Cover Sheet (NOAA Form 76-35A)

NOAA FORM 76-35A

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

Data Acquisition and Processing Report

Type of Survey HYDROGRAPHIC

Field No OPR-A366-KR-16

Registry No. H12885, H12884, H12887 & H12886

LOCALITY

State Maine

General Locality Penobscot Bay

Sublocality Covers the regions of Spaulding Island to Mosquito Island, Rockland Harbor, and North Haven Island to Vinalhaven Island.

2016

CHIEF OF PARTY

Dean Moyles

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DATE ....

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Title Sheet (NOAA Form 77-28)

NOAA FORM 77-28 (11-72) U.S. DEPARTMENT OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION **HYDROGRAPHIC TITLE SHEET**	REGISTER NO. H12885, H12884, H12887 & H12886
INSTRUCTIONS – The Hydrographic Sheet should be accompanied by this form, filled in as completely as possible, when the sheet is forwarded to the Office	FIELD NO.

State Maine

General Locality Penobscot Bay

Locality Covers the regions of Spaulding Island to Mosquito Island, Rockland Harbor, and North Haven Island to Vinalhaven Island

Scale 1:10,000 & 1:20,000 Date of Survey LiDAR 07/11/2016 – 07/18/2016
m MBES 07/21/2016 – 10/01/2016

Instructions dated March, 2016 Project No. OPR-A366-KR-16

Vessel R/V JAB (1229272), R/V Westerly (1231991), Beechcraft King Air A90 (N87Q)

Chief of party Dean Moyles

Surveyed by Moyles, Johnson, Cox, Blackbourn, Reynolds, Rokyta, Mount, Farley, Geiger, Klein et al.

Soundings taken by echo sounder, hand lead, pole Dual Head Reson 7125 (R/V JAB, Over the Stern Mount), Dual Head Reson 7125 (R/V Westerly, Over the Stern Mount), SHOALS-1000T (Airborne LiDAR Bathymetry)

Graphic record scaled by Fugro Personnel

Graphic record checked by Fugro Personnel

Protracted by N/A Automated plot by N/A

Verification by

Soundings in METERS at MLLW

REMARKS: The purpose of this survey is to update existing NOS nautical charts in a high commercial traffic area.

ALL TIMES ARE RECORDED IN UTC.

FUGRO PELAGOS INC.

3574 RUFFIN ROAD

SAN DIEGO, CA 92123

A – Equipment

The R/V JAB, R/V Westerly, and the Beechcraft King Air A90 acquired all sounding data for this project. The equipment list and vessel descriptions are included in Appendix I.

Sounding Equipment

The R/V JAB, 44 feet in length with a draft of 2 feet, was equipped with an over the stern pole that housed an underwater IMU and dual head Reson 7125 multibeam sonars (dual meaning two independent systems). The Reson 7125 is a dual frequency system operating at 200 and 400 kHz. The systems were operated in the Intermediate beam mode option; which forms 512 across-track beams (in 400 kHz), with a maximum swath coverage of 140°. Operating modes such as range scale, gain, power level, ping rates, etc. were a function of water depth and data quality and were noted on the survey line logs (see the Descriptive Report Separate 1).

The Reson systems and IMU were installed on a special mounting plate, where each Reson 7125 was rotated approximately 15°. The Reson systems were installed in their normal SV2 bracket, which included an SV70 probe (located in the nose cone) and were attached to the mounting plate by a flange. Refer to Appendix I for more information and graphics.

All 7125 multibeam data files were logged in the s7k format using WinFrog Multibeam (WFMB) v3.10.15.3. The bathy data from each Reson 7125 (records 7004/7006 & 7027) were stitched together in WFMB to create one s7k file with each ping containing 1024 beams.

