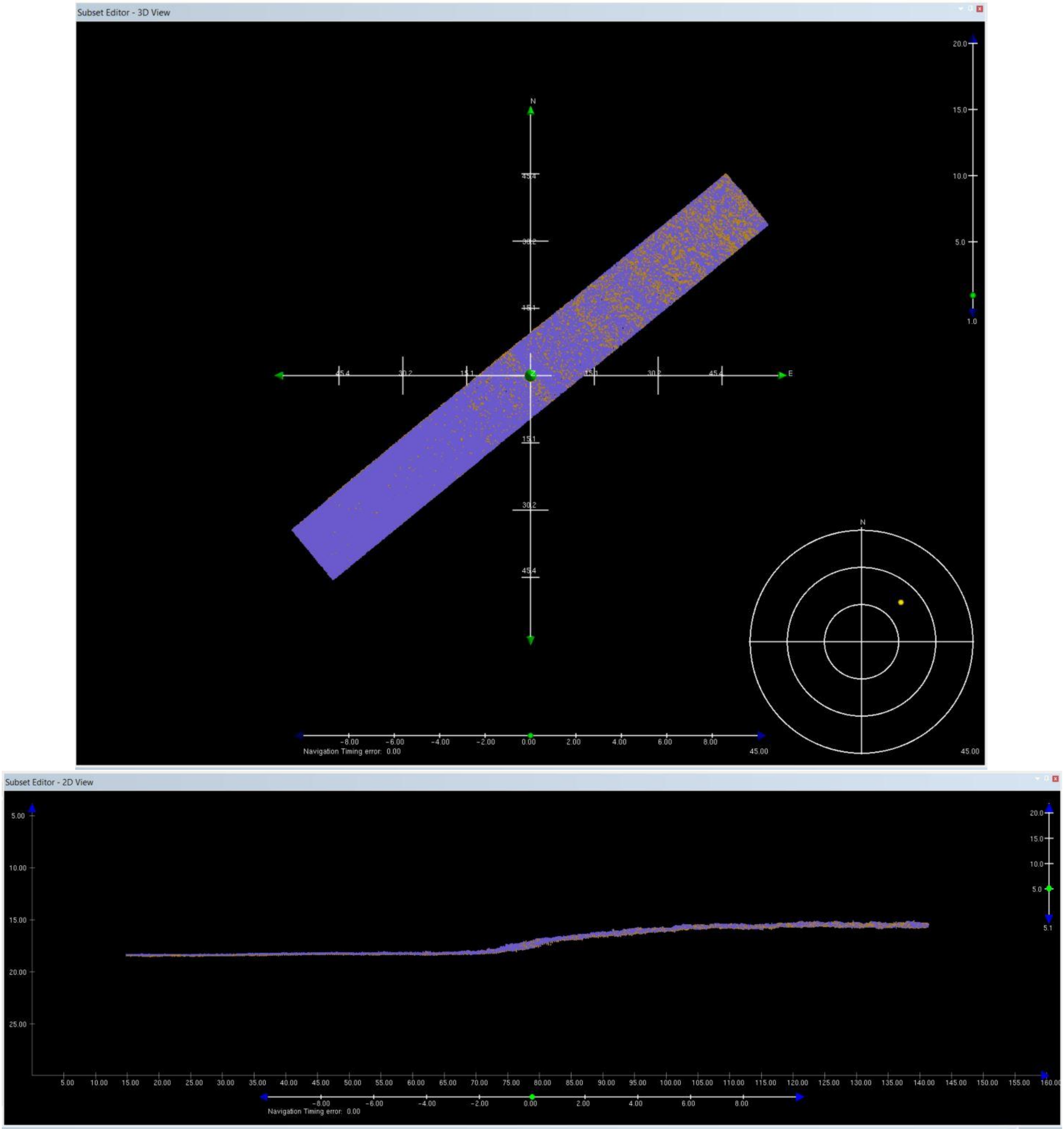


Figure 25. MBES latency test, pre- and post-calibration. NOTE: no correction applied for Latency.

ROLL TEST

To determine roll offset a single survey line was recorded in an area of flat and featureless lake floor. Two lines were recorded in opposite directions with consistent vessel speed (per Figure 26). When the motion and position corrected data sets were viewed in cross-section, roll offset appeared as divergence between the profiles which increased with distance off nadir.

The roll calibration was performed at the calibration site along a North/South run line at a depth of approximately 20 m. The roll calibration line was approximately 1700 m in length, surveyed in opposite directions (Figure 27) at an average speed of ~6.0 knots. Review of the data within the CARIS patch test utility indicated an adjustment of 2.950° was required. Figure 28 shows the pre- and post-calibration roll alignment of the processed MBES data.

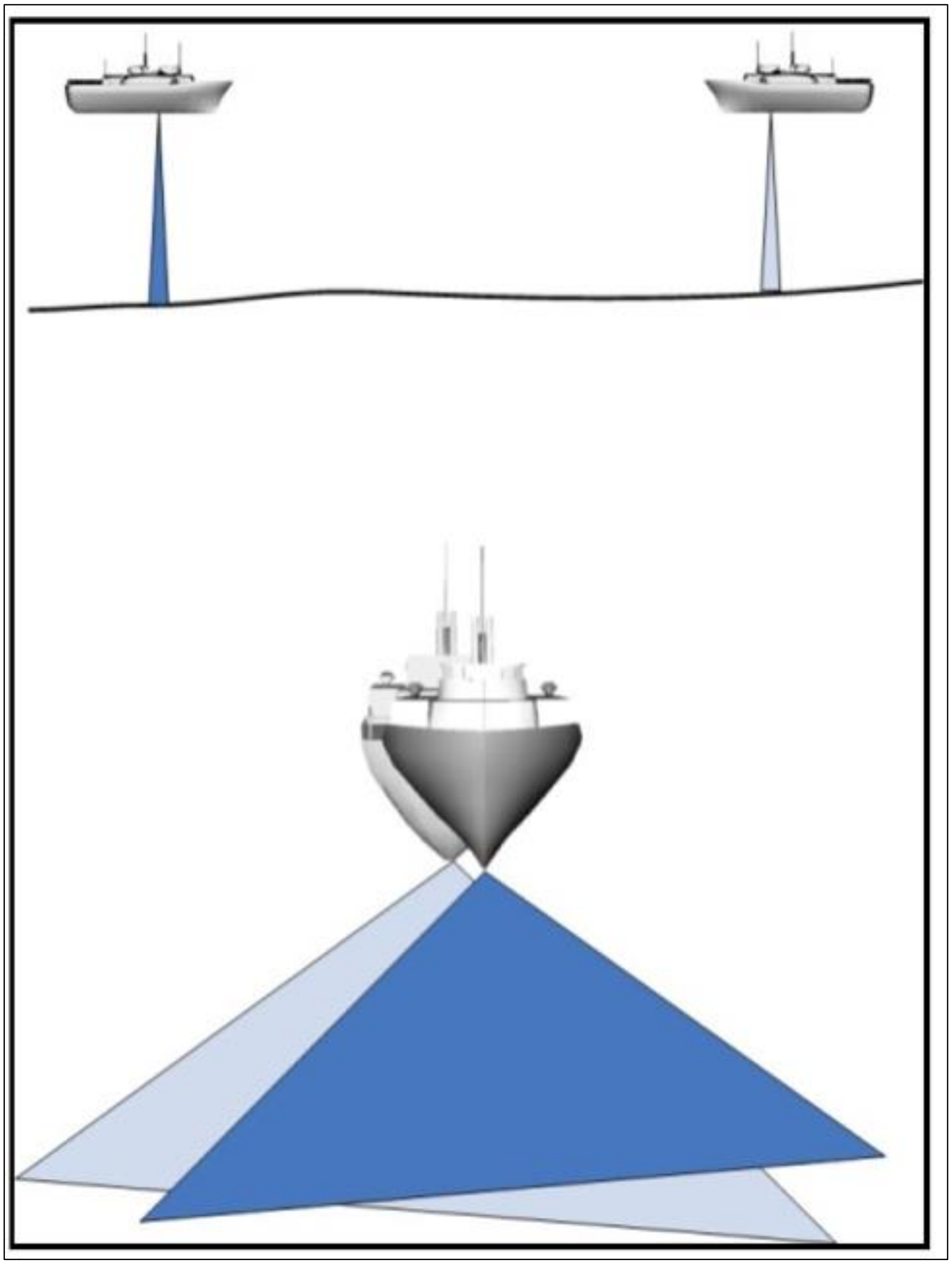


Figure 26. Roll calibration method. Image source: R2Sonic MBES Manual.

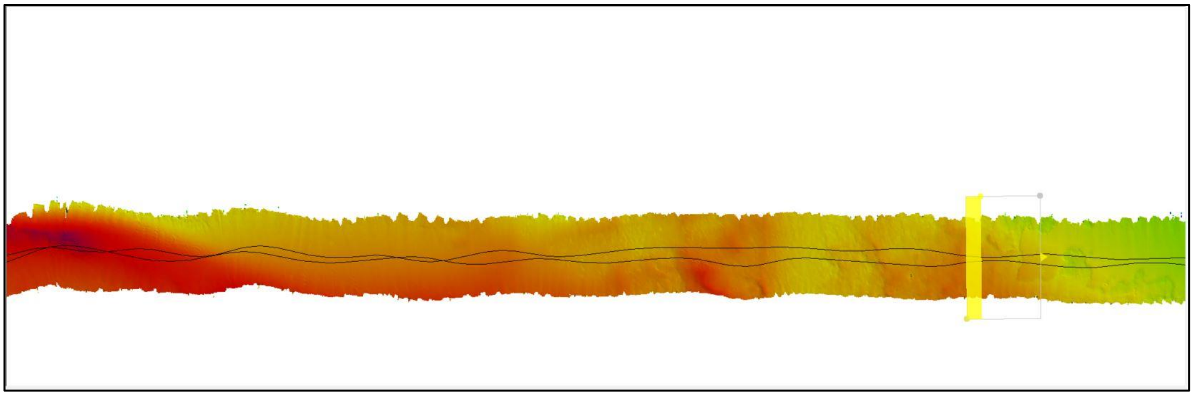
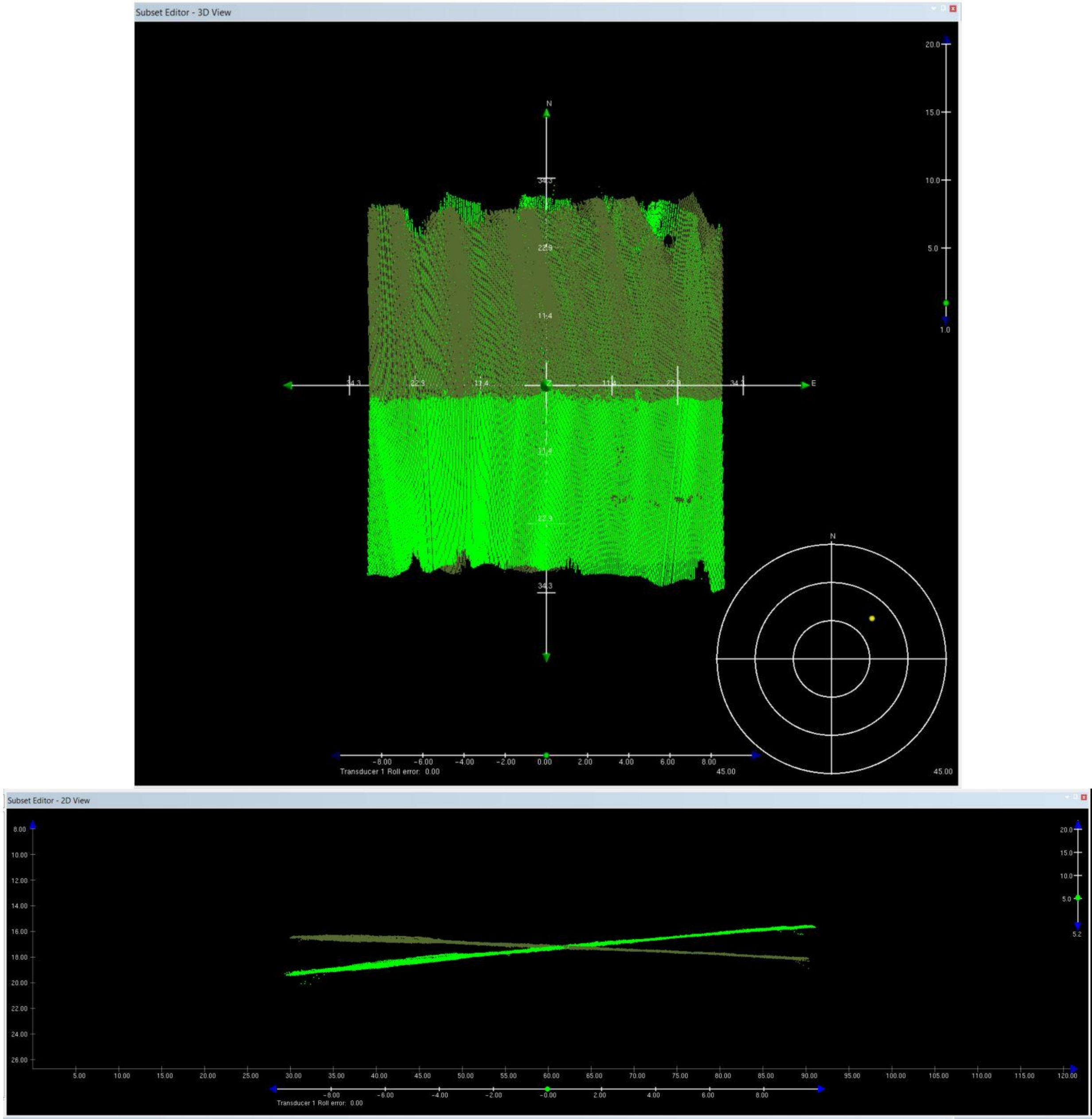


Figure 27. Survey run lines and cross section used for MBES roll calibration.



Subset Editor - 3D View
Transducer 1 Roll error: 0.00
Subset Editor - 2D View
Transducer 1 Roll error: 0.00

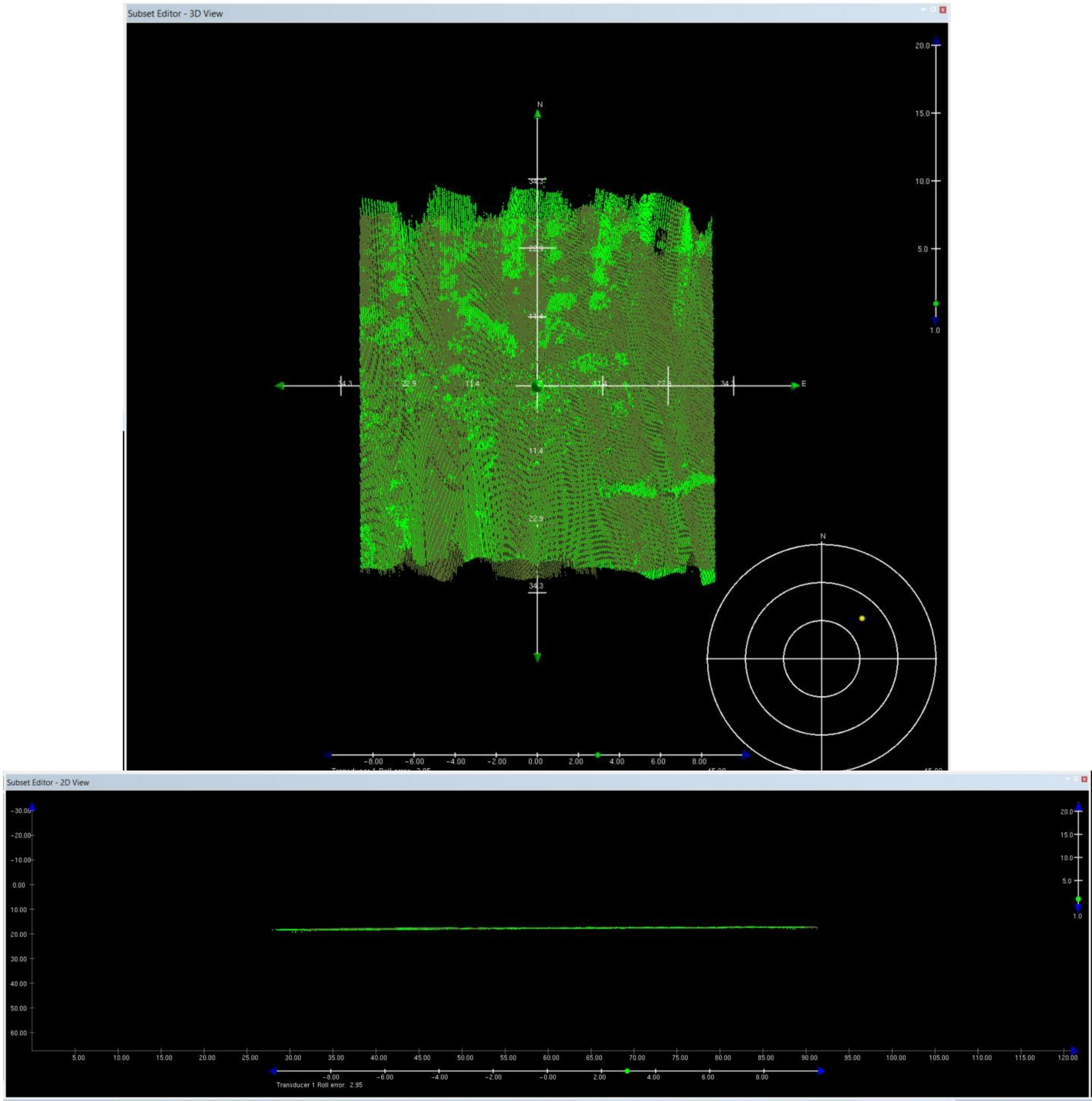


Figure 28. MBES roll alignment, pre- and post-calibration. Note that offset is 2.950°.

PITCH TEST

The pitch calibration was conducted over the same bathymetric feature utilized during the latency test. Unlike the latency test, however, the lines used for pitch calibration were run at the same speed in opposite directions (Figure 29). Acquired data for the pitch calibration occurred over run lines approximately 1700 m long at a speed of 6.0 knots (Figure 30). Postprocessing for pitch calibration utilized the portion of the acquired lines that crossed the edge of the sloping benthic feature at a depth of approximately 16-20 m.

Data from the nadir of overlapping reciprocal lines provided an offset pitch angle. The CARIS patch test utility was used to compute the pitch angle for the MBES. Review of the data within the CARIS patch test utility indicated an adjustment of 6.10° was required. Figure 31 show the pre- and post-calibration pitch alignment of the processed MBES pitch data.

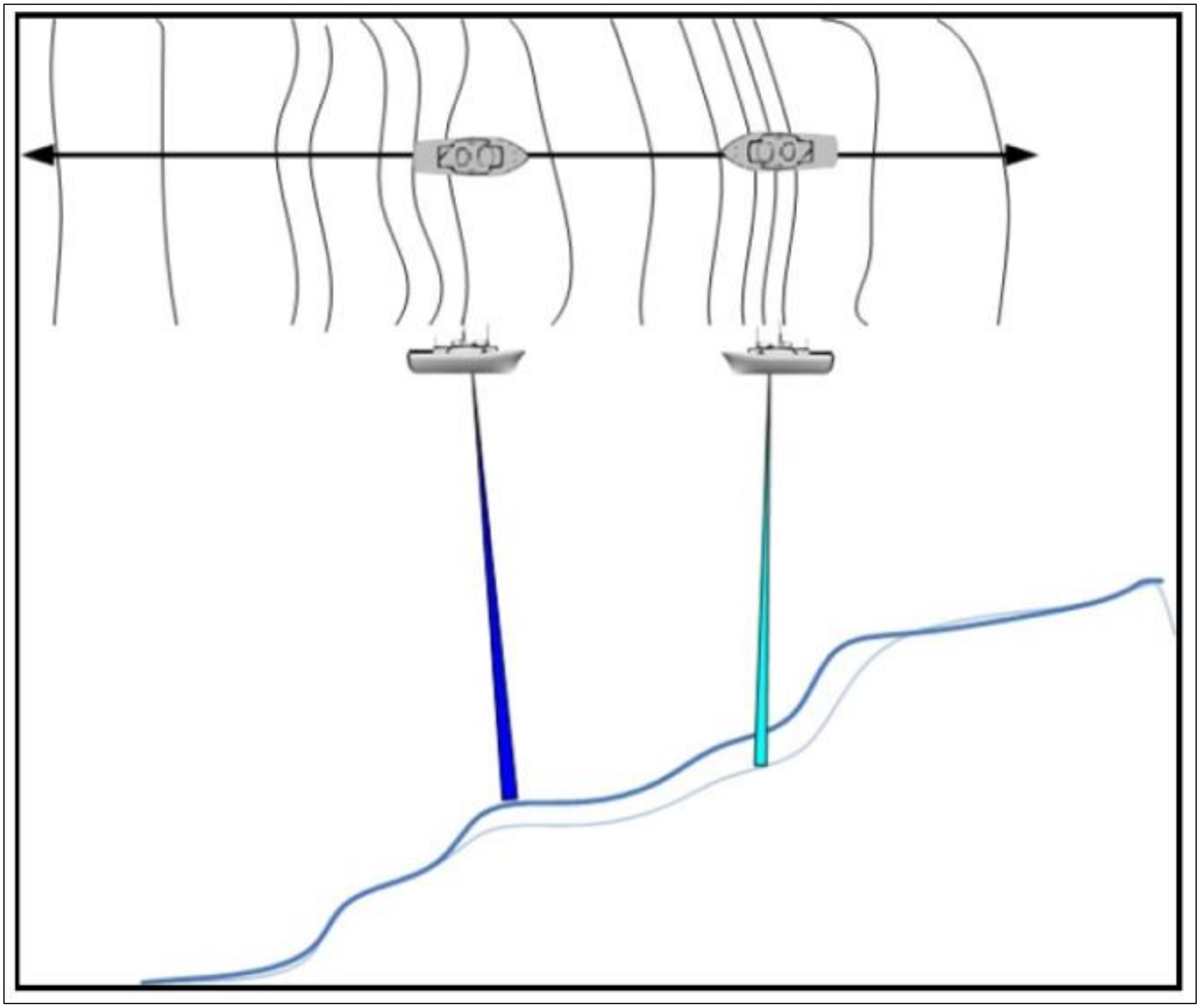


Figure 29. Pitch calibration method. Image source: R2Sonic MBES Manual.

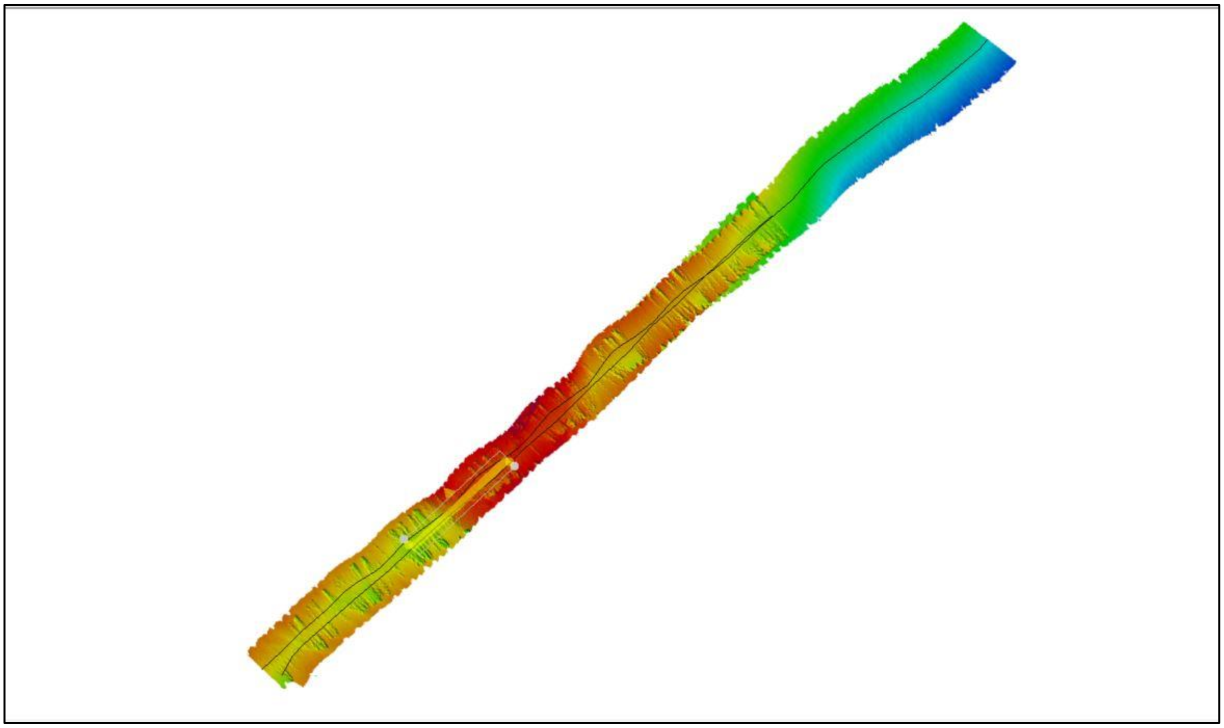
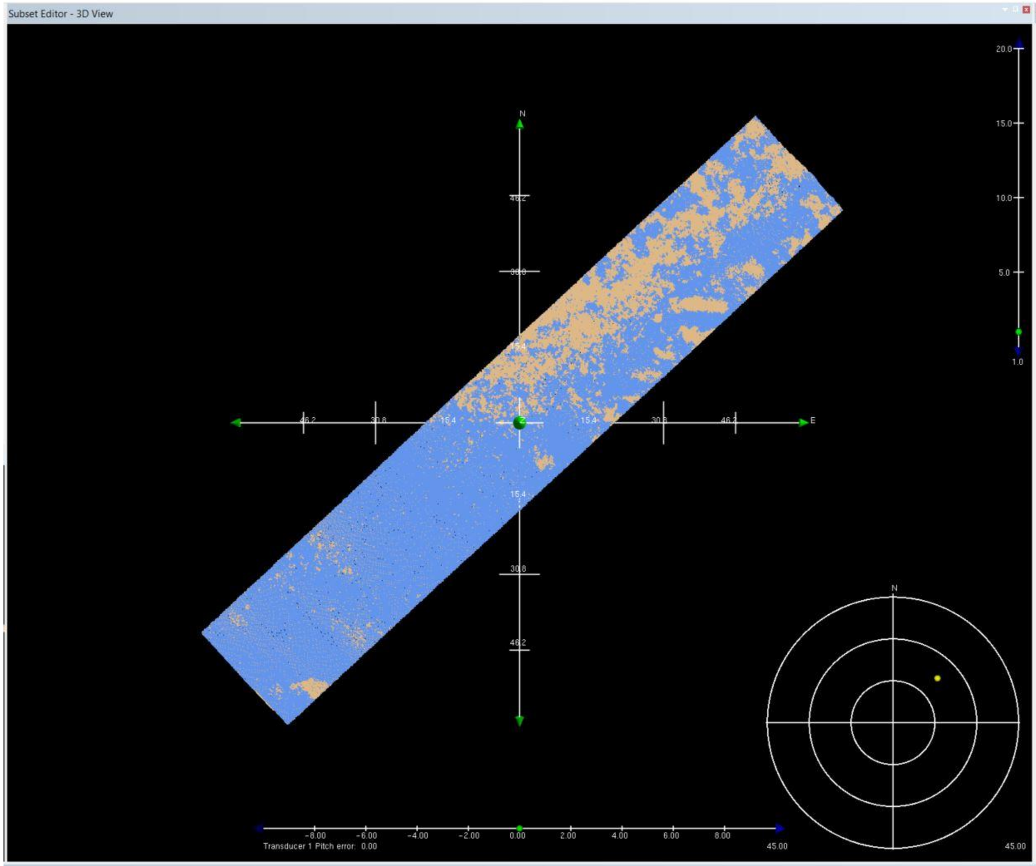
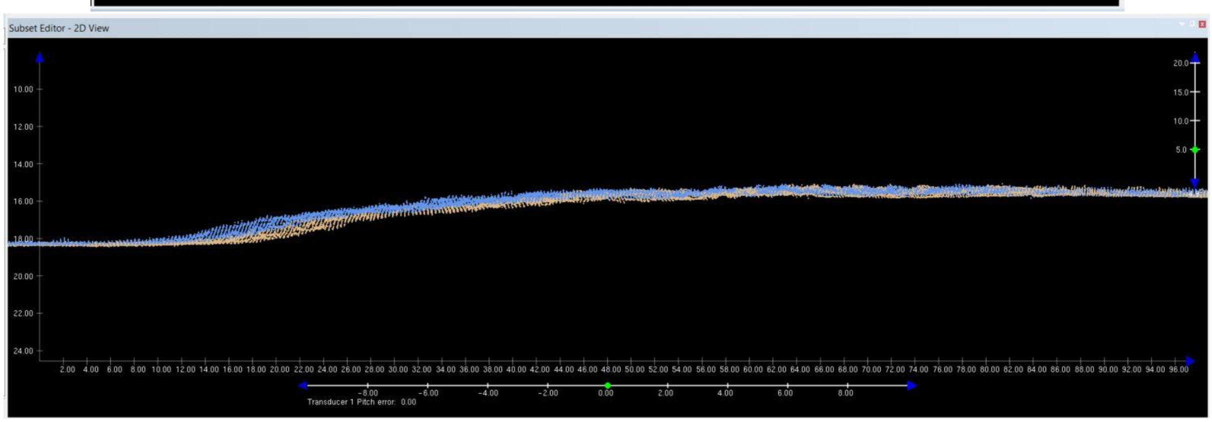


Figure 30. Survey run lines and cross section used for MBES pitch calibration.


Subset Editor - 3D View
N
E
Transducer 1 Pitch error: 0.00


Subset Editor - 2D View
Transducer 1 Pitch error: 0.00

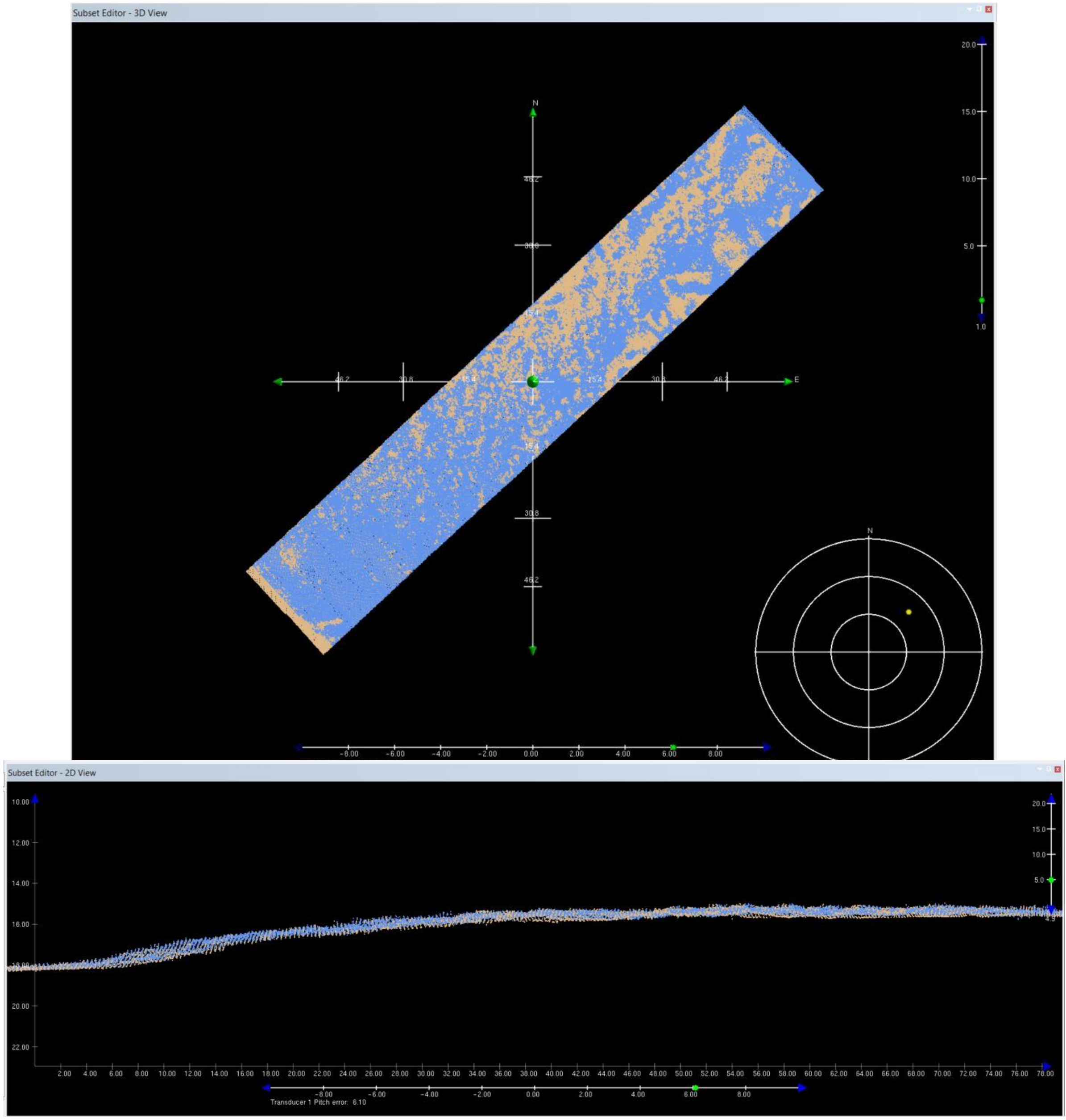


Figure 31. MBES pitch alignment test pre- and post-calibration. Note that offset is 6.10°.

HEADING (YAW) TEST

The heading angle was determined by running two parallel lines over a feature with different off-track distances. Heading calibration lines were plotted offset to each other while oriented perpendicular to the sloping benthic feature. Both lines were acquired in the same speed and direction. Misalignment of along-track position of the feature from the overlapping data between the two lines was used to determine the heading installation angle (Figure 32).

The two plotted run lines were surveyed in opposing directions at an average speed of 6.0 knots (Figure 33). CARIS's patch test utility was used to compute the heading angle for the MBES. This result indicated that the MBES required an adjustment of -4.28°. Figure 34 shows the MBES head alignment in respect to heading.

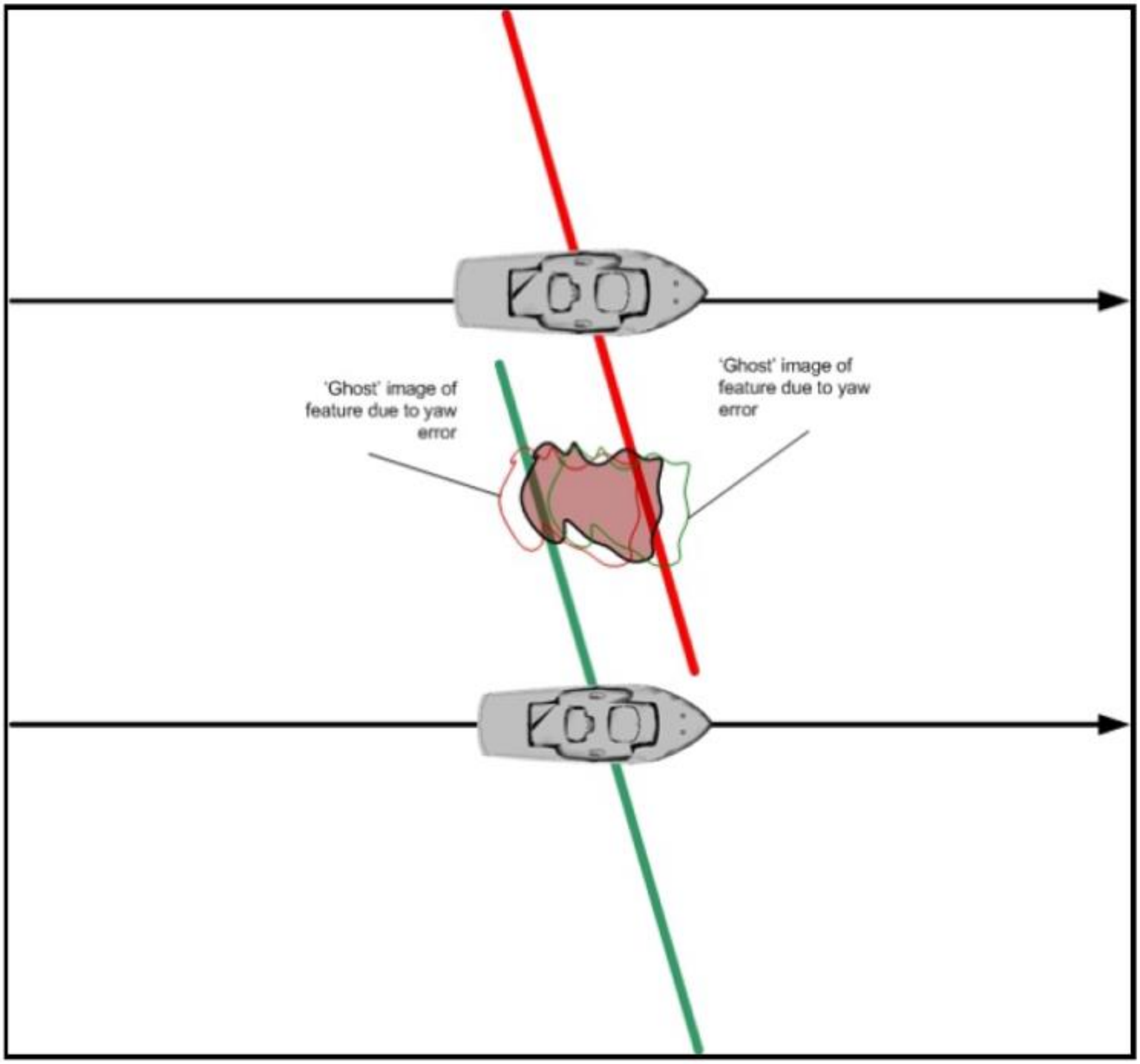


Figure 32. Heading calibration method. Image source: R2Sonic MBES Manual.

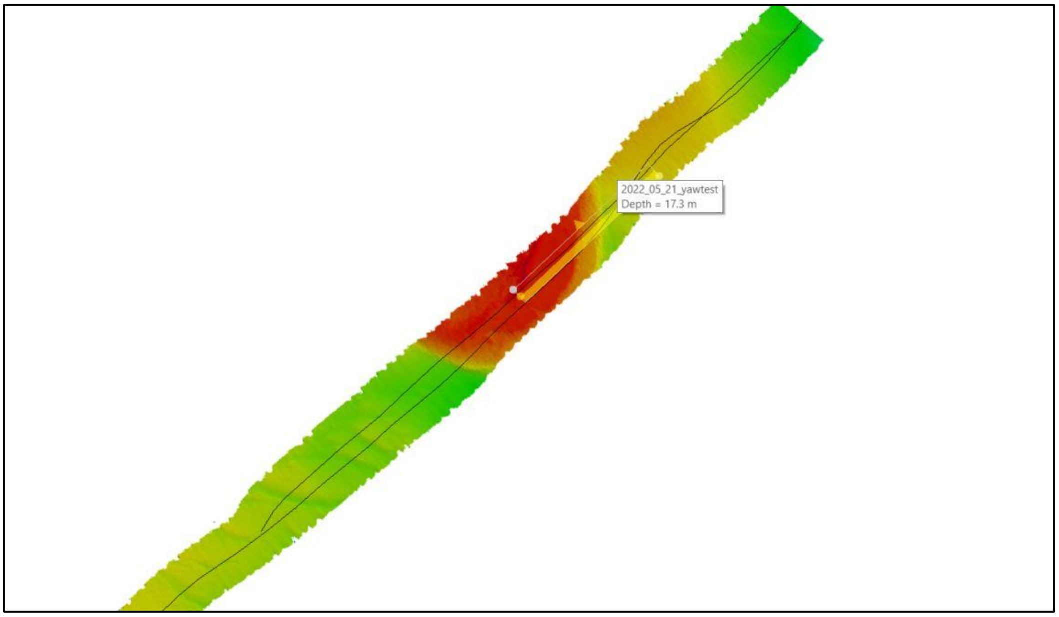
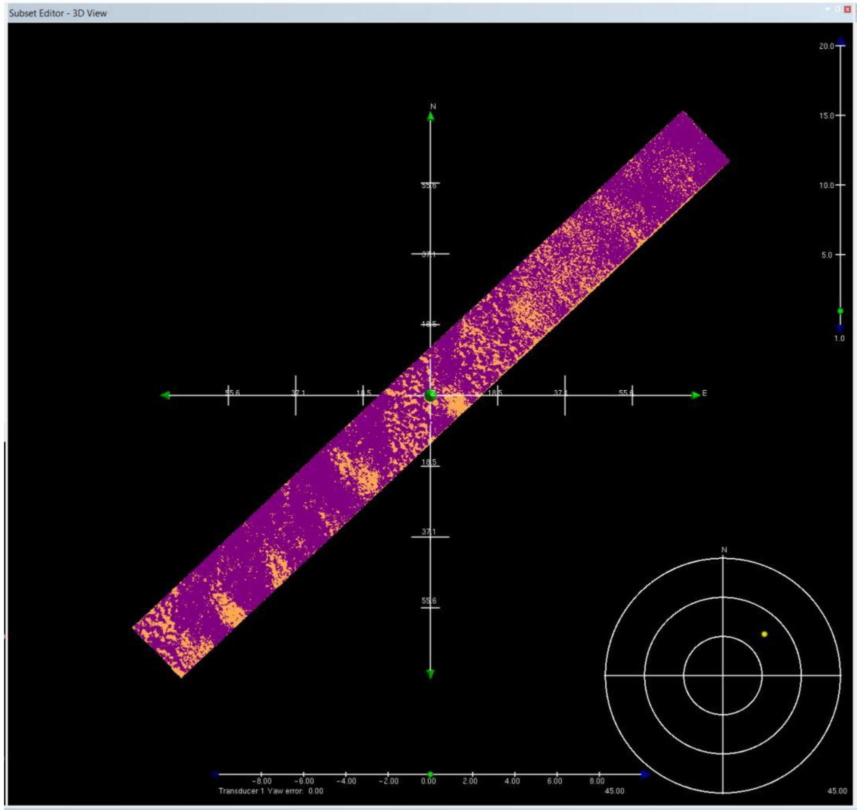
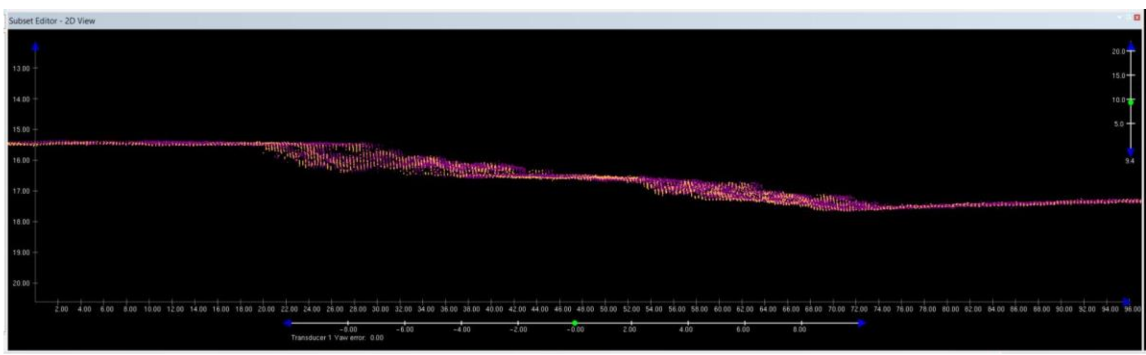


Figure 33. Survey run lines and cross section used for MBES heading calibration.


Subset Editor - 3D View
N
E
Transducer 1 Yaw error: 0.00


Subset Editor - 2D View
Transducer 1 Yaw error: 0.00

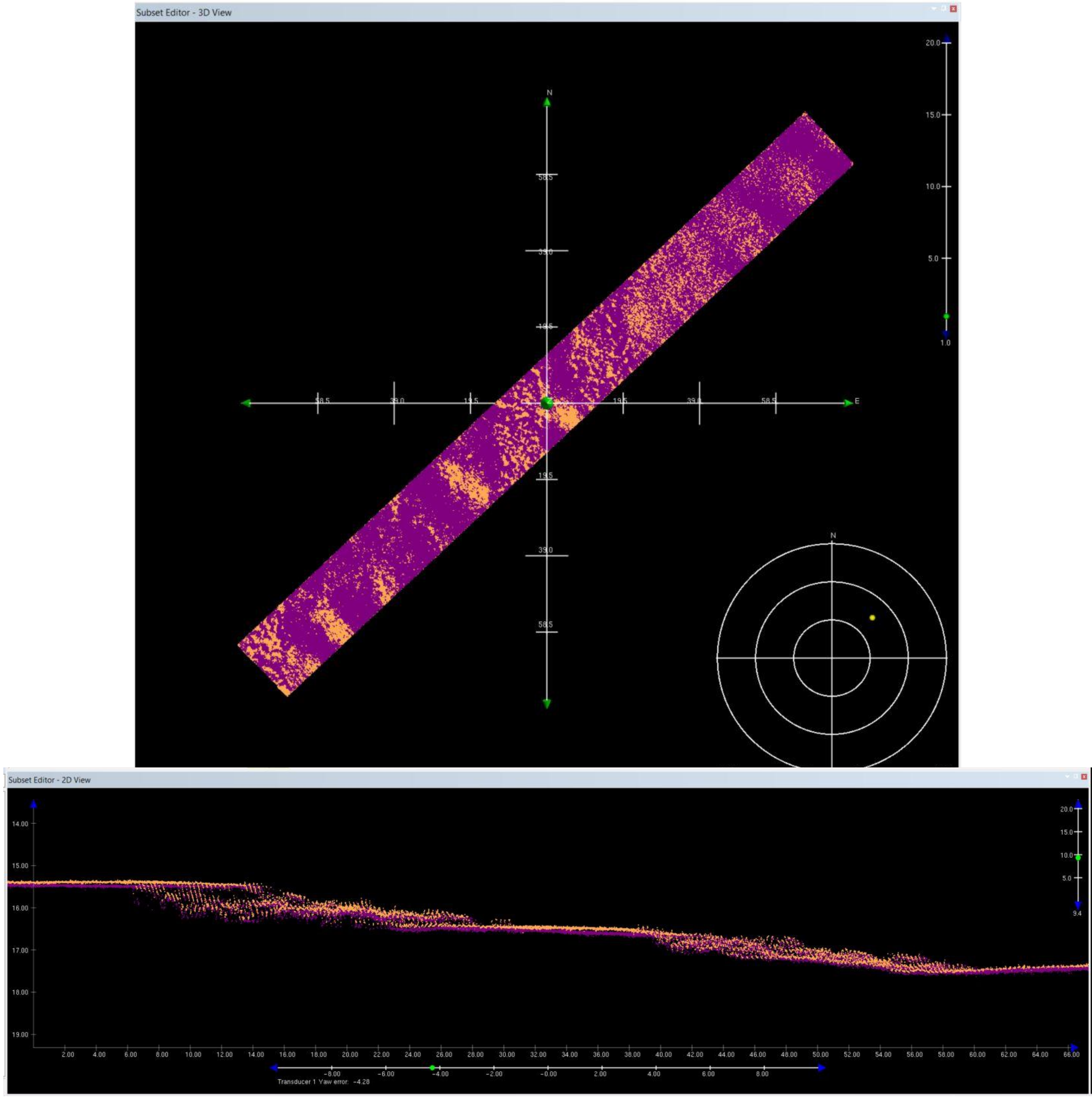


Figure 34 MBES heading alignment pre- and post-calibration. Note that offset is -4.28°.

MBES SAMPLE SURVEY TEST

All survey run lines collected during the MBES patch test were utilized as part of a sample survey dataset. These lines were imported into a CARIS project and processed through the preliminary QA/QC workflow. This involved application of the collected SVP file for sound velocity correction, generation and import of an SBET file from processed POSPac files, application of mounting angle offsets in the CARIS vessel file settings, referencing and mosaicking the MBES data, and generation of a gridded bathymetric surface comprising all associated soundings. Next, an acoustic backscatter mosaic was generated.

The raw, imported data is shown in Figure 35 prior to application of the preliminary QA/QC workflow; this data is uncorrected. Figure 36 shows the result after the above workflow and corrections were applied. Results of the sample survey indicated that instrument offsets, mounting angle offsets, as well as proper application of SVP and SBET information, adequately align the acquired MBES data and render a clean bathymetric product. SEE NOTE in Section 3, however, related to vertical reference issues noted.

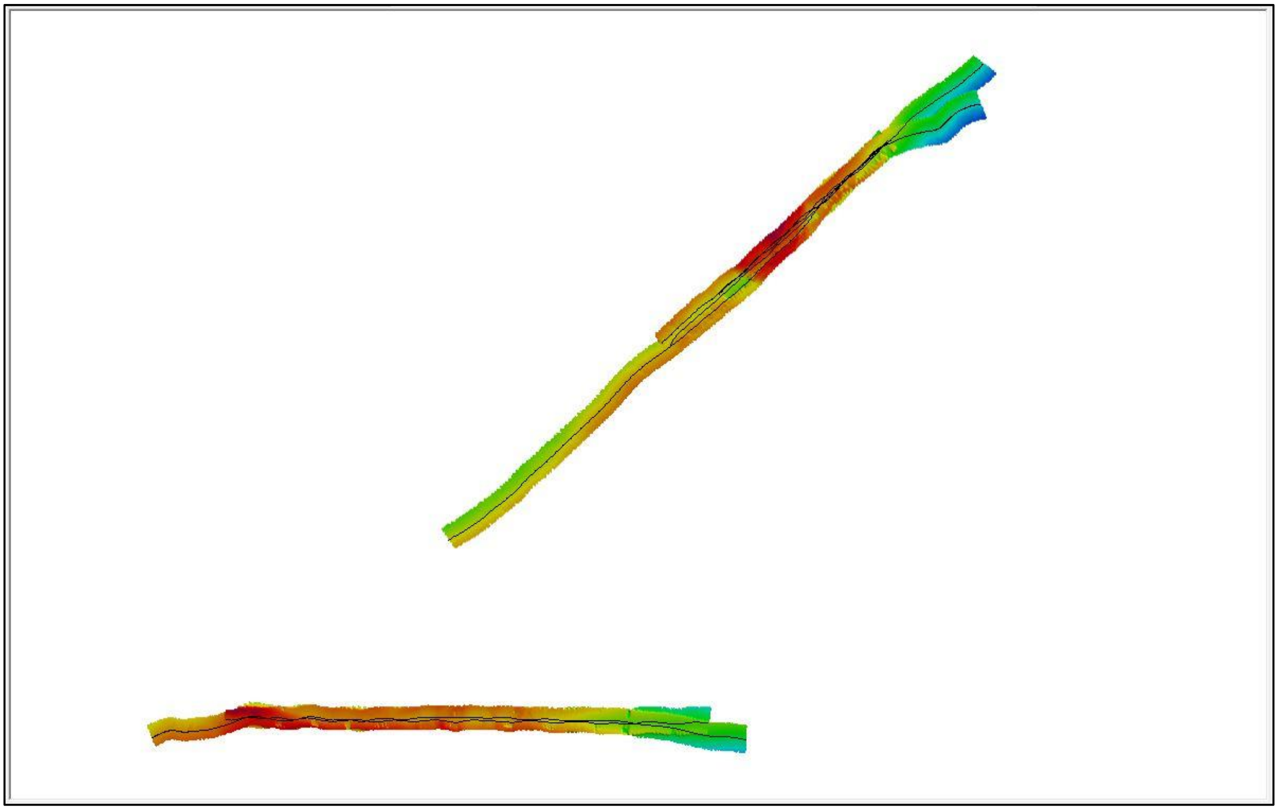
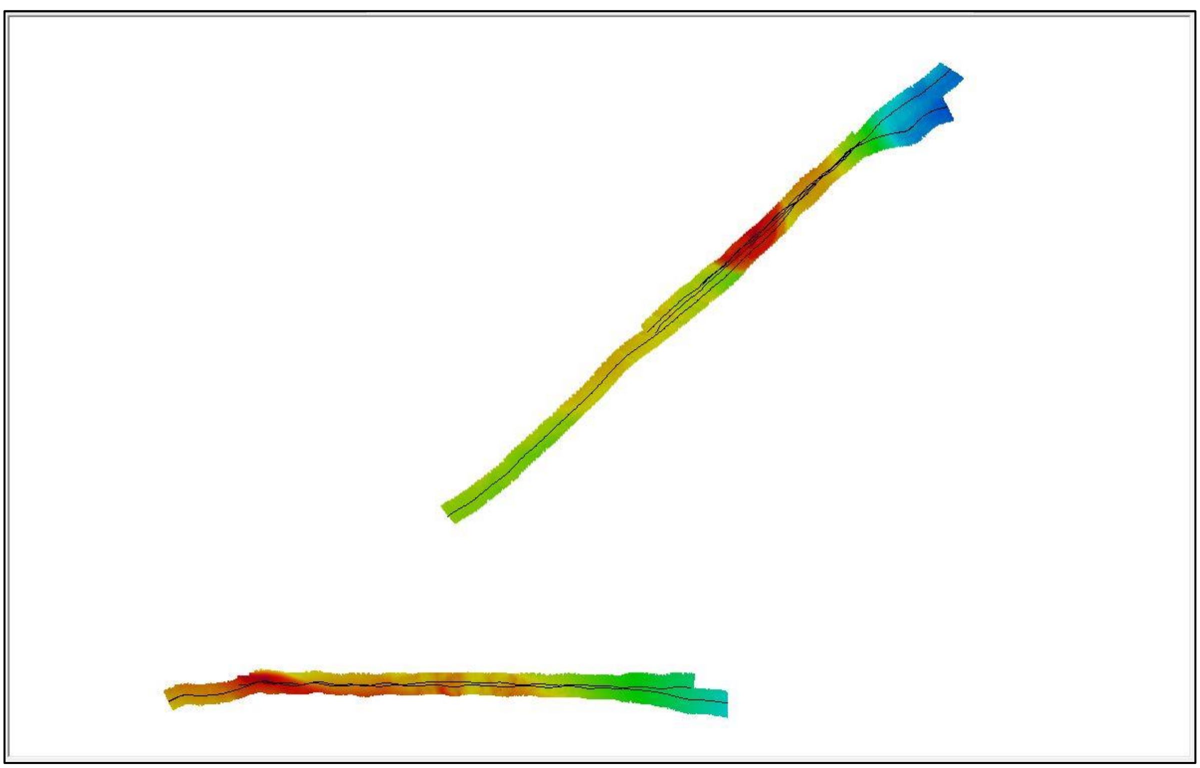


Figure 35. Uncleaned and uncorrected bathymetric surface produced from four lines collected during the MBES patch test plus three additional lines collected over a nearby shipwreck target, all collectively used as a sample survey dataset.



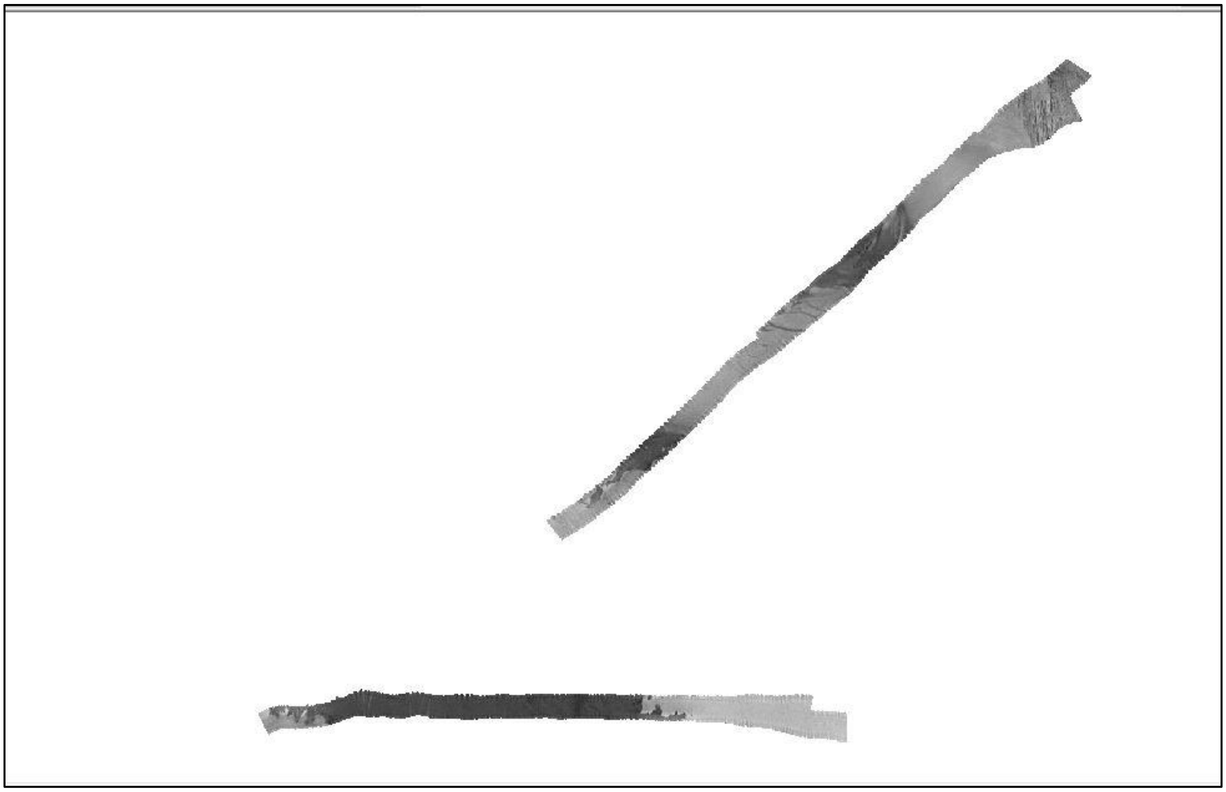


Figure 36. MBES bathymetric data (top) and acoustic backscatter (bottom) from sample survey (six lines) corrected with SVP and SBET files as well as patch test angular offsets to show file alignment and a cleaned surface result.

6. | SOUND VELOCITY SYSTEMS

Acoustic ray paths are a function of the water density, salinity and temperature through which they pass and uncertainties in these qualities will lead to significant errors in processed sonar data. Furthermore, the properties of the water column are largely unpredictable and vary both spatially and temporally. To ensure that the overall depth measurement accuracies are preserved, sound velocity (SV) observations must be observed with sufficient frequency, density and accuracy to preserve the required precision.

The sound velocity measurement systems onboard R5002 include:

- Valeport Mini SVS (S/N 70558) used as surface sound velocity sensor (SVS). It is mounted near the MBES head to measure speed of sound through water at the MBES unit during online mapping operations. Integrated directly with Kongsberg Maritime SIS program.
- SonTek CastAway CTD (S/N CC1930006) sound velocity profiler (SVP) deployed by hand over the side of the vessel to measure SV through water column during mapping operations.

The SVP units are factory calibrated every two years. For calibration certificates and calibration dates, refer to Appendix B.

SV NETWORK INTERFACE

Surface sound velocity data is collected in real time via a mounted Valeport Mini SVS system located adjacent to the MBES head. This device is connected to the SIS workstation via a RS-232 serial connection and provides continues, real time SV information during MBES operation.

Interval water column sound velocity profile data is collected via a SonTek CastAway CTD which is hand-deployed over the side of the vessel. This SonTek unit can communicate via Bluetooth radio; cast data is downloaded to the SIS workstation following each SVP deployment and then distributed locally within the data acquisition workgroup for file conversion, storage, and application to the SIS interface.

To interface with the vessel's network, the SonTek CastAway CTD software interface (v1.5) is used to download acquired sound velocity profile data from the instrument over a Bluetooth connection. Within this interface cast data is reviewed for correct position, time, data format, and depth. Next, new files are downloaded from the instrument onto a local workstation drive and saved in both CARIS (.svp) and CastAway (.csv with Info Header) formats. A second program, Sound Speed Manager (v2021.1.0) is then used to open the CastAway format (.csv) and convert to a Kongsberg format (.asvp) for direct upload into the SIS interface for real time application to raw MBES preview data. Sound Speed Manager is also used to convert each sound velocity cast into CARIS (.svp) format for post-processing. Since all workstations onboard R5002 are connected as a workgroup with data drives mapped between machines, this SV workflow allows for rapid distribution and sharing of SVP data while online.

Tests of this workflow were performed during the MAC in support of MBES data acquisition. Figure 37 shows sound velocity cast data collected on 21 May while underway. This file was collected with the SonTek CastAway device then downloaded and distributed to the SIS Workstation and Data Acquisition Computer.

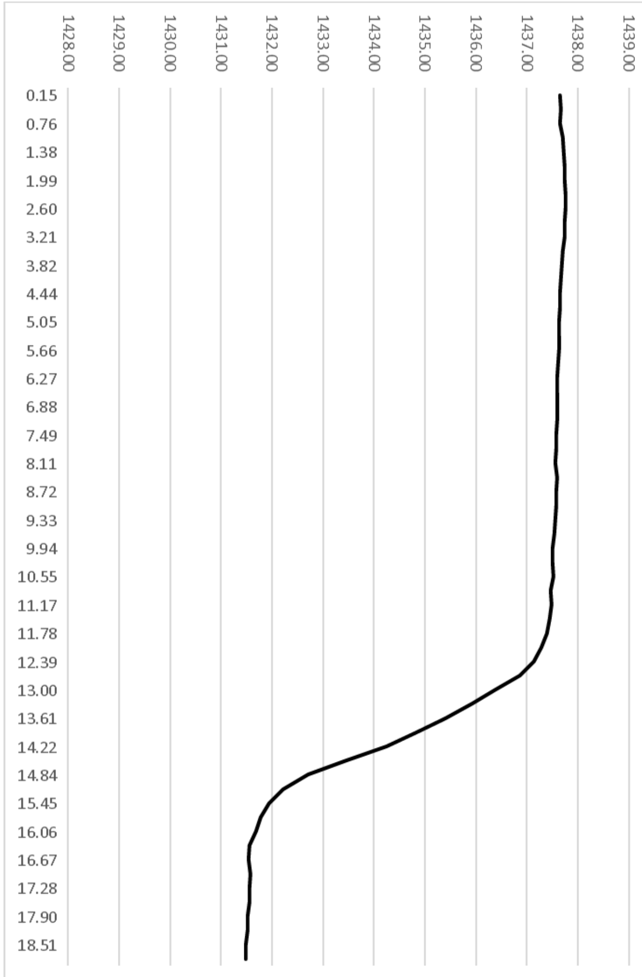


Figure 37. Sound velocity profile collected at the calibration site on 21 May 2022. This file was used to test the network distribution of the SVP file from the instrument to the DAC, SIS workstation, and appropriate raw file archive on the DAC, as well as a correction source for MBES files collected during MAC testing.

SV COMPARISON TEST

On 21 May 2022, a sample sound velocity cast was collected with SonTek CastAway CTD unit CC1930006. The results of this cast were compared with the values read at the same instance by the Valeport Mini SVS surface sound velocity sensor at the MBES head, situated at a depth of approximately 1.0 meters below the waterline. The surface values measured by the SonTek unit between 0.15 and 1.0 m depth were averaged and compared with the measured SV value recorded by the Valeport unit. These results are presented in Table 11, with a variance of only 0.20 m/s between the two units.

Table 11 Surface sound velocity comparison SVP device and SVS system installed near MBES head.

System	**Depth (m)**	**Sound Velocity SV (m/s)**
Valeport Mini SVS Sound Velocity Sensor, SN: 70558	0.60	1437.9
Sontek CastAway CTD, SN: CC1930006	0.60	1437.7
Variance	n/a	0.20

7. | VESSEL NETWORK AND INTERCONNECT INFORMATION

This final section is collection of notes on vessel interconnect and network settings. Information contained herein is arranged as annotations and notes for referencing during online activities by the survey team.

VESSEL IP ADDRESS INFORMATION

R5002 Workgroup Settings		
129.100.123.3	Data Acquisition Computer	DAC to switch
129.100.123.1	POS MV Computer	POS MV LAN to switch
129.100.123.4	SIS Workstation	SIS Workstation to switch
129.100.123.6	Kongsberg PU Ethernet 2 Adapter	PU to switch
Kongsberg PU Settings		
157.237.20.40	EM 2040C PU	PU to SIS workstation
157.237.20.41	SIS Workstation NA	SIS workstation to PU

DEVICE INTERCONNECT

APPLANIX POS MV

COM1 | OUTPUT | NMEA GGA and HDT at 4800 baud (to R5002 Nav & AIS system)

COM4 | OUTPUT| Navigation to SIS at 19200 baud (to EM2040C PU)

COM5 | OUTPUT | Motion to SIS at 115200 baud (to EM2040C PU)

LAN | Interface to vessel workgroup, MV POS View; OUTPUT to Ethernet Realtime (HYPACK, SIS PU); OUTPUT to Ethernet Logging

PPS | OUTPUT| Coaxial; electronic PPS signal (to EM2040C PU)

KONGSBERG MARITIME EM2040 PU

LAN | Interface to SIS; OUTPUT to SIS Logging

LAN | Interface to POS MV for Attitude/Velocity data over UDP (set to PU UPD 5)

COM 1 | INPUT | DB9/RJ45 Adapter | Position (GGK), Time (ZDA), and Heading (HDT) from POS MV at 19200 baud

COM 3 | INPUT | DB9/RJ45 Adapter | Motion from POS MV at 115200 baud

PPS | INPUT | Coaxial; electronic PPS signal

DAC WORKSTATION

LAN | Interface to Network Switch (connect to vessel workgroup)

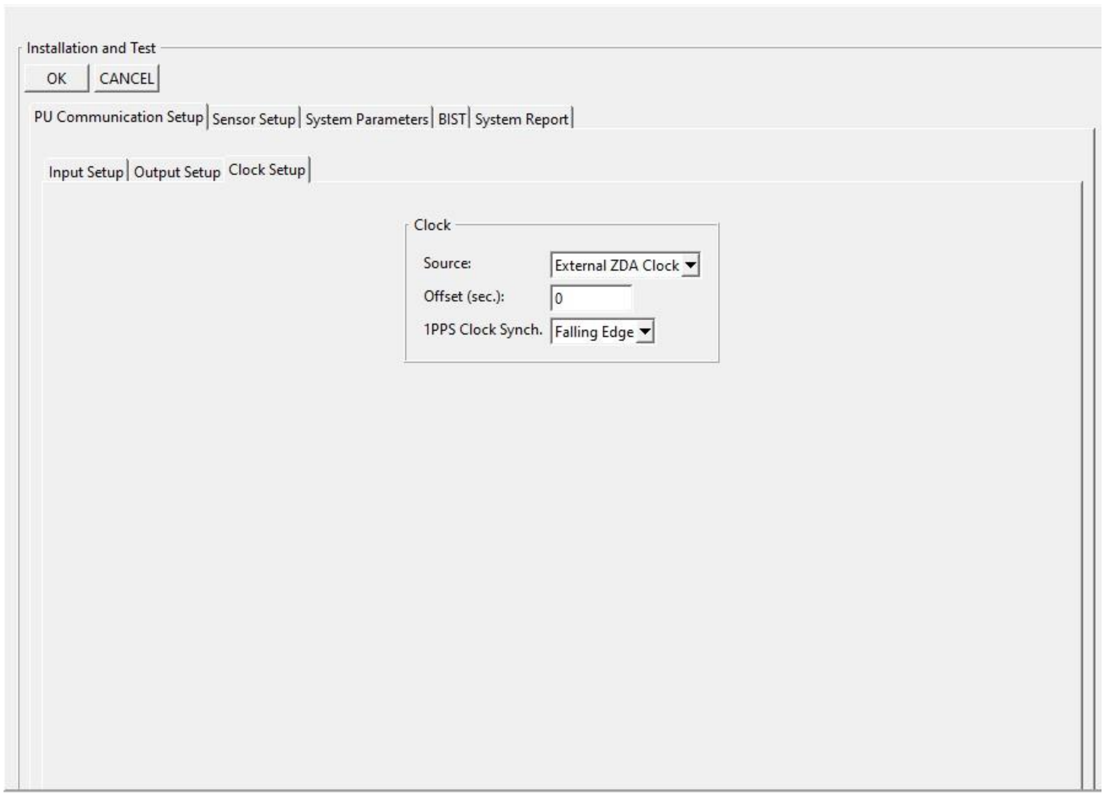
SIS WORKSTATION

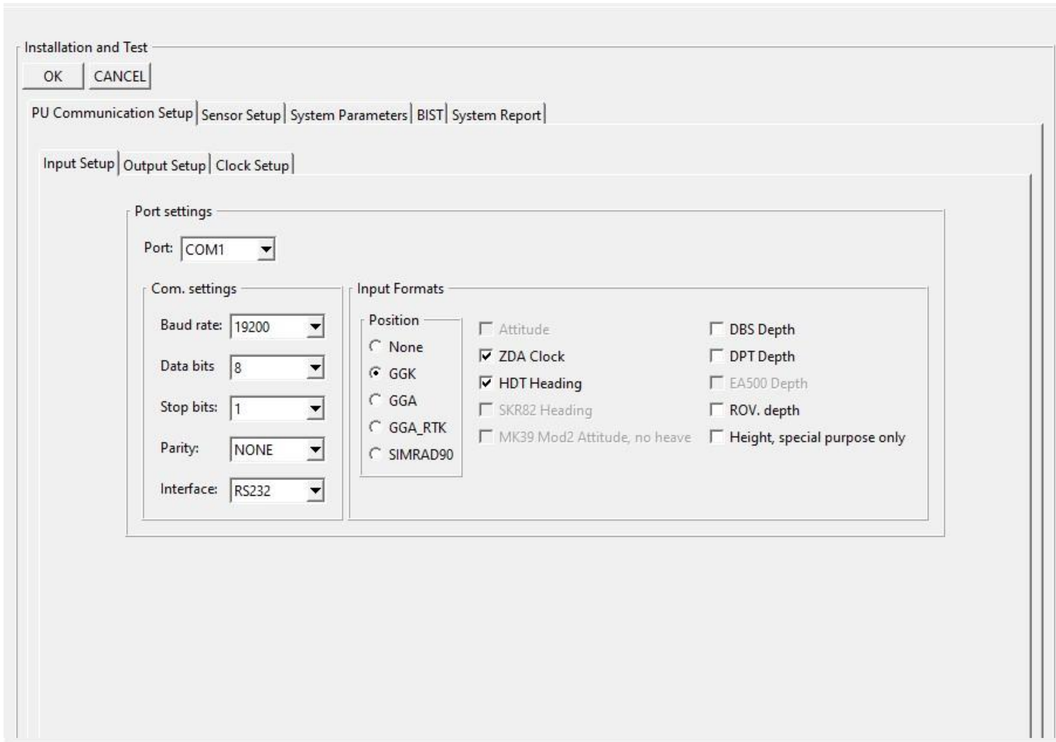
LAN: Interface to EM2040 PU

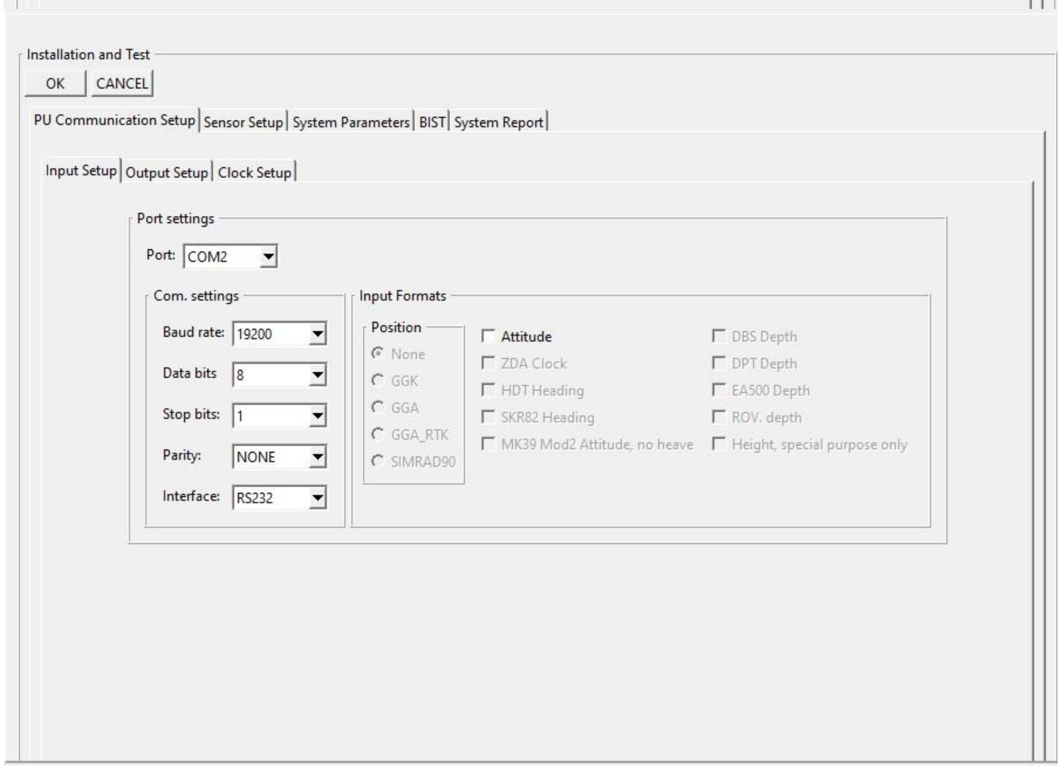
LAN: Interface to Network Switch (connect to vessel workgroup)

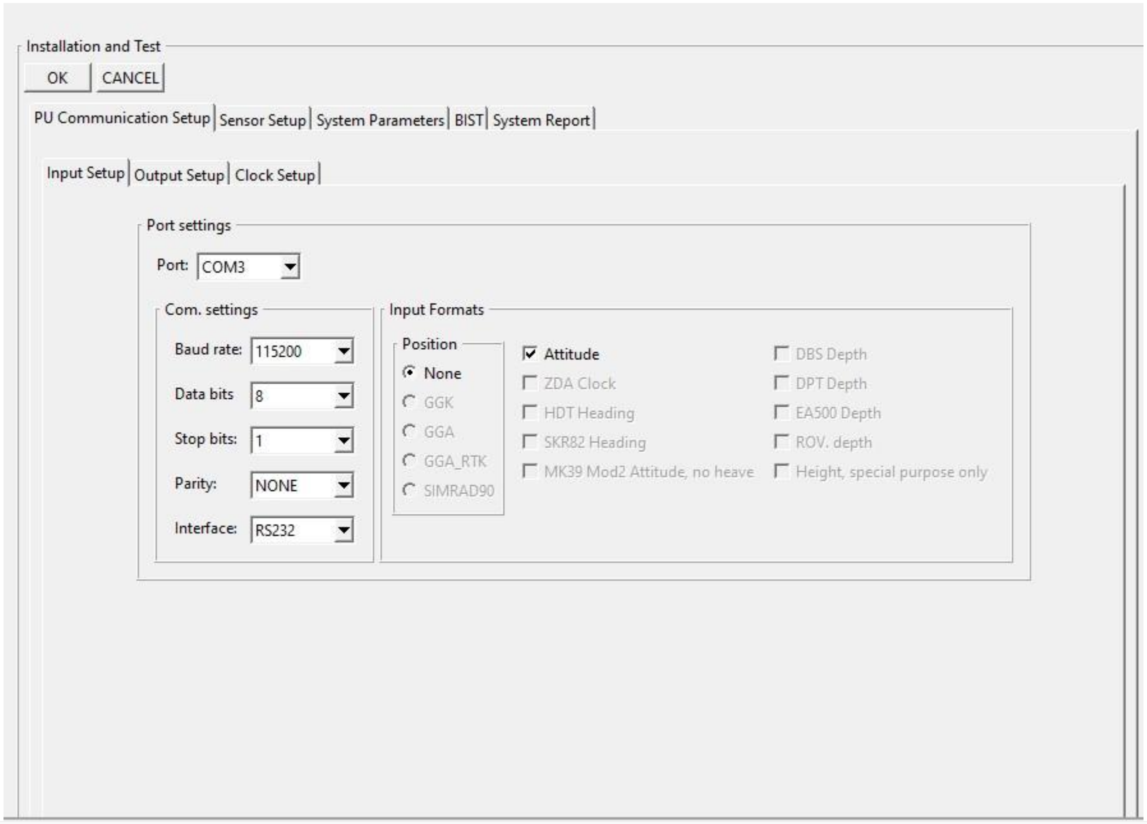
COM3 | INPUT | SVS data at 19200 baud, SV in m/s with three decimal places, sample rate 1 Hz

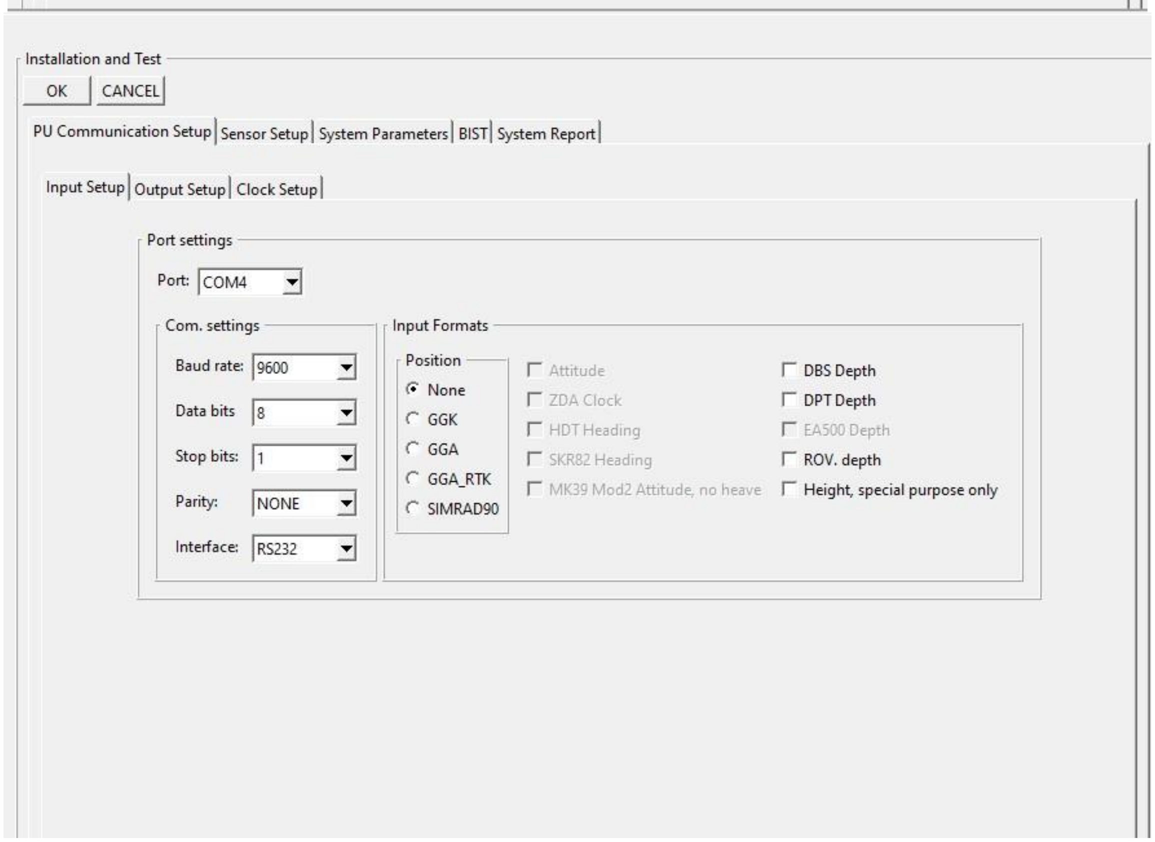
Select SIS Program settings shown below:

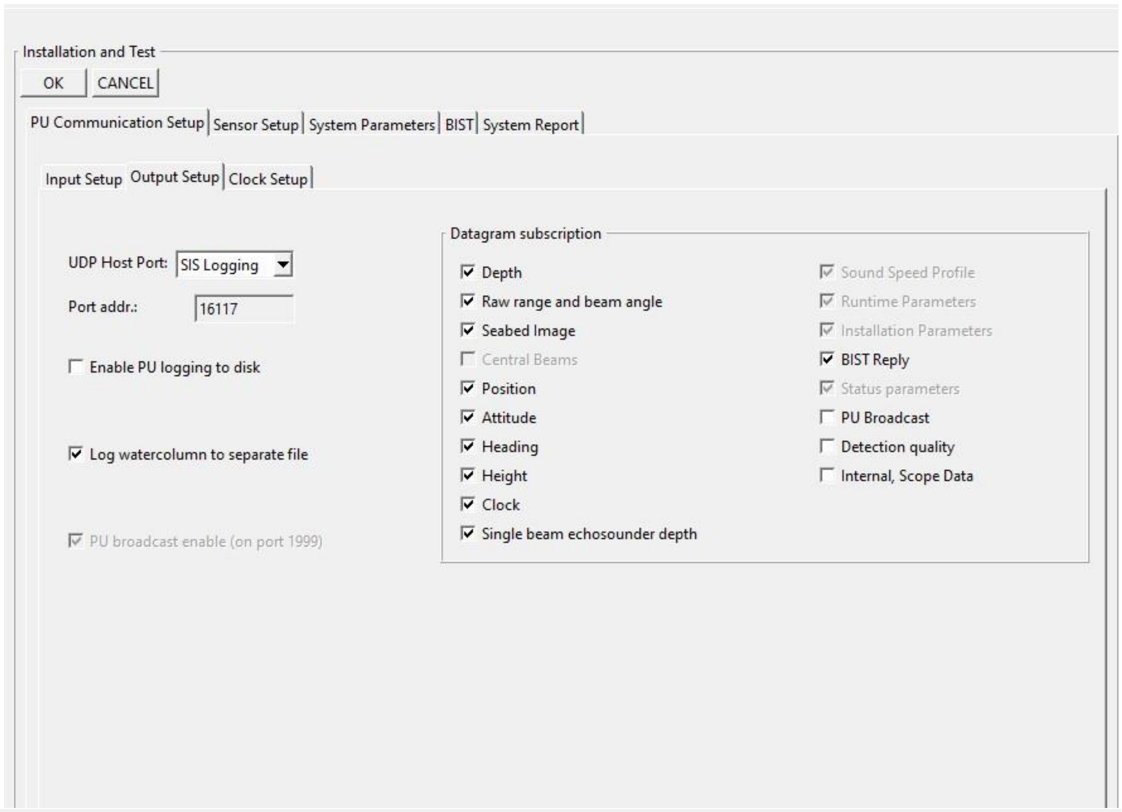


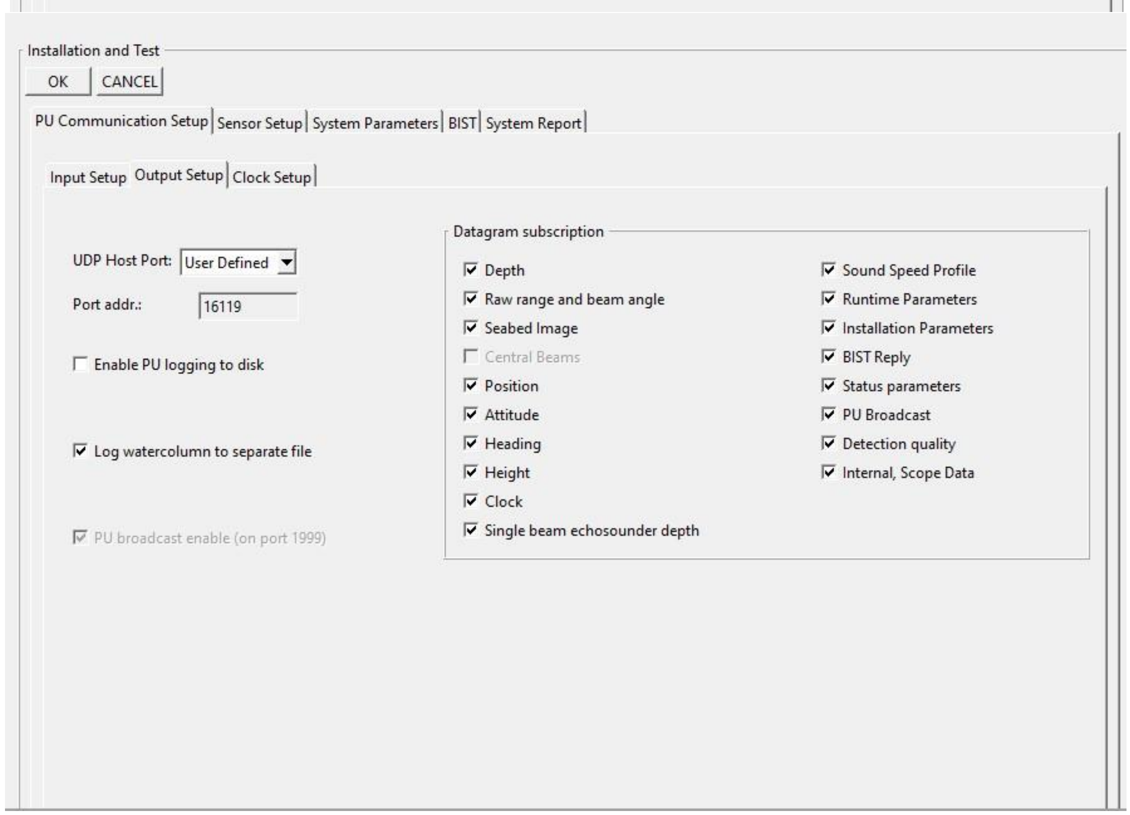

Installation and Test
OK
CANCEL
PU Communication Setup
Sensor Setup
System Parameters
BIST
System Report
Input Setup
Output Setup
Clock Setup
Port settings
Port: COM1
Com. settings
Baud rate: 19200
Data bits 8
Stop bits: 1
Parity: NONE
Interface: RS232
Input Formats
Position
None
GGK
GGA
GGA_RTK
SIMRAD90
Attitude
ZDA Clock
HDT Heading
SKR82 Heading
MK39 Mod2 Attitude, no heave
DBS Depth
DPT Depth
EA500 Depth
ROV. depth
Height, special purpose only

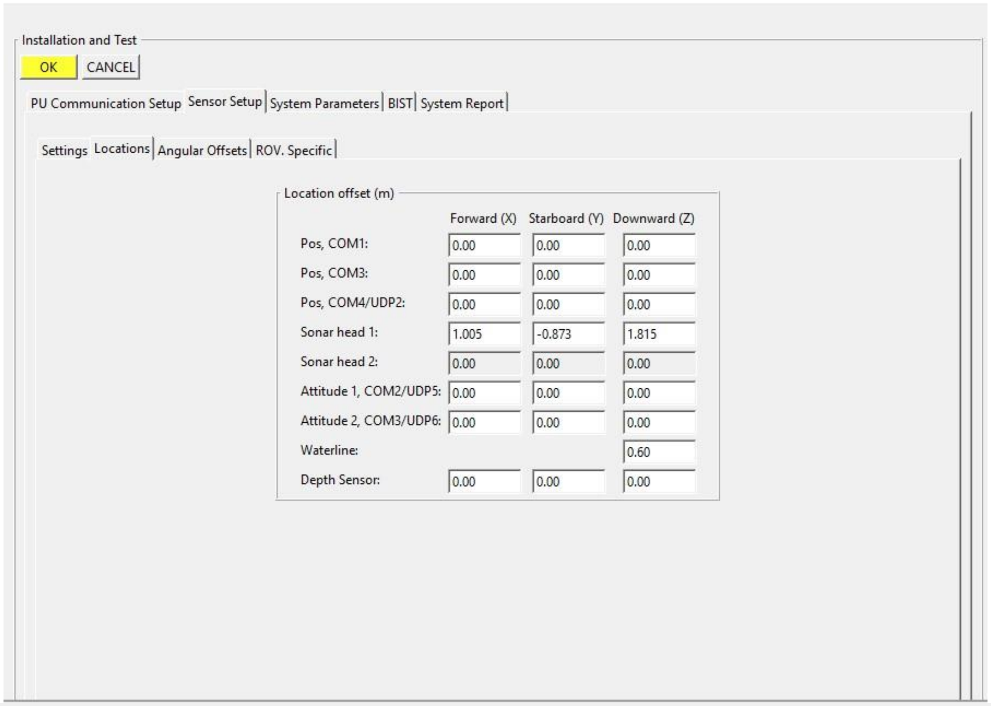

Installation and Test
OK
CANCEL
PU Communication Setup
Sensor Setup
System Parameters
BIST
System Report
Input Setup
Output Setup
Clock Setup
Port settings
Port: COM2
Com. settings
Baud rate: 19200
Data bits 8
Stop bits: 1
Parity: NONE
Interface: RS232
Input Formats
Position
None
GGK
GGA
GGA_RTK
SIMRAD90
Attitude
ZDA Clock
HDT Heading
SKR82 Heading
MK39 Mod2 Attitude, no heave
DBS Depth
DPT Depth
EA500 Depth
ROV. depth
Height, special purpose only

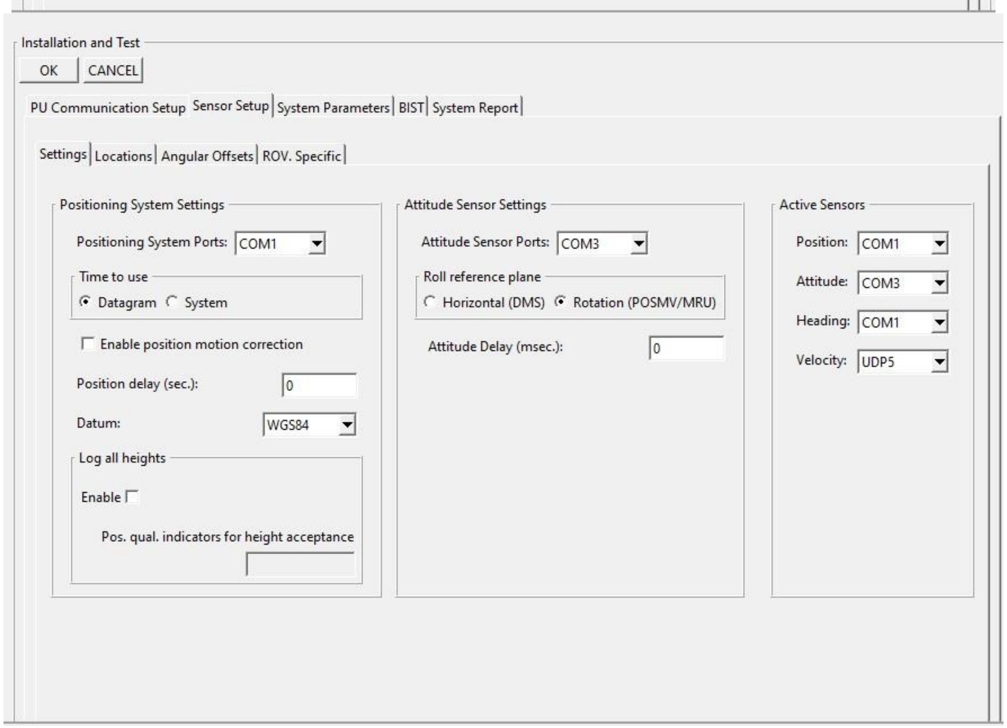

Installation and Test
OK
CANCEL
PU Communication Setup
Sensor Setup
System Parameters
BIST
System Report
Input Setup
Output Setup
Clock Setup
Port settings
Port: COM3
Com. settings
Baud rate: 115200
Data bits 8
Stop bits: 1
Parity: NONE
Interface: RS232
Input Formats
Position
None
GGK
GGA
GGA_RTK
SIMRAD90
Attitude
ZDA Clock
HDT Heading
SKR82 Heading
MK39 Mod2 Attitude, no heave
DBS Depth
DPT Depth
EA500 Depth
ROV. depth
Height, special purpose only

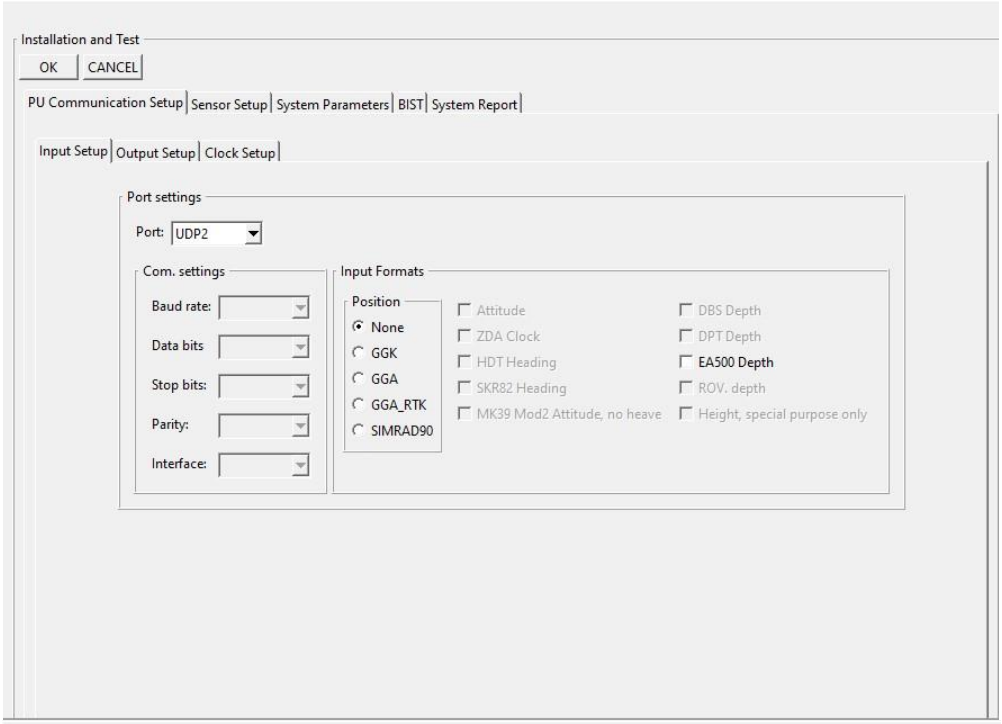

Installation and Test
OK
CANCEL
PU Communication Setup
Sensor Setup
System Parameters
BIST
System Report
Input Setup
Output Setup
Clock Setup
Port settings
Port: COM4
Com. settings
Baud rate: 9600
Data bits 8
Stop bits: 1
Parity: NONE
Interface: RS232
Input Formats
Position
None
GGK
GGA
GGA_RTK
SIMRAD90
Attitude
ZDA Clock
HDT Heading
SKR82 Heading
MK39 Mod2 Attitude, no heave
DBS Depth
DPT Depth
EA500 Depth
ROV. depth
Height, special purpose only

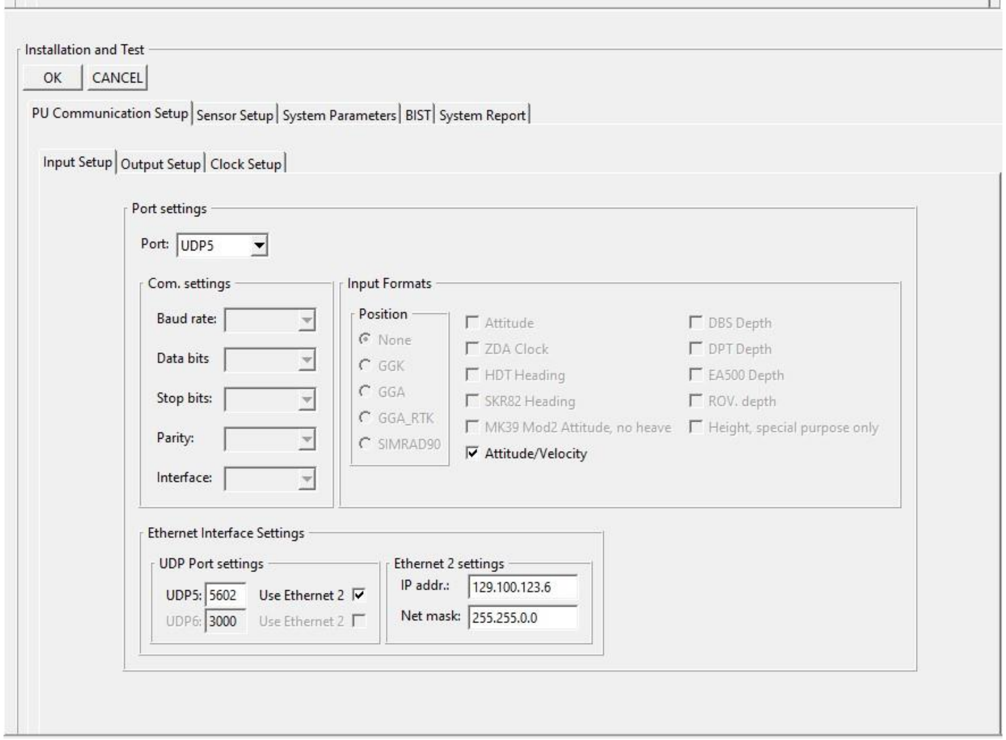

Installation and Test
OK
CANCEL
PU Communication Setup
Sensor Setup
System Parameters
BIST
System Report
Input Setup
Output Setup
Clock Setup
UDP Host Port:
SIS Logging
Port addr.:
16117
Enable PU logging to disk
Log watercolumn to separate file
PU broadcast enable (on port 1999)
Datagram subscription
Depth
Raw range and beam angle
Seabed Image
Central Beams
Position
Attitude
Heading
Height
Clock
Single beam echosounder depth
Sound Speed Profile
Runtime Parameters
Installation Parameters
BIST Reply
Status parameters
PU Broadcast
Detection quality
Internal, Scope Data

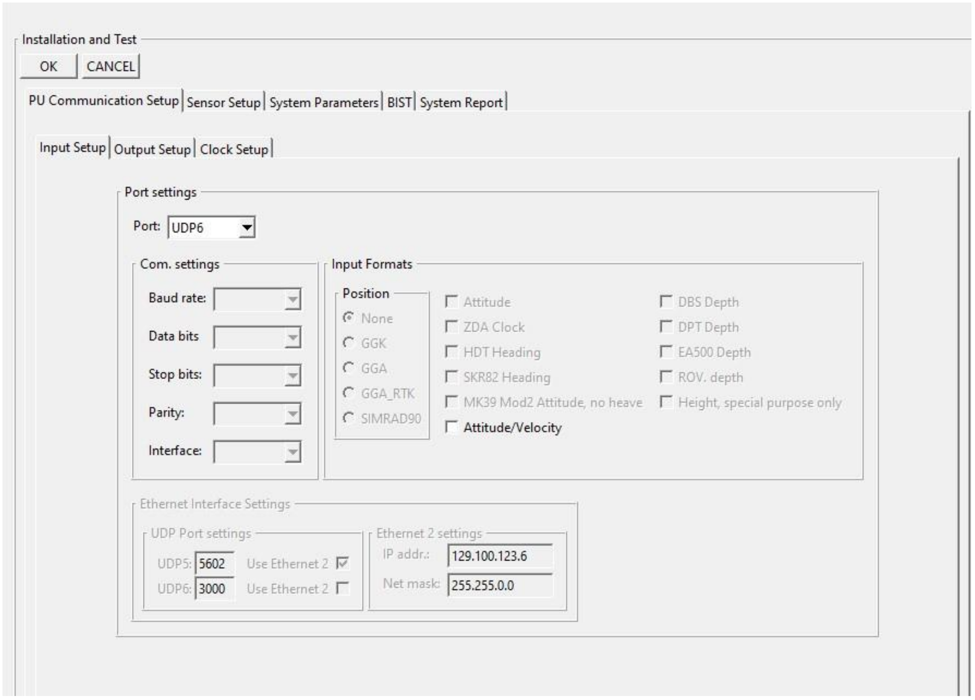

Installation and Test
OK
CANCEL
PU Communication Setup
Sensor Setup
System Parameters
BIST
System Report
Input Setup
Output Setup
Clock Setup
UDP Host Port:
User Defined
Port addr.:
16119
Enable PU logging to disk
Log watercolumn to separate file
PU broadcast enable (on port 1999)
Datagram subscription
Depth
Raw range and beam angle
Seabed Image
Central Beams
Position
Attitude
Heading
Height
Clock
Single beam echosounder depth
Sound Speed Profile
Runtime Parameters
Installation Parameters
BIST Reply
Status parameters
PU Broadcast
Detection quality
Internal, Scope Data


Installation and Test
OK
CANCEL
PU Communication Setup
Sensor Setup
System Parameters
BIST
System Report
Settings
Locations
Angular Offsets
ROV. Specific
Location offset (m)
Forward (X)
Starboard (Y)
Downward (Z)
Pos, COM1: 0.00 0.00 0.00
Pos, COM3: 0.00 0.00 0.00
Pos, COM4/UDP2: 0.00 0.00 0.00
Sonar head 1: 1.005 -0.873 1.815
Sonar head 2: 0.00 0.00 0.00
Attitude 1, COM2/UDP5: 0.00 0.00 0.00
Attitude 2, COM3/UDP6: 0.00 0.00 0.00
Waterline: 0.60
Depth Sensor: 0.00 0.00 0.00


Installation and Test
OK
CANCEL
PU Communication Setup
Sensor Setup
System Parameters
BIST
System Report
Settings
Locations
Angular Offsets
ROV. Specific
Positioning System Settings
Positioning System Ports: COM1
Time to use
Datagram
System
Enable position motion correction
Position delay (sec.): 0
Datum: WGS84
Log all heights
Enable
Pos. qual. indicators for height acceptance
Attitude Sensor Settings
Attitude Sensor Ports: COM3
Roll reference plane
Horizontal (DMS)
Rotation (POSMV/MRU)
Attitude Delay (msec.): 0
Active Sensors
Position: COM1
Attitude: COM3
Heading: COM1
Velocity: UDP5


Installation and Test
OK
CANCEL
PU Communication Setup
Sensor Setup
System Parameters
BIST
System Report
Input Setup
Output Setup
Clock Setup
Port settings
Port: UDP2
Com. settings
Baud rate:
Data bits
Stop bits:
Parity:
Interface:
Input Formats
Position
None
GGK
GGA
GGA_RTK
SIMRAD90
Attitude
ZDA Clock
HDT Heading
SKR82 Heading
MK39 Mod2 Attitude, no heave
DBS Depth
DPT Depth
EA500 Depth
ROV. depth
Height, special purpose only


Installation and Test
OK
CANCEL
PU Communication Setup
Sensor Setup
System Parameters
BIST
System Report
Input Setup
Output Setup
Clock Setup
Port settings
Port: UDP5
Com. settings
Baud rate:
Data bits
Stop bits:
Parity:
Interface:
Input Formats
Position
None
GGK
GGA
GGA_RTK
SIMRAD90
Attitude
ZDA Clock
HDT Heading
SKR82 Heading
MK39 Mod2 Attitude, no heave
Attitude/Velocity
DBS Depth
DPT Depth
EA500 Depth
ROV. depth
Height, special purpose only
Ethernet Interface Settings
UDP Port settings
UDP5: 5602
Use Ethernet 2
UDP6: 3000
Use Ethernet 2
Ethernet 2 settings
IP addr.: 129.100.123.6
Net mask: 255.255.0.0


Installation and Test
OK
CANCEL
PU Communication Setup
Sensor Setup
System Parameters
BIST
System Report
Input Setup
Output Setup
Clock Setup
Port settings
Port: UDP6
Com. settings
Baud rate:
Data bits
Stop bits:
Parity:
Interface:
Input Formats
Position
None
GGK
GGA
GGA_RTK
SIMRAD90
Attitude
ZDA Clock
HDT Heading
SKR82 Heading
MK39 Mod2 Attitude, no heave
Attitude/Velocity
DBS Depth
DPT Depth
EA500 Depth
ROV. depth
Height, special purpose only
Ethernet Interface Settings
UDP Port settings
UDP5: 5602 Use Ethernet 2
UDP6: 3000 Use Ethernet 2
Ethernet 2 settings
IP addr.: 129.100.123.6
Net mask: 255.255.0.0

General Information

Mission Information

Project name	R5002_20220525_1254-1326
Processing date	2022-05-26 10:07:03
Mission date	2022-05-25 12:55:08
Mission duration	00:32:03.000
Processing mode	IN-Fusion SmartBase
GPS Station	ASB

Rover Hardware Information

Product	POS MV 320 VER4 HW2.9-7
Serial number	S/N2544
IMU type	2
Receiver type	Unknown
Antenna type	Zephyr