The R/V Westerly, 44 feet in length with a draft of 2 feet, was equipped with an over the stern pole that housed an underwater IMU and dual head Reson 7125 multibeam sonars (dual meaning two independent systems). The Reson 7125 is a dual frequency system operating at 200 and 400 kHz. The systems were operated in the Intermediate beam mode option; which forms 512 across-track beams (in 400 kHz), with a maximum swath coverage of 140°. Operating modes such as range scale, gain, power level, ping rates, etc. were a function of water depth and data quality and were noted on the survey line logs (see the Descriptive Report Separate 1).

The Reson systems and IMU were installed on a special mounting plate, where each Reson 7125 was rotated approximately 15°. The Reson systems were installed in their normal SV2 bracket, which included an SV70 probe (located in the nose cone) and were attached to the mounting plate by a flange. Refer to Appendix I for more information and graphics.

All 7125 multibeam data files were logged in the s7k format using WFMB v3.10.15.3. The bathy data from each Reson 7125 (records 7004/7006 & 7027) were stitched together in WFMB to create one s7k file with each ping containing 1024 beams.

Both vessels, each equipped with dual head Reson 7125 sonars, were operated in the full rate dual head (FRDH) mode in the Reson topside.

The line orientation for all vessels was generally parallel to the coastline and bathymetric contours of the area. The line spacing was dependent on water depth and data quality, with an average line spacing of two to three times water depth. **Table 1** summarizes the sonar models and configurations used on each survey vessel.

Table 1 Vessel Sonar Summary

Vessel	R/V JAB	R/V Westerly
Mount Type	Over the Stern	Over the Stern
Sonar System	Dual Head Reson 7125 (FRDH)	Dual Head Reson 7125 (FRDH)

For the first several weeks on the R/V JAB, the transmitter and receiver were inadvertently mismatched, with the port receiver using the starboard system's transmitter, and vice versa. Proper reduction of soundings measured in this configuration requires that the sonar be treated as a bi-static system, and that the absolute locations of the transmitter and receiver be accounted for. Computer Aided Resource Information System (CARIS) Hydrographic Information Processing System (HIPS) is designed to handle such a situation, and offset information in the form of a 7030 record, which was added to each dual head s7k file to enable proper processing without an adjustment to the processing pipeline used by Fugro Pelagos, Inc. (Fugro). The methodology was validated using a postage stamp survey over a flat seafloor. Adjusted 7030 records were inserted into all applicable previously collected data and reprocessed in CARIS using Fugro's standard methodology for the processing of 7027 dual head records. Refer to the Appendix V for full report.

The R/V Westerly performed an additional patch test after needing to replace the leased IMU. The change out of the IMU with a Fugro-owned unit occurred on 10 August 2016. The patch test to calibrate the new IMU was performed on 13 August 2016.

The SHOALS-1000T Airborne LiDAR Bathymetry (ALB) system, is comprised of two main subsystems. The Airborne System (AS) is used to acquire raw bathymetric data, real-time inertial and Global Positioning System (GPS) data, and downward-looking digital imagery. The Ground Control System (GCS) is used to plan operations, calculate depth values from the raw data, apply post-processed kinematic GPS (KGPS) positioning, apply tidal corrections, provide tools to allow the collected data to be evaluated, and export digital data for the compilation of final survey deliverables. These two subsystems are complemented by other tools required for quality control activities; in particular, Fledermaus, for the visualization of vertical standard deviation, density, and 3-D bathymetric surfaces. Third party software such as, CARIS and Earth Resource Data Analysis System (ERDAS) also used for product compilation, imagery data creation, and survey management. The general data flow between the subsystems and tools is illustrated in **Figure 1**.