Project File List

Rover Data Files

File name	File type
R5002_20220525.000	POS Data

Input Files

File Name	File Type
Ephm1450.22g	GLONASS Broadcast Ephemeris
Ephm1450.22n	GPS Broadcast Ephemeris
igu22112_18.sp3	GPS Precise Ephemeris
igu22113_18.sp3	GPS Precise Ephemeris
hbch1450.22o	GNSS SingleBase
mial1450.22o	GNSS SingleBase
mio21450.22o	GNSS SingleBase
miog1450.22o	GNSS SingleBase
mitw1450.22o	GNSS SingleBase
nor31450.22o	GNSS SingleBase

Output Files

Filename	File type
sbet_Mission 1.out	SBET Trajectory File
ASCII_R5002_20220525_1254-1326_SmartBase.txt	ASCII Export Output

Rover Data Summary

First raw data file	R5002_20220525.000		
Last raw data file	R5002_20220525.000		
Start GPS week	2211		
Start time	305688.223 (5/25/2022 12:54:48 PM)		
End time	307613.295 (5/25/2022 1:26:53 PM)		
Start of fine alignment	305709.533 (5/25/2022 12:55:09 PM)		
Available subsystems	Primary GNSS, Secondary GNSS, GAMS, IMU		
POS Event Input	None		
Correction data	None		
IMU Installation Lever Arms & Mounting Angles			
Reference to IMU lever arm (m)	-0.008	-0.031	0.130
Reference to IMU mounting angles (deg)	0.000	0.000	0.000
Reference to Primary GNSS lever arm (m)	1.229	-0.916	-3.338
Reference to Primary GNSS lever arm std dev (m)	-1.000		
Reference to Secondary GNSS lever arm (m)	0.000	0.000	0.000
Vehicle to Reference mounting angles (deg)	0.000	0.000	0.000

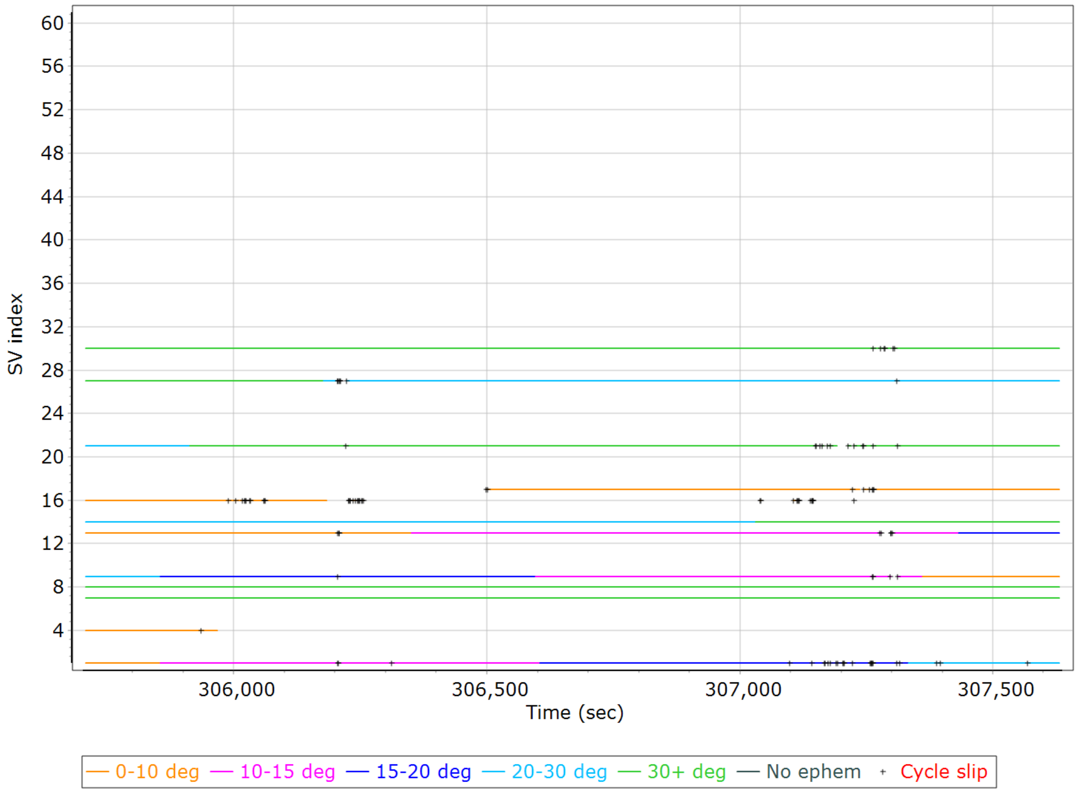
Rover Data QC

Raw IMU Import QC Summary

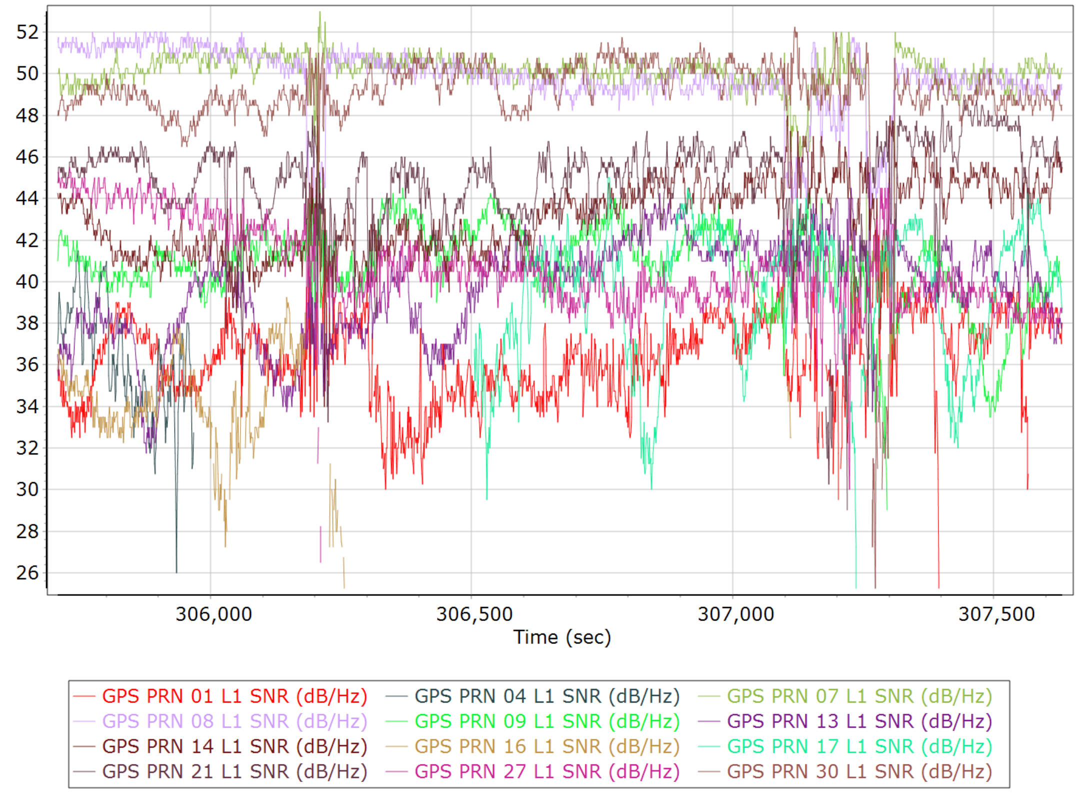
IMU data input file	imu_Mission 1.dat
IMU data check log file	imudt_Mission 1.log
IMU Records Processed	385168
Termination Status	Normal
IMU Anomalies	0

Primary Observables & Satellite Data

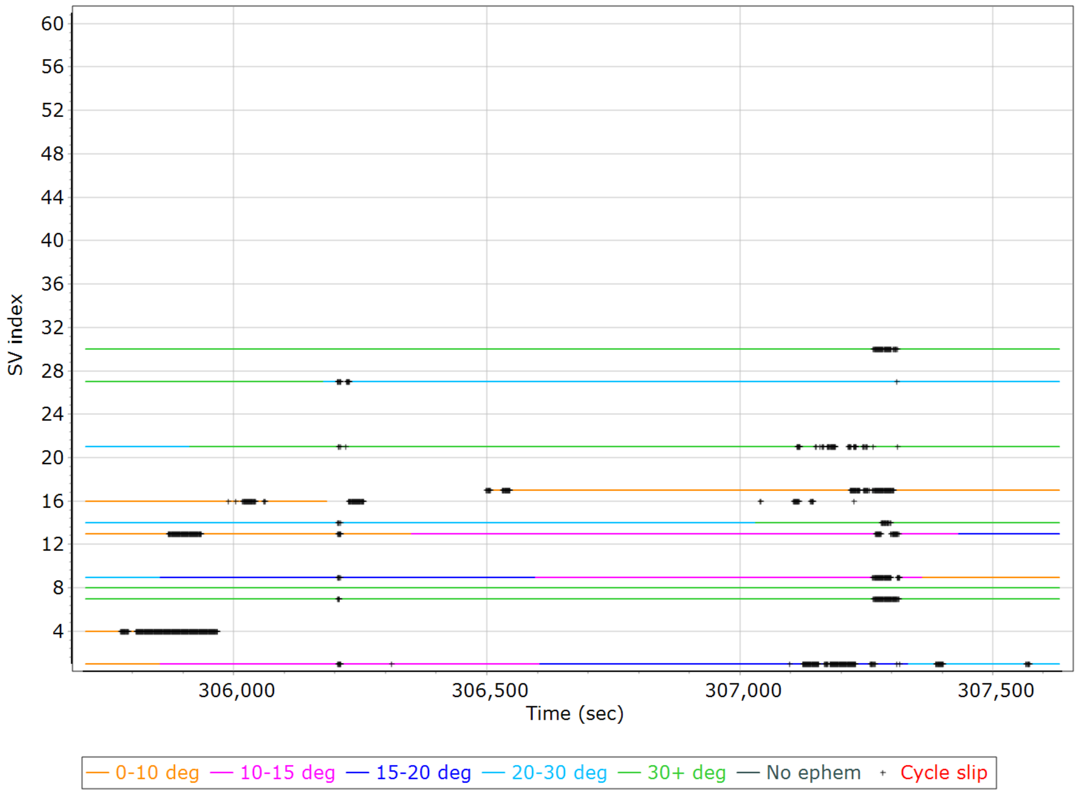
GPS/GLONASS L1 Satellite Lock/Elevation



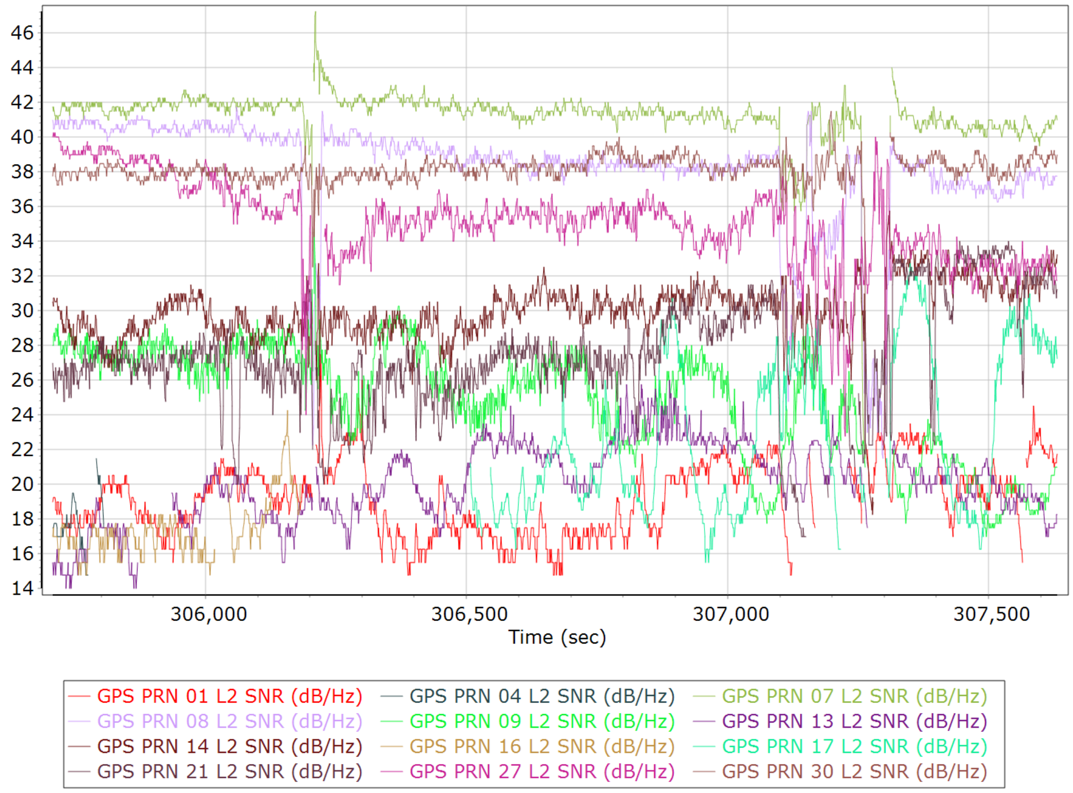
GPS L1 SNR



GPS/GLONASS L2 Satellite Lock/Elevation

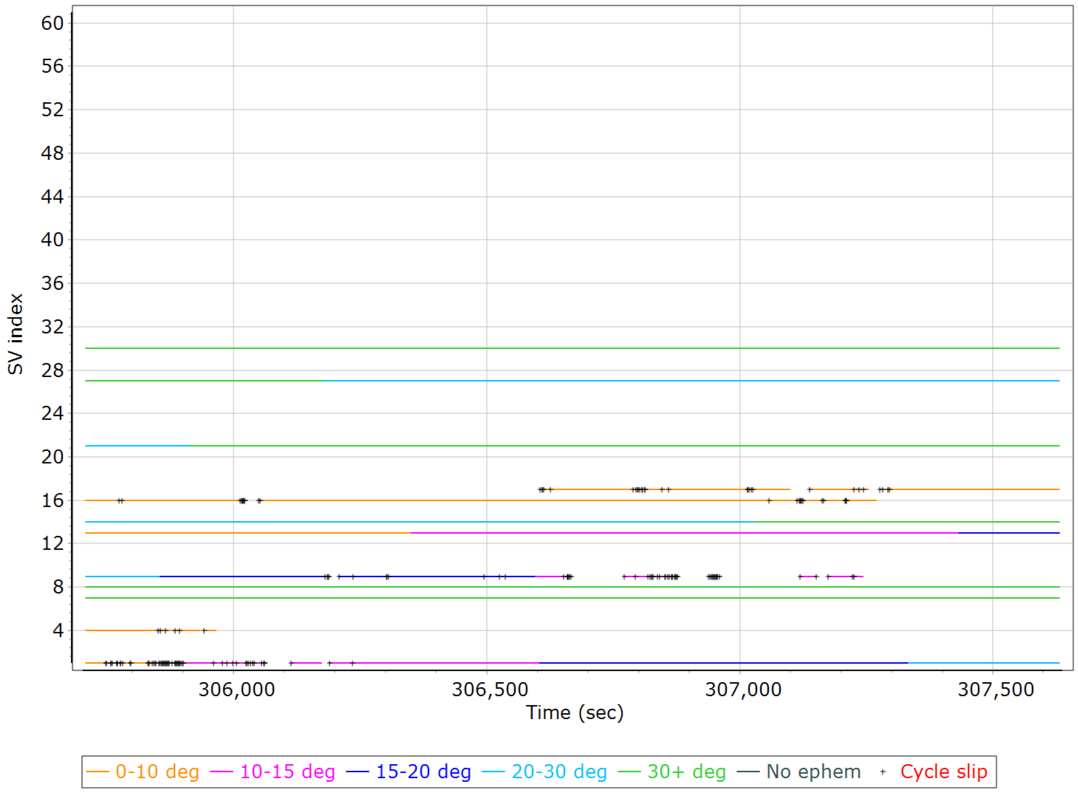


GPS L2 SNR

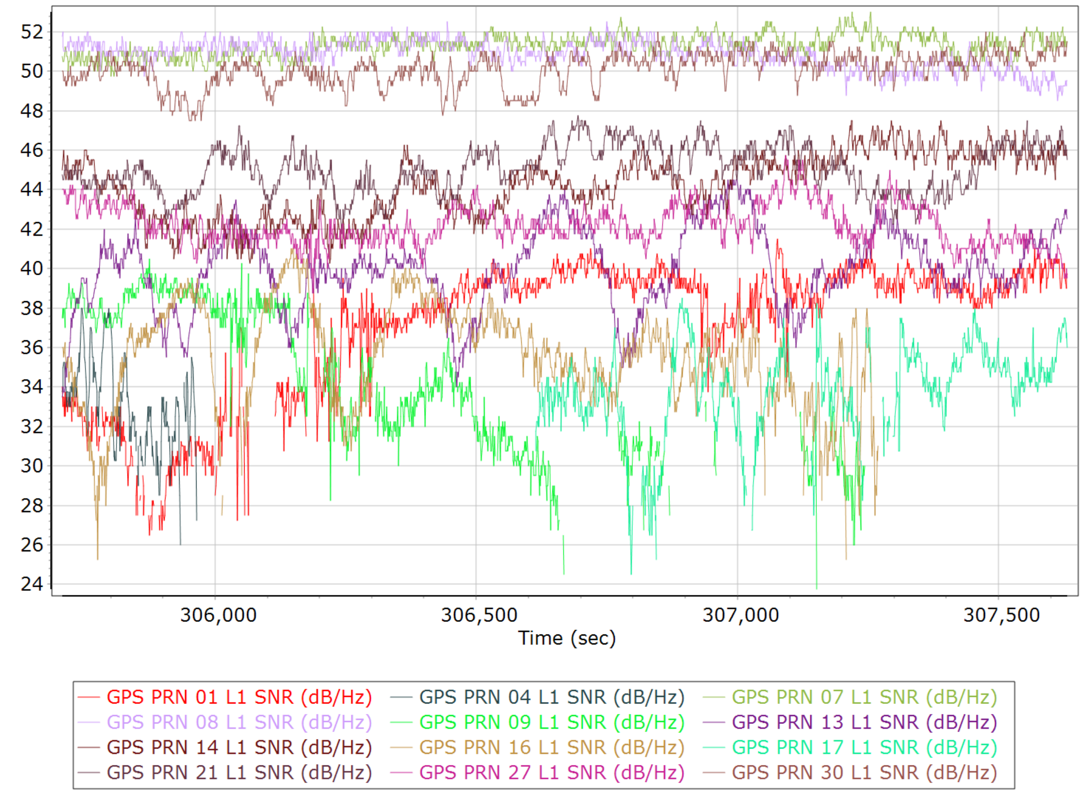


Secondary Observables & Satellite Data

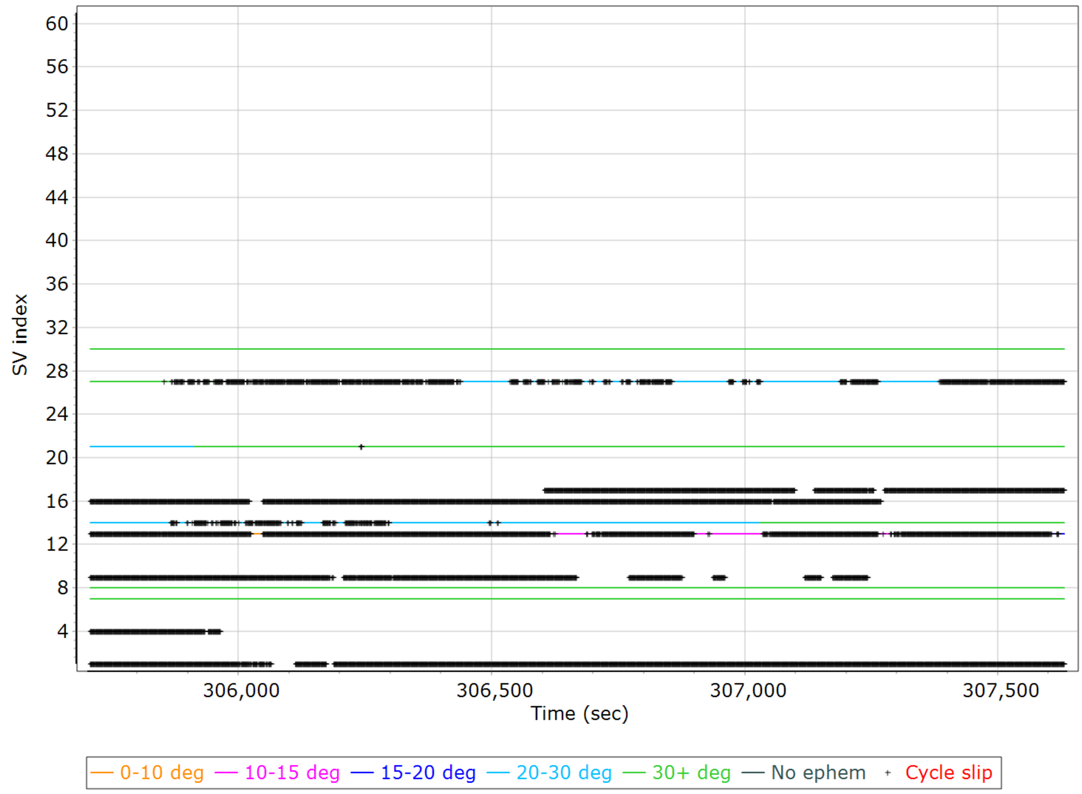
GPS/GLONASS L1 Satellite Lock/Elevation



GPS L1 SNR



GPS/GLONASS L2 Satellite Lock/Elevation

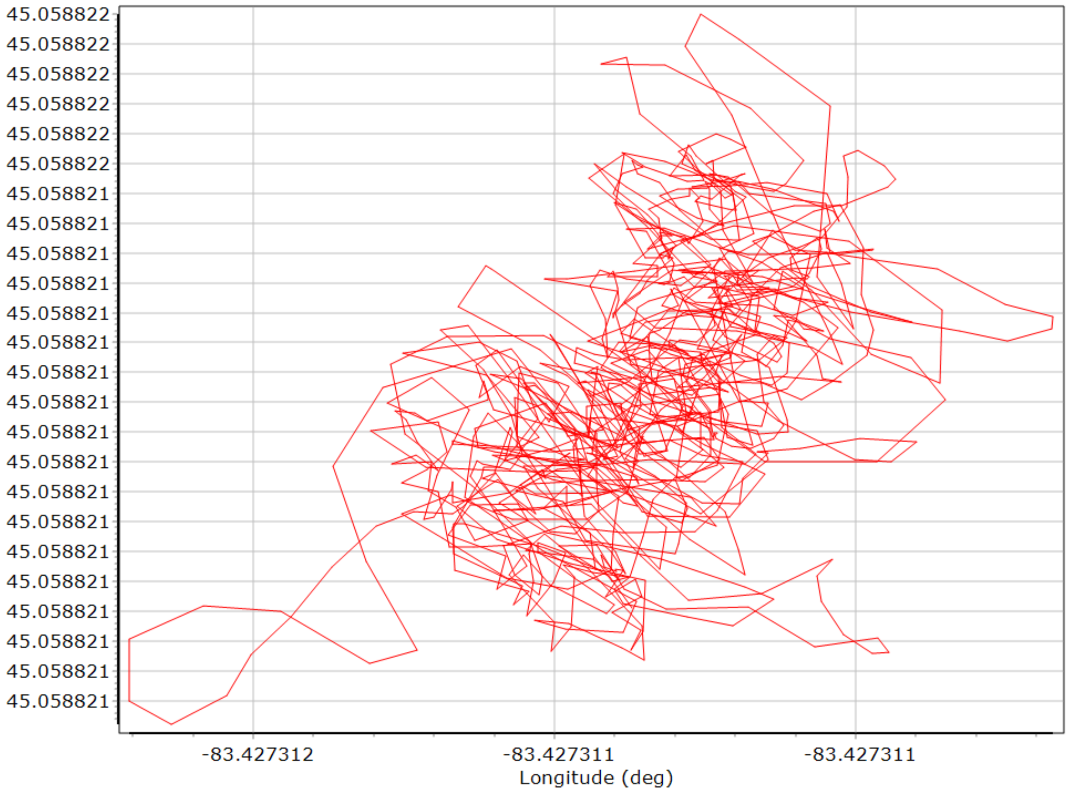


GPS L2 SNR

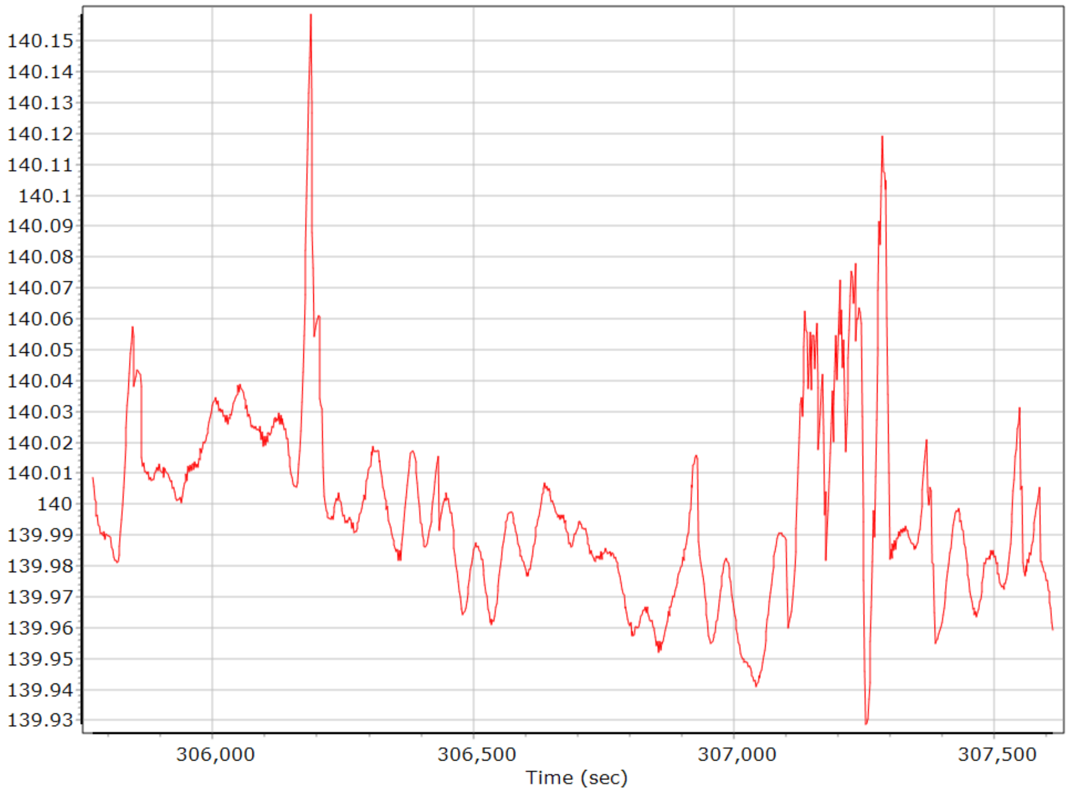

0
0
Time (sec)
GPS PRN 01 L2 SNR (dB/Hz)
GPS PRN 04 L2 SNR (dB/Hz)
GPS PRN 07 L2 SNR (dB/Hz)
GPS PRN 08 L2 SNR (dB/Hz)
GPS PRN 09 L2 SNR (dB/Hz)
GPS PRN 13 L2 SNR (dB/Hz)
GPS PRN 14 L2 SNR (dB/Hz)
GPS PRN 16 L2 SNR (dB/Hz)
GPS PRN 17 L2 SNR (dB/Hz)
GPS PRN 21 L2 SNR (dB/Hz)
GPS PRN 27 L2 SNR (dB/Hz)
GPS PRN 30 L2 SNR (dB/Hz)