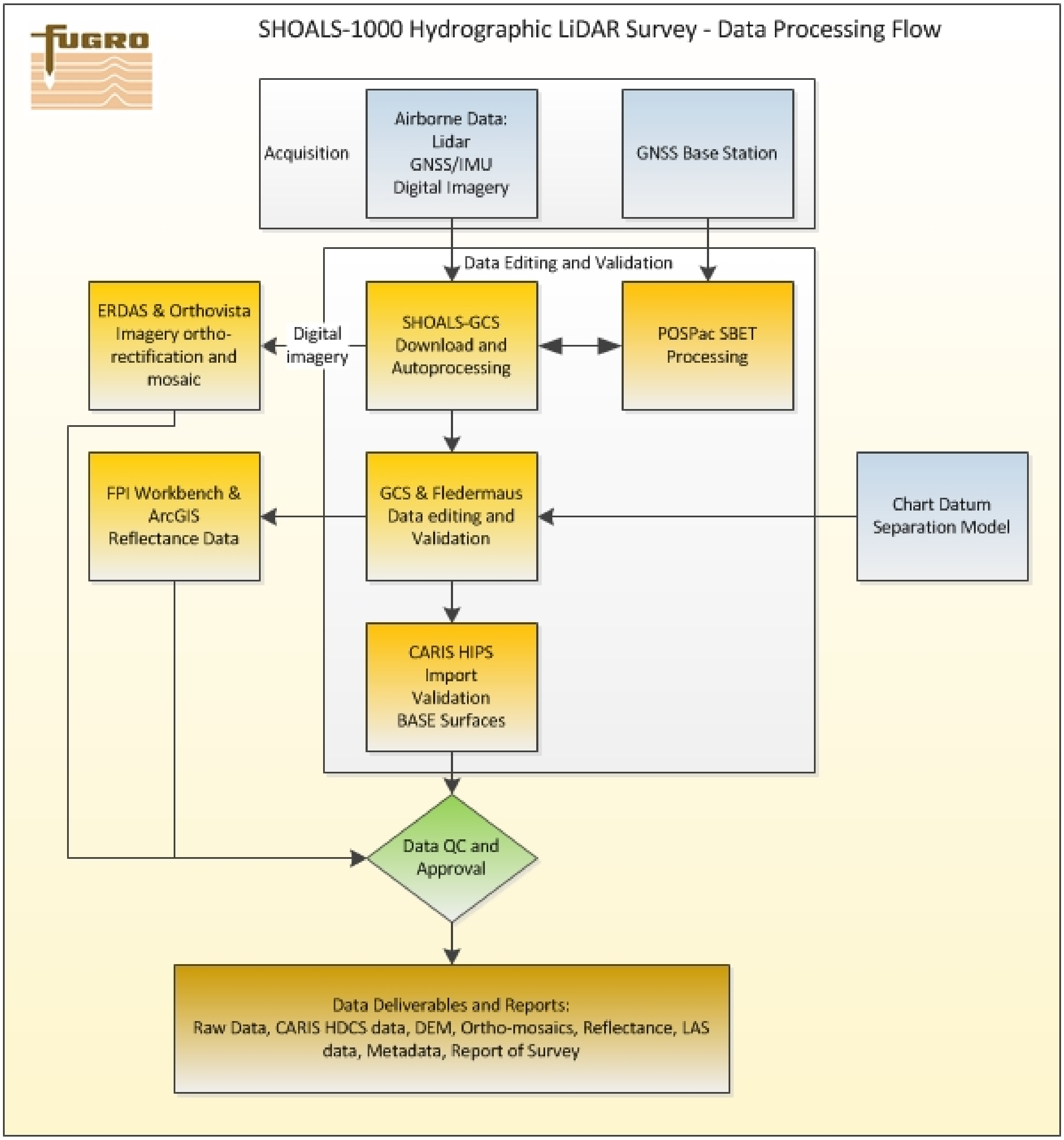


Figure 1 General Data Flow within FPI ALB System

The Optech SHOALS-1000T ALB system, serial number FPI-1 is capable of acquiring 2500 soundings per second in bathymetric mode. SHOALS soundings are acquired by the transmission of laser pulses from the aircraft through a scanning system and detecting return signals from land, the sea surface, the water column and the seabed. The scanning (transmitting) occurs on a stabilized platform that compensates for aircraft pitch and roll. The return signals are electronically amplified and conditioned prior to being digitized and logged.

The SHOALS-1000T can be configured to operate at many different sounding densities, namely

2 m x 2 m, 3 m x 3 m, 4 m x 4 m, and 5 m x 5 m spot spacing. A 2 m x 2 m sounding density is typically used for engineering applications where higher resolution may be required, whereas a 5 m x 5 m sounding density is typically used for larger scale, lower-resolution mapping requirements, such as resource planning or reconnaissance. All sounding densities meet the IHO Order 1 Depth and Position accuracy requirements. For OPR-A366-KR-16, the 5 m x 5 m sounding density was used and data was acquired at a survey altitude of 400 meters.

Data was collected and logged to solid state drives onboard the sensor in file formats native to SHOALS.

Line planning for the project was done using Optech SHOALS Ground Control System (GCS) software package; this suite contains a planning module called MAPS which is capable of importing a vector file of the project boundary as well as shoreline and other information. MAPS allows the user to quickly and easily adjust blocks of planned lines to ensure maximum efficiency, which is attained during flight while maintaining the standard of survey requirements outlined in the Project Instructions.

Planned lines ran parallel to the mainland shore with a maximum length of approximately 47 kilometers. The preliminary planned lines shown in **Figure 2** had some processing limitations with regards to multiple users. In order to allow simultaneous work during the processing stage, this particular survey area was split into three blocks. This division of the survey area is depicted in the **Figure 2** below. Crosslines were planned in accordance with the guidelines set out in the Hydrographic Survey Specifications and Deliverables (HSSD) 2016. The crosslines are also visible in **Figure 2**.