Smoothed Trajectory Information

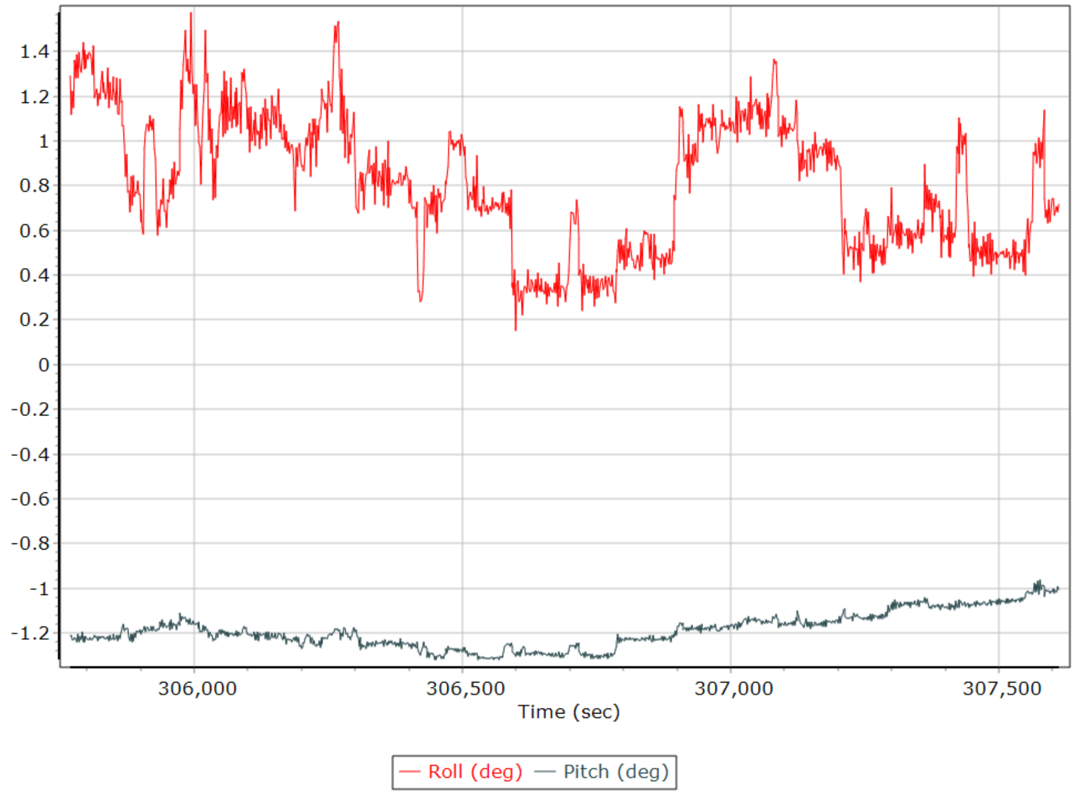
Top View



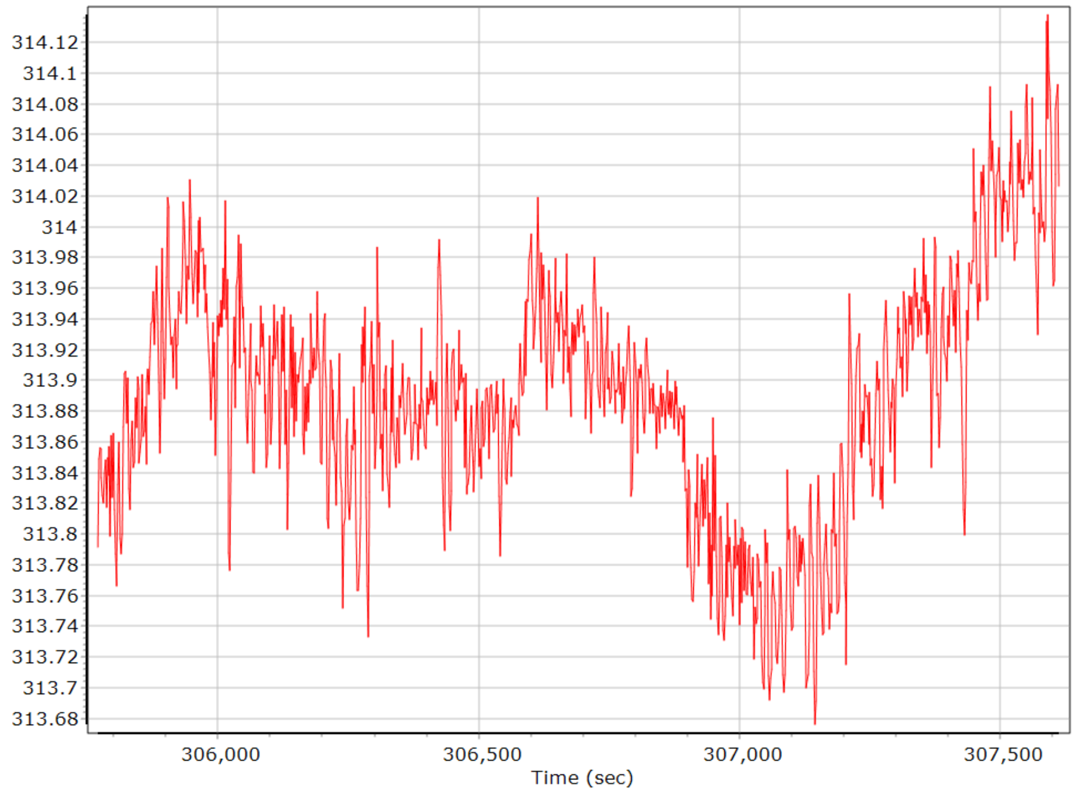
Altitude



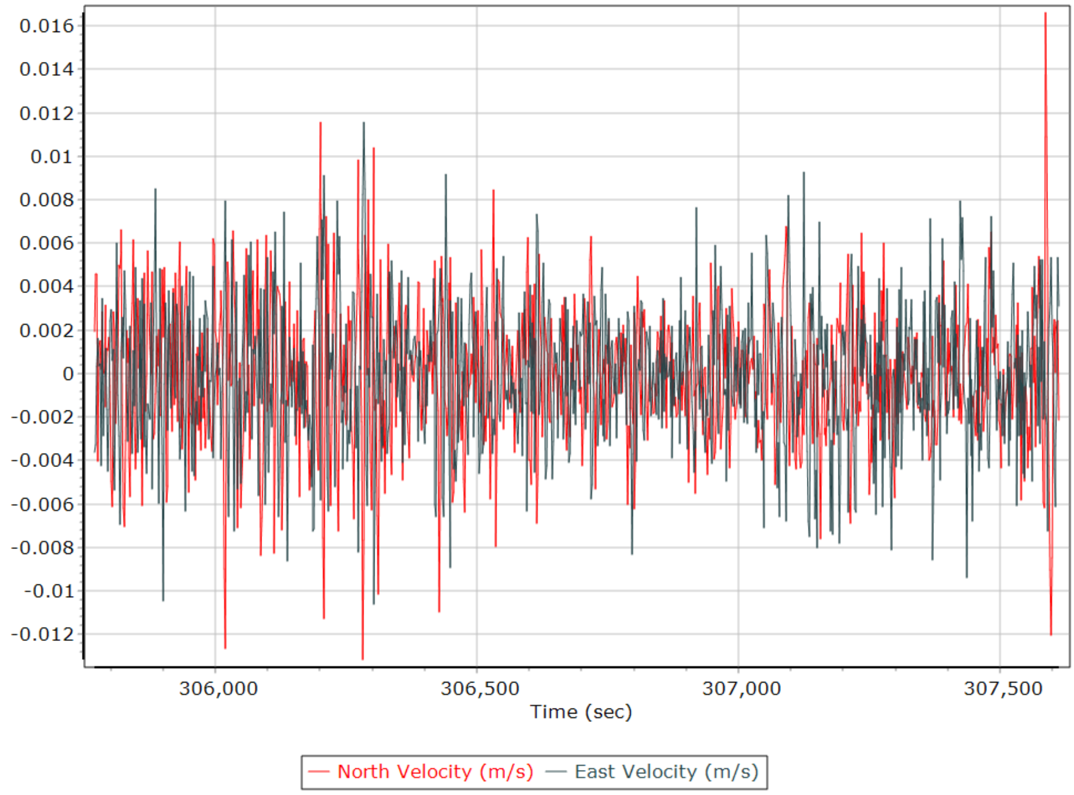
Roll/Pitch



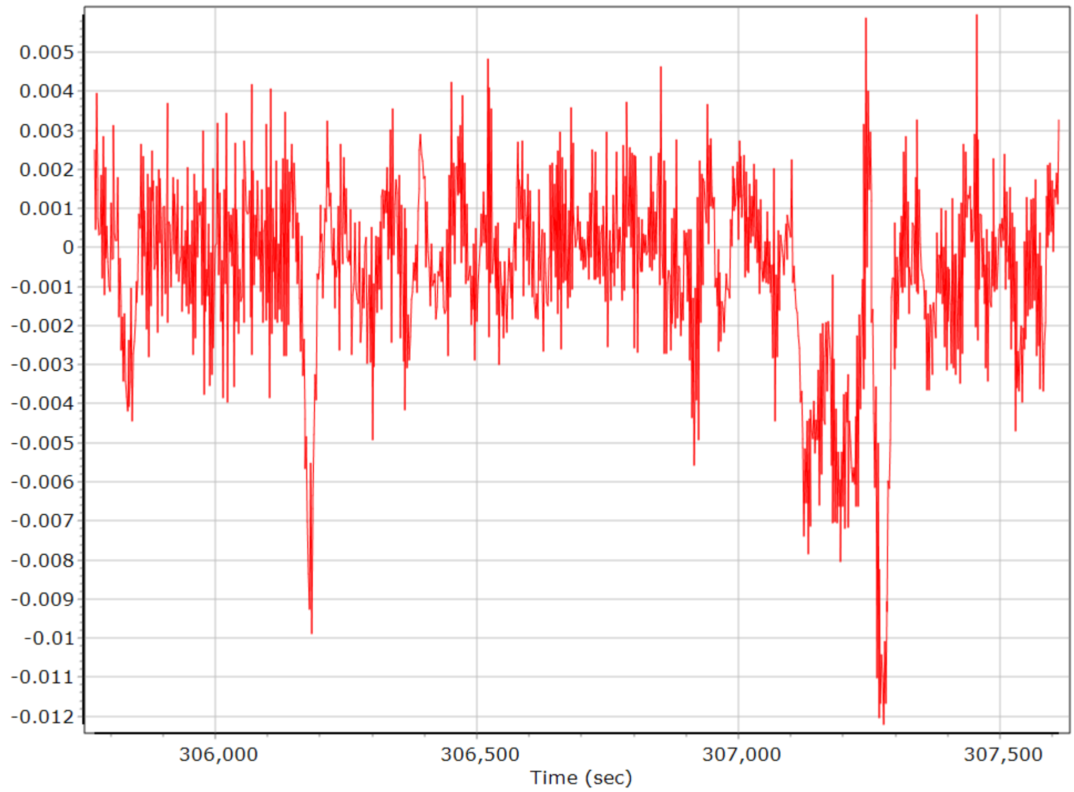
Heading



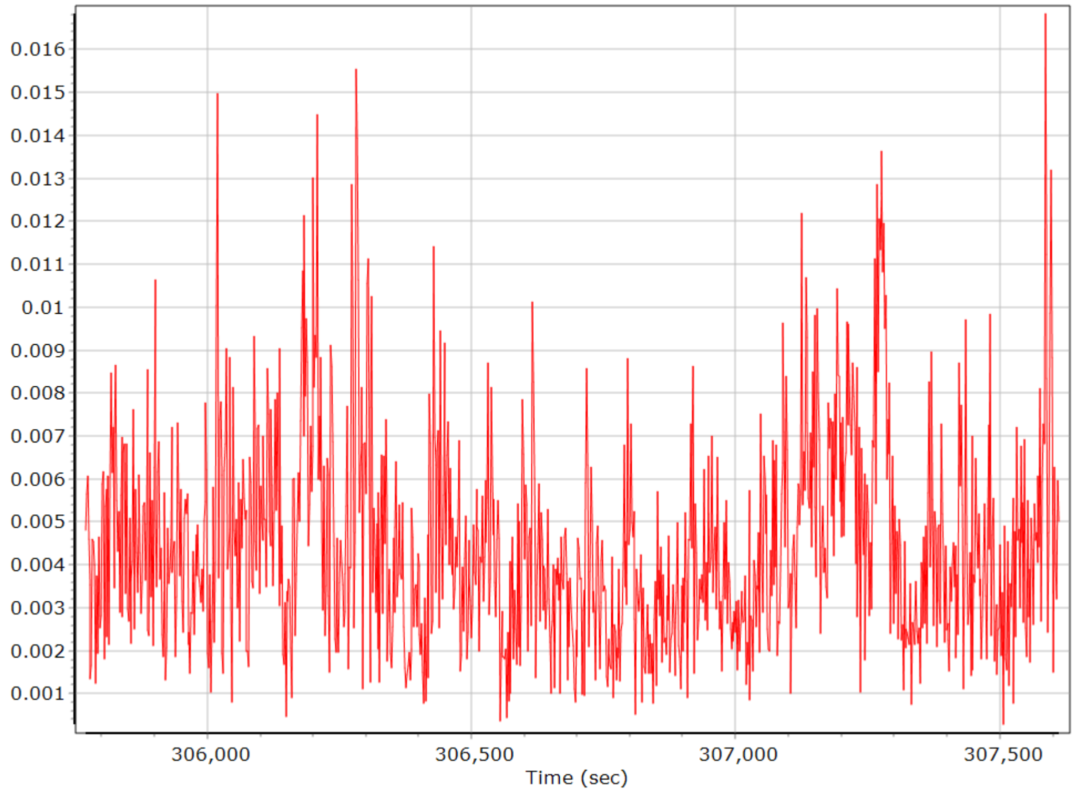
North/East Velocity



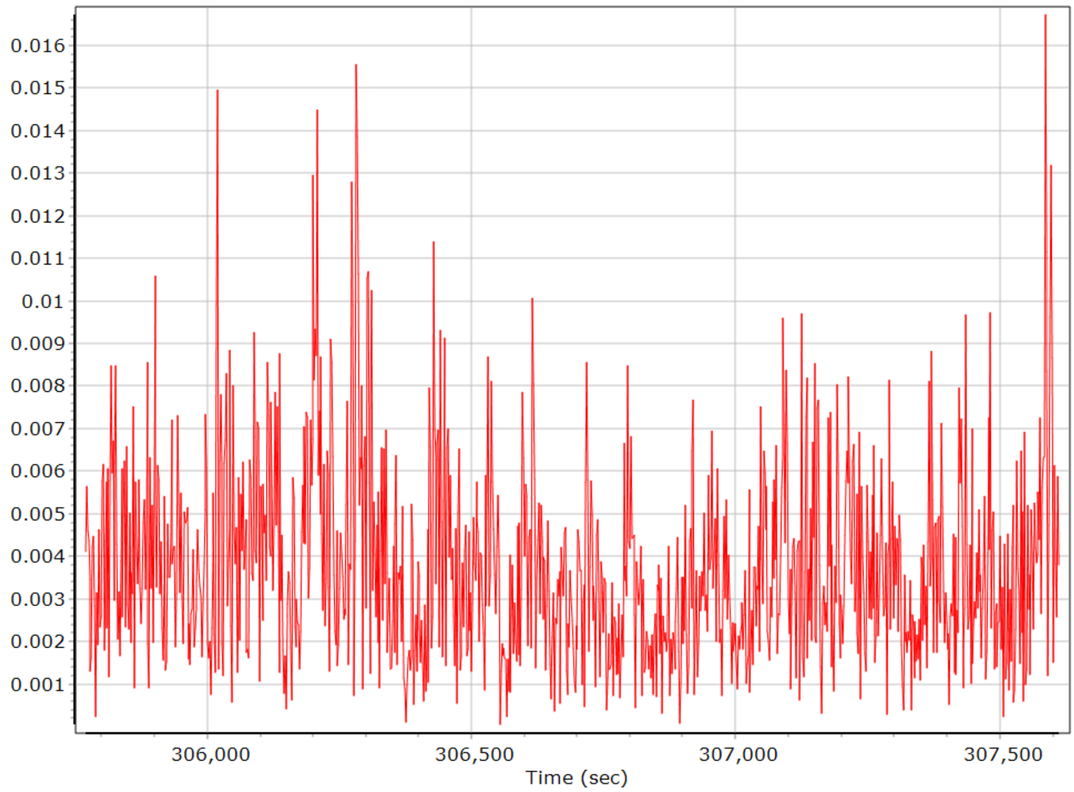
Down Velocity



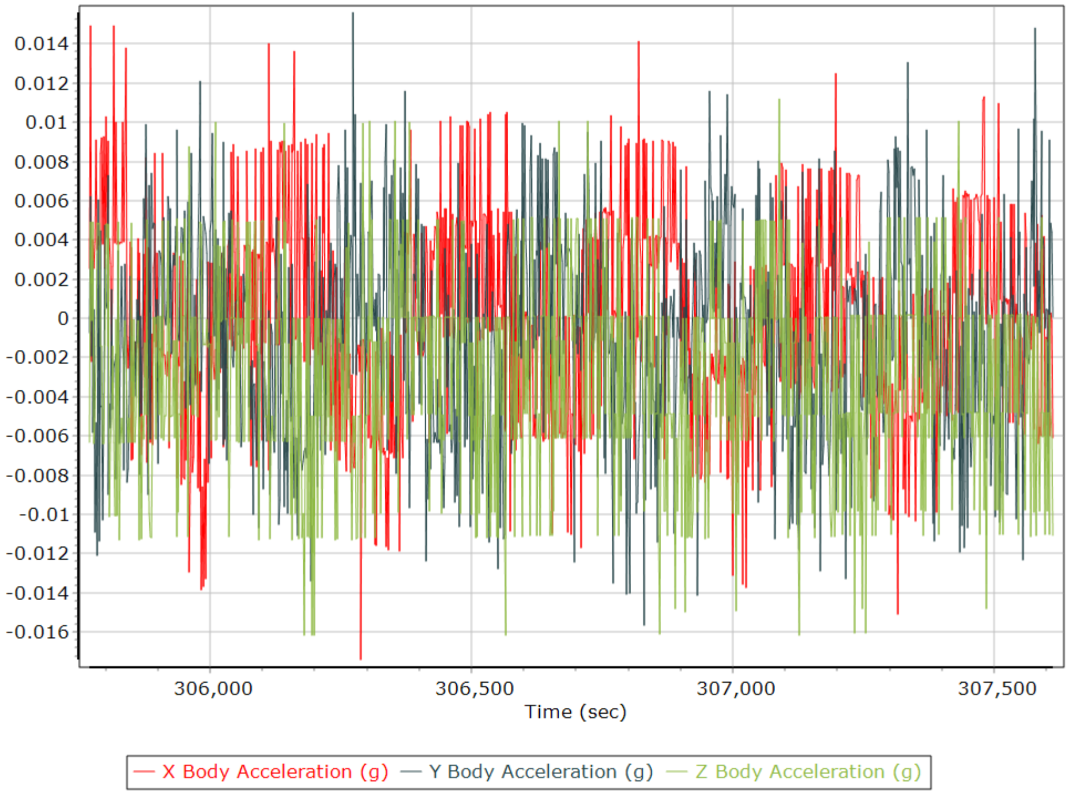
Total Speed



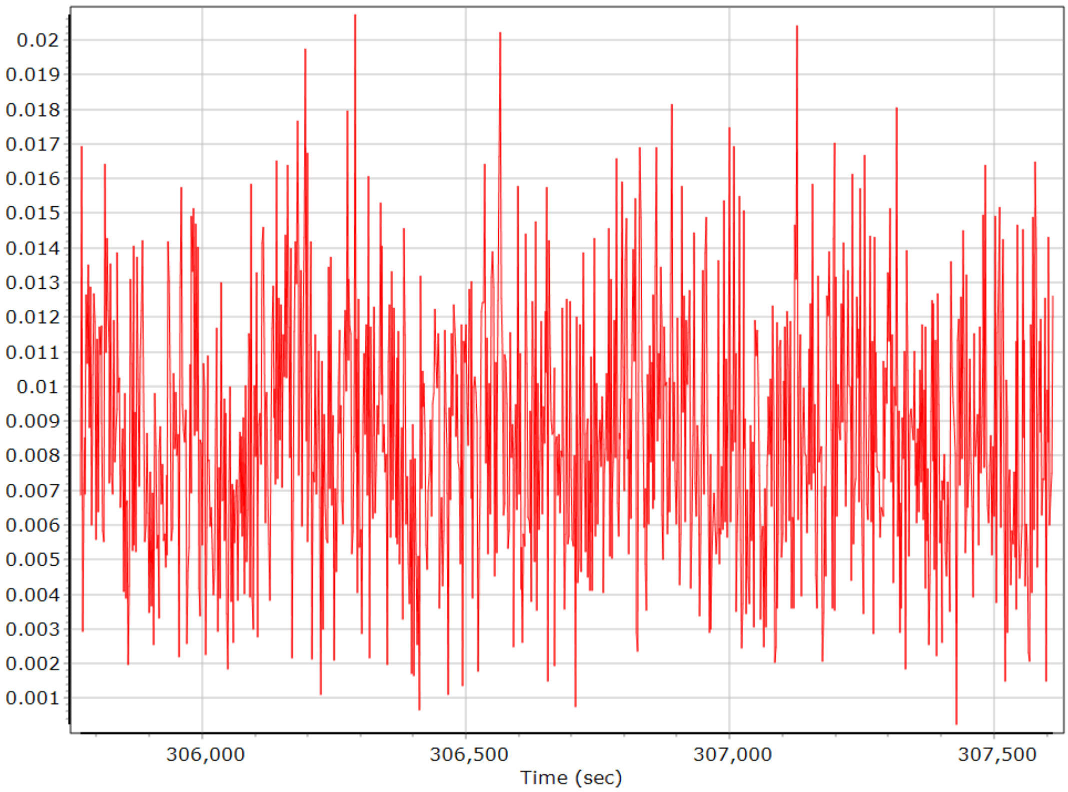
Ground Speed



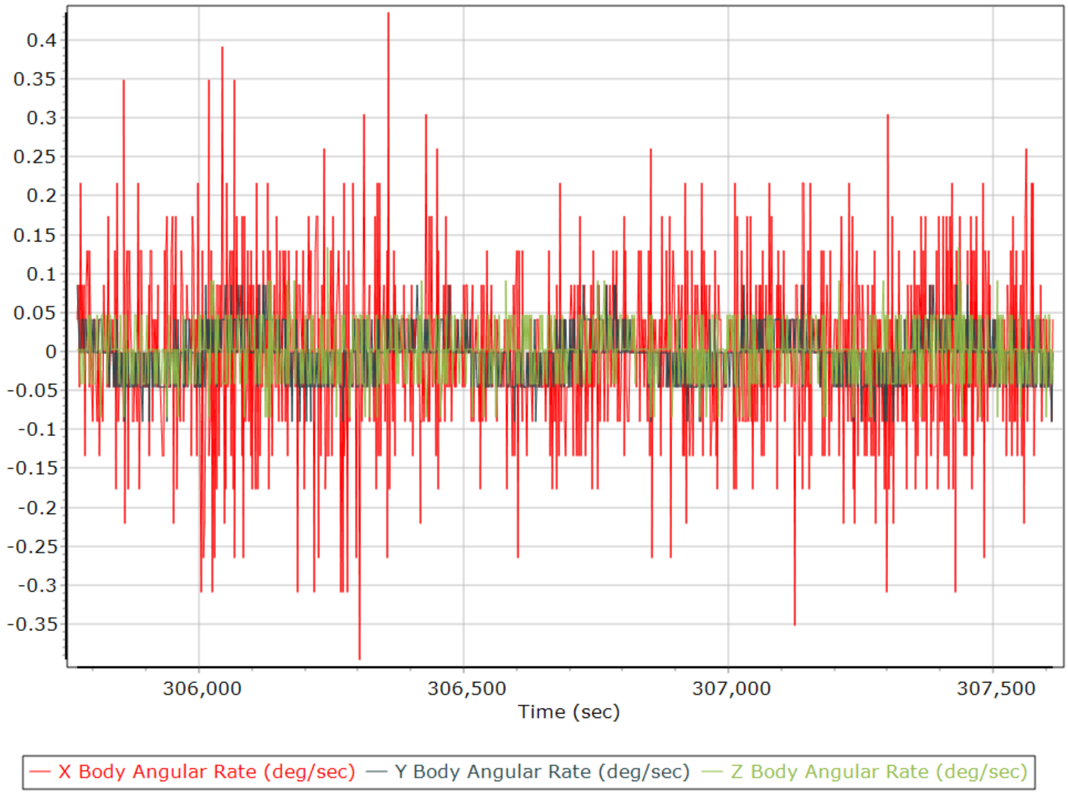
Body Acceleration



Total Body Acceleration

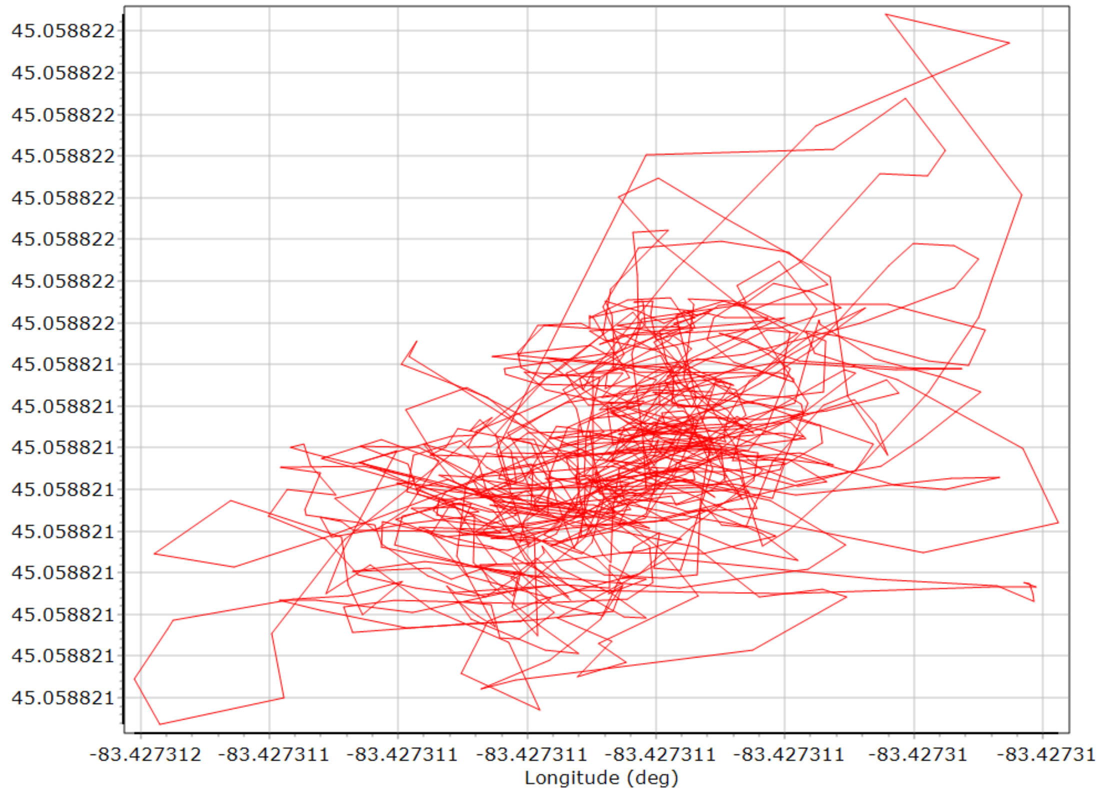


Body Angular Rate

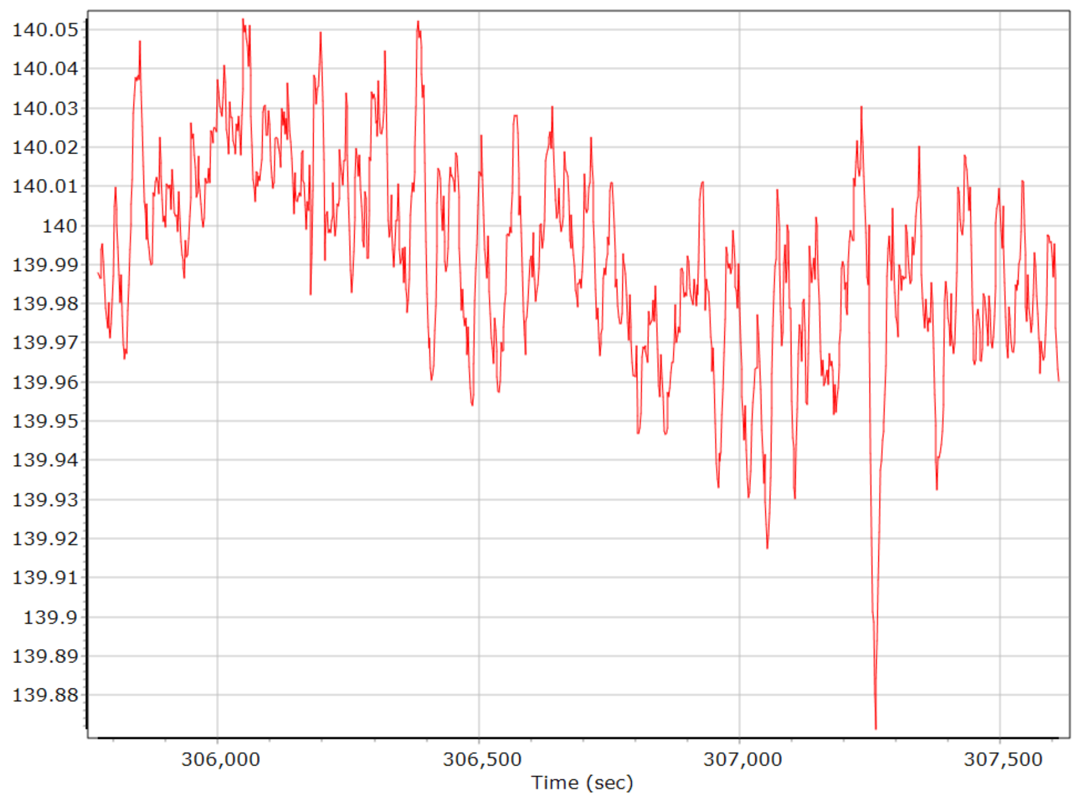


Forward Processed Trajectory Information

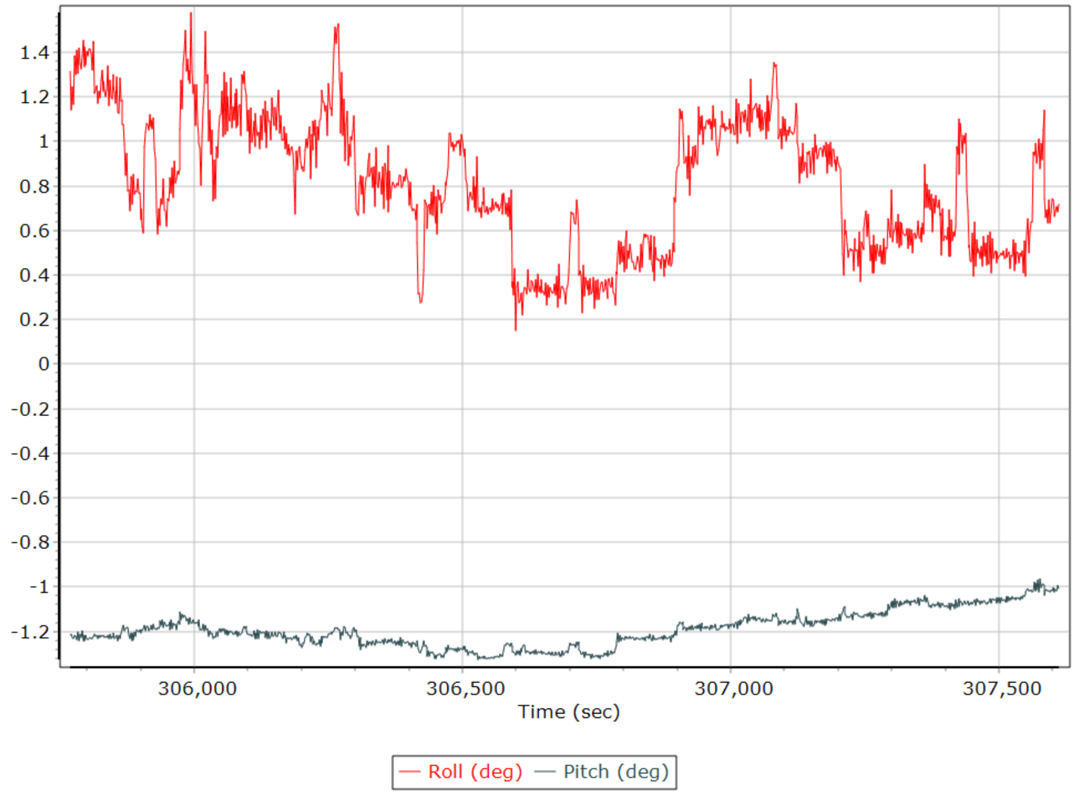
Top View



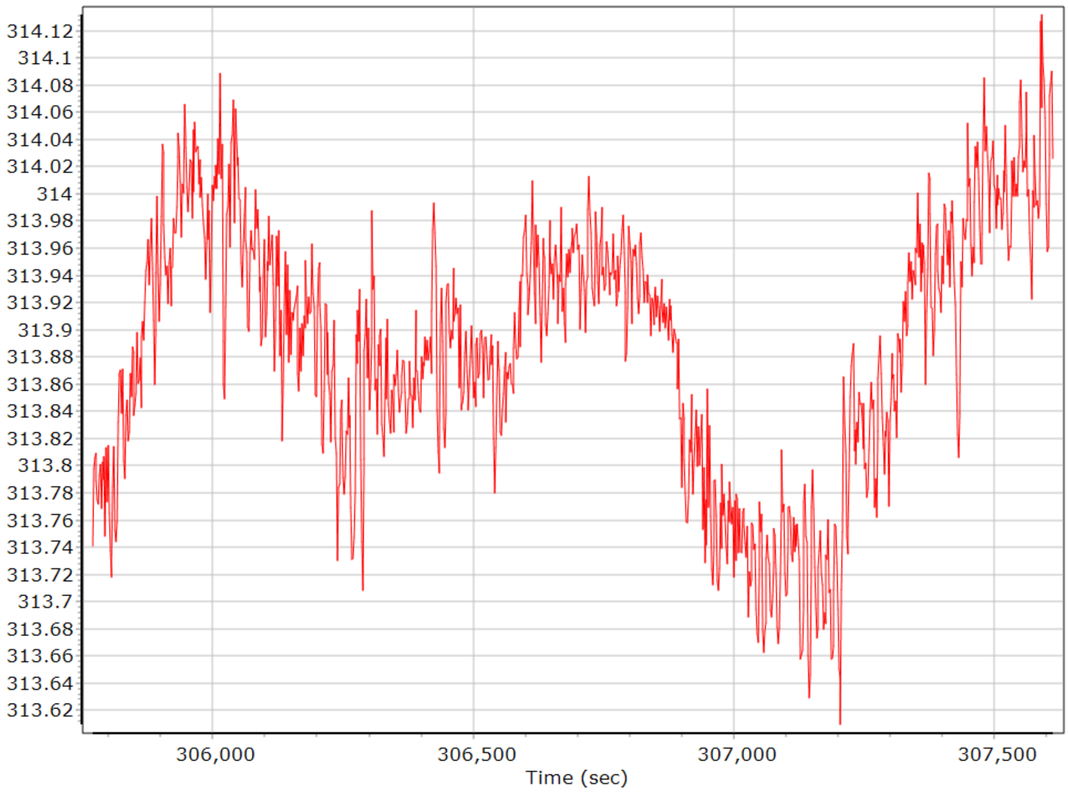
Altitude



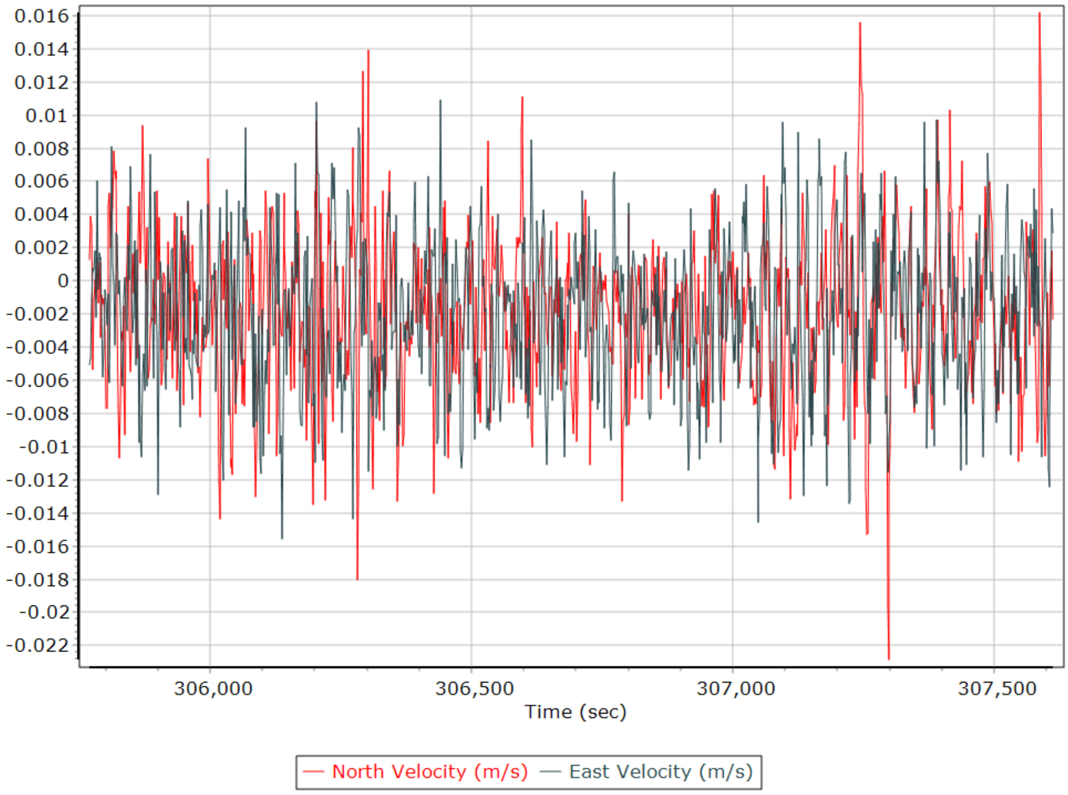
Roll/Pitch



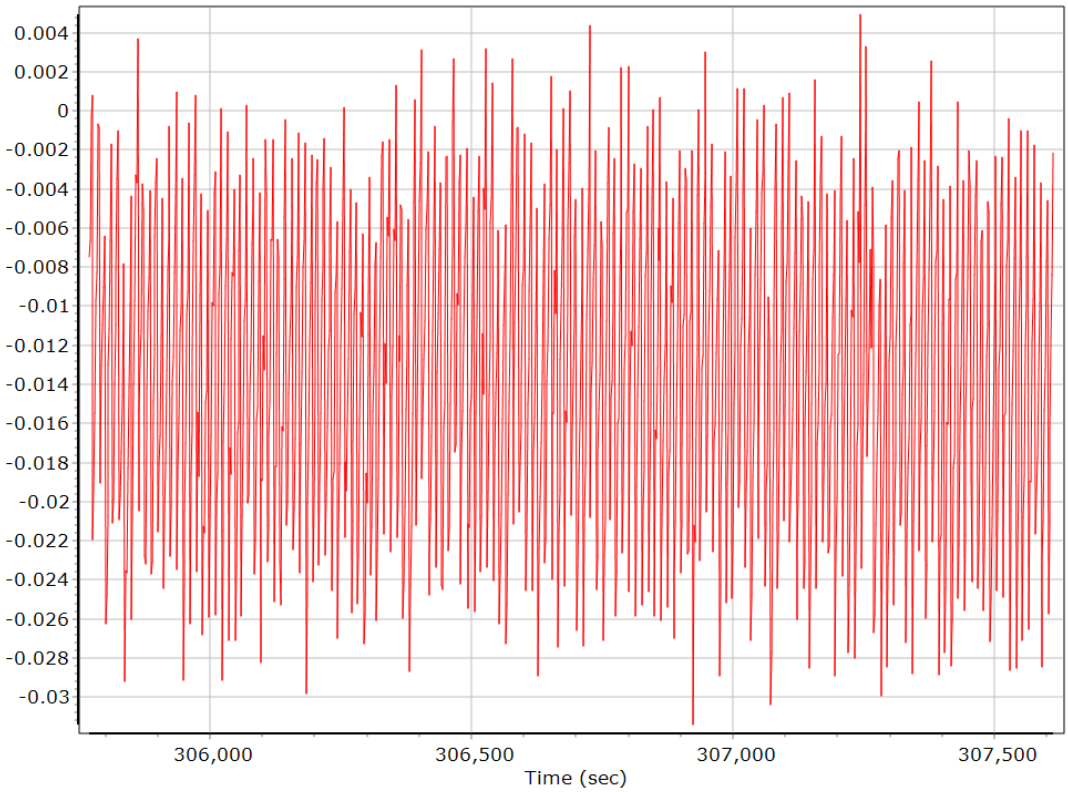
Heading



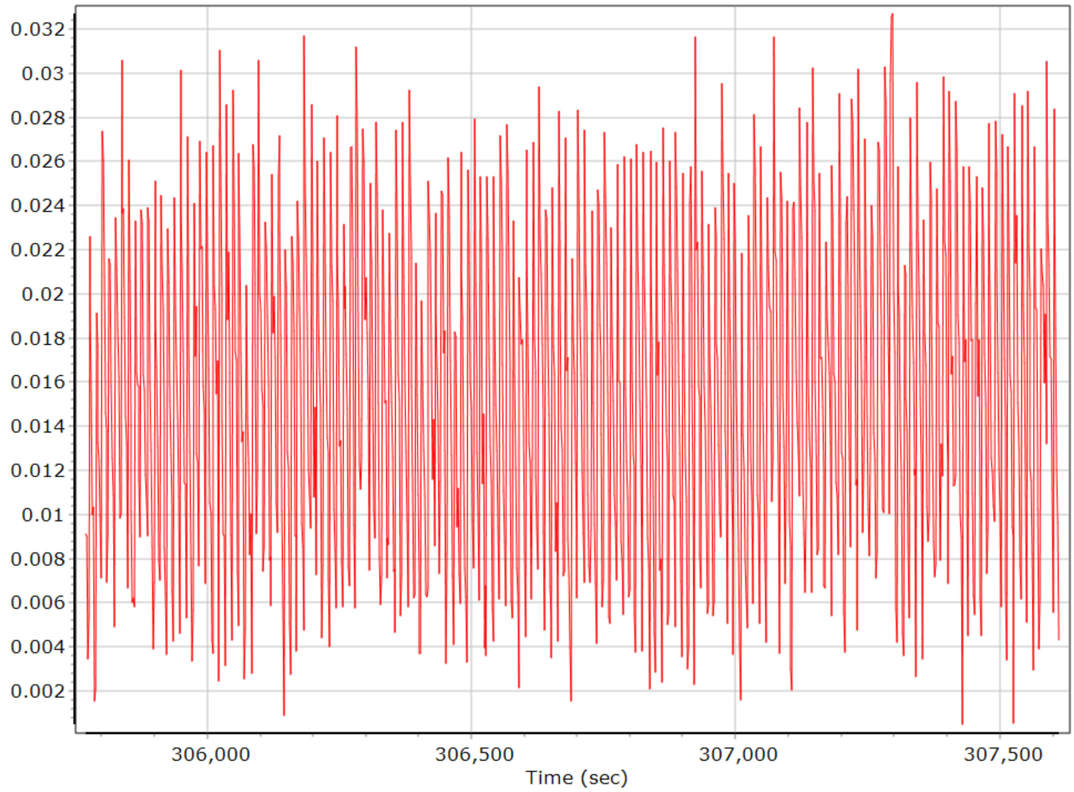
North/East Velocity



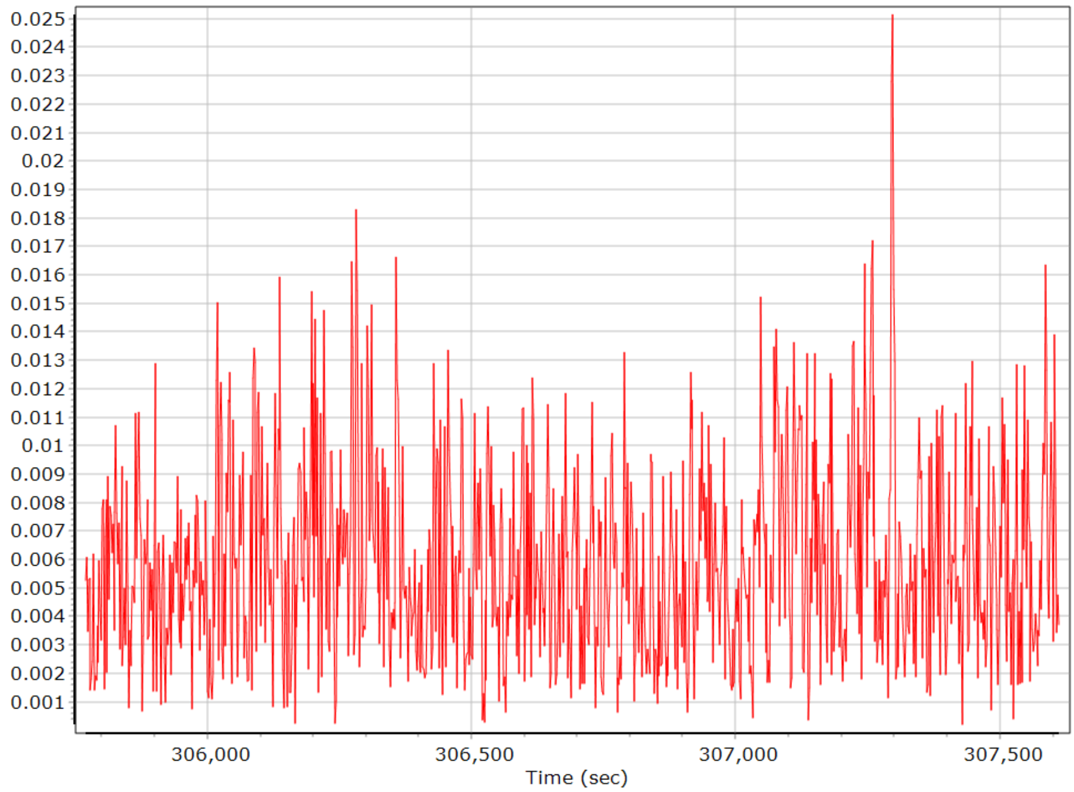
Down Velocity



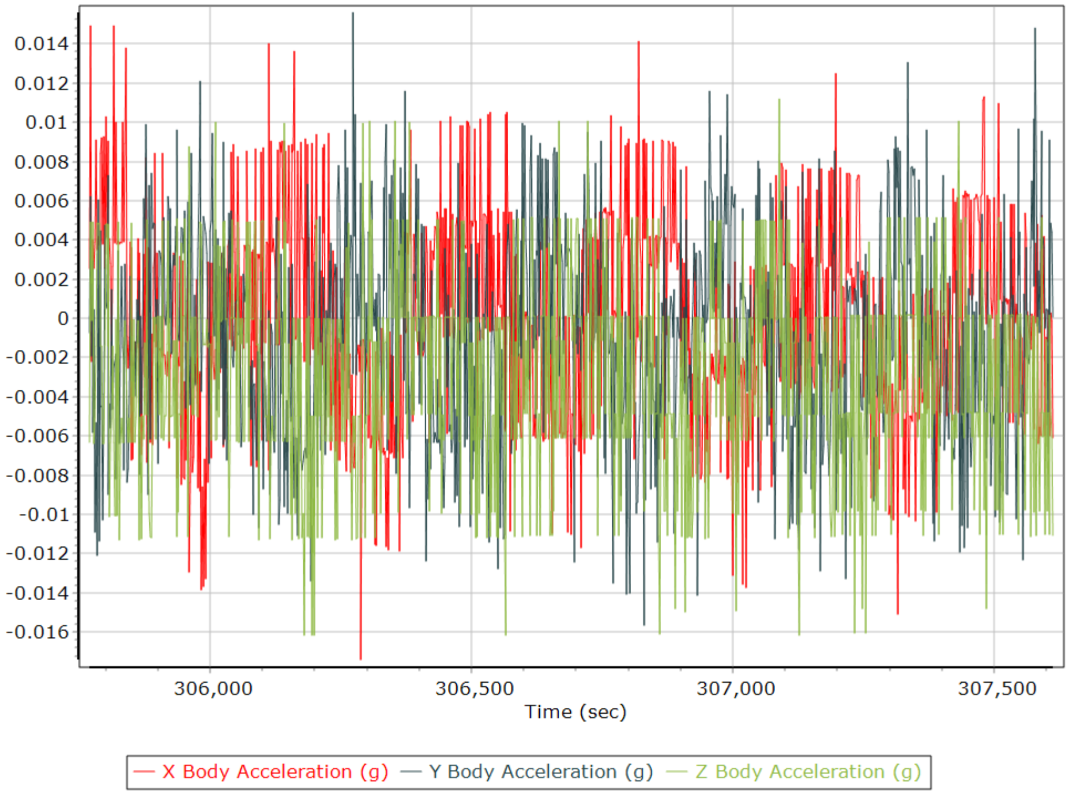
Total Speed



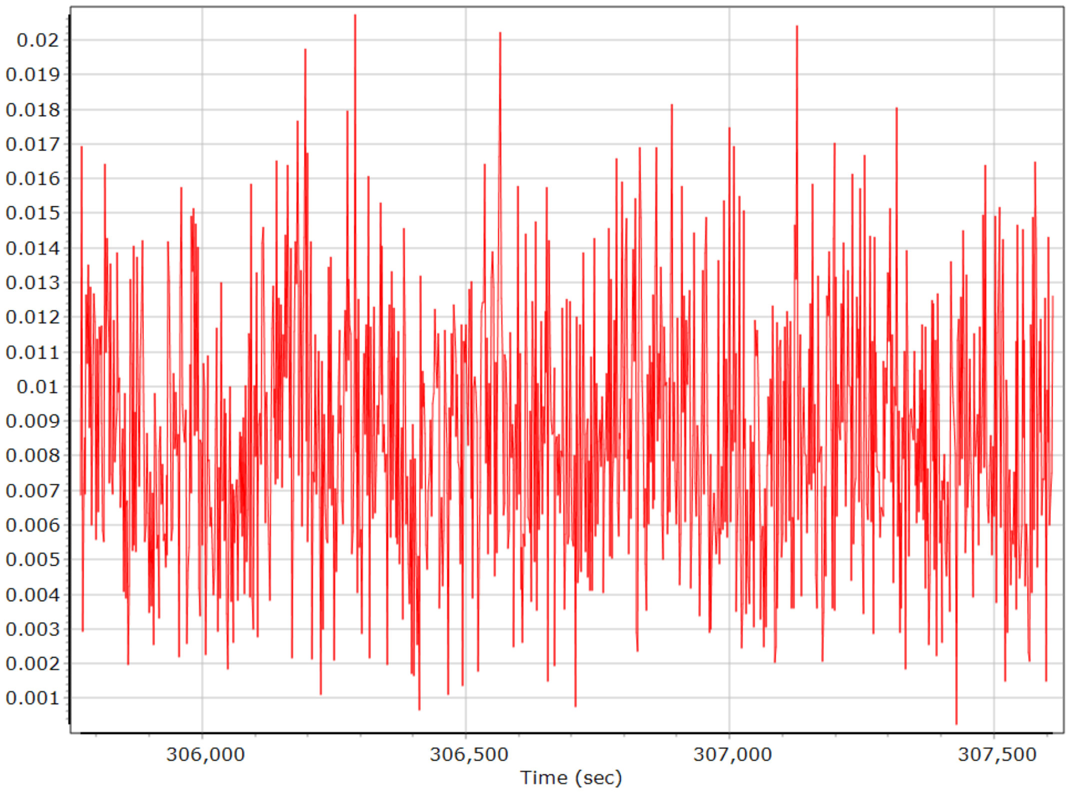
Ground Speed



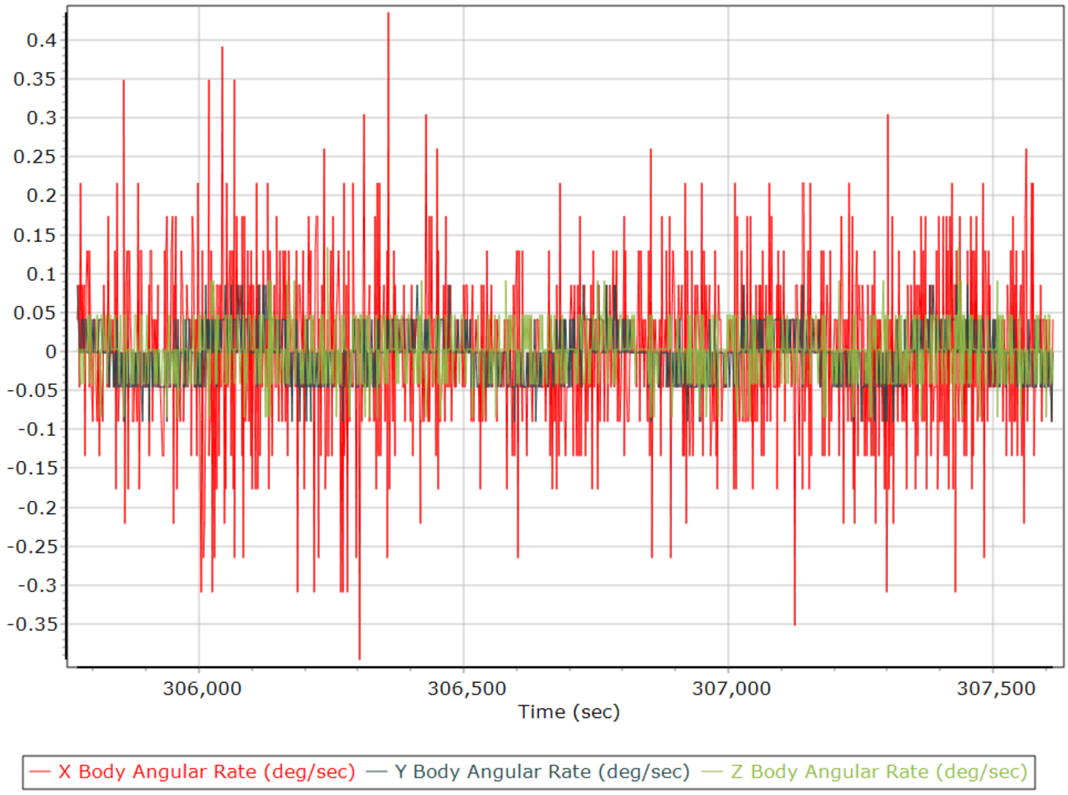
Body Acceleration



Total Body Acceleration



Body Angular Rate



SmartBase Processing Summary

Smart Select Options

Archive enabled	False
User database enabled	False
Include high-rate data sites	False
Include RINEX 3 data sites	False
Target GNSS Selection	GPS

Basestation Selection

Date	ID	Dist	System	Rate	Service	Database	Status
05/25/2022	MIAL	0.47	GNSS	30	CORS (daily)	Smart Base	Imported
05/25/2022	NOR3	11.18	GNSS	30	CORS (daily)	Smart Base	Imported
05/25/2022	MIO2	73.09	GNSS	30	CORS (daily)	Smart Base	Imported
05/25/2022	MITW	87.45	GNSS	30	CORS (daily)	Smart Base	Imported
05/25/2022	MIOG	100.77	GNSS	30	CORS (daily)	Smart Base	Imported
05/25/2022	HBCH	148.50	GNSS	30	CORS (daily)	Smart Base	Imported

SmartBase Results

SmartBase status	PROC_STATUS_OK
Primary station Id	MIAL
Primary station data rate (sec)	30.0
VRS/ASB generation rate (sec)	1.0
VRS/ASB timespan	1923 s (2211 305708 - 2211 307631)
Number of reference stations	6
Primary station GPS measurement usage (%)	93.4
Average number of satellites per epoch	8.4
Max number of GPS stations used	6
Min number of GPS stations used	3
Total full data gap (sec)	0
Total individual satellite data gap (sec)	1147
GPS precise vs. broadcast ephemeris used	100.0 % / 0.0 %
Termination Status	Normal

Base Station Information - HBCH

Station ID	HBCH		
Filename	hbch1450.22o		
Start date	5/25/2022 12:00:00 AM		
End date	5/25/2022 11:59:30 PM		
Duration	23:59:30.000		
Data type	GNSS		
Receiver manufacturer, model, serial no.	Leica	GR50	1870589
Antenna manufacturer, model	Leica	AR20 w/LEIM Dome	
Antenna height [m]	0.000		
Antenna measurement method	Bottom of antenna mount		
Offset from measured point to APC (m)	0.12674		
Latitude	N43°50'46.51417"		
Longitude	W82°38'35.09709"		
Ellipsoidal height (m)	145.60365		
Frame	ITRF00		
Epoch	2022.3945		
Ellipsoid	WGS84		
Velocity North (mm/y)	0.430190468380395		
Velocity East (mm/y)	-15.4203565724358		
Velocity Up (mm/y)	-2.20391185585366		

Base Station Information - MIOG

Station ID	MIOG		
Filename	miog1450.22o		
Start date	5/25/2022 12:00:00 AM		
End date	5/25/2022 11:59:30 PM		
Duration	23:59:30.000		
Data type	GNSS		
Receiver manufacturer, model, serial no.	Leica	GR50	1870751
Antenna manufacturer, model	Leica	AR20 w/LEIM Dome	
Antenna height [m]	0.000		
Antenna measurement method	Bottom of antenna mount		
Offset from measured point to APC (m)	0.12674		
Latitude	N44°18'05.79487"		
Longitude	W84°07'35.39534"		
Ellipsoidal height (m)	276.50275		
Frame	ITRF00		
Epoch	2022.3945		
Ellipsoid	WGS84		
Velocity North (mm/y)	0.0185552022199297		
Velocity East (mm/y)	-16.0871117623507		
Velocity Up (mm/y)	-0.799920785266693		

Base Station Information - MITW

Station ID	MITW		
Filename	mitw1450.22o		
Start date	5/25/2022 12:00:00 AM		
End date	5/25/2022 11:59:30 PM		
Duration	23:59:30.000		
Data type	GNSS		
Receiver manufacturer, model, serial no.	Leica	GR50	1834247
Antenna manufacturer, model	Leica	AR20 w/LEIM Dome	
Antenna height [m]	0.000		
Antenna measurement method	Bottom of antenna mount		
Offset from measured point to APC (m)	0.12674		
Latitude	N44°16'47.50297"		
Longitude	W83°35'01.10379"		
Ellipsoidal height (m)	170.47848		
Frame	ITRF00		
Epoch	2022.3945		
Ellipsoid	WGS84		
Velocity North (mm/y)	-0.738057382078704		
Velocity East (mm/y)	-16.0003541967027		
Velocity Up (mm/y)	-1.45689957606303		

Base Station Information - MIO2

Station ID	MIO2		
Filename	mio21450.22o		
Start date	5/25/2022 12:00:00 AM		
End date	5/25/2022 11:59:30 PM		
Duration	23:59:30.000		
Data type	GNSS		
Receiver manufacturer, model, serial no.	Leica	GRX1200+GNSS	458652
Antenna manufacturer, model	Leica	AR20 w/LEIM Dome	
Antenna height [m]	0.000		
Antenna measurement method	Bottom of antenna mount		
Offset from measured point to APC (m)	0.12674		
Latitude	N44°38'50.76532"		
Longitude	W84°08'55.35117"		
Ellipsoidal height (m)	286.10479		
Frame	ITRF00		
Epoch	2022.3945		
Ellipsoid	WGS84		
Velocity North (mm/y)	0.0292393079624241		
Velocity East (mm/y)	-16.186958268895		
Velocity Up (mm/y)	-0.802600540487912		

Base Station Information - NOR3

Station ID	NOR3		
Filename	nor31450.22o		
Start date	5/25/2022 12:00:00 AM		
End date	5/25/2022 11:59:30 PM		
Duration	23:59:30.000		
Data type	GNSS		
Receiver manufacturer, model, serial no.	Leica	GRX1200+GNSS	458283
Antenna manufacturer, model	Leica	AR20 w/LEIM Dome	
Antenna height [m]	0.000		
Antenna measurement method	Bottom of antenna mount		
Offset from measured point to APC (m)	0.12674		
Latitude	N45°04'06.90378"		
Longitude	W83°34'07.14253"		
Ellipsoidal height (m)	174.43907		
Frame	ITRF00		
Epoch	2022.3945		
Ellipsoid	WGS84		
Velocity North (mm/y)	-0.67660300628503		
Velocity East (mm/y)	-16.4088038296484		
Velocity Up (mm/y)	-1.16946804122239		

Base Station Information - MIAL

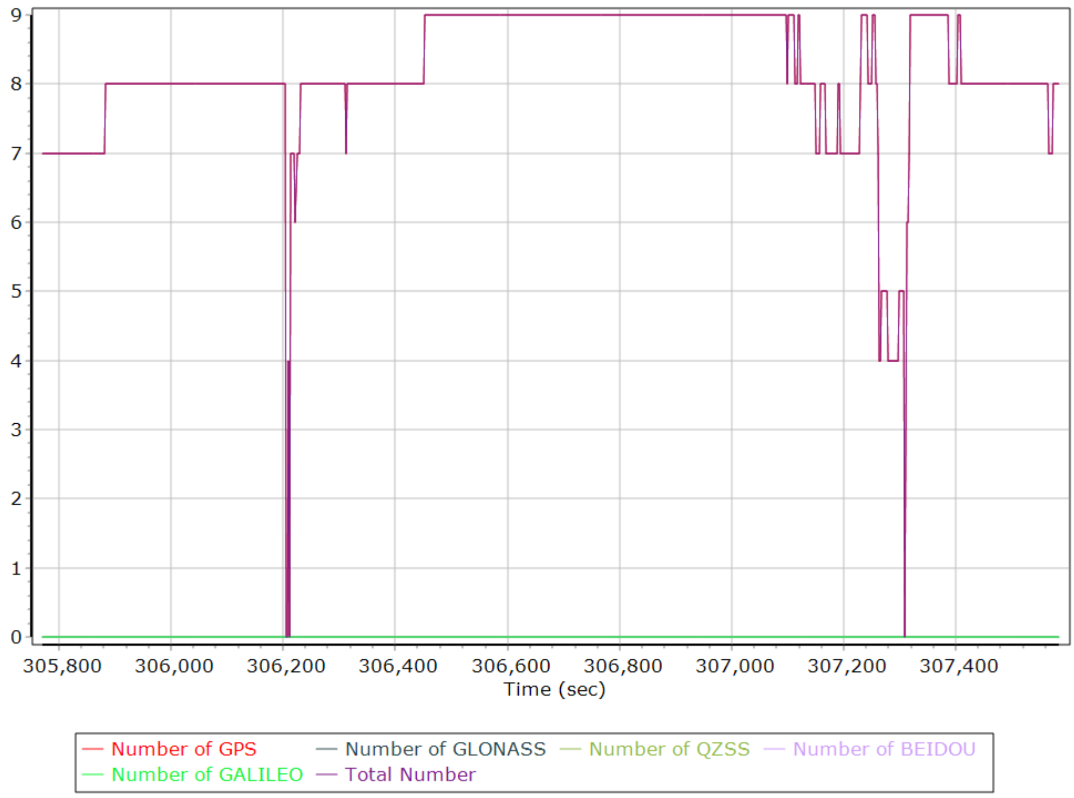
Station ID	MIAL		
Filename	mial1450.22o		
Start date	5/25/2022 12:00:00 AM		
End date	5/25/2022 11:59:30 PM		
Duration	23:59:30.000		
Data type	GNSS		
Receiver manufacturer, model, serial no.	Leica	GR50	1870586
Antenna manufacturer, model	Leica	AR20 w/LEIM Dome	
Antenna height [m]	0.000		
Antenna measurement method	Bottom of antenna mount		
Offset from measured point to APC (m)	0.12674		
Latitude	N45°03'46.75956"		
Longitude	W83°25'42.90433"		
Ellipsoidal height (m)	144.68676		
Frame	ITRF00		
Epoch	2022.3945		
Ellipsoid	WGS84		
Velocity North (mm/y)	-1.01464029259013		
Velocity East (mm/y)	-16.2995604960739		
Velocity Up (mm/y)	-0.598881286327899		

GNSS QC

GNSS QC Statistics

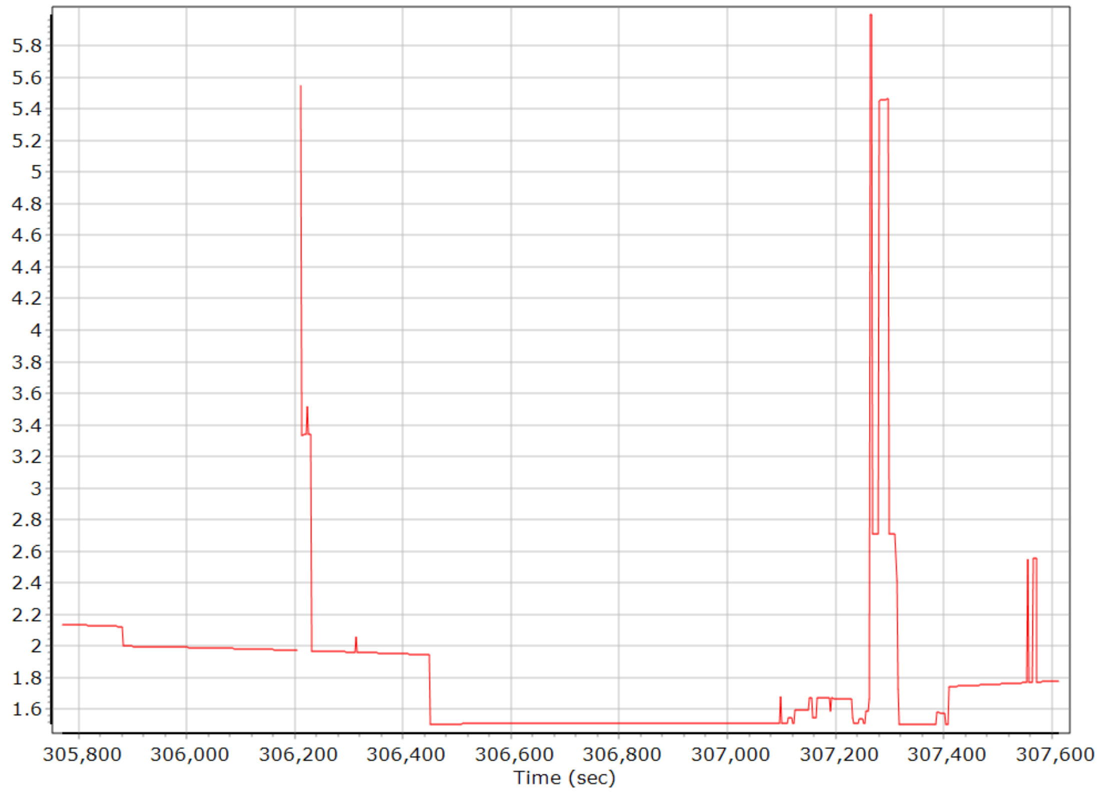
Statistics	Min	Max	Mean
Baseline length (km)	0.00	0.00	
Number of GPS SV	4	9	8
Number of GLONASS SV	0	0	0
Number of QZSS SV	0	0	0
Number of BEIDOU SV	0	0	0
Number of GALILEO SV	0	0	0
Total number of SV	4	9	8
PDOP	1.50	6.00	1.83
QC Solution Gaps	1.00	4.00	
Solution Type	Fixed	Float	No solution
Epoch (sec)	1825.00	44.00	7.00
Percentage	97.28	2.35	0.37

Num SVs in solution

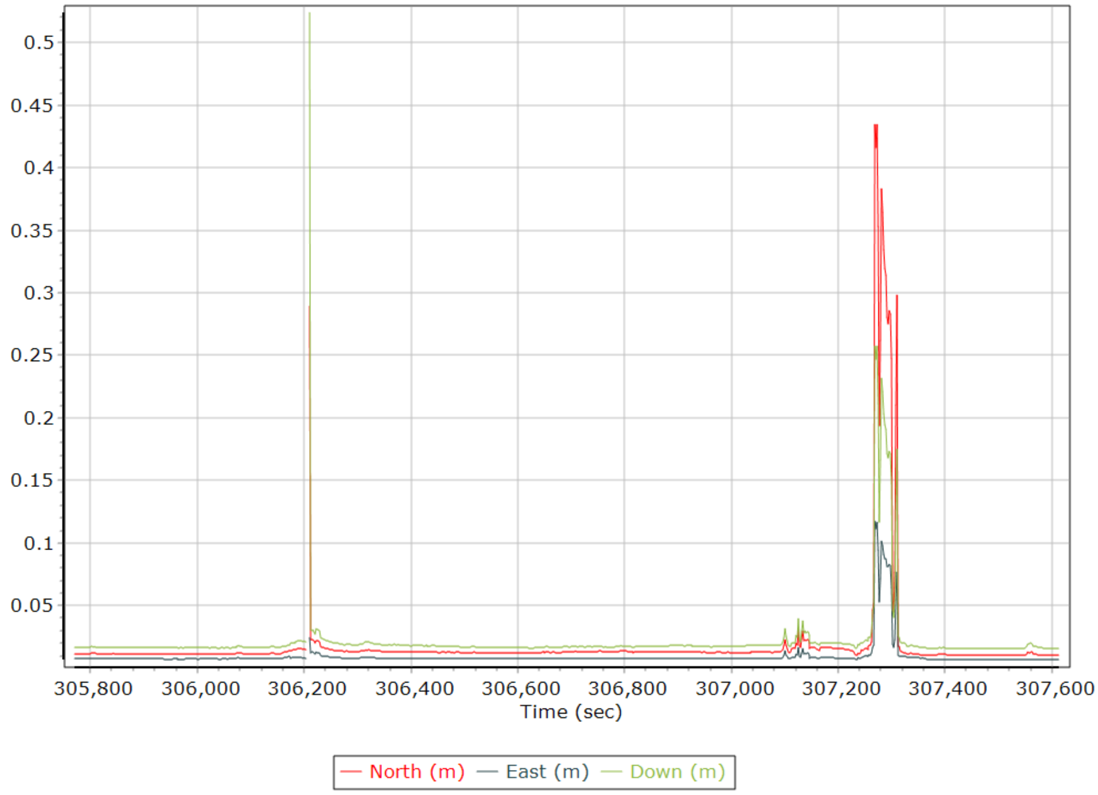


Forward/Reverse Separation

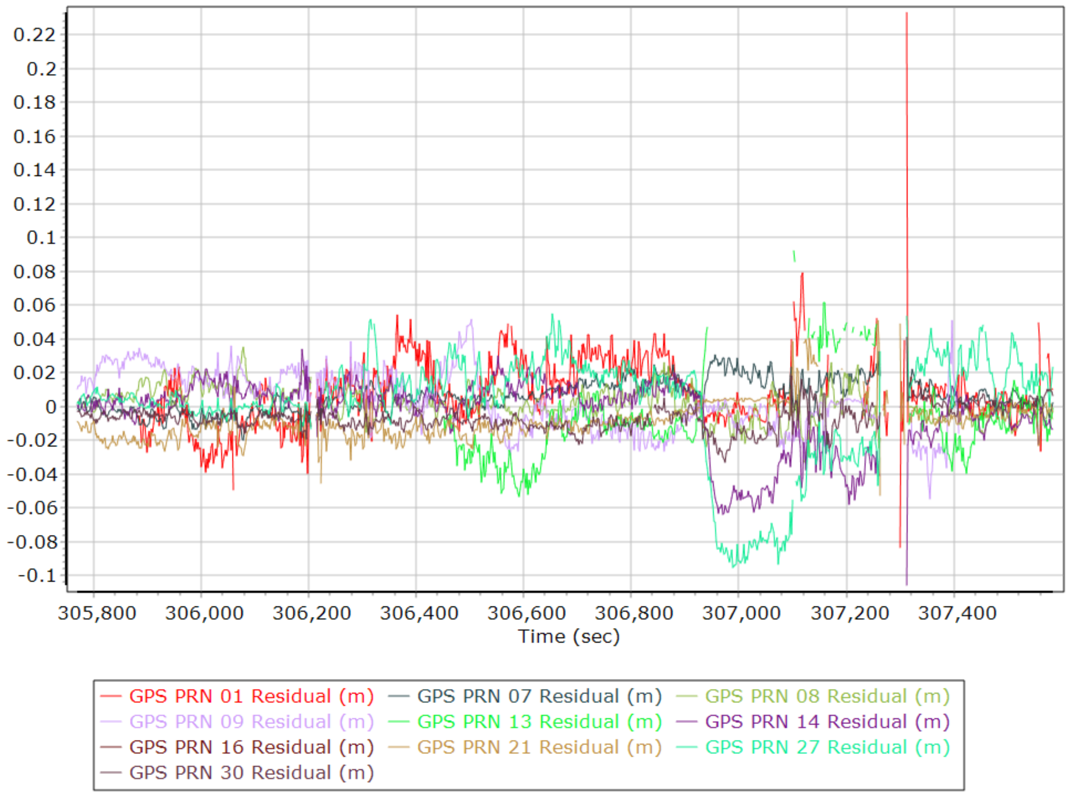
PDOP



Estimated Position Accuracy



GPS Residuals



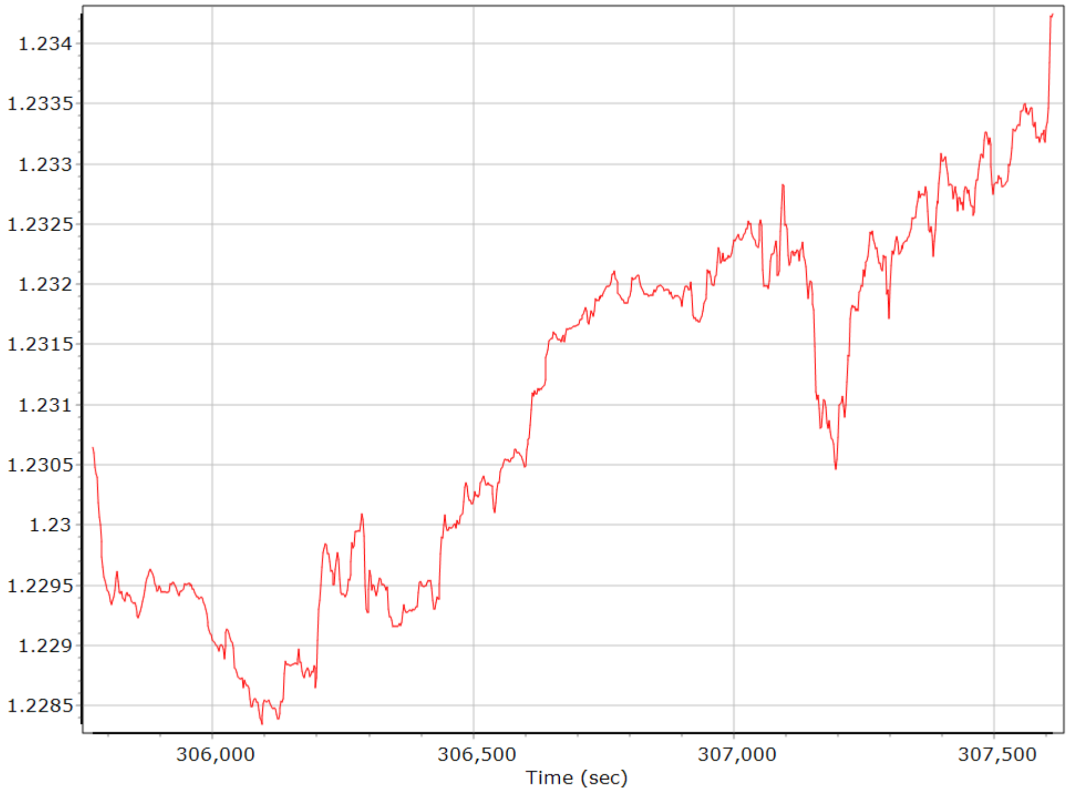
GNSS-Inertial Processor Configuration

Processing mode	IN-Fusion SmartBase		
Stabilized mount	False		
Base station	ASB		
Processing start time	305690.000 (5/25/2022 12:54:50 PM)		
Processing end time	307613.000 (5/25/2022 1:26:53 PM)		
Initial attitude source	GYRO Compass, GAMS or GNSS Compass		
IMU Sensor Context	Processing with Onboard IMU		
Reference to IMU lever arm (m)	0.000	0.000	0.000
Reference to IMU mounting angles (deg)	0.000	0.000	0.000
Reference to Primary GNSS lever arm (m)	1.229	-0.916	-3.338
Reference to Primary GNSS lever arm std dev (m)	0.100	0.100	0.100
Reference to Primary GNSS lever arm (m)	0.000	0.000	0.000
Reference to Primary GNSS lever arm std dev (m)	0.100	0.100	0.100
Vehicle to Reference mounting angles (deg)	0.000	0.000	0.000