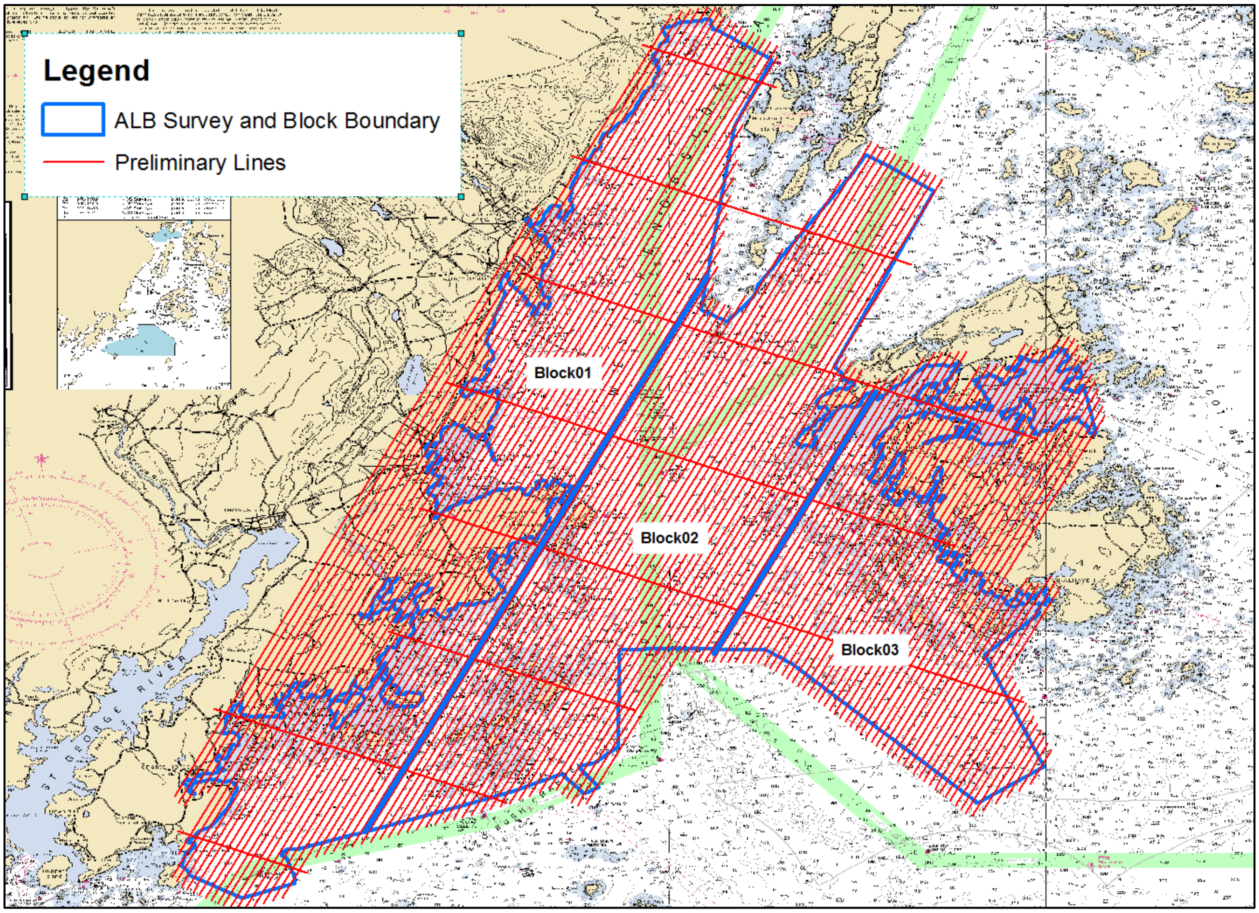


Figure 2 Overview of Preliminary Lines and Boundaries

Backscatter Imagery

Towed SideScan Sonar (SSS) operations were not required by this contract, but the backscatter and beam imagery snippet data from all multibeam systems were logged and are stored in the s7k files. All beam imagery snippet data was logged in the 7028 record of the s7k file for the project.

To yield the best results when processing the backscatter from the dual head 7125 systems, we recommend using the CARIS SIPS Backscatter routine. Currently CARIS only uses the Beam Average, but in the upcoming release of CARIS v10 will apply the Time Series backscatter data.

Sound Velocity Profilers

R/V JAB and R/V Westerly were equipped with AML 1000 dbar Sound Velocity & Pressure (AML SV&P) Smart Sensors. The AML SV&P directly measures sound velocity through a time of flight calculation, and measures pressure with a temperature compensated semiconductor strain gauge at a 10Hz sample rate. The instrument has a 0.015 m/s resolution with a ± 0.05 m/s accuracy for sound velocity measurements, and a 0.01 dbar resolution and a ±0.5 m dbar accuracy for pressure.

Each vessel was equipped with two AML SV&Ps. The instruments were mounted within a weighted cage and deployed using a hydraulic winch that contained 350 meters of shielded Kevlar reinforced cable via a stern mounted A-Frame.

Fugro's MB Survey Tools was used to check the SV profiles graphically for spikes or other anomalies, and produce an SVP file compatible with CARIS HIPS. The WFMB acquisition package also provided quality control (QC) for surface sound velocity. This was accomplished by creating a real-time plot from the sound velocity probe at the Reson sonar head and notifying the user (via a flashing warning message) if the head sound velocity differed by more than 5 m/s from a defined reference sound velocity. This message was used as an indication that the frequency of casts may need to be increased. The reference sound velocity was determined by averaging 50 sound velocities produced at the head. The reference sound velocity was reset after each cast and when a cast was performed due to a significant deviation from the reference sound velocity.