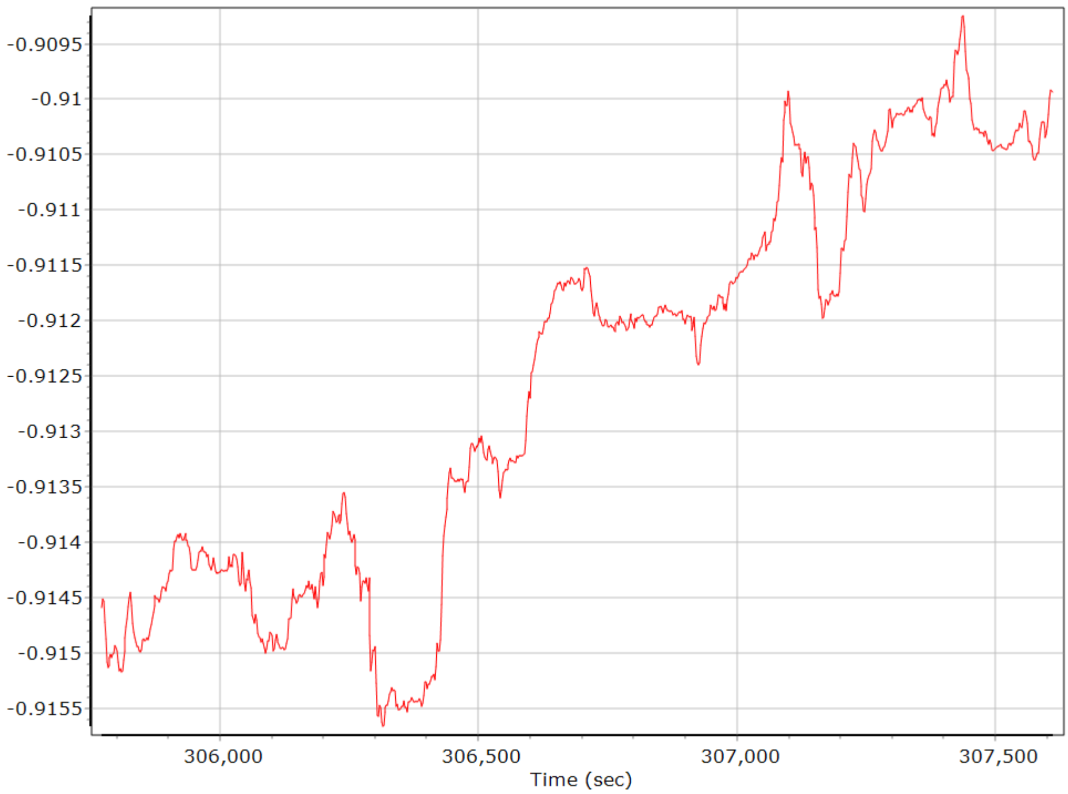
Calibrated Installation Parameters

Reference-Primary GNSS Lever Arm (m)

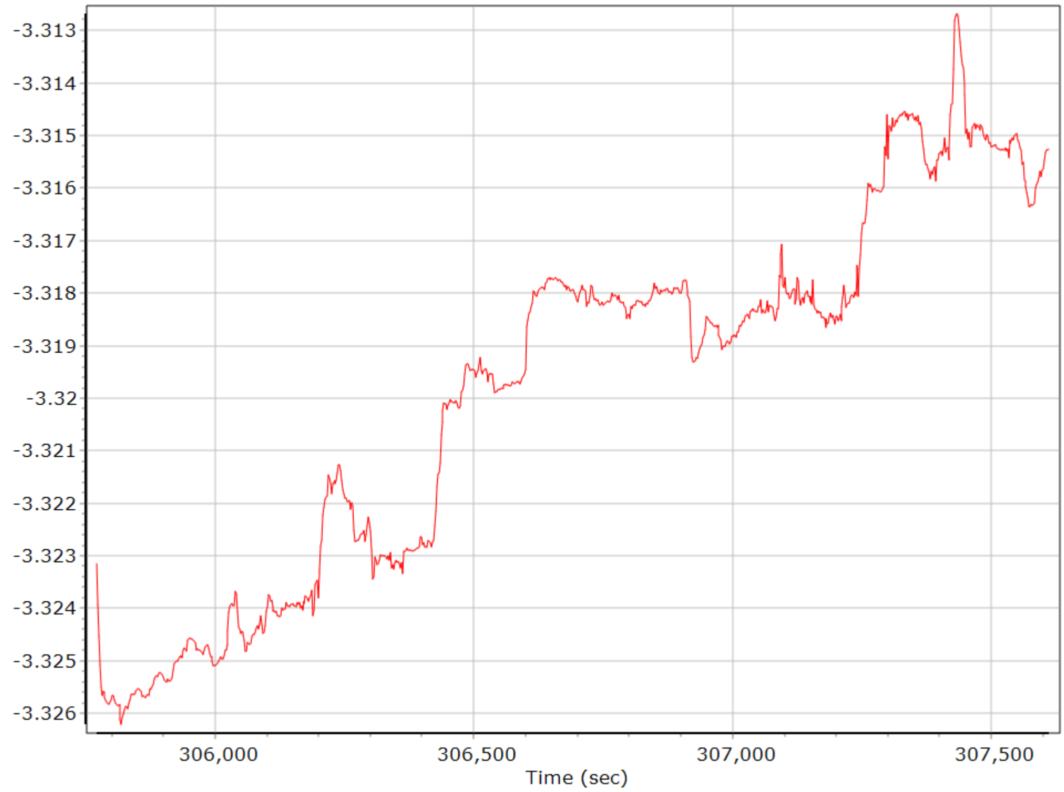
X Reference-Primary GNSS Lever Arm (m)



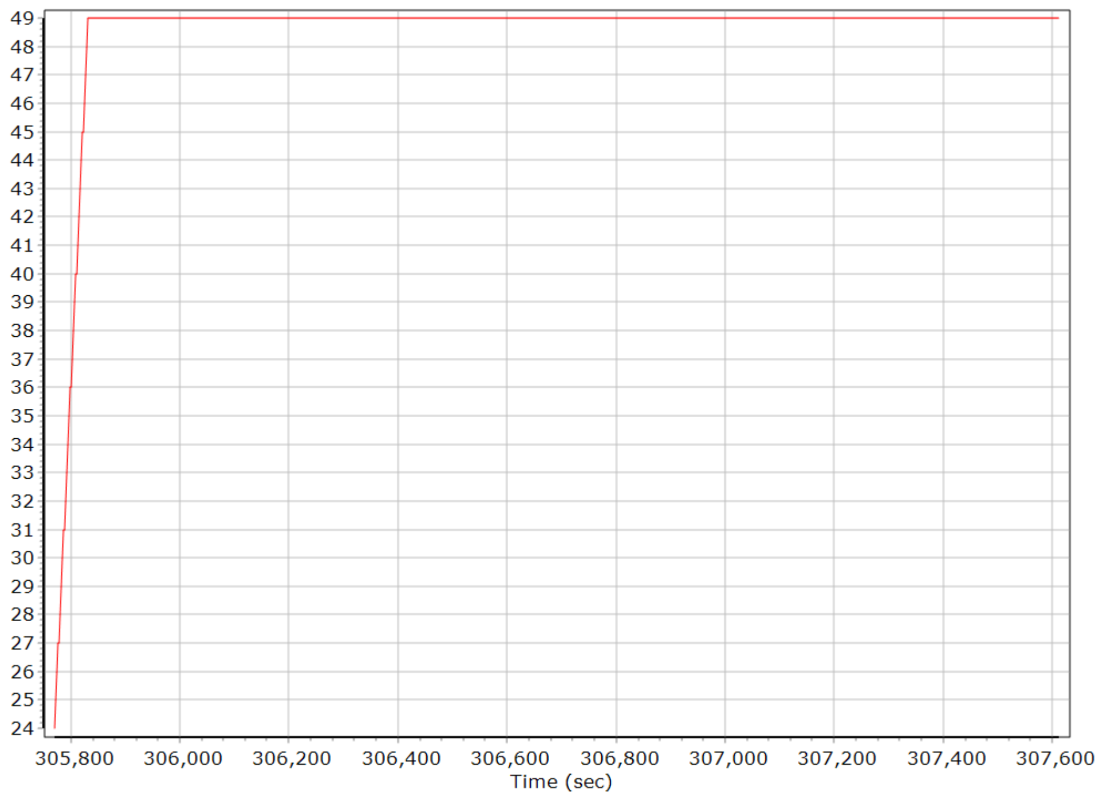
Y Reference-Primary GNSS Lever Arm (m)



Z Reference-Primary GNSS Lever Arm (m)

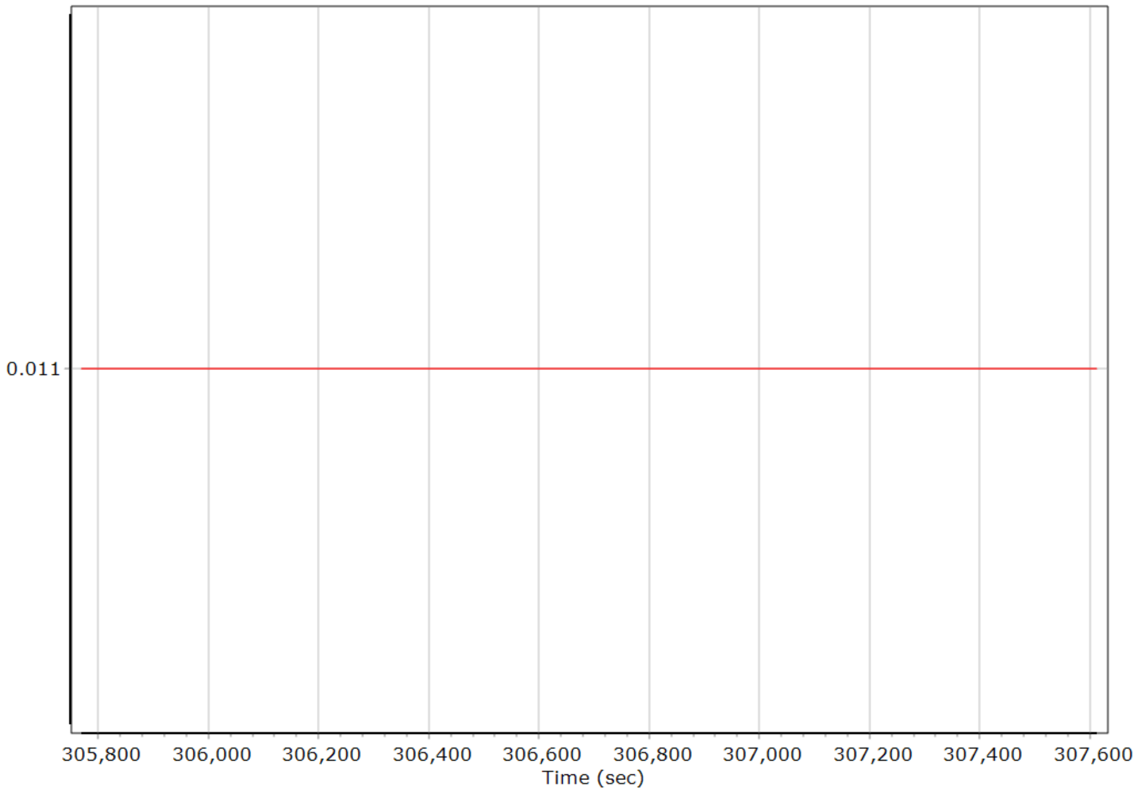


Reference-Primary GNSS Lever Arm Figure of Merit

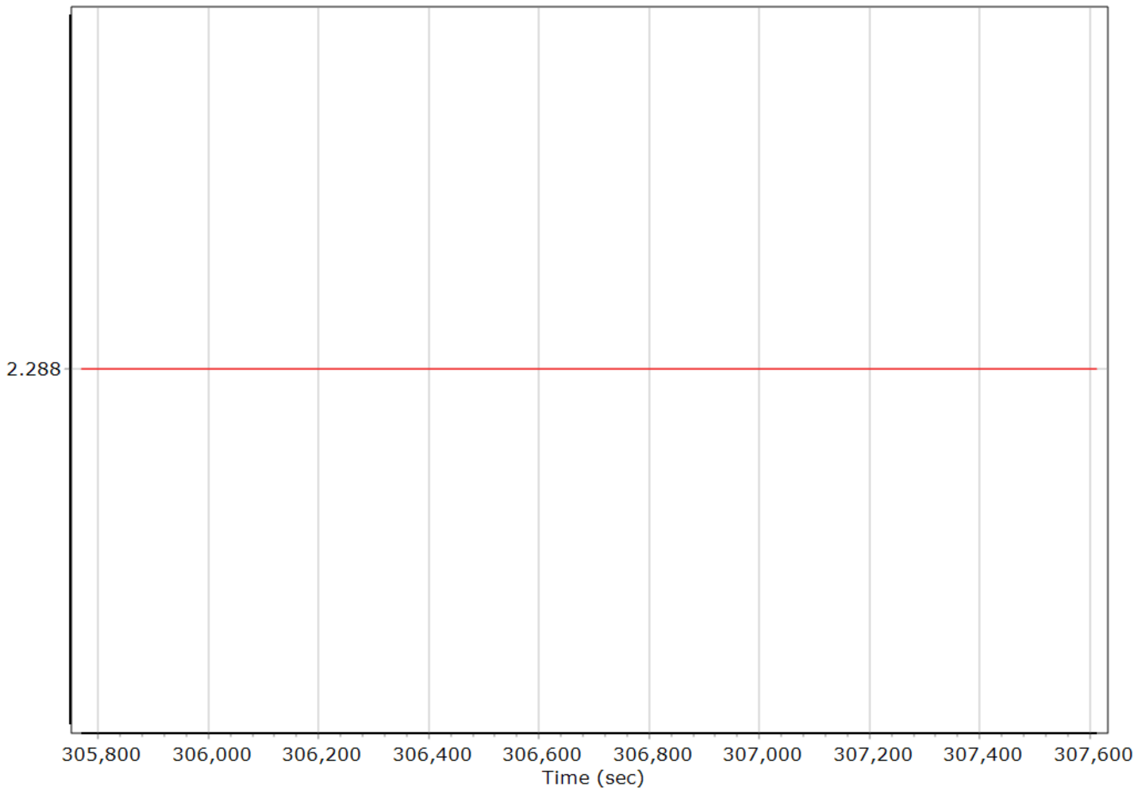


GAMS Lever Arm

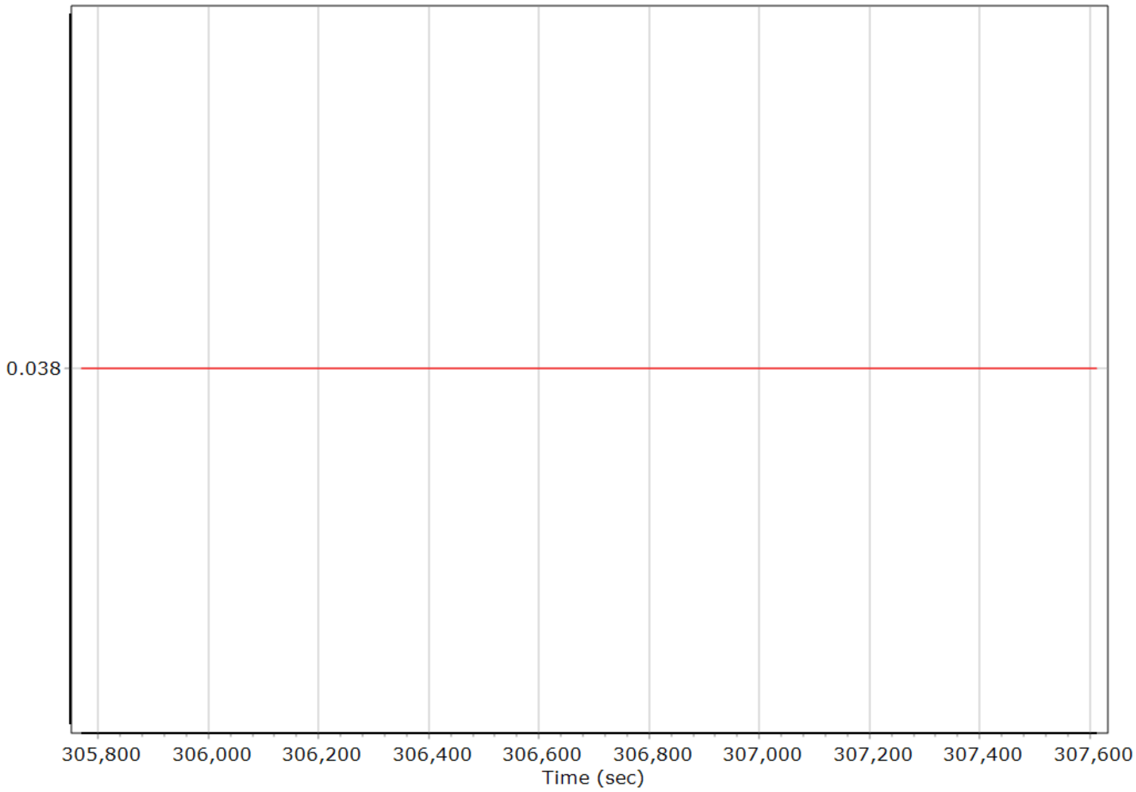
X GAMS Lever Arm (m)



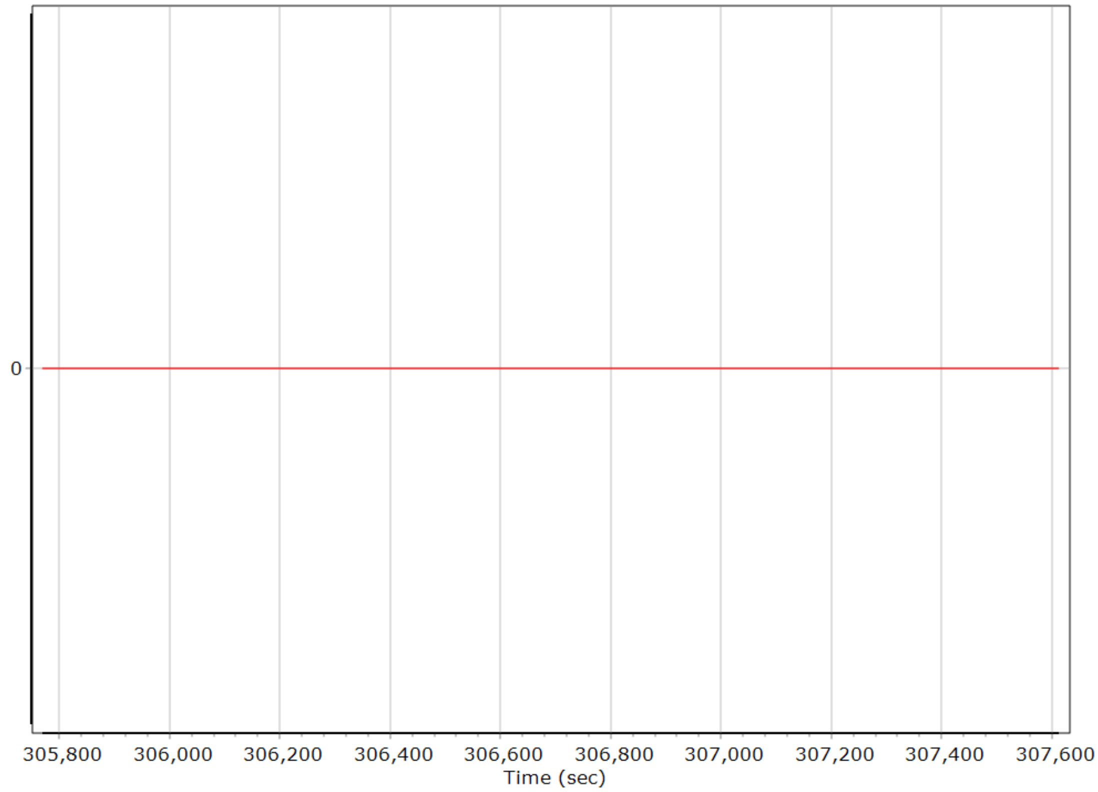
Y GAMS Lever Arm (m)



Z GAMS Lever Arm (m)



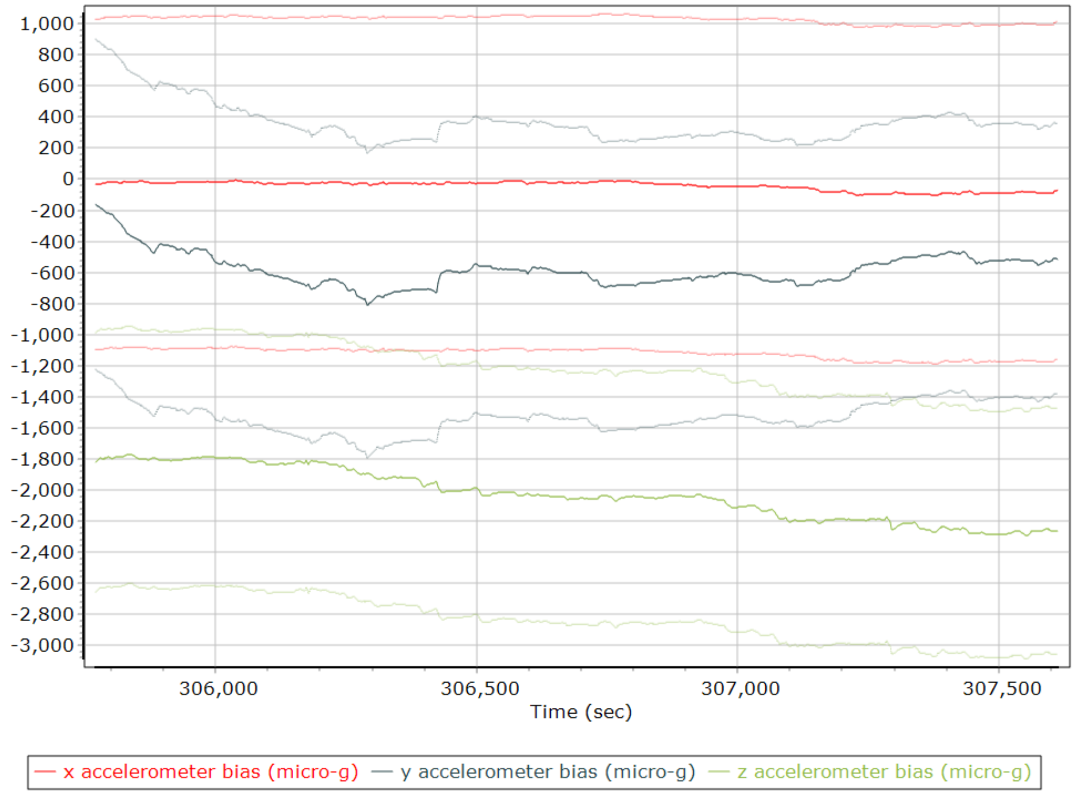
GAMS Lever Arm Figure of Merit



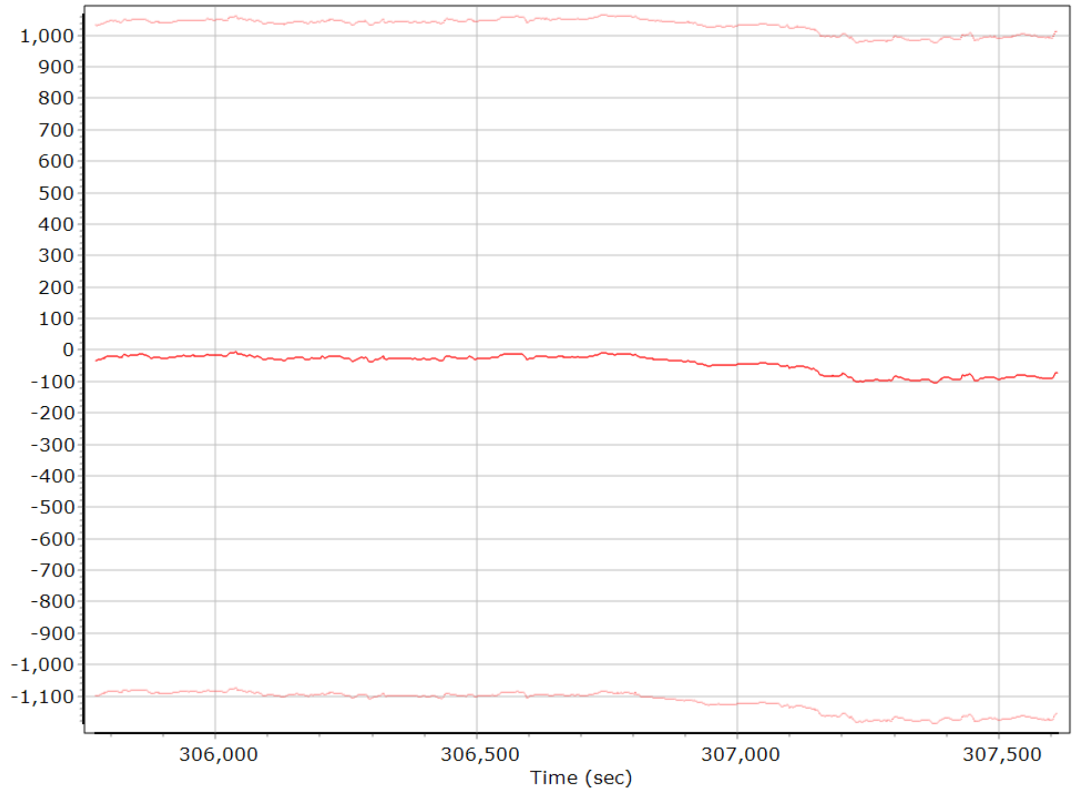
IN-Fusion QC

Forward Processed Estimated Errors, Reference Frame

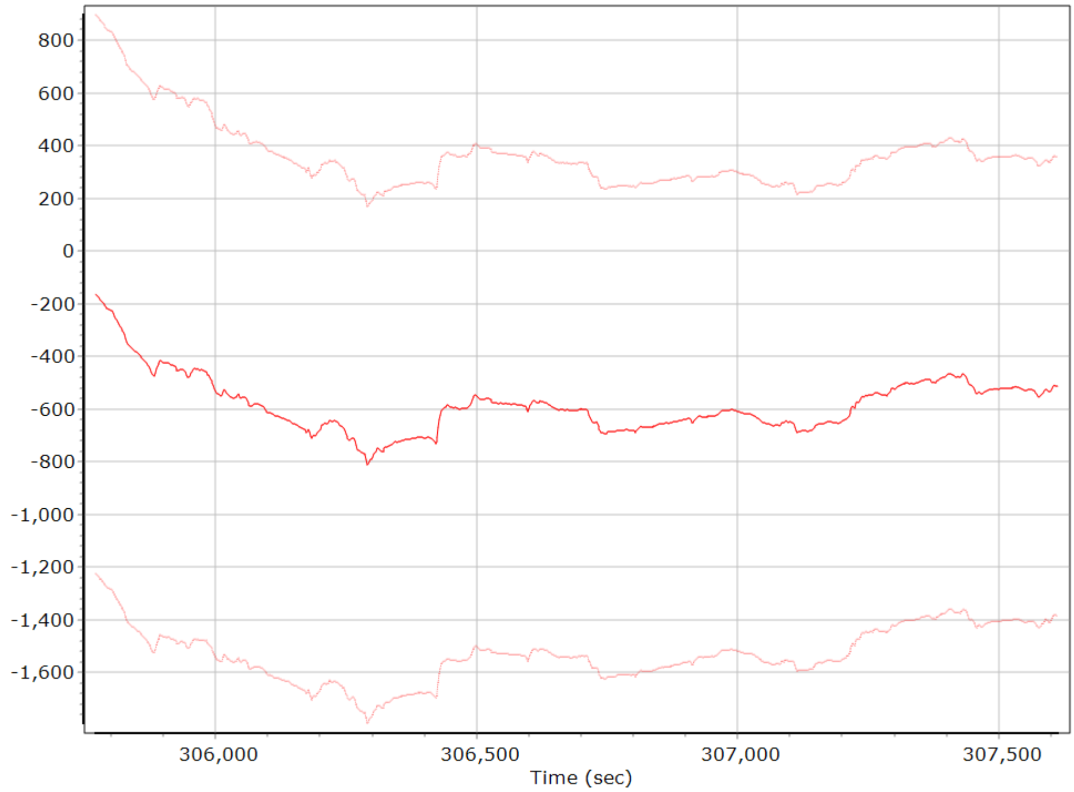
Accelerometer Bias (micro-g)



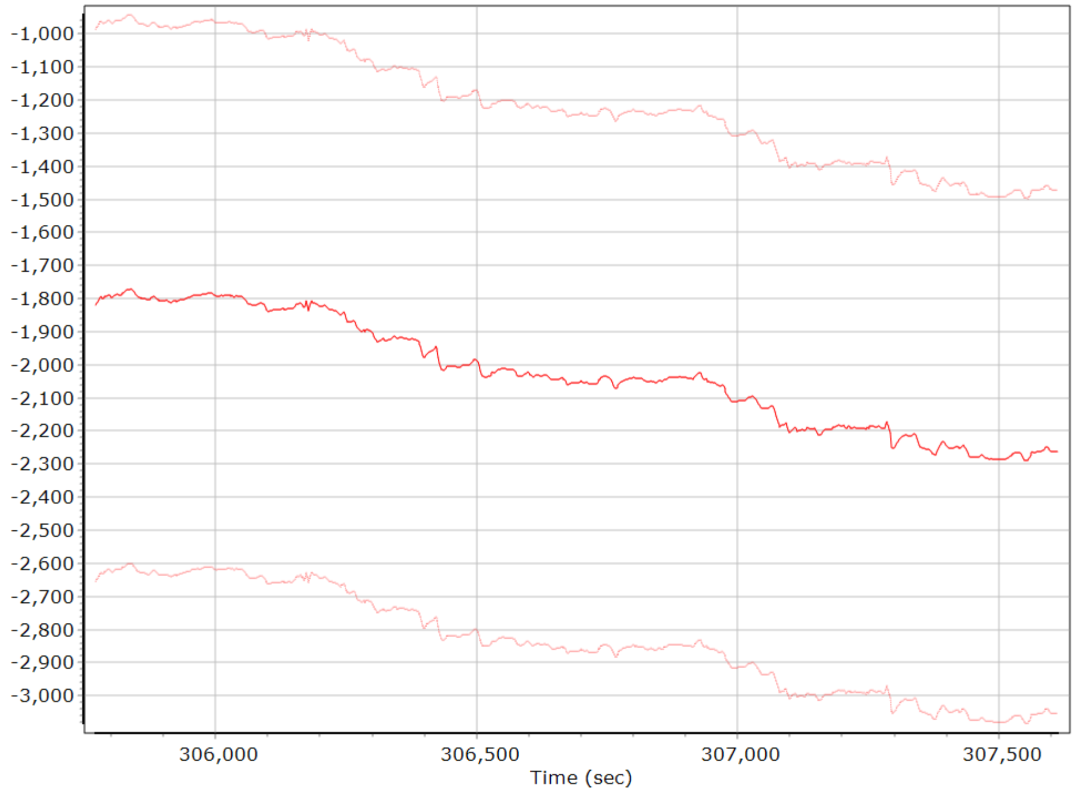
X Accelerometer Bias (micro-g)



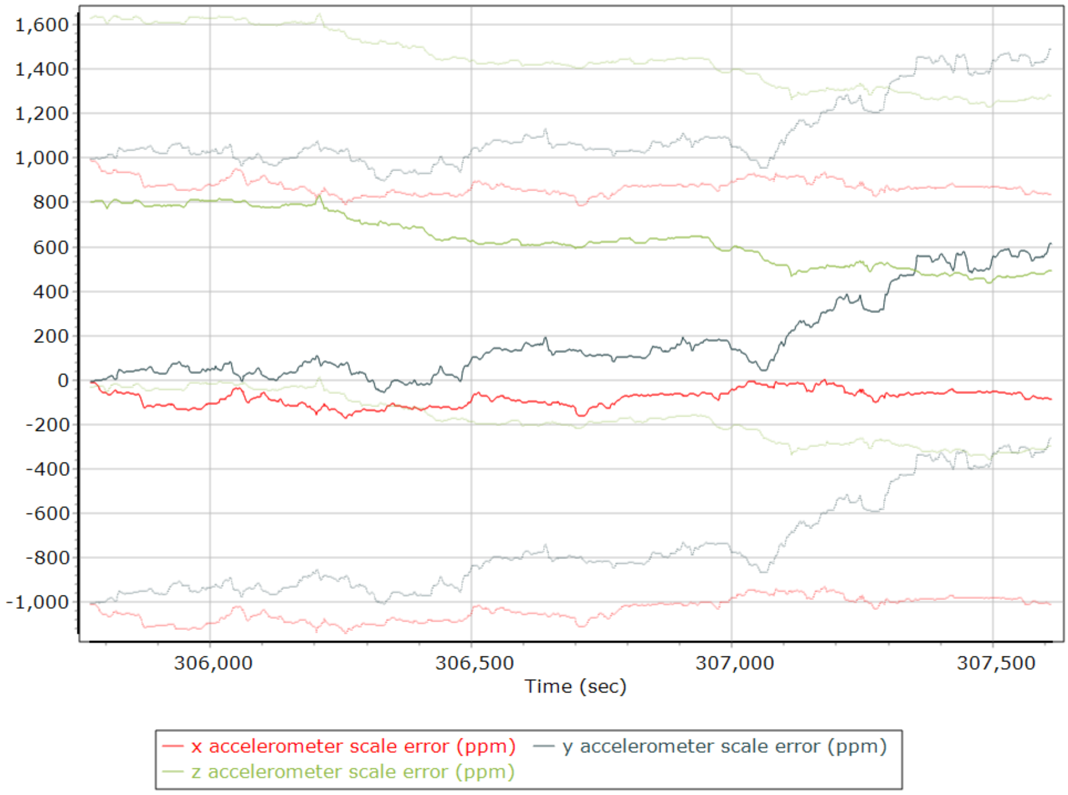
Y Accelerometer Bias (micro-g)



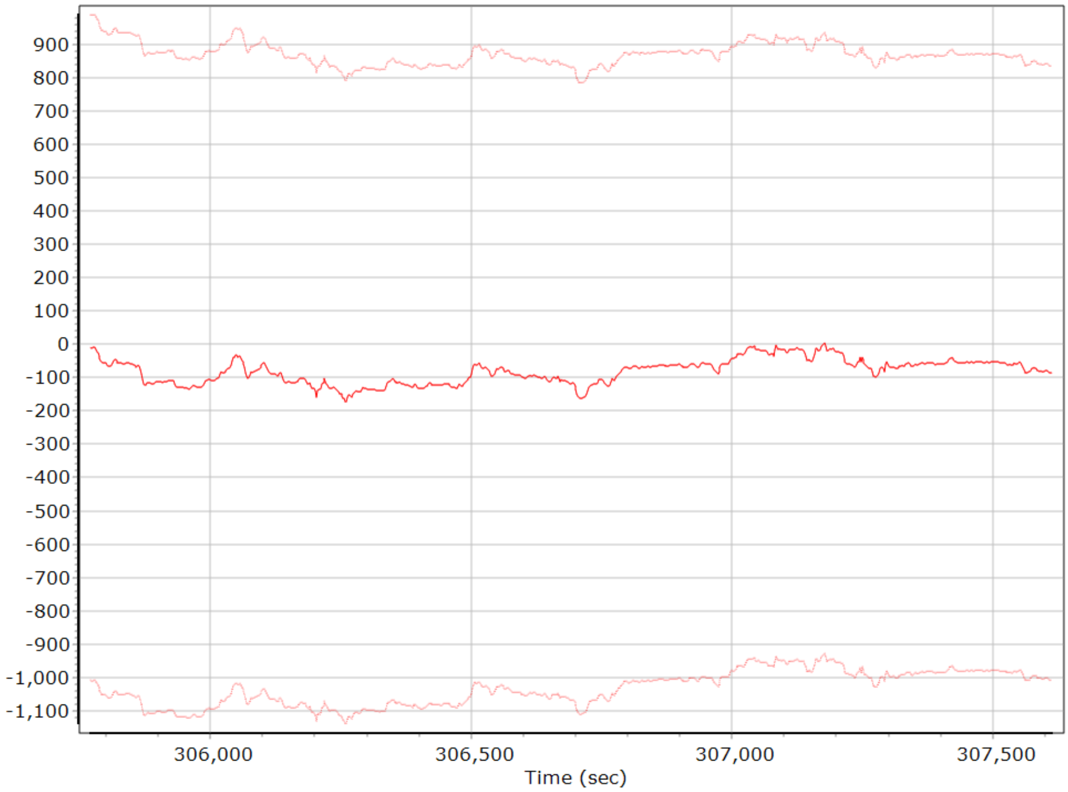
Z Accelerometer Bias (micro-g)



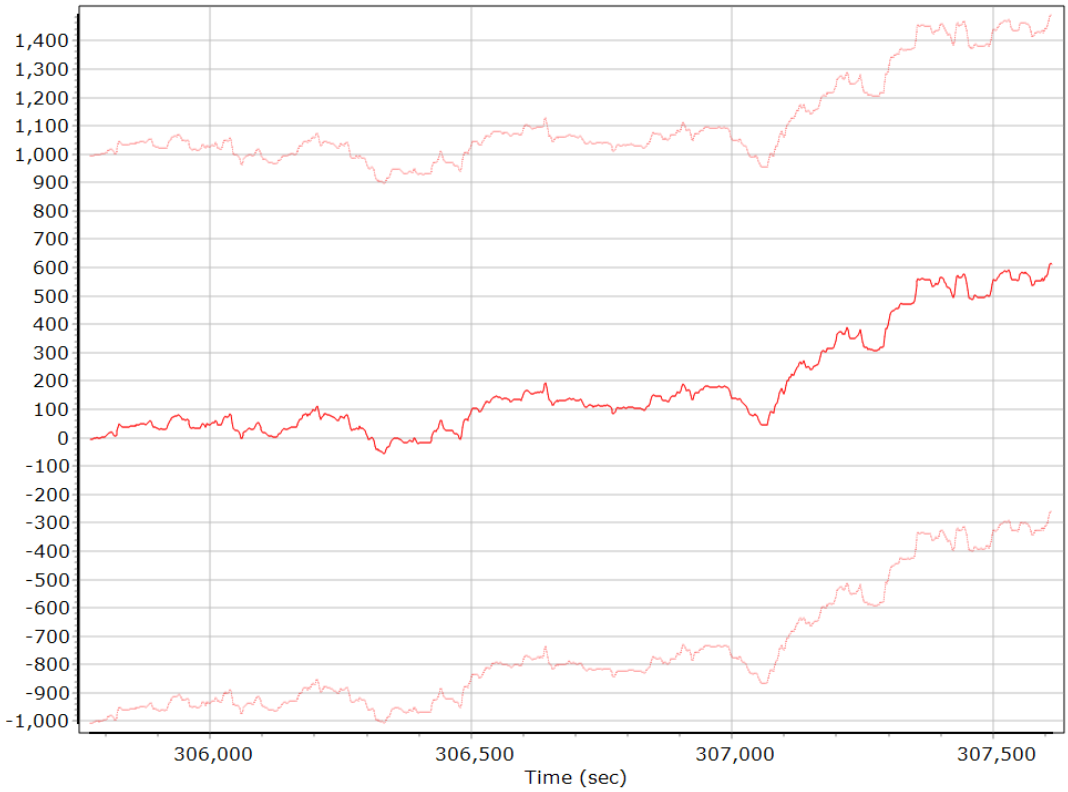
Accelerometer Scale Error (ppm)



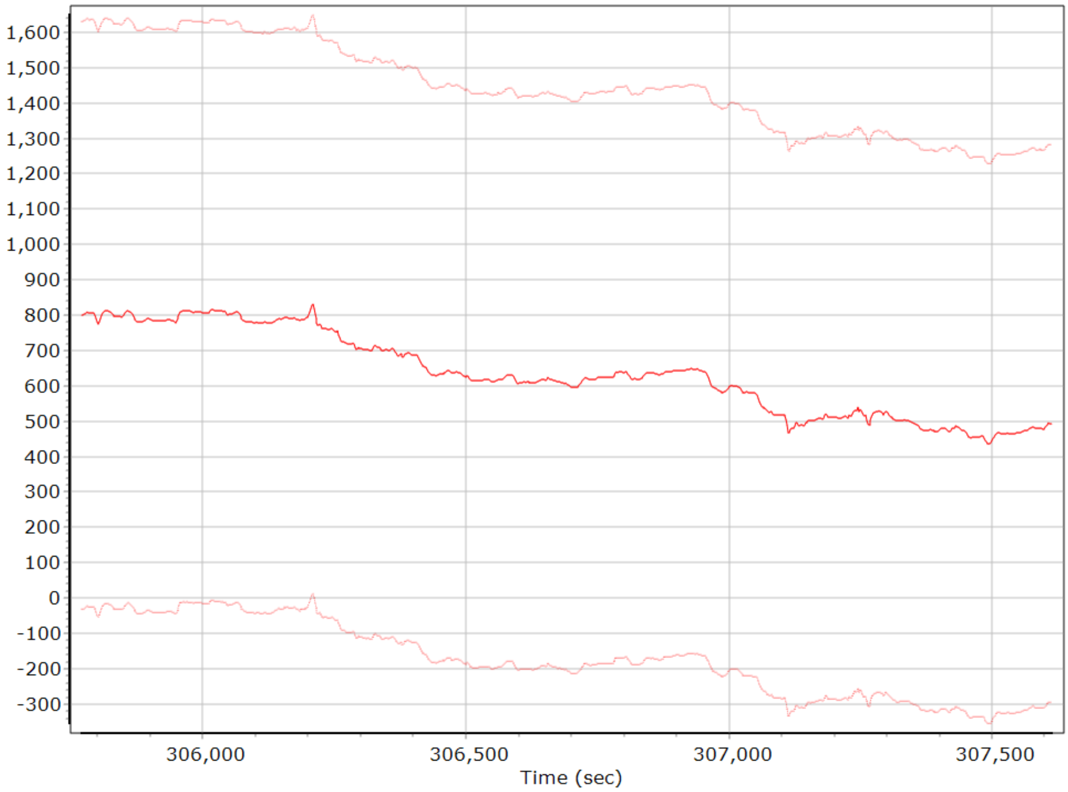
X Accelerometer Scale Error (ppm)



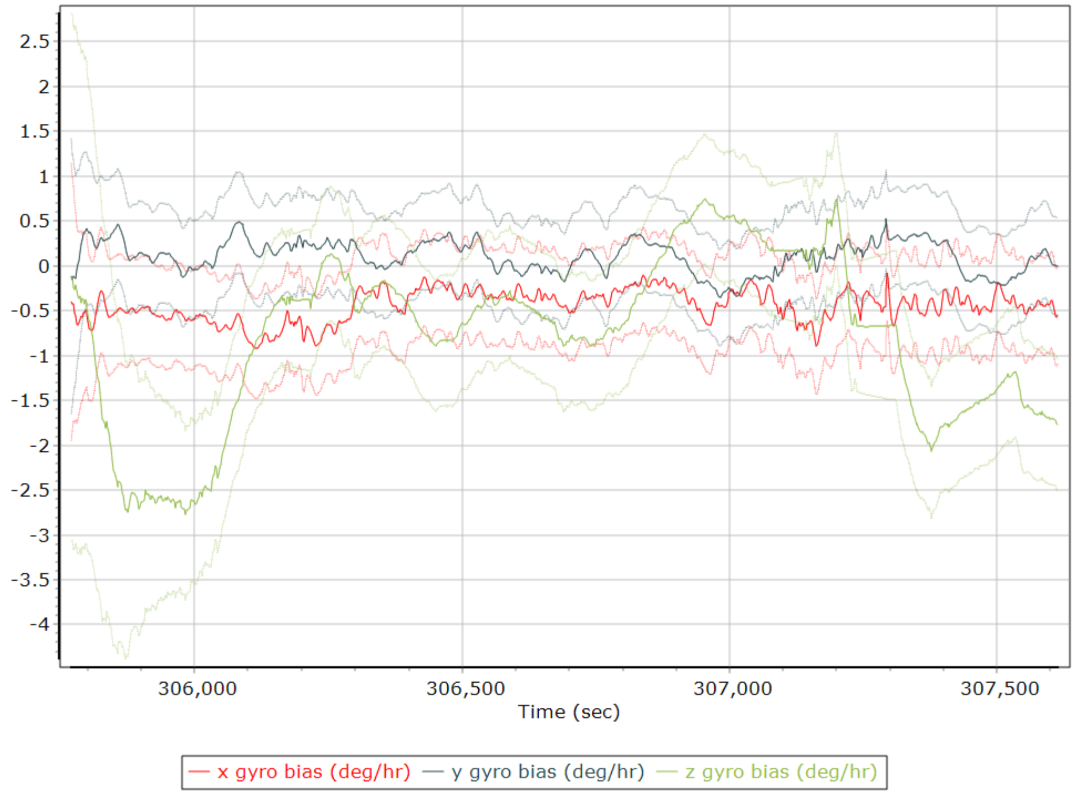
Y Accelerometer Scale Error (ppm)



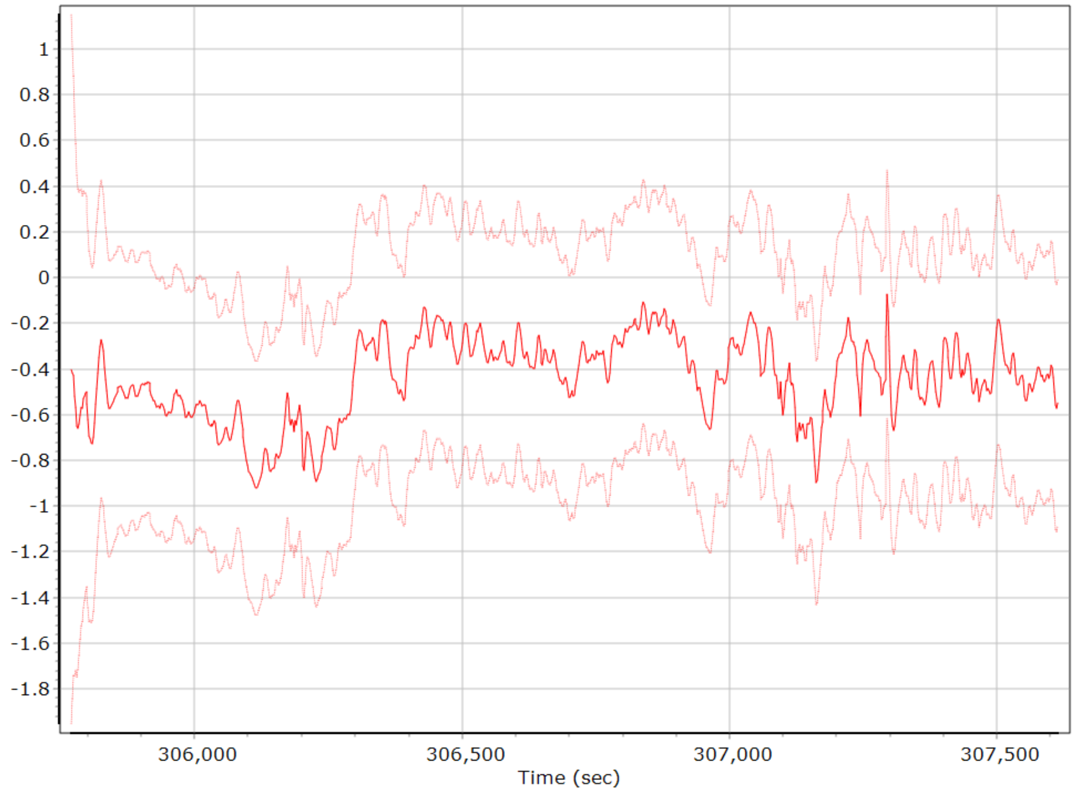
Z Accelerometer Scale Error (ppm)



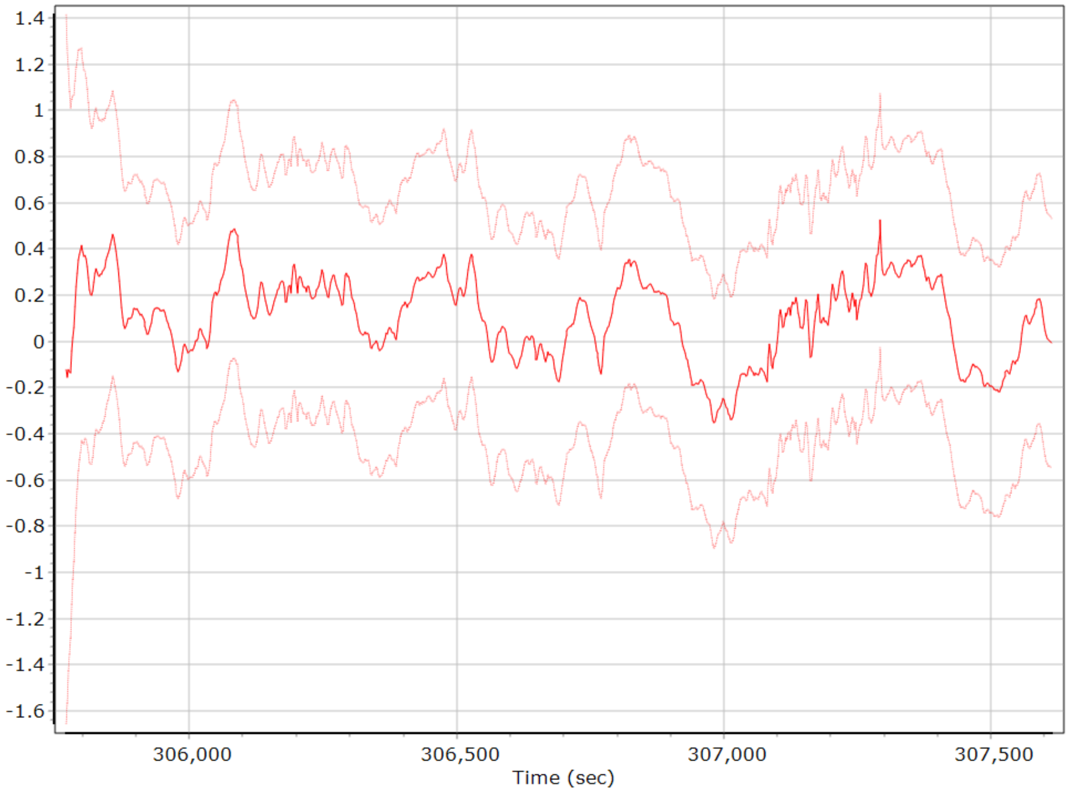
Gyro Bias (deg/h)



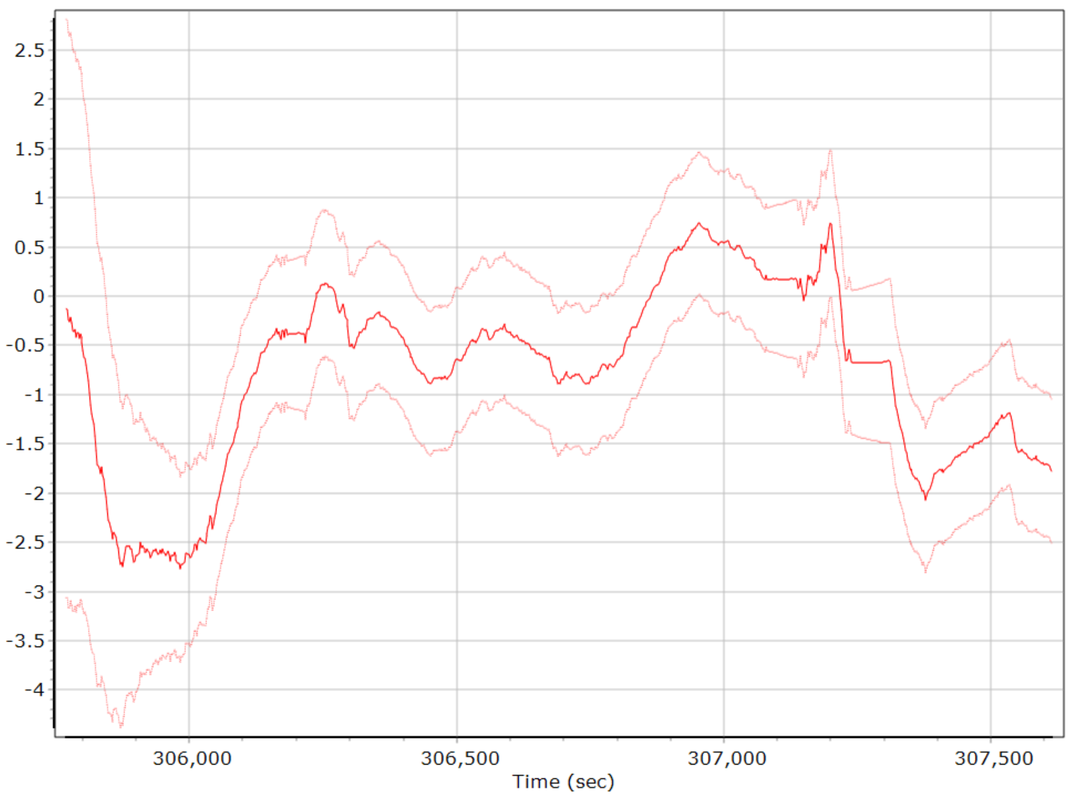
X Gyro Bias (deg/h)



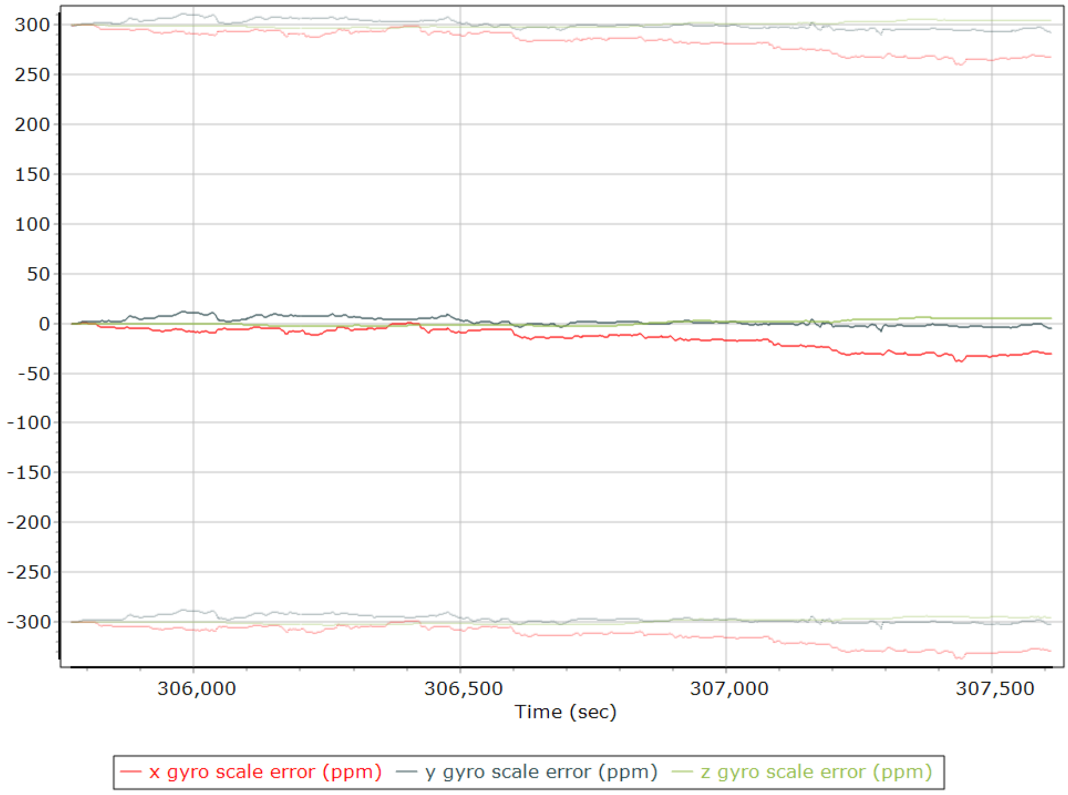
Y Gyro Bias (deg/h)



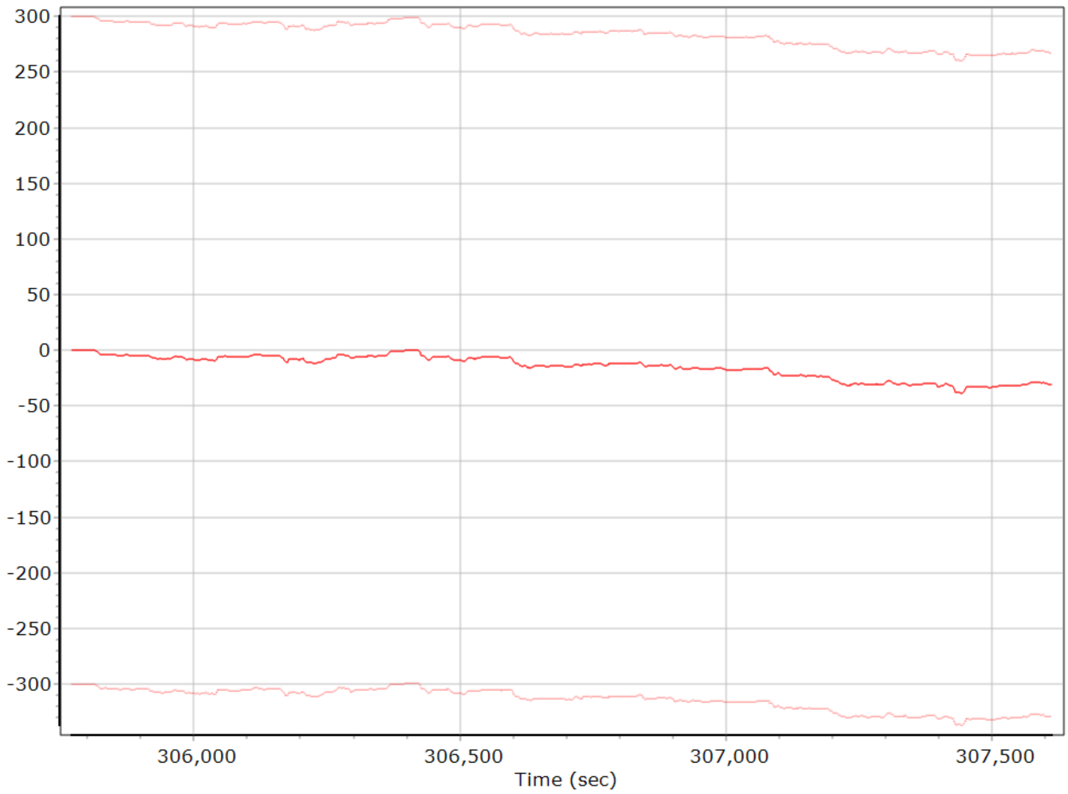
Z Gyro Bias (deg/h)



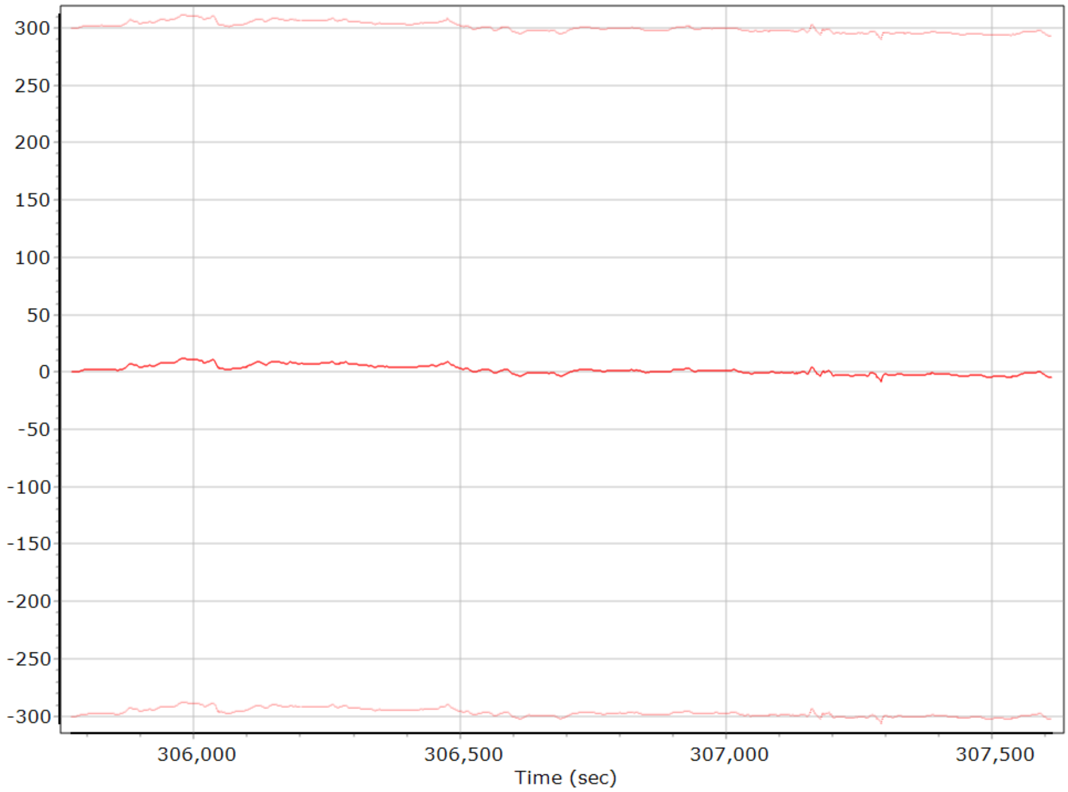
Gyro Scale Error (ppm)



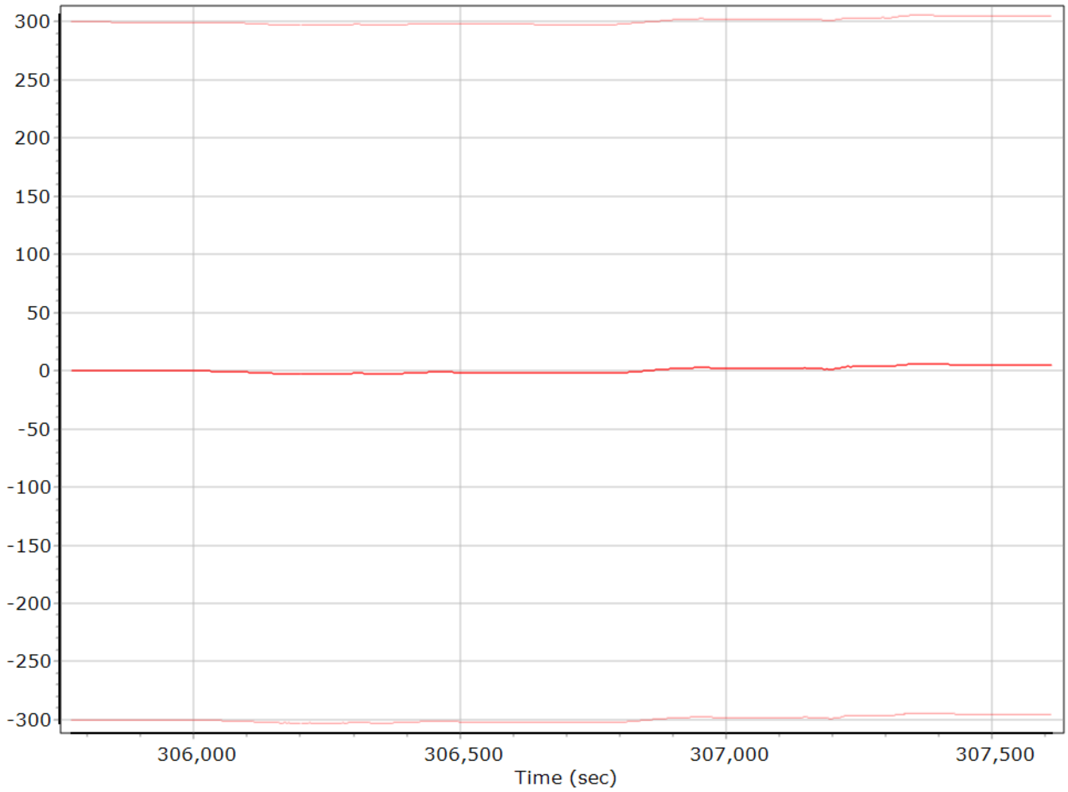
X Gyro Scale Error (ppm)



Y Gyro Scale Error (ppm)

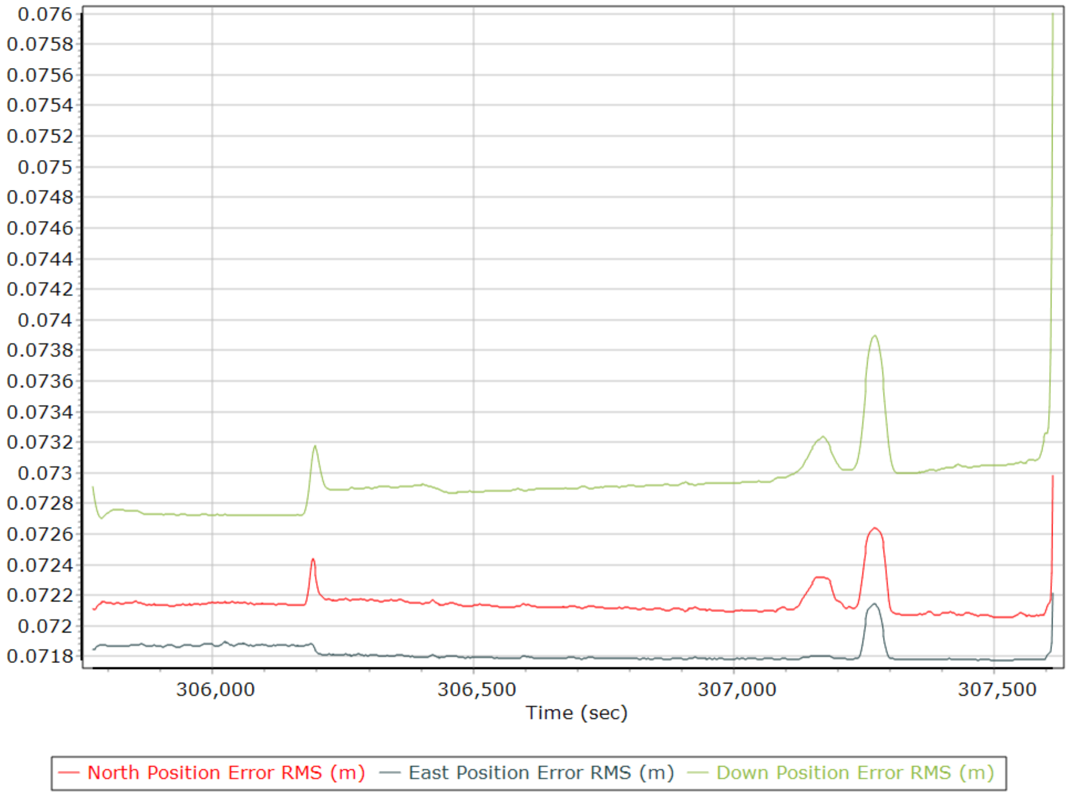


Z Gyro Scale Error (ppm)

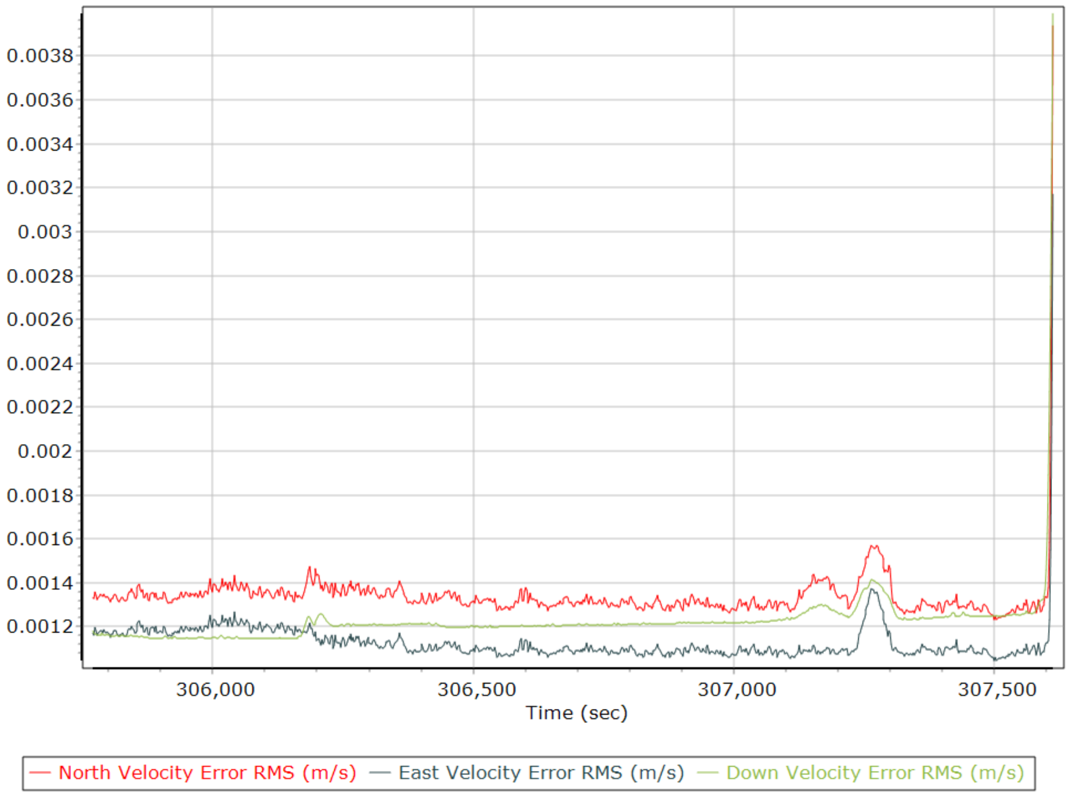


Smoothed Performance Metrics

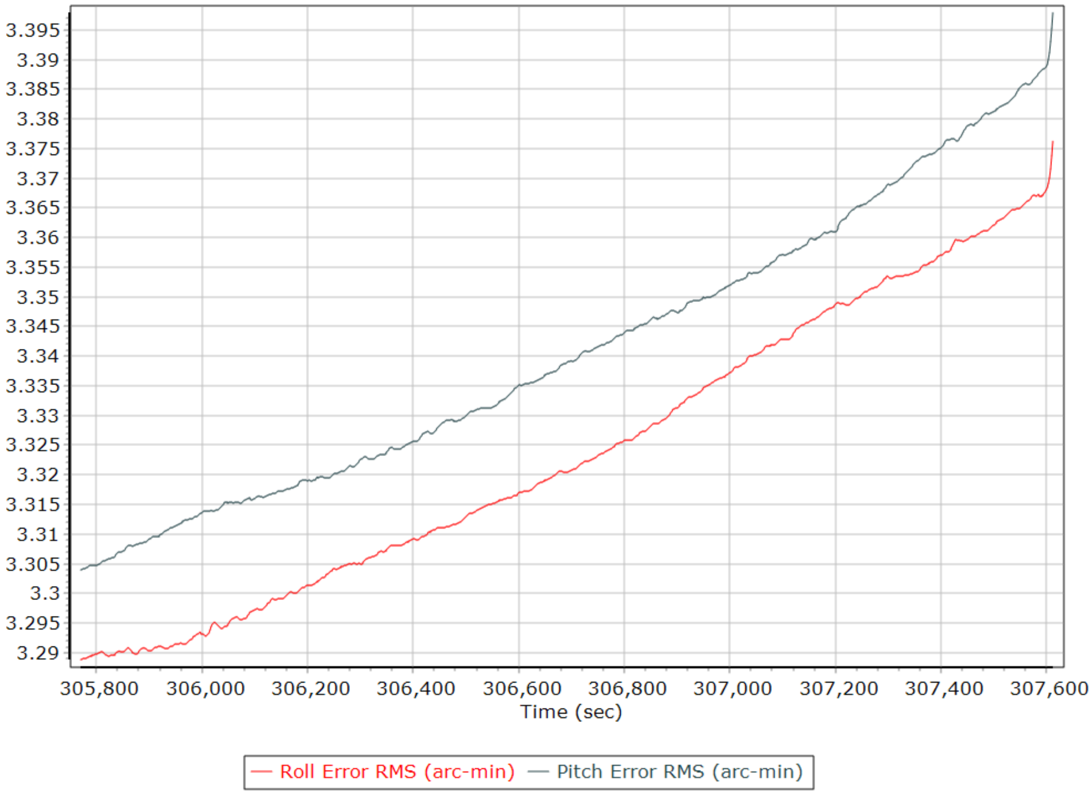
Position Error RMS (m)



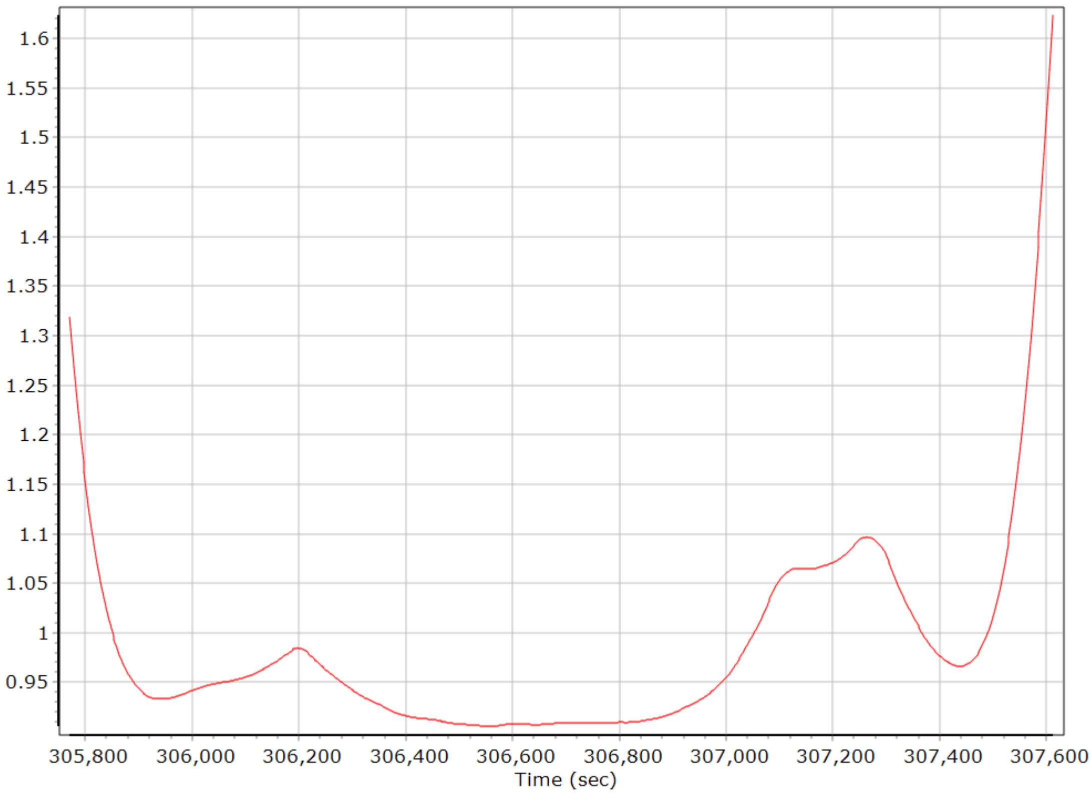
Velocity Error RMS (m/s)



Roll/Pitch Error RMS (arc-min)

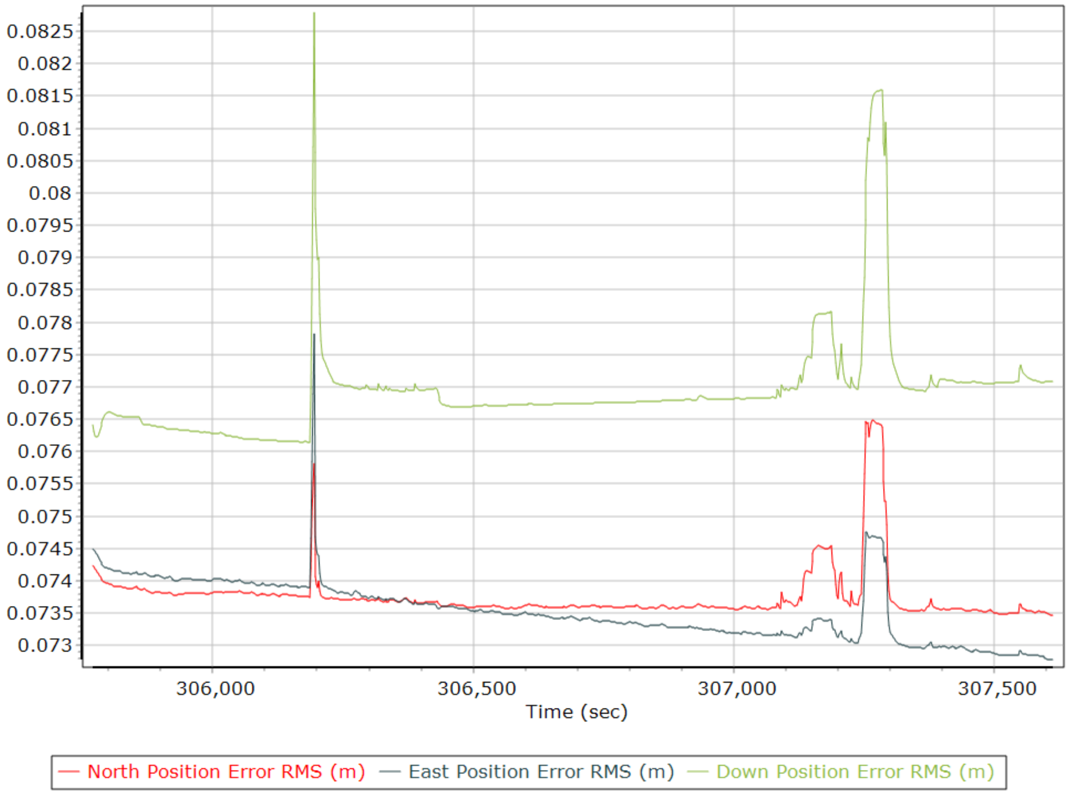


Heading Error RMS (arc-min)

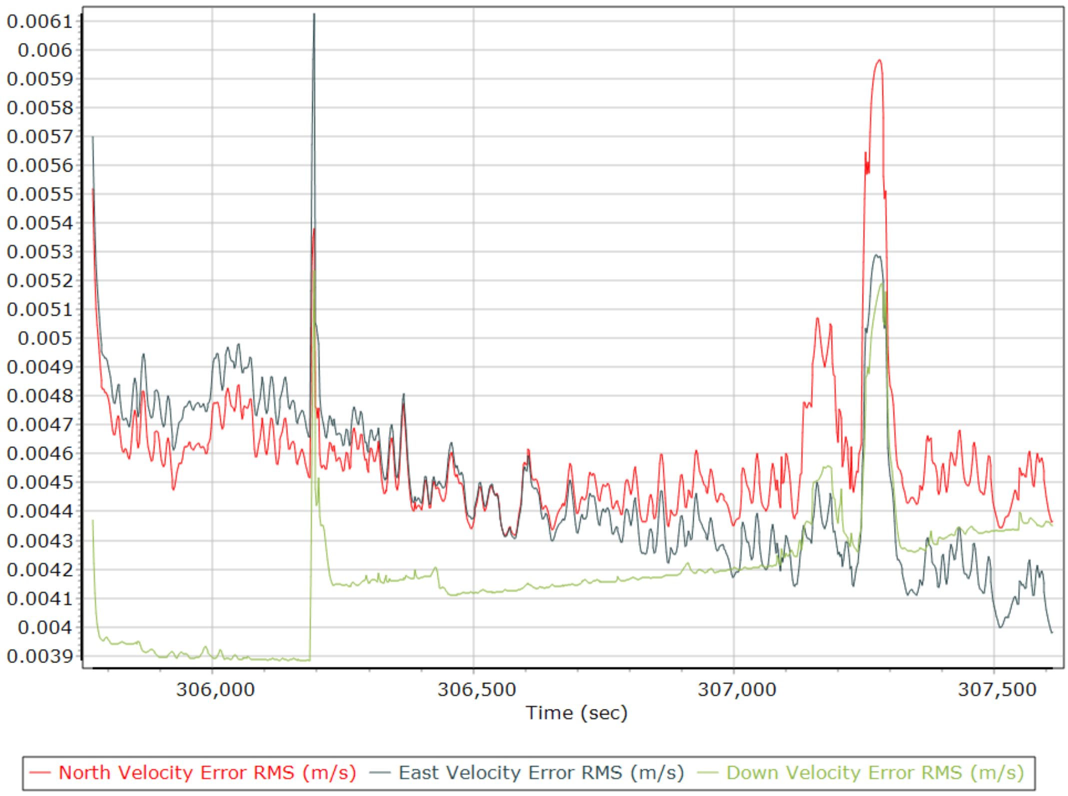


Forward Processed Performance Metrics

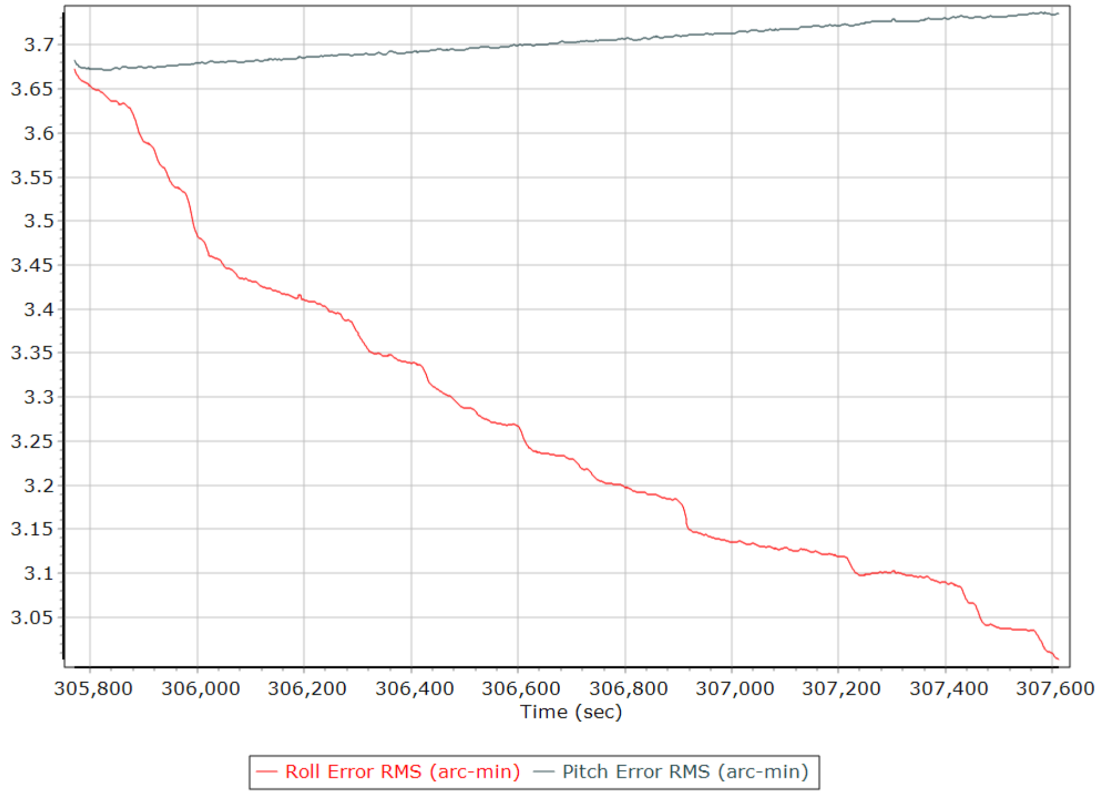
Position Error RMS (m)



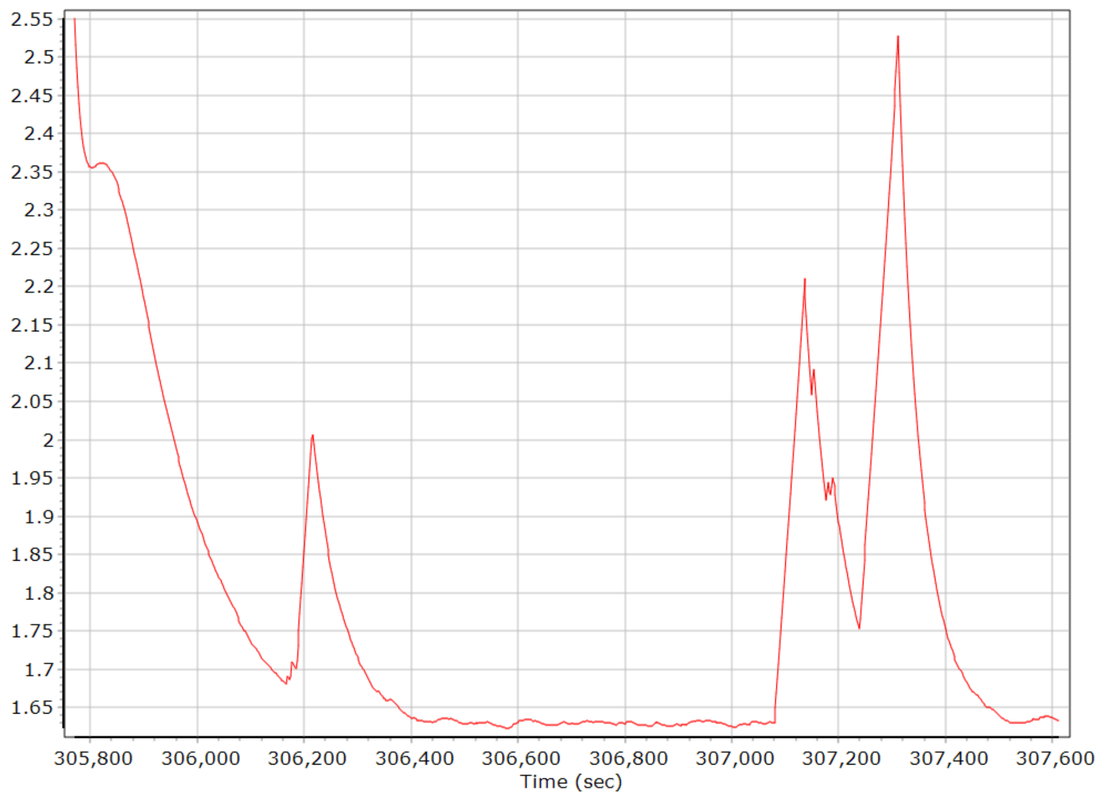
Velocity Error RMS (m/s)



Roll/Pitch Error RMS (arc-min)

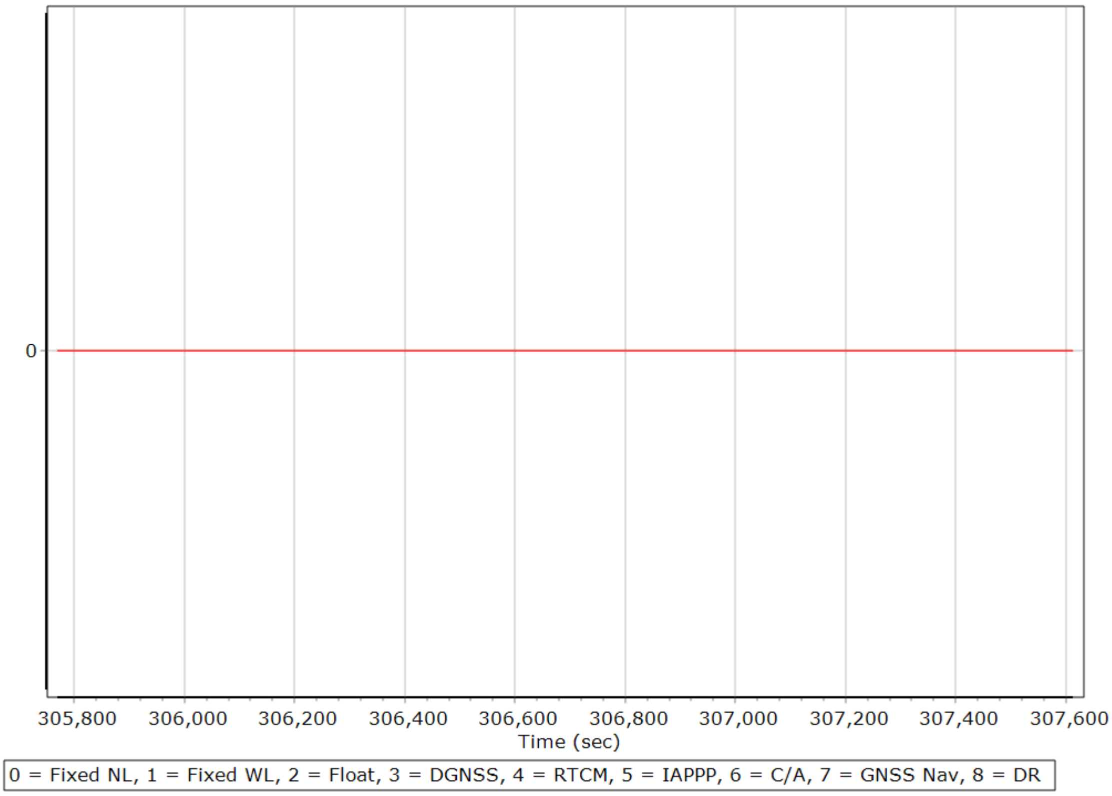


Heading Error RMS (arc-min)

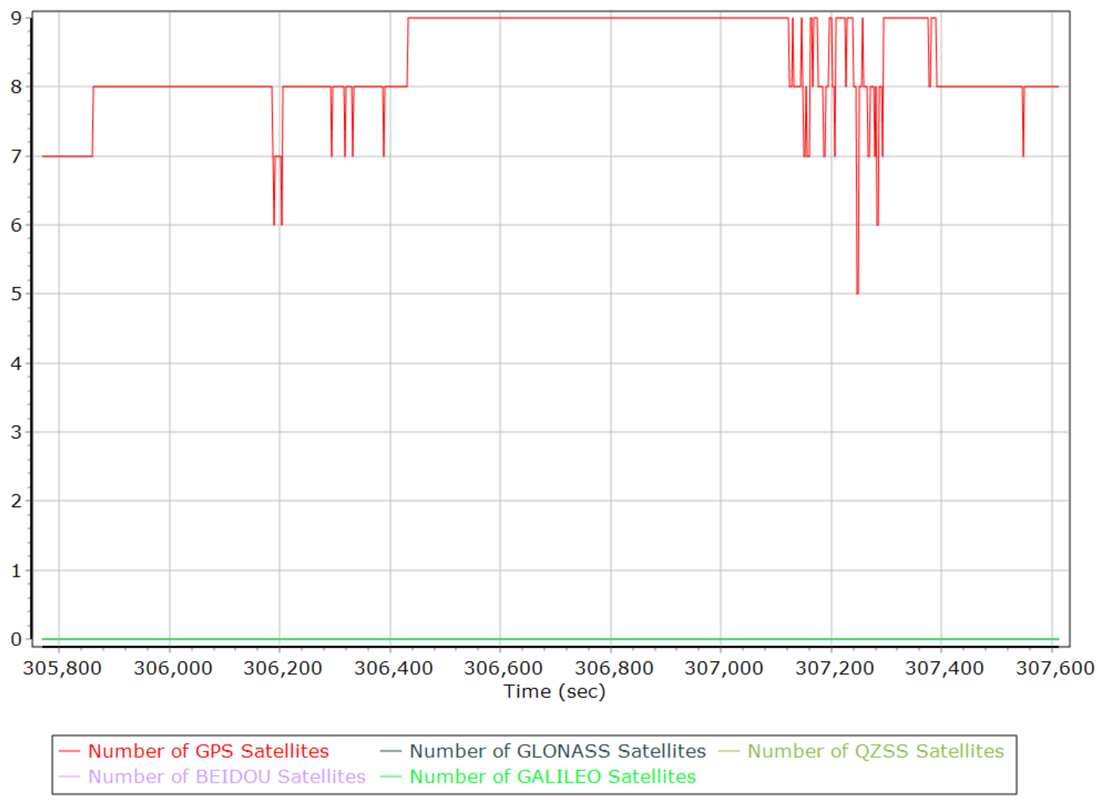


Smoothed Solution Status

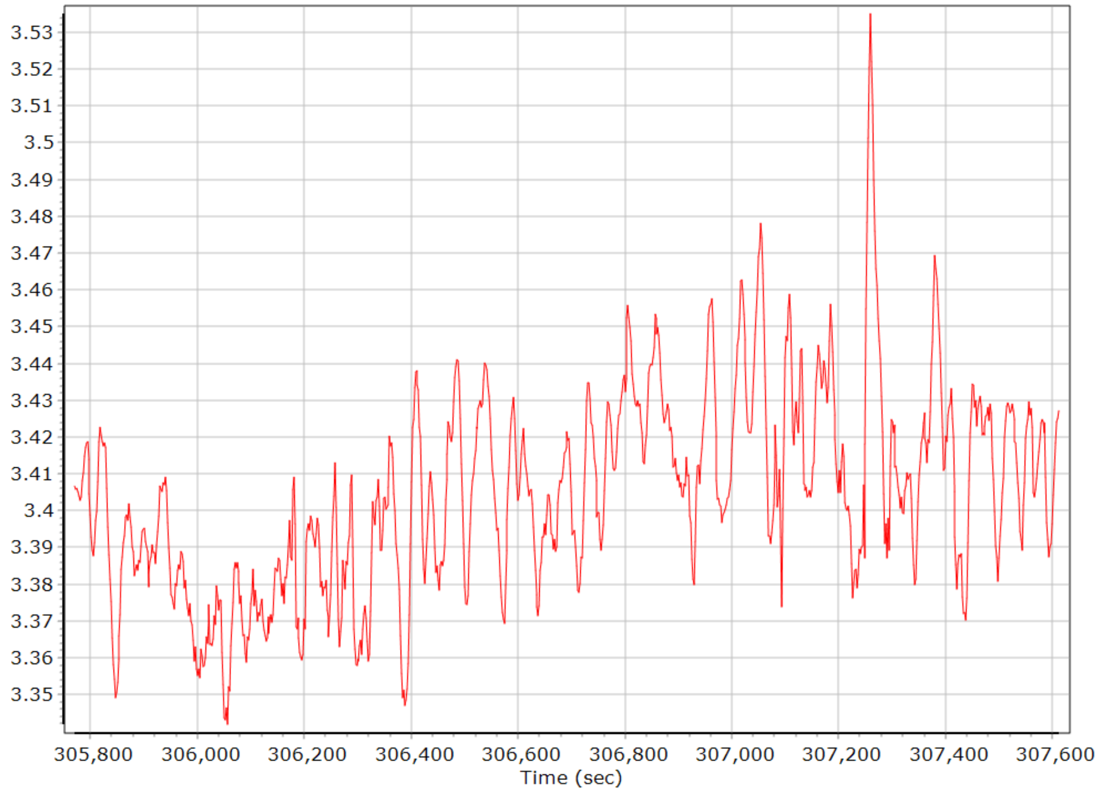
Processing Mode



Number of Satellites

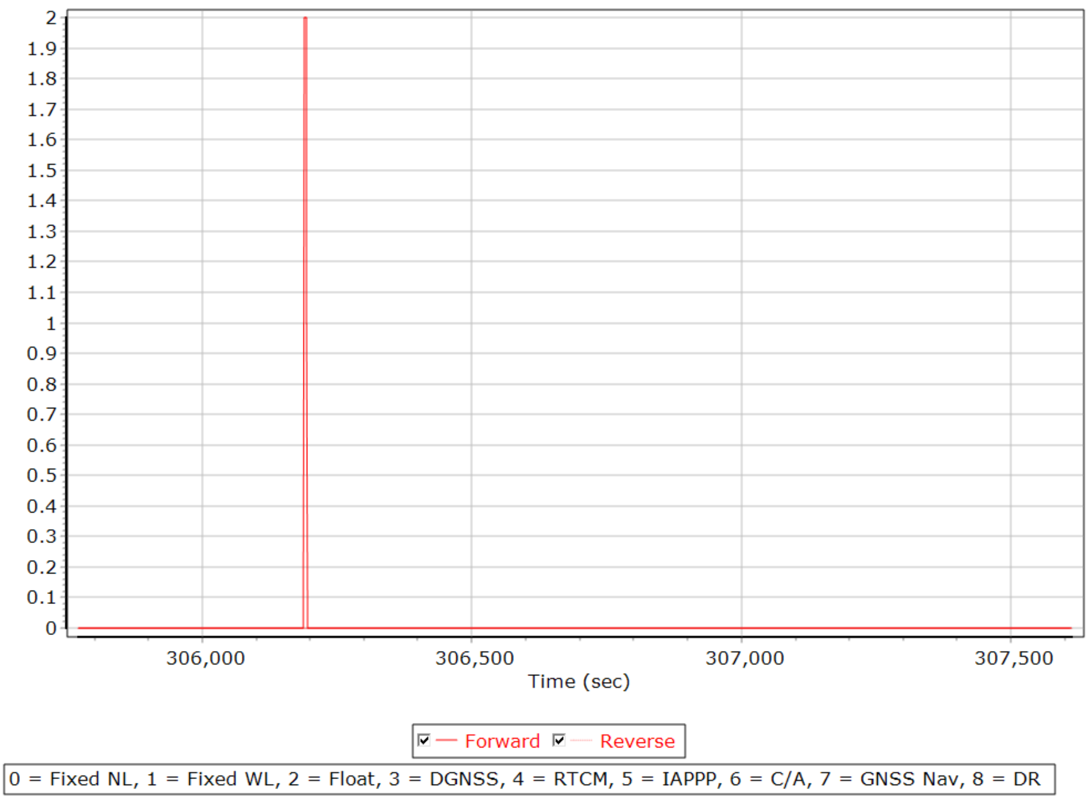


Baseline Length

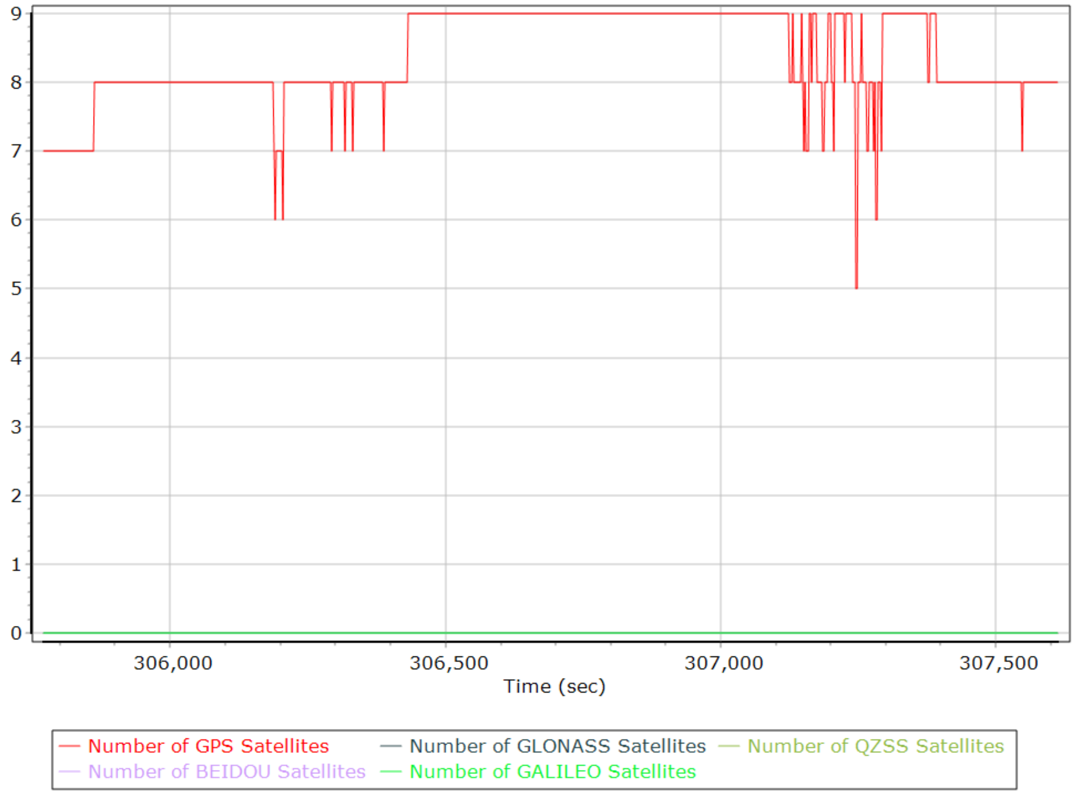


Forward Processed Solution Status

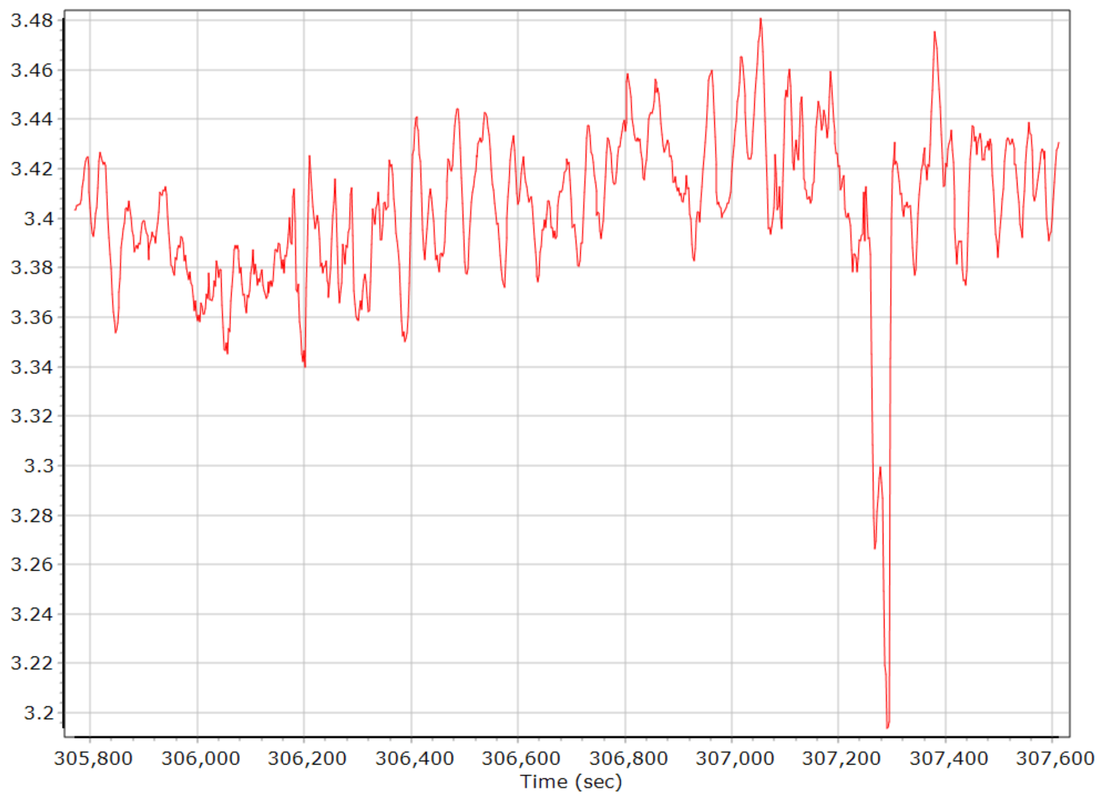
Processing Mode



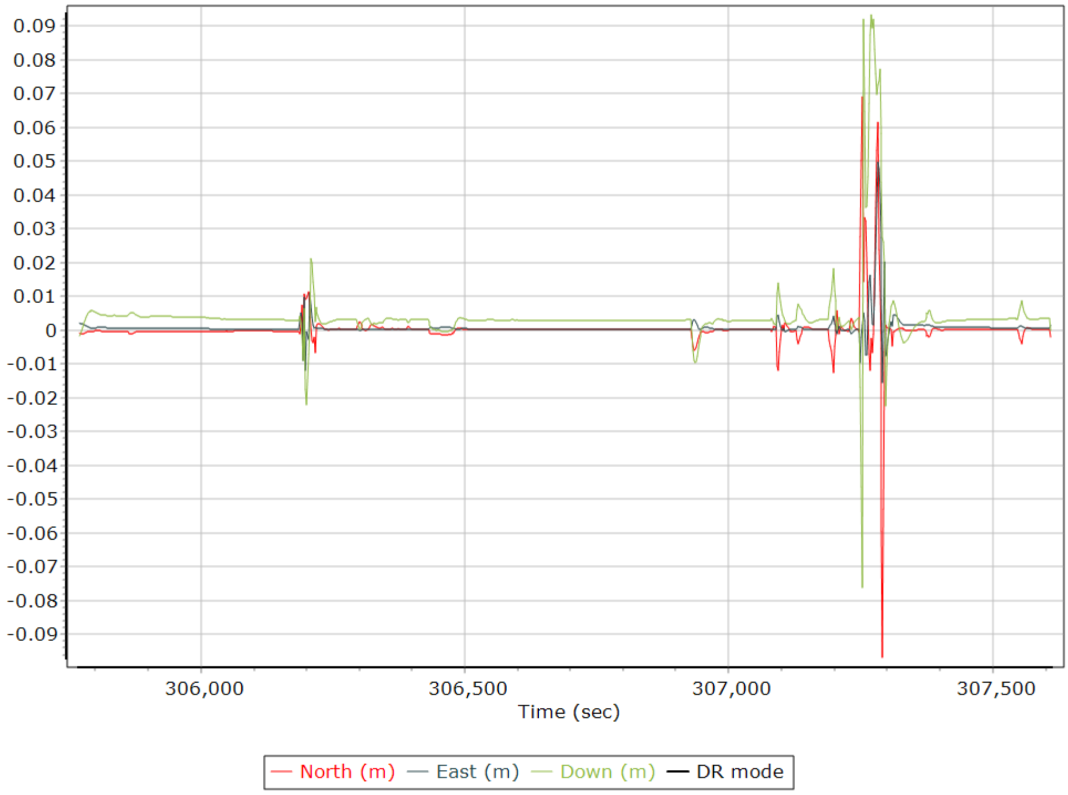
Number of Satellites



Baseline Length



SBET IAKAR Separation



Export Summary

Export file	ASCII_R5002_20220525_1254-1326_SmartBase.txt		
Export format	ASCII		
Solution in use	Post-processed		
Output rate	Specified Time Interval		
Time Interval (sec)	1.000		
Reference to Output lever arm (m)	0.000	0.000	0.000
Reference mounting angles (deg)	0.000	0.000	0.000
Output units (Coordinate / Lat & Lon)	Meter	Deg Decimal	
Export start time	305731.005 (5/25/2022 12:55:31 PM)		
Export end time	307613.005 (5/25/2022 1:26:53 PM)		
Height option	Ellipsoid Height		
WGS84 height flag	False		
Grid	Universal Transverse Mercator		
Zone	UTM North 17 (84W to 78W)		
Datum	WGS84		
Ellipsoid	WGS84		
Local Transformation	NONE		
Target Epoch	2022.394521		

SonTek

a xylem brand

9940 Summers Ridge Road
San Diego, CA 92121
Tel: (858) 546-8327
support@sontek.com

CALIBRATION CERTIFICATE

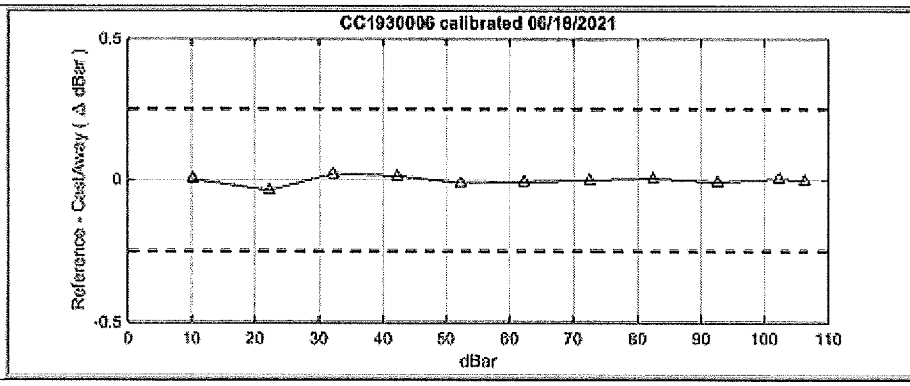
SYSTEM INFO

System Type	CastAway-CTD
Serial Number	CC1930006
Firmware Version	1.63
Date	06/21/2021

POWER CONSUMPTION

Standby Mode (A)	0.2295 / PASS
Supply Voltage	2.9V

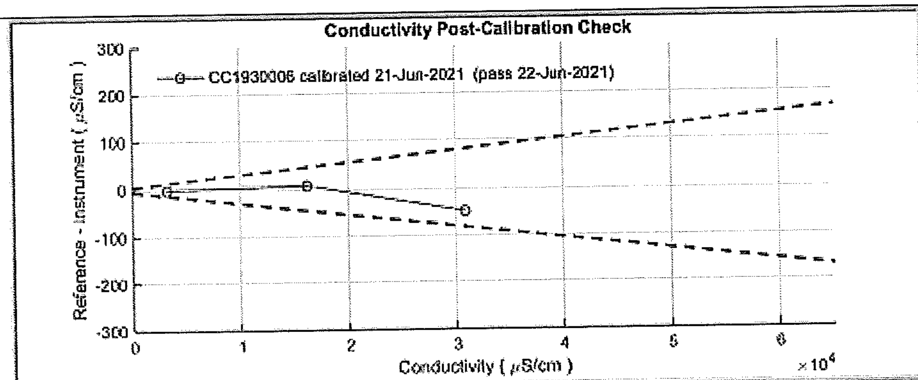
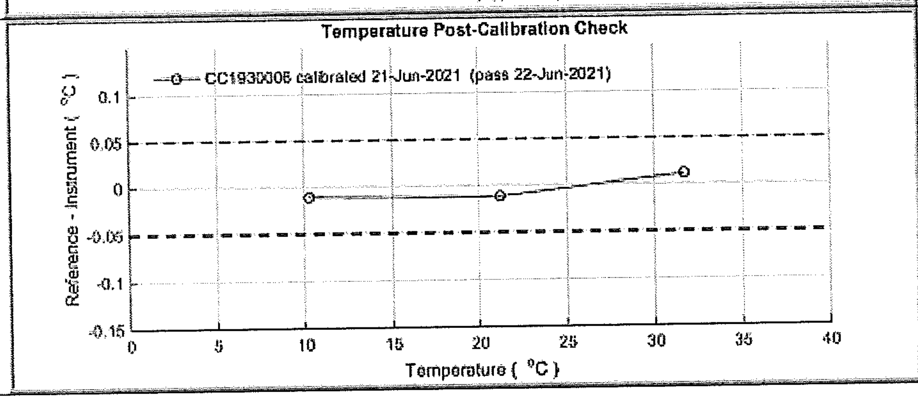
CALIBRATION

GPS	Passed
Pressure	

SonTek

a xylem brand

9949 Summers Ridge Road • San Diego, CA 92121 • Telephone (858) 546-8327 • Fax (858) 546-8150 • Internet: www.sontek.com

Conductivity	
Temperature	

Verified by: jcadena
This report was generated on: 6/23/2021

ATTENTION: New Warranty Terms as of March 4, 2013:
This system is covered under a two year limited warranty that extends to all parts and labor for any malfunction due to workmanship or errors in the manufacturing process. The warranty is valid only if you properly maintain and operate this system under normal use as outlined in the User's Manual. The warranty does not cover shortcomings that are due to the design, or any incidental damages as a result of errors in the measurements.
SonTek will repair and/or replace, at its sole option, any product established to be defective with a product of like type. CLAIMS FOR LABOR COSTS AND/OR OTHER CHARGES RESULTING FROM THE USE OF SonTek GOODS AND/OR PRODUCTS ARE NOT COVERED BY THIS LIMITED WARRANTY.
SonTek DISCLAIMS ALL EXPRESS WARRANTIES OTHER THAN THOSE CONTAINED ABOVE AND ALL IMPLIED WARRANTIES, INCLUDING BUT NOT LIMITED TO WARRANTIES OF MERCHANTABILITY AND/OR FITNESS FOR A PARTICULAR PURPOSE. SonTek DISCLAIMS AND WILL NOT BE LIABLE, UNDER ANY CIRCUMSTANCE, IN CONTRACT, TORT OR WARRANTY, FOR ANY SPECIAL, INDIRECT, INCIDENTAL OR CONSEQUENTIAL DAMAGES OF ANY KIND, INCLUDING BUT NOT LIMITED TO LOST PROFITS, BUSINESS INTERRUPTION LOSSES, LOSS OF GOODWILL, OR LOSS OF BUSINESS OR CUSTOMER RELATIONSHIPS.
If your system is not functioning properly, first try to identify the source of the problem. If additional support is required, we encourage you to contact us immediately. We will work to resolve the problem as quickly as possible.
If the system needs to be returned to the factory, please contact SonTek to obtain a Service Request (SR) number. We reserve the right to refuse receipt of shipments without SRs. We require the system to be shipped back in the original shipping container using the original packing material with all delivery costs covered by the customer (including all taxes and duties). If the system is returned without appropriate packing, the customer will be required to cover the cost of a new packaging crate and material.
The warranty for repairs performed at an authorized SonTek Service Center is one year.

SonTek
a xylem brand

9940 Summers Ridge Road
San Diego, CA 92121
Tel: (858) 546-8327
support@sontek.com

CALIBRATION CERTIFICATE

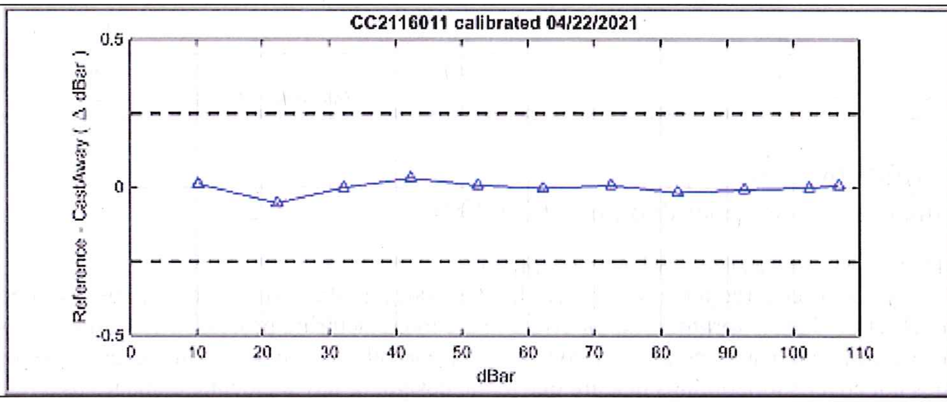
SYSTEM INFO

System Type	CastAway-CTD
Serial Number	CC2116011
Firmware Version	1.63
Date	04/29/2021

POWER CONSUMPTION

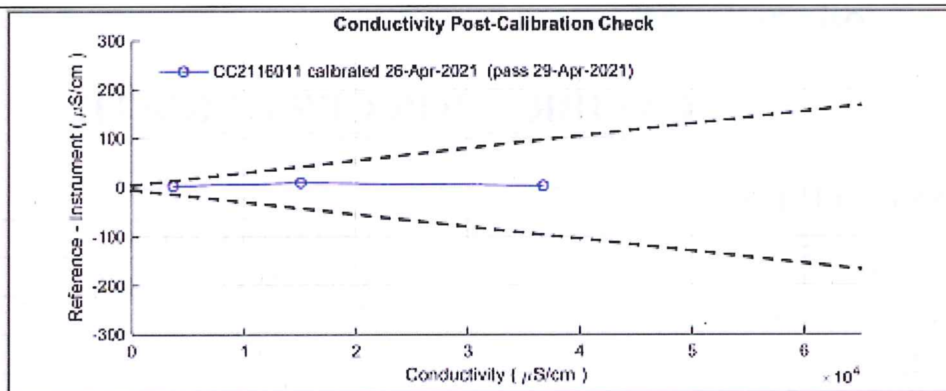
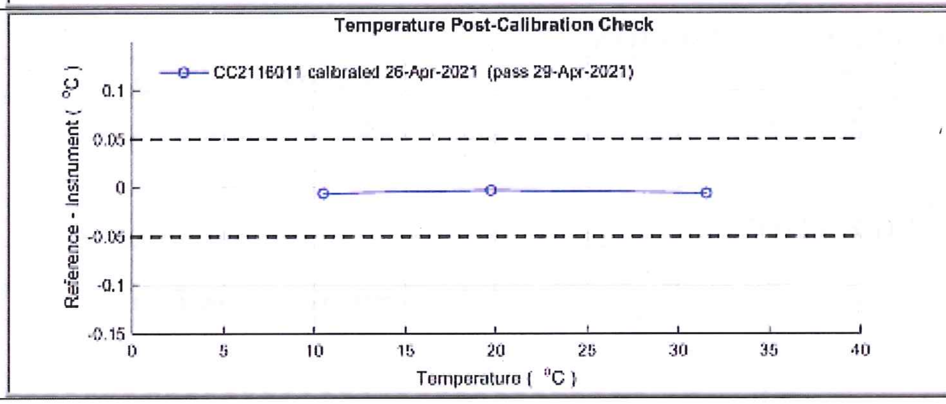
Standby Mode (A)	0.2764 / PASS
Supply Voltage	2.9V

CALIBRATION

GPS	Passed
Pressure	

SonTek
a xylem brand

9949 Summers Ridge Road • San Diego, CA 92121 • Telephone (858) 546-8327 • Fax (858) 546-8150 • Internet: www.sontek.com

Conductivity	
Temperature	

Verified by: ale
This report was generated on: 4/29/2021

ATTENTION: New Warranty Terms as of March 4, 2013:
This system is covered under a two year limited warranty that extends to all parts and labor for any malfunction due to workmanship or errors in the manufacturing process. The warranty is valid only if you properly maintain and operate this system under normal use as outlined in the User's Manual. The warranty does not cover shortcomings that are due to the design, or any incidental damages as a result of errors in the measurements.
SonTek will repair and/or replace, at its sole option, any product established to be defective with a product of like type. CLAIMS FOR LABOR COSTS AND/OR OTHER CHARGES RESULTING FROM THE USE OF SonTek GOODS AND/OR PRODUCTS ARE NOT COVERED BY THIS LIMITED WARRANTY.
SonTek DISCLAIMS ALL EXPRESS WARRANTIES OTHER THAN THOSE CONTAINED ABOVE AND ALL IMPLIED WARRANTIES, INCLUDING BUT NOT LIMITED TO WARRANTIES OF MERCHANTABILITY AND/OR FITNESS FOR A PARTICULAR PURPOSE. SonTek DISCLAIMS AND WILL NOT BE LIABLE, UNDER ANY CIRCUMSTANCE, IN CONTRACT, TORT OR WARRANTY, FOR ANY SPECIAL, INDIRECT, INCIDENTAL OR CONSEQUENTIAL DAMAGES OF ANY KIND, INCLUDING BUT NOT LIMITED TO LOST PROFITS, BUSINESS INTERRUPTION LOSSES, LOSS OF GOODWILL, OR LOSS OF BUSINESS OR CUSTOMER RELATIONSHIPS.
If your system is not functioning properly, first try to identify the source of the problem. If additional support is required, we encourage you to contact us immediately. We will work to resolve the problem as quickly as possible.
If the system needs to be returned to the factory, please contact SonTek to obtain a Service Request (SR) number. We reserve the right to refuse receipt of shipments without SRs. We require the system to be shipped back in the original shipping container using the original packing material with all delivery costs covered by the customer (including all taxes and duties). If the system is returned without appropriate packing, the customer will be required to cover the cost of a new packaging crate and material.
The warranty for repairs performed at an authorized SonTek Service Center is one year.

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Ocean Service
National Geodetic Survey
Field Operations Branch

NOAA Boat – R 5002 (STORM)
IMU and MULTI-BEAM Component Spatial Relationship Survey
Field Report

Kevin Jordan
April, 2010

NOAA Boat – R 5002
IMU and MULTI-BEAM Survey

PURPOSE

The intention of this survey was to accurately position the Inertial Measuring Unit (IMU) and MULTI-BEAM (MBES) components for NOAA Research Vessel (R) 5002 (STORM).

PROJECT DETAILS

This survey was conducted on April 7, 2010 at Torresen Marine, 3003 Lakeshore Drive, Muskegon, MI. The boat was set on stands for the installation of components and maintenance. There were no existing bench marks for reconnaissance. New bench marks were set for future recovery.

INSTRUMENTATION

The TOPCON GPT 3000 Series Total Station was used to make all measurements.

A SECO 25 mm Mini Prism System configured to have a zero mm offset was used as target sighting and distance measurements.

SOFTWARE AND DATA COLLECTION

TDS Survey Pro Ver. 4.7.1

ForeSight DXM Ver. 3.2.2 was used for post processing.

PERSONNEL

Kevin Jordan NOAA/NOS/NGS/Field Operations Branch 757-441-3603

Joseph Kordosky NOAA/NOS/NGS/Field Operations Branch 757-441-6265

NOAA Boat – R 5002
IMU and MULTI-BEAM Survey

SURVEY PROCEDURES

New Stations

B – Bow

P – Port

S – Starboard

Centerline – This station was stamped, but not labeled.

G – GPS

M – Moon Pool – Located on top of multibeam sensor at data collection position.

IMU RM – No Photo – This station was stamped, but not labeled. Reference mark located forward of the future installation site of the IMU.

Establishing the Centerline

To conduct this survey a local coordinate reference frame was established, where the X axis runs along the centerline of the boat and is positive from the primary reference point towards the bow of the boat. The Y axis is perpendicular to the centerline of the boat (X axis), and is positive from the primary reference point towards the right, when looking at the boat from the stern. The Z axis is positive in an upward direction from the primary reference point.

A temporary centerline mark (TCL) was established to align horizontally with station "B". This was performed by measuring port to starboard at the stern of the boat and placing a temporary ink mark at the center. The theodolite was setup on this point and initialized on station "B" with an azimuth of 0° 00' 00". The theodolite was turned to an azimuth of 180° 00' 00" and a temporary station was set off the boat on solid ground and labeled TP1. The theodolite was also rotated to an azimuth of 90° 00' 00" and a temporary station, TP2, was set off the boat and on solid ground. The majority of data collection was conducted from these two stations. A third temporary station, TP3, was established to observe station "M" due to its position within the hull of the boat.

POST PROCESSING

Since the project was initialized using assumed positions and elevations, the collected points needed to be translated to a referenced coordinate system. Using ForeSight DXM, our observed IMU RM was translated N 0.000(m), E 0.000(m), and Elev 0.000(m). See table 1

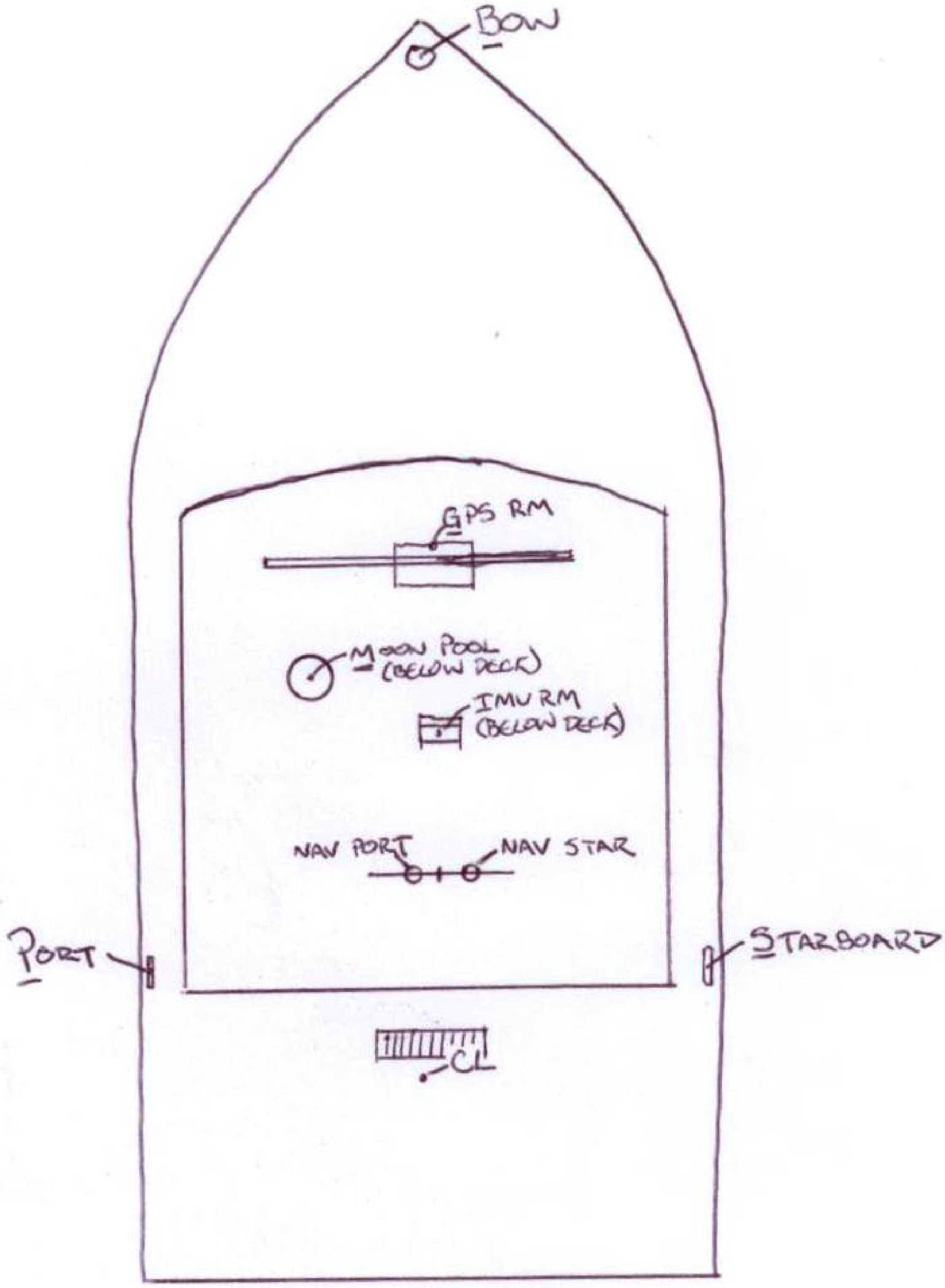
DISCUSSION

All sensor/benchmark coordinates are contained in spreadsheet "R 2010 2010.xls."

The following table includes stations that were observed from more than one setup and for each, an inverse was computed to identify possible setup errors. Each station checked with favorable results.

INVERSE COMPARISON		
NAME	**Horizontal (X,Y) Meters**	**Vertical (Z) Meters**
CK PORT BM	0.019	-0.006
CK STAR BM	0.019	-0.006
CK CL	0.014	-0.006
CK NAV STAR	0.011	0.000
CK MOON POOL	0.003	0.000

NOAA BOAT R 5002 (STORM)			
	Reference Point IMU RM		
NAME	X (Meters)	Y (Meters)	Z (Meters)
CL	-5.080	0.002	0.379
STAR BM	-3.730	2.277	0.480
PORT BM	-3.723	-2.296	0.461
IMU RM	0.000	0.000	0.000
BOW	6.783	0.002	1.530
GPS RM	1.067	-0.011	3.262
NAV STAR	-2.730	0.288	5.580
NAV PORT	-2.669	-0.387	5.460
MOON POOL	0.780	-0.830	-0.284


BOW
GPS RM
MOON POOL (BELOW DECK)
IMU RM (BELOW DECK)
NAV PORT
NAV STAR
PORT
STARBOARD
CL

R5002 - STORM

Appendix B Multibeam Sonar Data Processing Workflow

Detailed geophysical data processing workflows are herein provided to report their stepwise completion as utilized during WSCNMS site mapping operations. Three main tasks were associated with rendering sonar and navigation data into final outputs: file management, navigation data processing, and sonar data processing. File management encompassed the organization, naming, and backup of all project data and is addressed separately in Appendix C. While integral to geophysical mapping tasks, file management occurred throughout all aspects of WSCNMS site mapping operations including project planning, mobilization, data acquisition, as well as data processing, deliverable generation, reporting, and data delivery. File management task scope, therefore, extended beyond multibeam sonar mapping and processing tasks outlined in this appendix.

Navigation data processing involved the import of raw INS files into a workspace where they were combined with correction files used to compute refined position and motion reference information. Outputs from navigation processing were then used to improve sonar data quality. Sonar data processing involved the application of numerous correction sources—sound velocity, vertical datum adjustments, and the processed navigation files—to acquired sonar files before the generation of preliminary data products. As new files were collected they were treated thusly and added to the preliminary archive. Meanwhile, comprehensive point cloud cleaning was completed on all imported sonar files. Cleaning of the files after corrections were applied rendering a cleaned, deliverable-quality archive of sonar data. From this archive, final outputs were generated.

Navigation Data Processing

During survey operations, the Applanix INS recorded POSPac files storing data on the system's position, heading, timing, and motion at a rate of 100 Hz, or 100 samples per second. These files were post-processed on a rolling, 24-hour basis as daily GNSS correction and ephemeris data became available on the internet for this purpose (post-processed GNSS navigation improvements). When incorporated, these correction sources were merged with information extracted from POSPac files and subjected to a workflow whereby improved vessel position and motion was computed via removal of real-time ambiguities. This workflow produced a smoothed best estimate of trajectory (SBET) file at the termination of each day's processing which greatly improved horizontal and vertical reference within the navigation data. As SBET files were generated, they were stored for later incorporation into the multibeam sonar processing workflow to overwrite stored sounding reference with the improved solution.

All navigation data processing results were tracked in a digital data processing worksheet saved as an Excel workbook in the following project directory:

6-Logs\3-Data_Processing_Log\ 202210_POSPac_SBET_Log_ProcessingResults.xlsx

Employing an Excel workbook template sheet, each processing day's results were captured on a single sheet with sheet-naming derivative of raw data record. Each day's entry captured processing parameters and results as well as auto-generated names for the Applanix Mobile Mapping Suite (MMS) processing project and output SBET files.

Raw navigation and motion data were recorded by the Applanix POSMV inertial navigation system throughout project operations. Standard procedure required logging INS navigation data for no less than 20 minutes prior to sonar data recording as well as a minimum of 20 minutes after the cessation of sonar data recording. Since all WSCNMS site mapping operations onboard R5002 were daylight-only, all INS navigation data was naturally confined to separate 24-hour periods separated by UTC midnight. Since sonar data recording was likewise separated into daily intervals, post-processing flows were managed by developing a dedicated sonar data archive for each day which was paired with its corresponding navigation corrections. This allowed for a 1:1 parity between sonar archives and processed navigation outputs.

Raw INS navigation files were stored in a raw data directory folder named according the following convention:

2-Raw_Data\R5002\Positioning_and_INS\POSMV_Raw\yyyymmdd

Raw INS files were named according to the following convention:

RNNNN_yyyymmdd.000

Where:

R: NOAA vessel prefix designator
NNNN = NOAA vessel number or name
yyyy= calendar year, number
mm= calendar month, number
dd= calendar day, number

Files were logged at a rate of 100 Hz and set at a maximum size of 128 MB. When the file size limit was reached the program automatically initiated recording of the next file, indicated by a single positive integer increase in the file extension digits, e.g. .000 to .001 to .002, etc.

Processing of raw INS navigation files took place in the Applanix Mobile Mapping Suite (MMS), version 8.7, with version 8.7 Service Pack 2 installed. The workflow for the Applanix MMS processing is as follows:

- Open Applanix MMS 8.7, create a New Default Project template
- Open navigation processing log spreadsheet (*202210_POSPac_SBET_Log_ProcessingResults.xlsx*)
- Import POSPac files for a given (single) survey day. This was accomplished with a drag-and-drop of selected POSPac files from their raw data archive
- When prompted, define GNSS antenna type (Trimble Zephyr)
- Following file import, verify map extents, real-time vehicle frame track plot, and file recording start/end times (checked versus Online Log for POSPac file recording times).
- Create new sheet in processing log for survey day; transfer file recording date/times to sheet and use derived POSPac project name from logbook to save Applanix MMS project in local directory workspace.

- Confirm Lever Arm Offsets, GAMS Parameters, and IMU Offsets relative to vessel installation parameters in MMS project settings (under GNSS-Inertial Processor branch).
- Download and import base station data; utilizing Applanix SmartBase search option; initiate via "Find Base Stations" option on toolbar ribbon.
- Set an Applanix SmartBase reference network; initiate via "Applanix SmartBase (ASB)" option on the toolbar ribbon.
- Review and copy GNSS QC Statistics output to the DP log.
- Run GNSS Inertial Processor** through all steps to completion.

**Any anomalies, termination, or other errors which manifest in the two steps prior need to be diagnosed through the Message Logs and Display Plots and appropriately mitigated.

- When completed, review map extends for processed vehicle frame; copy screen grab of map to processing log.
- Review and copy time-series plot of SBET altitude to processing log; set min/max extents to 149/153 m at a 0.1 m grid interval.
- Review and copy time-series position error statistics plots to processing log (north, east, and down); set min/max extents to 0.01/0.1 at a 0.01 m grid interval.
- Review display plots for Solution Status, GAMS solution, and satellite connection.
- Begin the SBET export process; review sensor frame (use vessel CRP) and copy settings to processing log. Review export file type, interval settings, and geodetic parameters and copy settings to processing log. Set a custom mapping frame based on 9 June 2022 transformation parameters.
- Utilize auto-generated SBET file name from processing log to define export SBET file name.
- Export SBET file (.OUT).
- Copy SMRMSG error statistics file for Applanix project PROC folder to EXPORT folder; overwrite default SMRMSG file name with auto-generated error statistics file name in processing log.
- Save and close Applanix MMS project; copy entire project to PROCESSED data folder in project archive. Copy SBET and SMRMSG files to the SBET archive also within the PROCESSED data folder.

File naming for the SBET files will be auto-generated in the processing log as follows:

SBET_R5002_yyyymmdd_[SOL-EOL]_StationType.OUT

Where:

SBET = smoothed best estimate of trajectory
yyyy= calendar year, number
mm= calendar month, number
dd= calendar day, number
[SOL-EOL]= start of logging time – end of logging time in hhmm, UTC
StationType= correction station, e.g. SmartBase

File naming for the SMRMSG files (saved in the Applanix .OUT format) as follows:

SMRMSG_R5002_yyyymmdd_[SOL-EOL]_StationType.OUT

Where:

SMRMSG = RMS error statistics message file
yyyy= calendar year, number
mm= calendar month, number
dd= calendar day, number
[SOL-EOL]= start of logging time – end of logging time in hhmm, UTC
StationType= correction station, e.g. SmartBase

Both output file types were stored in the following directory:

3-Process\R5002\1-Data\POSPac\SBET

Sonar Data Processing

Multibeam sonar files were recorded in the Kongsberg Maritime .ALL file format with data logging managed through their SIS software interface. The SIS interface incorporated measured offsets between the INS reference point (atop the IMU) and the phase center of the MBES head. While in operation, SIS accounted for these offsets while assigning positions to each ping as well as during computation of motion occurring at the MBES head as a lever arm relative to the IMU. As a result, recorded raw (.ALL) files could be processed with raw navigation adjusted to the location of the MBES head without requiring any additional offsets within the CARIS vessel file. Likewise, since real time position was output from the INS at the node established atop the IMU, SBET corrections based on this same reference frame were generated and supplied for sonar corrections.

HYSWEEP files, on the other hand, were recorded for archival and backup purposes only. A real time coverage map (.MTX) file was produced in the HYPACK Survey program during data acquisition. This assisted online surveyors with ensuring coverage between adjacent sonar lines. The HYPACK Survey program, however, experienced frequent daily crashes which prevented iterative saving of the coverage maps. As a result, preliminary coverage files were exported from CARIS each day and supplied to the boat to establish the limits of the prior day's coverage in the absence of a reliable HYPACK file set.

Raw file logging was manually controlled by the online surveyor. Kongsberg Maritime sonar files were stored in a default SIS directory on the computer workstation and then copied (daily) to the raw data archive folder on the same workstation. This folder's pathway within the project archive was as follows:

2-Raw_Data\R5002\MBES_SIS\EM_2040\yyyymmdd

Raw Kongsberg sonar files were named according to the following convention:

nnnn_yyyymmdd_hhmmss_R5002.ALL

Where:

nnnn = iterative 4-digit file count, ascending

yyyy= calendar year, number
mm= calendar month, number
dd= calendar day, number

Sonar files were logged continuously while online up to a maximum single file recording time of 30 minutes per file. When logging continued beyond this time limit, a new file automatically started without any interruption in data coverage. SIS immediately began writing the new file and applying a new file name as well. As previously mentioned, at the end of each operational day, sonar files were copied from the default SIS data archive to the project archive on the data acquisition computer (DAC). Consolidation of raw files into the archive, which applied an identical folder schema used in the field office, allowed for simple data transfers using directory synchronization instead of manual file or folder copying.

All sonar data processing took place in the CARIS HIPS and SIPS software, version 11.4. Workflow steps and results were noted in a digital data processing worksheet saved as an Excel workbook in the 202207 project directory pathway below. This workbook tracked project file management, workflow progress, and QA/QC task completion. A copy of this logbook is provided in Appendix E.

6-Logs\3-Data_Processing_Log\ 202210_Data_Processing_Log_CARIS.xlsx

To begin the workflow, a given day's sonar files were imported into the CARIS processing project. The file import process followed the steps outlined in Appendix F: CARIS Manual Workflow Reference Document. Since the CARIS stored pathways to file inputs, it was necessary to complete all the file management tasks prior to importing sonar files into the CARIS project. To manage other files generated during sonar data processing, in particular the HIPS directories produced through the conversation of raw sonar files, a standardized CARIS project directory was established with the pathway below and used the organization presented in Table 9.

3-Process\R5002\1-Data\CARIS\202210_GLRI_Benthic_Mapping

Within this directory, each daily import of raw sonar files generated a corresponding HIPS directory. Likewise, SVP files that were collected online and converted to the.SVP format were stored, unsorted, within a common folder. Separation model files used to convert recorded ellipsoidal heights to orthometric heights referencing IGLD85 LWD were also saved within the project. A copy of R2802's CARIS vessel file was stored in a dedicated file. Lastly, assorted background files—NOAA nautical charts, AOI boundary shapefiles, etc.—were placed in a folder for quick visualization alongside acquired data. Fixed resolution surfaces generated and updated during processing were sorted into a folder named QA_QC_Surfaces. Lastly, an export directory was established for file outputs made during processing tasks.

Table B1. CARIS HIPS and SIPS Project directory structure used during WSCNMS for managing sonar data processing tasks.

Project Folder	Sub-Folder	File Name
202210_WSCNMS_Doc_Sites	14901	14901_1.KAP
	14903	14903_1.KAP | 14903_2.KAP | 14903_3.KAP
	14904	14904_1.KAP | 14904_2.KAP | 14904_3.KAP | 14904_4.KAP | 14904_5.KAP
	yyyymmdd	yyyymmdd.hips | TrackLines_yyyymmdd
	Export	[various file formats of output products]
	HeightModel	WSCNMS_VDatum_WGS84-LWD_IGLD85.csar
		WSCNMS_VDatum_WGS84-LWD_IGLD85.csar0
		WSCNMS_VDatum_WGS84-LWD_IGLD85.log
	QA_QC_Surfaces	20220609_sites_025M.csar | 20220609_sites.csar | 20220610_sites.csar | 20220612_sites_035M.csar | 20220612_sites.csar | 20220615_SC_025M.csar | 20220615_sites.csar
	Raw_Files	[yyyymmdd] folder containing daily .ALL sonar files
	SBET	SBET_R5002_yyyymmdd_SOL-EOL_SmartBase.out | SMRMSG_R5002_yyyymmdd_SOL-EOL_SmartBase.out
	SVP	[InstrumentID]_yyyymmdd_hhmmss_[DailyCastNumber].svp
	Vessel File	2022_R5002_EM2040C.hvf
		202210_WSCNMS_Doc_Sites.proj

The workflow used for multibeam sonar data processing in CARIS HIPS and SIPS proceeded as follows:

- Raw Kongsberg Maritime sonar file (.ALL) import.

  If first day:

- Define .ALL to HIPS conversion settings including proper geodetics (raw files in WGS 84 UTM Zone 15N); settings should follow guidelines in the ***CARIS Manual Workflow Reference.***

  Else:

- Verify .ALL >> HIPS settings prior to file imports.
- Define new HIPS file for acquisition day, named using the *yyyymmdd* format; saved to HIPS_dirs folder.
- Define R5002 vessel file.
- Upon import verify inclusion of all files into newly created HIPS directory; e.g. if 10 files were input ensure 10 track lines result otherwise check Output Log for error messages.
- Verify imported track lines appear on map in proper location.

Prior to SBET file generation

- Georeference Bathymetry with Sound Velocity Correct, TPU, and Vertical Reference (None).
- Consult ***CARIS Manual Workflow Reference*** documentation for parameters in setting established in the Georeference Bathymetry utility.
- Add any new SVP files into the CARIS project as an addition to other referenced SVP files.
- Select SVP correction based on Nearest in Distance within Time; set time to 4 hours.
- Use default TPU settings.
- DO NOT VERTICALLY REFERENCE PRIOR TO SBET UPLOAD.
- Once referenced, export raw track line information per the schema contained in the *daily_TL_export.xml* file to the \Export folder as *yyyymmdd_rawtracks.txt.*
- Export georeferenced, raw track lines as a shapefile to *5-Products\Tracklines\MBES\RAW.*

When SBETs are available:

- Import the Applanix SBET and SMRMSG files corresponding to the newly created HIPS directory (1:1) using the FILE>>IMPORT>>ANCILLARY DATA>>Applanix [SBET];[RMS] command. Ensure each set of Applanix files is applied only to the corresponding HIPS directory.
- Monitor message log in the Output pane to see that SBET and RMS message records are applied to individual track lines.
- Georeference files with Sound Velocity Correction, TPU, and Vertical Reference (GPS).
  - Consult ***CARIS Manual Workflow Reference*** documentation for parameters in setting established in the Georeference Bathymetry utility.
  - Add any new SVP files into the CARIS project as an addition to other referenced SVP files.
  - Select SVP correction based on Nearest in Distance within Time; set time to 4 hours.
  - Use default TPU settings.

    - Compute GPS Vertical Adjustment [True] and define/verify separation model file pathways and parameters.
- Run Georeference bathymetry; verify application of SV, SBET, TPU, and vertical corrections applied to each track line via HIPS file information table.
- Verify results (note color change of track lines).

  If first day:

- Generate new fixed resolution 1M surface for QA/QC of coverage and data quality, save to CARIS Project QA_QC_Surfaces folder with logical file name.

  Else:

- Add new lines (selected) to existing fixed resolution surface.
- Recompute existing 1M QA/QC fixed resolution surface.
- Check daily HIPS files for motion and SV artefacts as well as alignment between survey days. Mark coverage gaps for infill or any lines requiring re-run due to data quality errors; note start/end coordinates of gaps and transcribe for addition to vessel online navigation program.
- Export processed track lines as shapefile to directory pathway: *5-Products\Tracklines\MBES\PROC.*
- Save CARIS Project.
- Using the CARIS-DataBackup template in FreeFileSync, update the backup copy of the CARIS processing project in the project data archive.

The steps constituted preliminary data processing steps necessary for basic field QA/QC and technical survey management. Additional processing, however, was required to clean individual sonar files, remove misalignments or artefacts from SV or GNSS height drops, and otherwise clean raw soundings. These steps included:

- Individual track line point cloud cleaning in the CARIS SWATH EDITOR utility.
- Spot cleaning of multiple line areas in the CARIS SUBSET EDITOR utility.
- Backscatter surface generation (via SIPS Mosaic engine) upon completion of point cloud cleaning.
- Gridded surface file export at minimum mapping unit of 1M, higher resolution where sounding density was sufficient to prevent gaps in the gridded files (e.g. at more shallow sites).

CARIS Manual Workflow Reference

NOAA Kongsberg MBES Manual Workflow SOP for CARIS HIPS 11

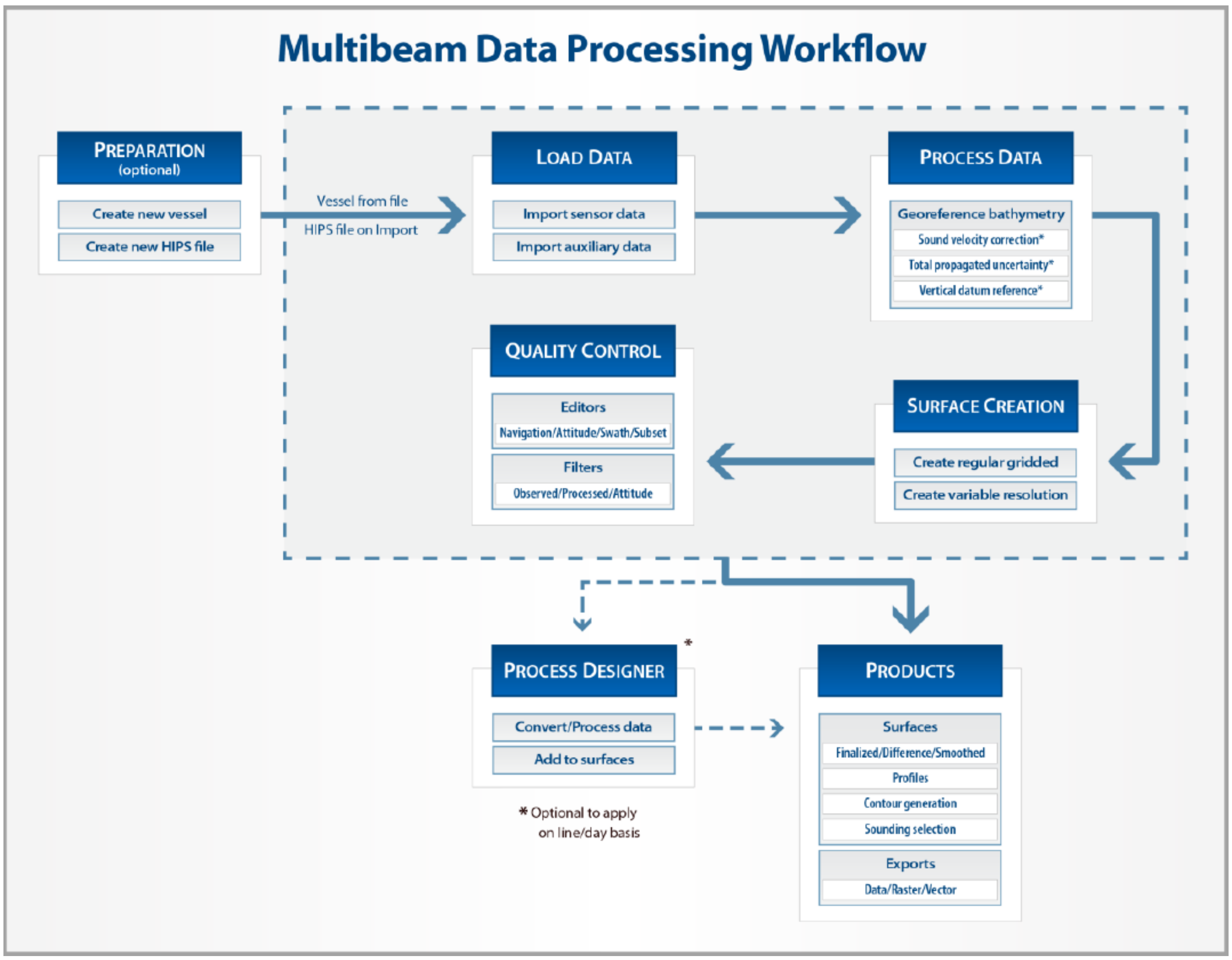
John Doroba, HSTB, March 2020, v11.3.0

NOAA hydrographic platforms use Kongsberg multibeam echosounders (MBES) for bathymetric data acquisition. The reference point (RP) for Kongsberg systems is at the phase center of the transmit array. One exception to this rule is the NOAA Ship Thomas Jefferson, which has two Kongsberg MBES and one IMU that is the RP for both MBES systems. NOAA accounts for this via HVF files.

When Installing HIPS/SIPS or License Manager, use .exe, not .msi file

Procedure

There are several new changes to HIPS including direct read of raw data (no need for HVF), changes to the "Merge" process (Georeference Bathymetry), HDCS file structure modified (no longer required to maintain CARIS directory structure except line folders), improved rendering times, and GUI modification (New windows and methods).



Create New HIPS File

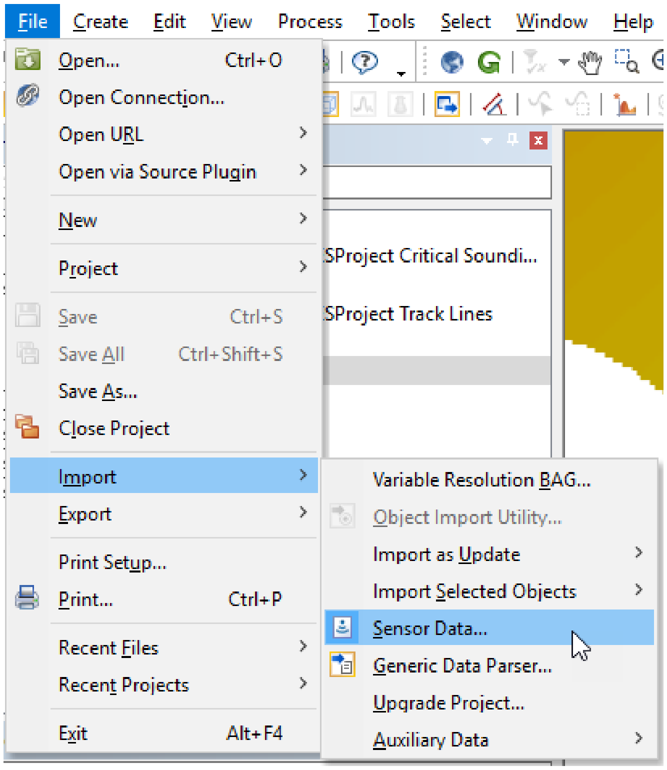
Conversion

HIPS 11 allows the user to import all data directly from the raw data format without an HVF. However, certain TPU values are not present in the raw data and cannot be input directly into the data. If TPU values are not present, then CUBE surfaces cannot be computed. CUBE surfaces are a required NOAA deliverable. Therefore, NOAA will still use HVF files. There is no hybrid method, in that the user will either decide to process with a fully populated HVF or not. For example one cannot populate TPU values in HVF and read all other offsets from .all files.

Import Sensor Data

Process used to import raw MBES data into a format that is useable for processing in CARIS.

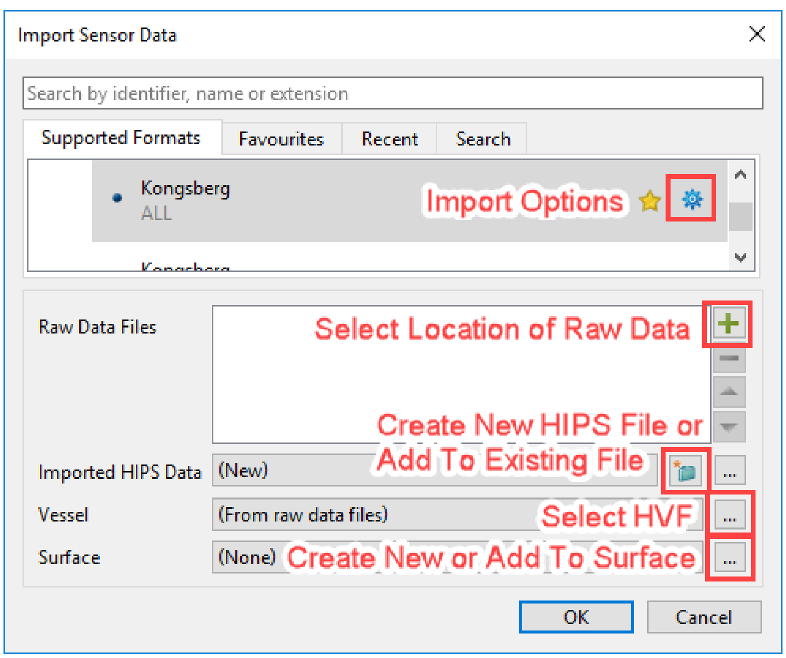
If processing WCD, keep .wcd files in same location as .ALL files. Initial conversion and processing creates links between .hips file and .wcd files during conversion. If they are not present during this process, the link is not created. If they are moved after the fact, the link to .hips file is broken.



CARIS data conversion: Import Sensor Data.

Note: User no longer selects day number when converting data. The converted data is now placed under the day number when logging started. If data is logged past UTC midnight the lines will fall in a different day than they were acquired.

For example, if the ship begins logging on DN001 and logs through and/or after UTC midnight, any data that was started logging after UTC midnight will be converted to DN002.



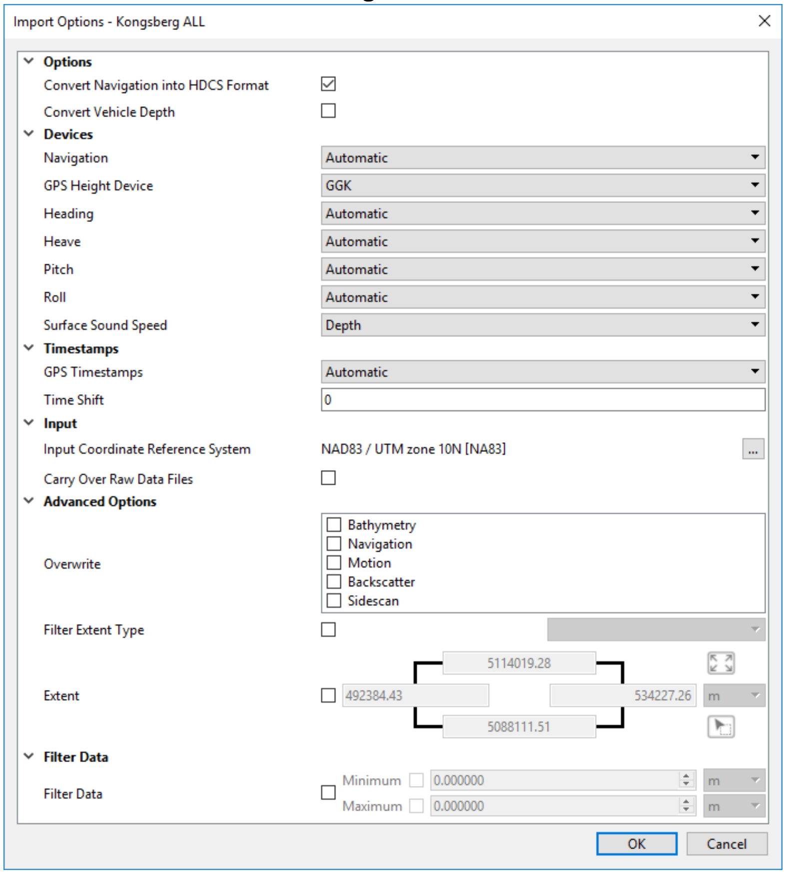
Import Options (Kongsberg) allow user to modify how data will be converted (see below).

Select Raw Data Files. If processing WCD data, the .wcd files will not be selected here. They will automatically be associated with .all and .hips file during conversion.

Select HIPS project. One can also create a new HIPS project at initial conversion.

Select HVF file from preferred location. It is no longer part of HDCS folder and can be stored wherever desired.

A preliminary surface can be created to



Select CARIS Hydrographic Data Cleaning System (HDCS) format in order to work exclusively from CARIS HDCS as opposed to reading/writing corrections to Kongsberg .ALL files.

Do Not Convert Vehicle Depth. Only, select if sonar has associated depth of sensor (ie: AUV).

Select Automatic in order to use datagram that is active in acquisition.

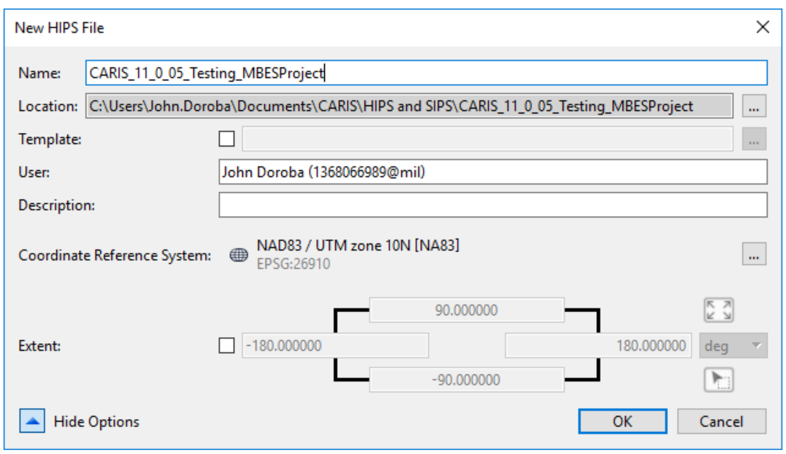
Select GGK which is fleet standard because it contains the ellipsoid height. If the real time solution is sufficient quality, then this could be used without SBETs. It is usually not, and SBETs used to override navigation and height same as GGA, etc.

Select Depth Surface Sound Speed for sound velocity at transducer.

Select Coordinate Reference System of the Raw Data. For Kongsberg, can be left unchecked or as WGS84 (from POS).

Do Not Carry Over Raw Data Files. Only select if one desires a copy of raw .all files in HDCS folder.

Do not apply navigation or depth filters to data during conversion. Depth filtering is mostly used for finer filtering which involves knowing the dataset before applying filters. Navigation filtering is somewhat outdated and served a purpose when GPS fliers were regularly encountered.



Name the project.

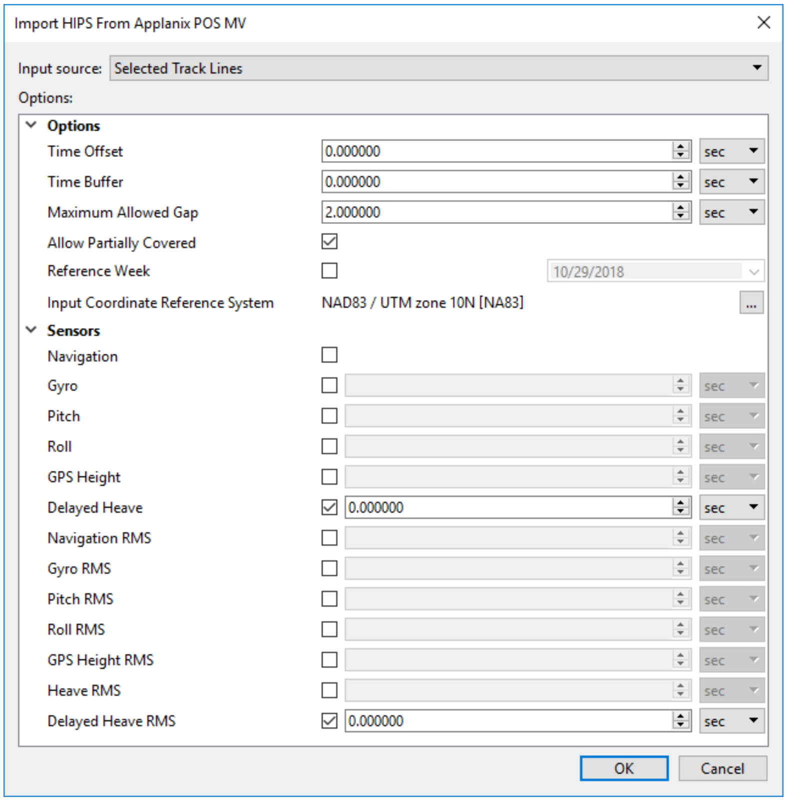
Select project destination.

Select project CRS.

Data is only imported at this point. Corrections are not applied.

Import Auxiliary Data

Delayed Heave



The default Maximum Allowed Gap is 2.0, but can be modified/documented by OPS, CST, etc. to resolve minor issues. Making the gap too large can lead to data artifacts, in which case, the data must be re-acquired.

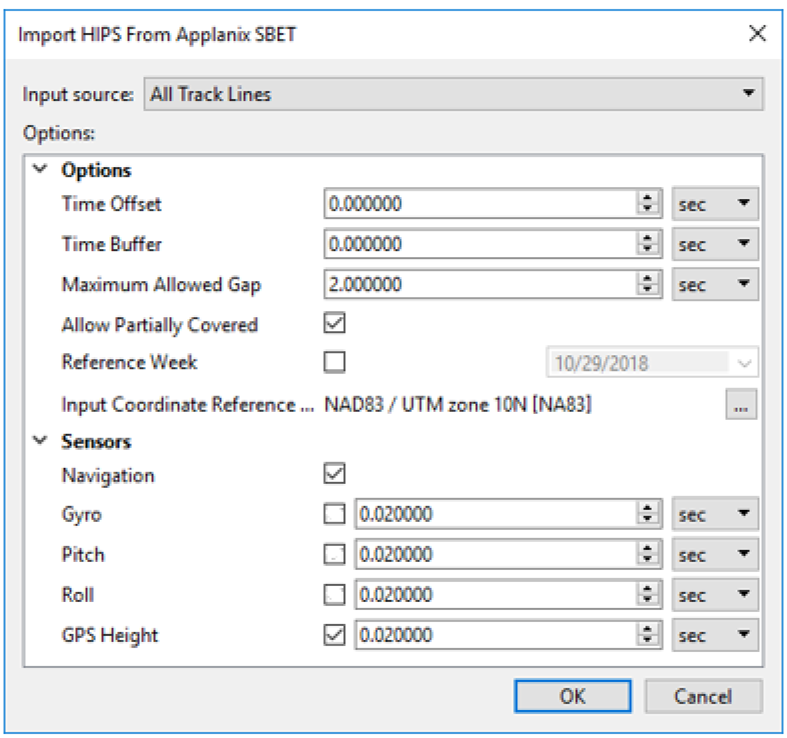
Allow partially covered, but be aware that sections to which the .000 file did not apply may need to be reacquired or another Delayed Heave file.

Select the Reference Week when Delayed Heave files are not the same GPS week as data (data acquired past UTC midnight on Saturday without starting new file).

Select Coordinate Reference System of the POS Data.

Only apply Delayed Heave corrections and error files. Nav/Att will use realtime values corrected via SBET/RMS.

SBET

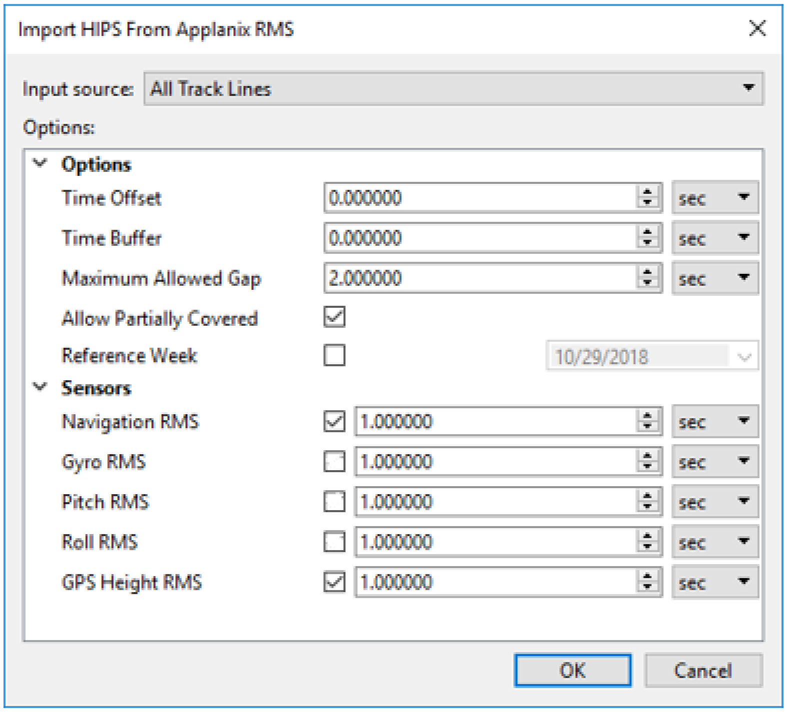


All SBET correctors are applied, but down-sampled because Applanix export data is excessive and output at a higher rate (200 Hz) than we acquire (50Hz).

Select Coordinate Reference System of the SBET Data.

**Attitude is not applied in SBET/RMS because it will overwrite timing offset implemented in SIS. The timing offset (~7-10ms) between the RP and IMU is experimentally derived and accounted for in SIS. Applying SBET/RMS attitude overwrites the offset in Kongsberg data.*

RMS



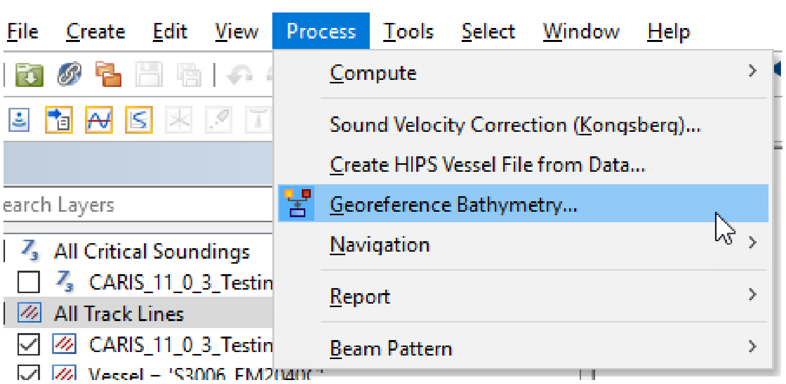
All associated RMS errors are applied, but these are not down-sampled because RMS values are similar to those acquired.

Data is only imported at this point. Corrections are not applied.

Process Data

HIPS 11 combines three processes (sound velocity corrections, TPU computations, and vertical datums transformations) that were performed separately along with “merge” to correctly position each sounding. The process, Georeference Bathymetry, combines the application of vertical and horizontal correctors with the merge function. The user defines the way by which imported data is utilized via the Georeference Bathymetry process. Once these parameters are defined, the process uses the correctors to process the data.

Georeference Bathymetry



This process converts along track/across track depths in raw data into latitude, longitude, and depth by combining the ship navigation with the horizontal and vertical offsets from the HIPS vessel file and ancillary files (POS, SBET, SVP). This geographically references the sounding position and depth.

Ellipsoidally Referenced Survey

Select Lines to be georeferenced

Select SVC in order to use SVP files, NIDWT

Select TPU in order to apply TPU

Select GPS (ERS) or traditional tides

Select Vertical Offset "0" or deselect box for SEP model

Select Delayed Heave

Do Not Select Refraction Coefficients or Delta Draft/Subsea Depth. Delta draft is not the same as dynamic draft in this situation although the terms are often used synonymously. This option is only for sonars with a depth of sensor associated with it (ie: ROV w/ MBES and vehicle depth sesnor)

Do Not Smooth Sensors or perform a data Shift unless special circumstance exists.

*Select SVP files to CARIS SVC and choose method. To use .all SVP leave box unchecked. *Even though raytracing was performed in near real time by SIS, SVC must be applied in order to apply Delayed Heave when the Reference Point (RP) is not at the Transducer for Kongsberg Systems. If Realtime Heave is applied to Konsgberg data and the RP is not at the transducer, then there will be heave artifacts. Furthermore, if Delayed Heave is applied elsewhere (ie: Import POS) there will also be heave artifacts as the other correctors are not applied using the same heave. Concatenated SVP files are no longer required, user can select multiple indiv. SVP files.*

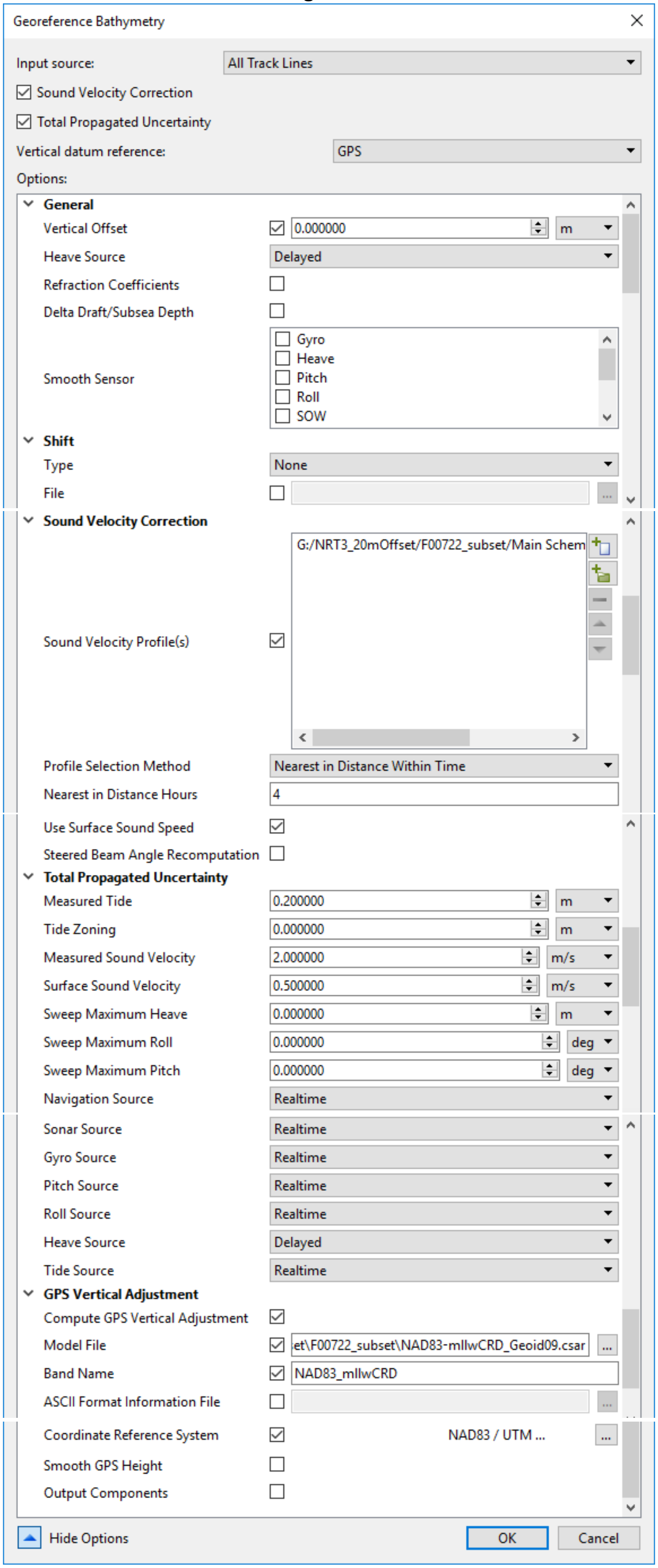
Tide (measure and zoning) uncertainties will change by project. Sound Speed (measured and surface) will change with method. SEP model only uses Tide Zoning. For TCARI, Tide Meas./Zoning are zero.

Select Realtime for uncertainty values that come from data (MBES, SBET, etc). If vessel is selected, the uncertainty values will come from the HVF. If "Realtime" is selected, but uncertainty values are not available in the raw data, then the "Vessel" .HVF values will be used.

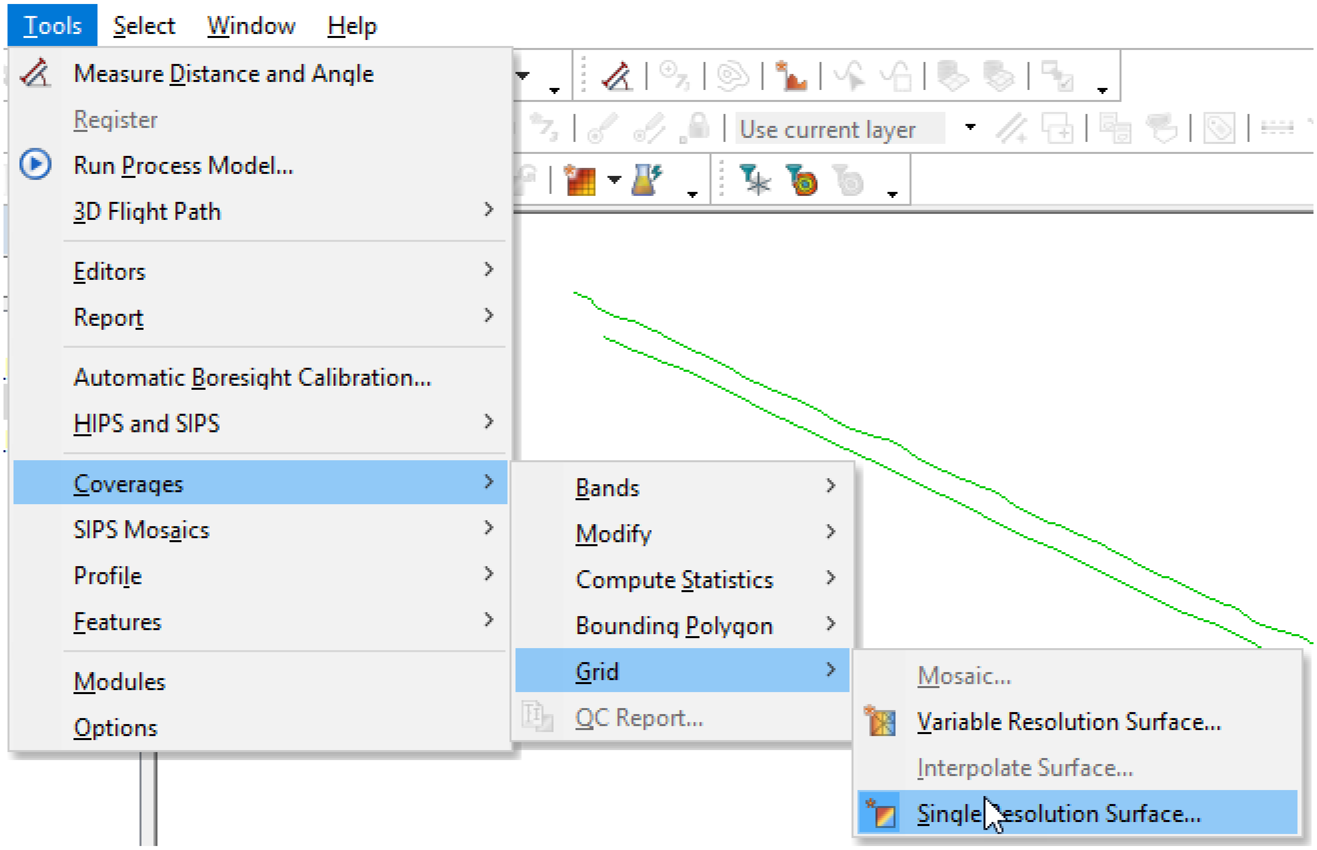
Select Delayed for Heave Source if delayed heave has been applied during processing.

Select Static to use tides values entered in dialogue for SEP and zone tides. If using TCARI, value should be Realtime.

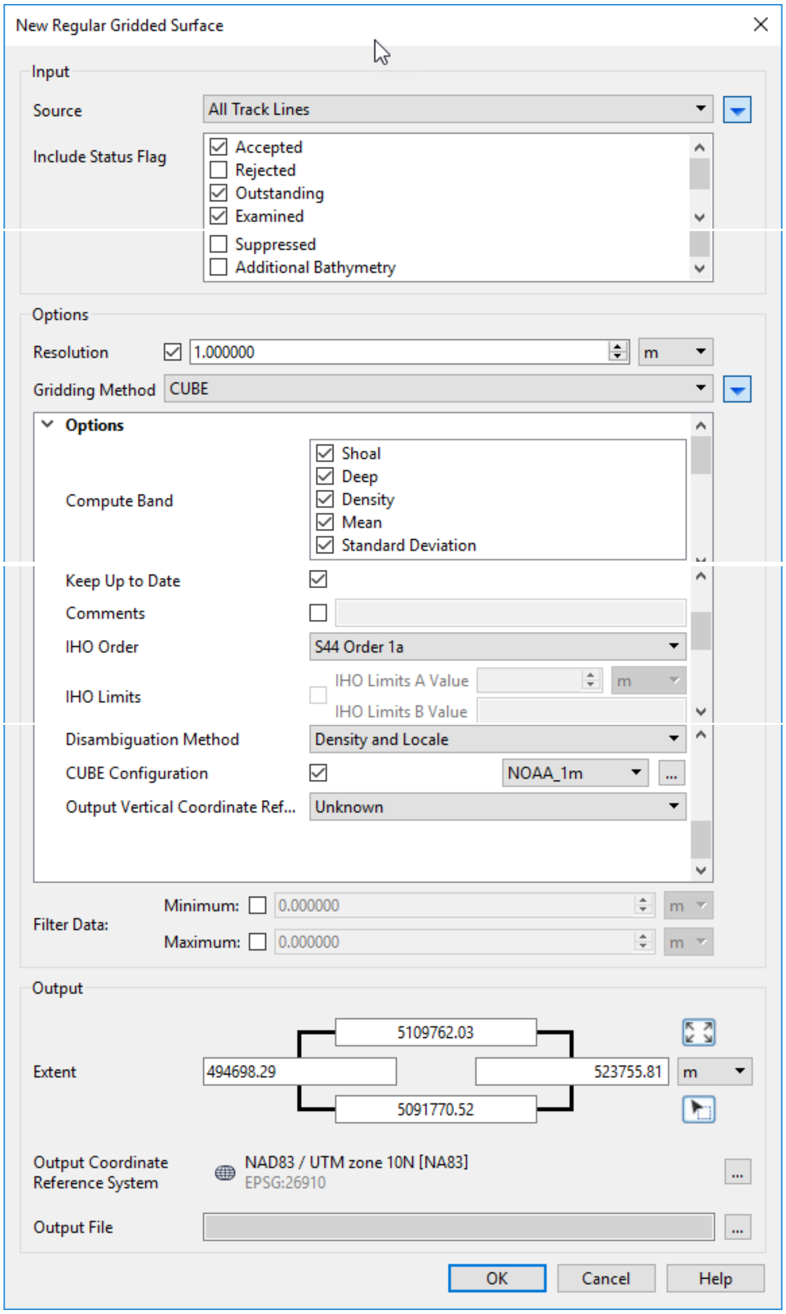
*If TCARI values are loaded but a separation model is loaded after, be sure to select static not realtime if you want to use SEP (or any other static method) TPU values.


Georeference Bathymetry
Input source:
All Track Lines
Sound Velocity Correction
Total Propagated Uncertainty
Vertical datum reference:
GPS
Options:
General
Vertical Offset
0.000000
m
Heave Source
Delayed
Refraction Coefficients
Delta Draft/Subsea Depth
Smooth Sensor
Gyro
Heave
Pitch
Roll
SOW
Shift
Type
None
File
Sound Velocity Correction
Sound Velocity Profile(s)
G:/NRT3_20mOffset/F00722_subset/Main Schem
Profile Selection Method
Nearest in Distance Within Time
Nearest in Distance Hours
4
Use Surface Sound Speed
Steered Beam Angle Recomputation
Total Propagated Uncertainty
Measured Tide
0.200000
m
Tide Zoning
0.000000
m
Measured Sound Velocity
2.000000
m/s
Surface Sound Velocity
0.500000
m/s
Sweep Maximum Heave
0.000000
m
Sweep Maximum Roll
0.000000
deg
Sweep Maximum Pitch
0.000000
deg
Navigation Source
Realtime
Sonar Source
Realtime
Gyro Source
Realtime
Pitch Source
Realtime
Roll Source
Realtime
Heave Source
Delayed
Tide Source
Realtime
GPS Vertical Adjustment
Compute GPS Vertical Adjustment
Model File
et\F00722_subset\NAD83-mllwCRD_Geoid09.csar
Band Name
NAD83_mllwCRD
ASCII Format Information File
Coordinate Reference System
NAD83 / UTM ...
Smooth GPS Height
Output Components
Hide Options
OK
Cancel

Surface Creation



Single Resolution



Use this option for creating a single resolution CUBE surface.

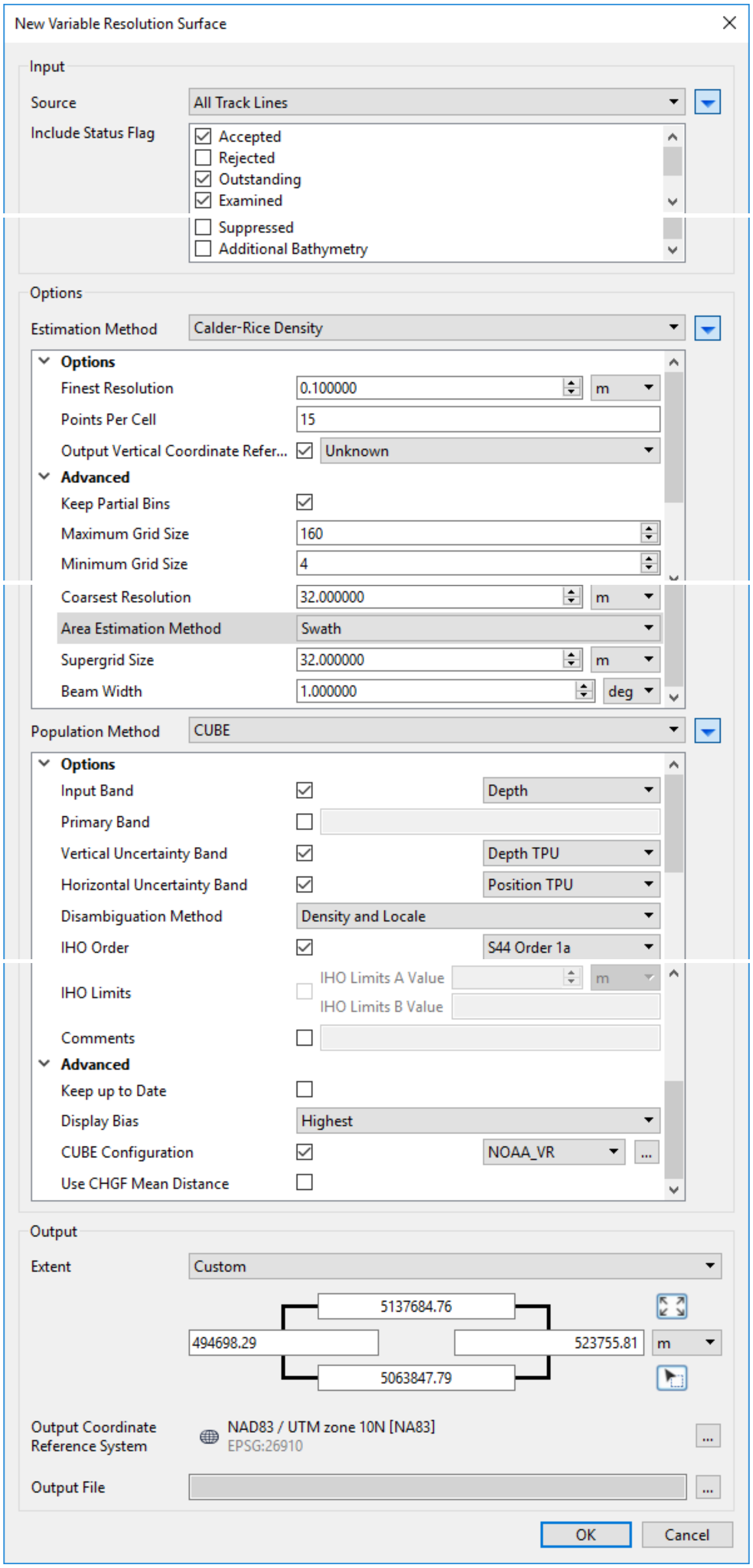
Compute Band: Select all layers

Keep Up To Date: When used on conjunction with Automatic Surface Update (Tools>Options>Coverage), this will enable small area recompute in Subset Editor.

IHO Order: The IHO order specified here is used to filter which soundings contribute to CUBE, however, it is over-ridden by the capture distance radius in the CUBE Parameters file (all soundings within the capture radius, regardless of IHO order, will contribute to CUBE). So does not matter.

Disambiguation Method: When multiple hypotheses exist for a node, “disambiguation” is used to select one hypothesis over others. Locale and Density selects the hypothesis that contains the greatest number of soundings and is also consistent with neighboring nodes.

Variable Resolution (Calder Rice)



Use this option for creating a variable resolution CUBE surface using the Calder-Rice Density estimation method.

Estimation Method: Calder-Rice Density

Finest Resolution: 0.1m is finest allowable. Use 1m for Full coverage; 50cm for Object Detection. Change at discretion. This parameter defines the finest allowable resolution within the VR surface.

Points Per Cell: 15. This parameter defines the target number of points per cell to use in resolution estimation. Note: this number is an average, not a minimum.

Keep Partial Bins: Enable. When enabled, HIPS keeps the estimated resolution values instead of adjusting them to a number evenly divisible by the tile dimensions.

Maximum/Minimum Grid Size: 160/4. These values specify the upper and lower limits for the number of rows and columns each tile can support.

Coarsest Resolution: 32. This parameter defines the coarsest allowable resolution within the VR surface.

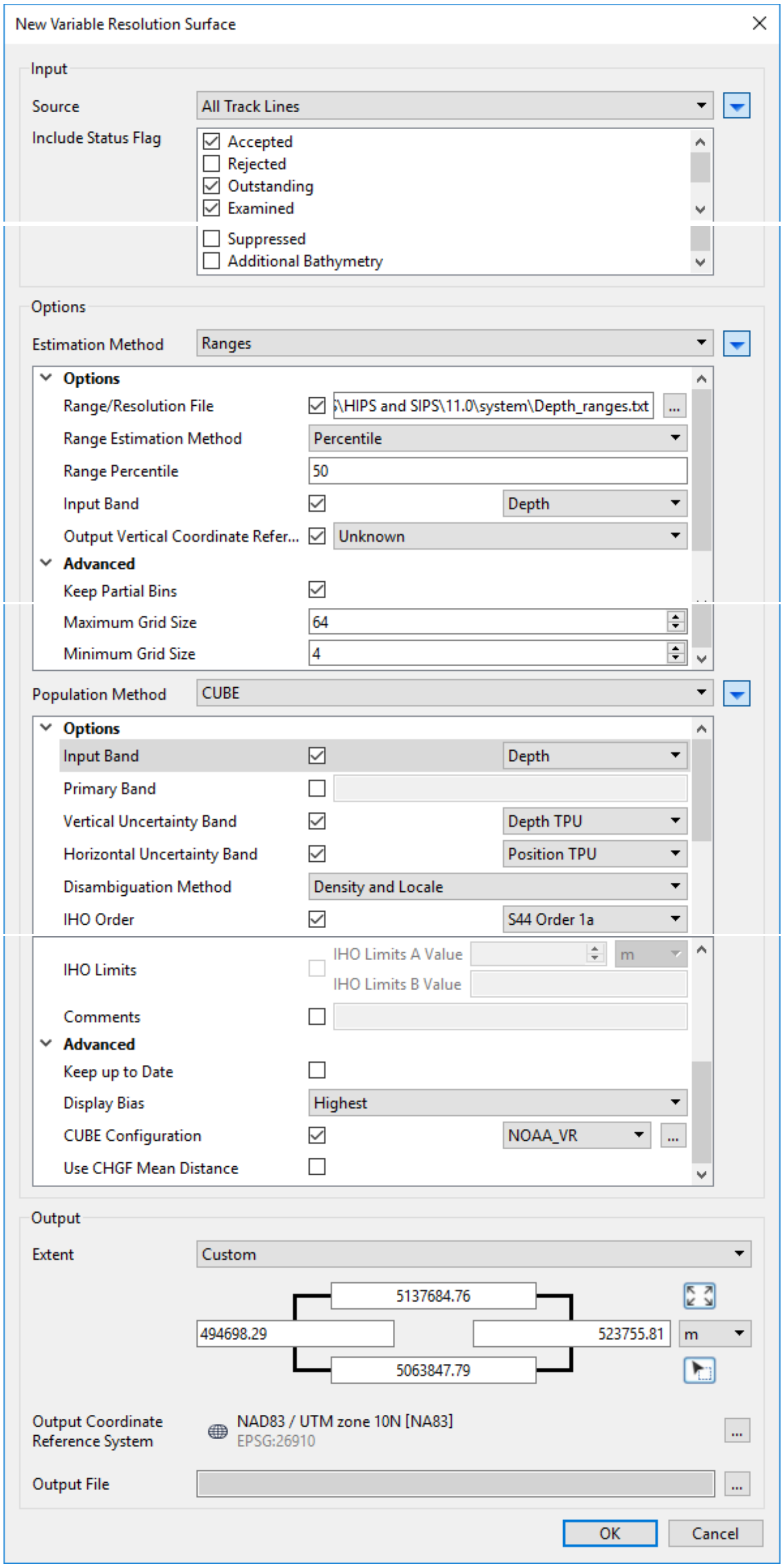
Area Estimation Method: Swath. This parameter is used to estimate the total ensonified area within the supergrid tile.

Supergrid Size: 32. This parameter specifies the initial size of the supergrid tiles in meters.

Display Bias: Highest. This parameter is used for display purposes only and ensures that the shoalest soundings will be drawn in the surface mesh display regardless of zoom level.

Use CHGF Mean Distance: Disable this. This would greatly increase time required for CUBE processing.

Variable Resolution (Depth Range)



Use this option for creating a variable resolution CUBE surface using the Depth Ranges estimation method.

Estimation Method: Ranges

Range/Resolution file: Select depth range look up table (e.g., NOAA_DepthRanges-CompleteCoverage.txt for Complete Coverage survey)

Range Estimation Method: This is the method used for deriving the depth value that is used to determine resolution from the look up table. "Percentile" stacks all the depths within a tile from deep to shallow and selects the depth based on the user-defined Range Percentile parameter (e.g., Range Percentile = 50 selects the median depth value within a tile).

Keep Partial Bins: Enable this. When enabled, HIPS keeps the estimated resolution values instead of adjusting them to a number evenly divisible by the tile dimensions.

Maximum/Minimum Grid Size: These values specify the upper and lower limits for the number of rows and columns each tile can support. 64/4 is recommended for most NOAA surveys. If you observe issues change max. grid size to 128 (Image 1 & 2 below).

Display Bias: Highest. This parameter is used for display purposes only and ensures that the shoalest soundings will be drawn in the surface mesh display regardless of zoom level.

Use CHGF Mean Distance: Disable this. This would greatly increase time required for CUBE processing.

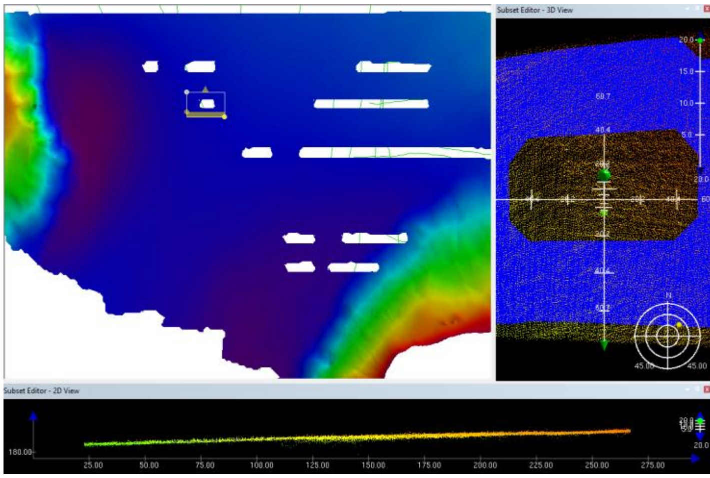


Image 1

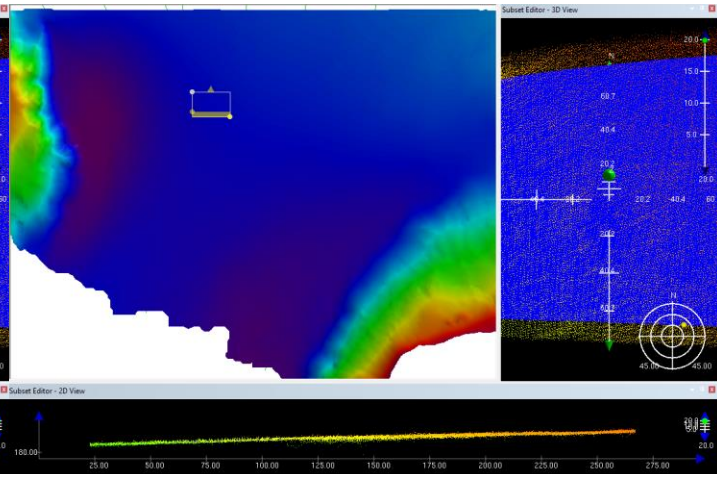


Image 2

This is an example of inappropriate minimum and maximum grid size for depth range VR surfaces. In Image 1, the min/max is 4/64, and in Image 2 min/max is 4/128. Larger maximum values create longer processing times, but can be modified to accommodate contradictions in situations described below.

The issue often reveals itself in coarser resolutions/deeper depths (ie: 16m & 32m). It is a result of range settings exceeding grid settings, which means there is a contradiction since max grid size does not actually set the limit.

Appendix C Geophysical Survey Data Archive Information

Two broad categories of data were generated during WSCNMS site mapping operations; raw and processed data. Raw files, those recorded from geophysical survey instruments onboard R2808, include sonar files, navigation files, sound velocity files, etc. Raw files are never modified after recording but are instead converted or copied for processing. Processed files, therefore, are additions to the data archive using raw files as inputs. As data is processed, the files are cleaned, refined, corrected, and otherwise adjusted, and then generated as output files.

In addition to the raw and processed files, other data files were utilized or generated during operations. These files, however, were much smaller quantity in terms of file count and storage volume. They included digital logs used to record details associated with major workflows and procedures occurring throughout data acquisition and processing as well as project-related files such as study area boundaries, background data files, and other information which served as useful references and source information. Benthic mapping data management, therefore, occupied a considerable level of effort during the field campaign. Proper file organization and process implementation was critical to effectively managing immense volumes of data in a coherent, consistent manner.

Numerous types of raw data files were recorded onboard R5002 during WSCNMS site documentation operations. These raw files included:

- Raw Multibeam Sonar Files:
    - Kongsberg Maritime instrument format (.ALL)
    - HYSWEEP format (.HSX).
- Raw Navigation Files:
    - Vessel Navigation in HYPACK format (.RAW)
    - Applanix Inertial Navigation System (INS) native POSPac format (.000)
- HYPACK Navigation Project Files, in addition to Nav and Sonar, including:
    - Planned line files (.LNW)
    - Border files (.BRD)
    - Matrix coverage files (.MTX)
    - Device settings (.INI)
    - Other HYPACK/HYSWEEP system files
- Sound Velocity Profile Files
    - Native instrument format (SonTek CastAway .CSV) converted in real time to:
    - Kongsberg Maritime format (.ASVP) for input into sonar acquisition program
    - CARIS format (.SVP) for utilization during post-processing corrections
- Logbooks in MS Excel (.XLSX) format

Online vessel navigation and motion data was provided by the Applanix POSMV INS system installed aboard R5002. Navigation data was broadcast over a computer network onboard to supply position/motion information to the Kongsberg Seafloor Information System (SIS) sonar interface and the HYPACK/HYSWEEP online navigation project. Simultaneously, the same data packets being broadcast by the INS system were recorded to a user defined folder in the vessel's raw data archive.

Sonar data was generated by the Kongsberg Maritime sonar processing unit (PU) computer. This device interfaced directly with the EM2040C MBES, combining raw pings with navigation/motion data supplied by the Applanix INS and SV data which was provided by the SVS and user-input SVP files. Raw sonar files were written to a user-defined folder in the vessel's raw data archive. Sonar information was also broadcasted over the vessel's computer network to be received in the HYSWEEP interface. This allowed the HYPACK/HYSWEEP online navigation program to plot a real time coverage surface (the Matrix) to aide in vessel navigation during data acquisition.

At interval, sound velocity casts were taken manually by surveyors onboard R5002. Data from the SVP instrument was uploaded to the vessel's data acquisition computer and stored in a series of folders within the raw data archived, as determined by file type. From the single source file downloaded from the instrument, several additional file types were produced through conversions and thereafter supplied to various applications used in the acquisition and processing workflows.

Online surveyors recorded significant events onboard R5002 in an Excel-based digital logbook. These events included file logging start/stop times, file names, sound velocity collection events, device settings, and comments on events.

Numerous types of processed data files were generated in the WSCNMS field office during operations. These processed files included:

- CARIS HIPS and SIPS sonar processing project
    - A single processing project where new files were added each day they were collected
    - HIPS directories of sonar information (folder and .HIPS)
    - Separation Model files (.CSAR, .TXT)
    - Vessel File (.HVF)
    - Fixed Resolution Surfaces (.CSAR)
    - Trackline and surface summaries (.TXT)
    - Sound velocity profiles (.SVP)
    - CARIS project file (.PROJ)
- Applanix Mobile Mapping Suite (MMS) processing projects
    - One per acquisition day, naming derivative of date/time
    - MMS input files
        - POSPac raw files
        - GNSS Ephemeris files
        - Reference/Correction station files
    - MMS 'Mission' archive
        - Export
            - SMRMSG File (.OUT)
            - SBET File (.OUT)
            - Export Log (.TXT)
        - Extract Archive (system files)
        - Proc Archive (system files)
- Geospatial and GIS Files
    - Vector features (shapefiles, feature classes, etc.)

- Raster features (gridded data, coverage maps, etc.)

After raw data files were acquired, they were copied to a transfer drive which was returned to the field office. Newly created raw files were added to the project data archive, thereafter introduced into data processing workflows. A series of preliminary processing steps were performed on all data within 24-hours of acquisition. Timely conduct of preliminary processing enabled the field team to perform a thorough QA/QC on sonar data quality, survey progress, and survey coverage. In several instances data quality issues were identified which resulted in changes to online parameters including SVP cast intervals, review of GNSS antenna connections, and adjustment of vessel speed and swath sector as a function of environmental conditions.

The preliminary processing workflow consisted of two main tasks: sonar file import into the CARIS HIPS and SIPS processing project and navigation data processing in the Applanix Mobile Mapping Suite. Raw sonar files were added to the CARIS HIPS and SIPS project into a single HIPS directory for each day's data. As they were imported, R2802's vessel file was defined as a reference for MBES mounting angle offsets (e.g. patch test values) which were used to adjust raw sounding data. Next, the imported sonar files were georeferenced with raw navigation used for sounding location and corrections for sound velocity—both profiles and surface SV—were applied. Afterwards, once the bathymetry data was properly referenced, it was then merged into an iterative fixed resolution grid file incorporating all sonar data to date.

Meanwhile, raw INS navigation files (POSPac files) were added into the Applanix Mobile Mapping Suite (MMS) program as a new default project for each mapping day. As files are imported, MMS used an internet connection to automatically retrieve associated GNSS corrections and ephemeris data (which become available within 24-hours of each acquisition day). Next, MMS re-computed position information and recalculated motion information at a user-defined reference frame. During several semi-automated stages of file processing, MMS generated numerous outputs which were reviewed as time-series plots and charts allowing the user to ascertain information about file quality and the accuracy of data outputs. Once completed, two correction files were generated: the smoothed best estimate of trajectory (SBET) file as well as an error statistics file, both in the Applanix .OUT format. Both .OUT files were then imported into the CARIS project and applied to their corresponding day's sonar files. After the SBET and RMS error statistics files were added, data in the associated HIPS directory were re-referenced. Replacement of the raw navigation with post-processed SBET navigation provided cleaned GNSS height information for the associated bathymetry data. At this point in the workflow, bathymetry was vertically referenced by converting the GNSS ellipsoidal heights supplied in the SBET file to an orthometric reference (IGLD 85 LWD) via a gridded separation model file which provided location-specific conversion values between WGS 84 ellipsoidal heights used during acquisition and the output vertical referenced datum listed above. Afterwards, the fixed resolution sonar data surface was recomputed using the improved navigation, motion, and vertical reference information.

Aside from the preliminary processing steps outlined above, several data processing tasks remained. Namely, the sonar files required point cloud cleaning. Lines were cleaned individually to remove fliers and instrument noise, then groups of lines were cleaned to address any misalignments resulting from SV artefacts, height dropouts, or motion artefacts. Point cloud cleaning proceeded opportunistically during the field survey: on mornings or evenings before vessel operations, weather days, breaks between the field acquisition, etc. Periodic exports, such as daily track line reports or surface QA/QC reports, were made as .TXT files to assist in quantitative survey tracking (number of line files, run line distances, coverage amounts, etc.) and project documentation. Simultaneously, all data processing tasks were tracked, recorded, and detailed in digital logbooks.

Table C1 presents an inventory of raw and processed survey data generated during online WSCNMS site mapping operations. This inventory was generated while mapping within WSCNMS and does not include R5002's MAC data from May 2022. Instead, Table C1 values only relate to the data files produced towards the completion of WSCNMS mapping objectives. Likewise, these files were produced in the field and field office. Additional project management files were utilized throughout operations (such as AOI shapefiles and background LiDAR data) are not included. Final outputs, likewise, are not included. Instead Table C1 shows data generated while field operations were underway.

Completion of field operations and subsequent data processing workflows following the project's demobilization enabled the creation of numerous data file outputs. These outputs were the deliverable files produced by the NOAA team which included processed, cleaned bathymetry data. Outputs were assessed to determine updated site position and depth information as well as distribution along the lakebed. Finalized data files, moreover, will be shared with WSCNMS partners as needed to support additional research, mapping, and documentation tasks.

Table C1. Inventory of geophysical survey data collected by NOAA vessel R5002 during WSCNMS site mapping operations, Juner 2022. * HYPACK Project Directory includes .RAW and .HSX files.

Data Type	File Format	Number of Files	Directory Size (bytes)
Raw Vessel Navigation	HYPACK (.RAW)	41	458,809,344
Raw INS Navigation	POSPac (.000)	23	2,634,932,224
Processed INS Navigation	SBET (.OUT)	4	1,498,177,536
Processed INS Navigation Error Statistics	SMRMSG (.OUT)	4	4,415,488
Raw Sonar	Kongsberg Maritime (.ALL)	48	1,414,963,200
Raw Sonar	HYSWEEP (.HSX)	41	1,083,236,352
Raw Sound Velocity Cast	CastAway (.CSV)	13	323,584
Raw Sound Velocity Cast	CARIS (.SVP)	13	53,248
Raw Sound Velocity Cast	Kongsberg Maritime (.ASVP)	13	53,248
Online Data Acquisition Log	MS Excel (.XLSX)	5	249,856
Online Navigation Project	HYPACK Project Directory*	184	3,791,228,928
Offline Processing Project	CARIS HIPS and SIPS Directory	2,251	5,493,075,968

File Management

A standardized file archive was implemented to organize and manage all digital data related to WSCNMS site mapping operations. The project archive was named as such: 202210_WSCNMS_Doc, describing the archive with its job number, the agency partner dictating technical scope, and survey type. This project naming convention carried through to file naming, processing project names, data backups and downstream data management tasks. Within this archive were six sub-folders that were populated throughout operations. These folders included:

- **1-MAC:** Archive of all data recorded during the mobilization and calibration (MAC) process with files organized by vessel. All MAC tasks are necessary for instrument setup and project preparation but did not occur within WSCNMS or contribute to mapping of those areas. Instead, these files are only relevant to the testing and calibration of geophysical instruments onboard R5002. Within the main archive is a vessel folder for R5002, subdivided into folders for raw and processed data results as well as report materials. A detailed organization of this archive is presented in Table C2.
- **2-Raw_Data:** All raw files recorded during online survey activities. This folder contains a nested archive for R2802 divided into folders for different instrument/data types. See detailed contents in Table C3.
- **3-Process:** Manages processed files and processing project directories utilized to complete various navigation and sonar data processing workflows. These projects were iterative and updated on a daily basis as mapping operations proceeded. Primarily, these files are associated with a cumulative CARIS HIPS and SIPS project as well as individual Applanix Mobile Mapping Suite projects used to generate SBET files for each day of data acquisition. See detailed contents in Table C4.
- **4-Project**: A workspace for managing an array of project specific files including planning documents, background materials, data files (e.g. GIS features) sent by partners, report materials, as well as the standalone folders for data deliveries.
- **5-Products:** A directory used as a workspace for saving and storing preliminary data products as needed. Most files in this archive were iteratively updated, overwritten, or modified as operations proceeded and additional data was collected.
- **6-Logs:** All digital logs generated during WSCNMS site mapping operations. These include the Online Survey Log and two data processing logs (one for navigation and another for sonar data), data transfer log, survey overview log, and additional documentation related to mapping procedures and operations.

Since the 4-Project, 5-Products, and 6-Logs subfolders were not differentiated by vessel nor did they feature complex, nested folder trees, they are presented together in Table C5.

Table C2. Directory schema for storage of project mobilization and calibration (MAC) data.

<table>
<tr><td rowspan="10"><u>1-MAC</u></td><td rowspan="10">R5002</td><td rowspan="5">1-Raw_Data_MAC</td><td colspan="2">HeightModel</td></tr>
<tr><td colspan="2">HYPACK_Raw</td></tr>
<tr><td colspan="2">MBES_SIS</td></tr>
<tr><td colspan="2">Positioning_and_INS</td></tr>
<tr><td colspan="2">SVP</td></tr>
<tr><td rowspan="5">2-Process_MAC</td><td rowspan="3">1-Data</td><td>CARIS</td></tr>
<tr><td>HYPACK_Process</td></tr>
<tr><td>POSPac</td></tr>
<tr><td rowspan="2">2-Report</td><td>Images_Report</td></tr>
<tr><td>MAC_Report</td></tr>
</table>

Table C3. Directory schema for storage of project raw survey data.

<table>
<tr><td rowspan="7"><u>2-Raw_Data</u></td><td rowspan="7">R5002</td><td colspan="3">HeightModel</td></tr>
<tr><td colspan="2">HYPACK_Raw</td><td>[HYPACK project files]</td></tr>
<tr><td>MBES_SIS</td><td>EM_2040</td><td>yyyymmdd</td></tr>
<tr><td>Positioning_and_INS</td><td>POSMV_Raw</td><td>yyyymmdd</td></tr>
<tr><td colspan="2" rowspan="3">SVP</td><td>ASVP</td></tr>
<tr><td>CSV</td></tr>
<tr><td>SVP</td></tr>
</table>

Table C4. Directory schema for storage of project processed data. A single iterative CARIS project was developed throughout WSCNMS site mapping operations.

<table>
<tr><td rowspan="4"><u>3-Process</u></td><td rowspan="4">1-Data</td><td>ArcGIS</td><td></td></tr>
<tr><td>CARIS</td><td></td></tr>
<tr><td>HYPACK_Process</td><td></td></tr>
<tr><td>POSPac</td><td>Projects</td></tr>
</table>

			SBET
		QGIS	
	Work	[workspace for assorted files generated during processing]	

Table C5. Directory schema for storage other additional project data.

4-Project	01_Delivery
	02_Reporting
	03_Project_Specification
	04_Lessons_Learned
	05_Project_Logos
	06_Project_Metadata
	Background_Information
	From_NOAA_OCM
	From_TBNMS
	From_Vessel
	To_Vessel
5-Products	Contacts_and_Anomalies
	Contours
	DTM_MBES
	GeoTiff
	MBES_Accepted_Points

	MBES_GSF
	Report_Images
	SVP
	Tracklines
6-Logs	01-Handovers
	02-Online_Log
	03_Data_Procssing_Log
	04_Data_Trasnfer_Log
	05_Survey_Overview

Two 5 TB portable hard drives were used as the main project data repositories in the field (one active, the other as a synchronized backup). These storage accessories were kept in the project's field office. Raw data files from the vessel were supplied after each acquisition day via a separate 5TB transfer drive. Copies of all raw files were also maintained onboard R5002's data acquisition computer (DAC) in the same raw folder schema shown in Table C3. Likewise, copies of raw files were maintained in the transfer drive. As a result, the maintenance of raw file copies on the vessel, transfer drive, and field office NAS provided tertiary backup redundancy.

Processed data files and all the information in the 1-MAC, 3-Process, 4-Project, 5-Products, and 6-Logs folders were maintained on the field office NAS. Backups of the full project archive were generated by synchronizing folders on the NAS with a dedicated 5TB portable hard drive. This device was a separate drive from the transfer drive and remained in the field office for the sole purpose of providing an independent backup of all files.

Following demobilization of the field office, the archive was relocated to the NOAA (TBNMS) facility in Alpena, MI. Data processing and reporting tasks continued until completion with backup copies of data managed throughout. Once data delivery is finalized, a copy of the archive will be moved permanently onto a NOAA-managed storage volume at TBNMS.

Data Point of Contact

NOAA Thunder Bay National Marine Sanctuary
John Bright
500 W Fletcher St
Alpena, MI 49707

john.bright@noaa.gov
989-312-3461

Project Archive: 202210_WSCNMS_Doc