Positioning & Attitude Equipment

The R/V JAB was equipped with an Applanix Position and Orientation System for Marine Vessels (POS/MV) V4 (underwater IMU) to calculate position and vessel attitude. Position was determined in real-time using a Trimble Zephyr L1/L2 GPS antenna, which was connected to a Trimble BD950 L1/L2 GPS card residing in the POS/MV. An Inertial Measurement Unit (IMU) provided velocity values to the POS/MV allowing it to compute an inertial position along with heading and attitude. The POS/MV was configured to accept Fugro's Marinestar G2 corrections. Marinestar is a decimeter level, phase-based service using satellite 'clock and orbit' data valid worldwide, based upon GPS L1 and L2 frequencies, and provides a horizontal accuracy of 10 cm and vertical accuracy of 15 cm.

The operational accuracy specifications for this system, as documented by the manufacturer, are as follows:

Table 2 POS/MV Specifications

POS/MV Accuracy	
Pitch and Roll	0.02°
Heading	0.02°
Heave	5% or 5-cm over 20 seconds

The R/V Westerly was equipped with an Applanix Position and Orientation System for Marine Vessels (POS/MV) V5 (underwater IMU) to calculate position and vessel attitude. Position was determined in real-time using a Trimble Zephyr L1/L2 GPS antenna, which was connected to a Trimble BD950 L1/L2 GPS card residing in the POS/MV. An Inertial Measurement Unit (IMU) provided velocity values to the POS/MV allowing it to compute an inertial position, along with heading, and attitude. The POS/MV was configured to accept Fugro's Marinestar G2 corrections. Marinestar is a decimeter-level, phase based service using satellite 'clock and orbit' data valid worldwide, based upon GPS L1 and L2 frequencies, and provides a horizontal accuracy of 10 cm and vertical accuracy of 15 cm.

Initially the (POS/MV) V5 system on the R/V Westerly was leased. During the project this leased system was replaced with a Fugro-owned (POS/MV) V5 system.

The operational accuracy specifications for this system, as documented by the manufacturer, are as follows:

Table 3 POS/MV Specifications

POS/MV Accuracy	
Pitch and Roll	0.02°
Heading	0.02°
Heave	5% or 5-cm over 20 seconds

The PosMvLogger and POS/MV controller software's real-time QC displays were monitored throughout the survey to ensure that the positional accuracies specified in the NOS HSSD were achieved. These include, but are not limited to, the following: GPS Status, Positional Accuracy, Receiver Status, which included Horizontal Dilution of Position (HDOP) & Precise Dilution of Position (PDOP), and Satellite Status.

The SHOALS and VQ-820-G LiDAR sensors employ an Applanix POS/AV v6 (integrated with the SHOALS system) to provide high accuracy 3D positioning and orientation for the sensor platform. The POS/AV is an inertial navigation system (INS) aided by high accuracy Global Navigation Satellite System (GNSS) positions. The POS/AV is comprised of an inertial measurement unit (IMU), a GNSS receiver with antenna, and a processing computer unit (PCS) producing a full inertial navigation solution.

The IMU contains accelerometers and gyroscopes to measure linear acceleration and angular rates on the three axes of the reference body. The IMU measurements, position, velocity, and orientation (roll, pitch, heading), are returned to the PCS where an inertial navigator produces position and orientation data. The INS navigation solution errors that build over time are controlled by the continuous input of GNSS positioning integrated into the POS/AV. A Trimble BD690 board, coupled with a GNSS/L band high-gain antenna, and the corrections of the Marinestar G2 augmentation service produce the high-accuracy positioning observables that are integrated by the inertial navigator into position and orientation of the reference platform in real-time.

Fugro Marinestar G2 service is a real-time GPS and GLObal Navigation Satellite System (GLONASS) Precise Point Positioning (PPP) providing refined satellite 'clocks and orbit' data to any GNSS receiver with a valid service subscription. Signal on the L-band with corrections is broadcasted by geo-stationary satellites. At least three of them covered the geographic region of the survey area, see **Figure 3**, and was received by the integrated GNSS/L-band antenna. Fugro uses the G2 service signal as the standard in the POS/AV embedded Marinestar receiver.

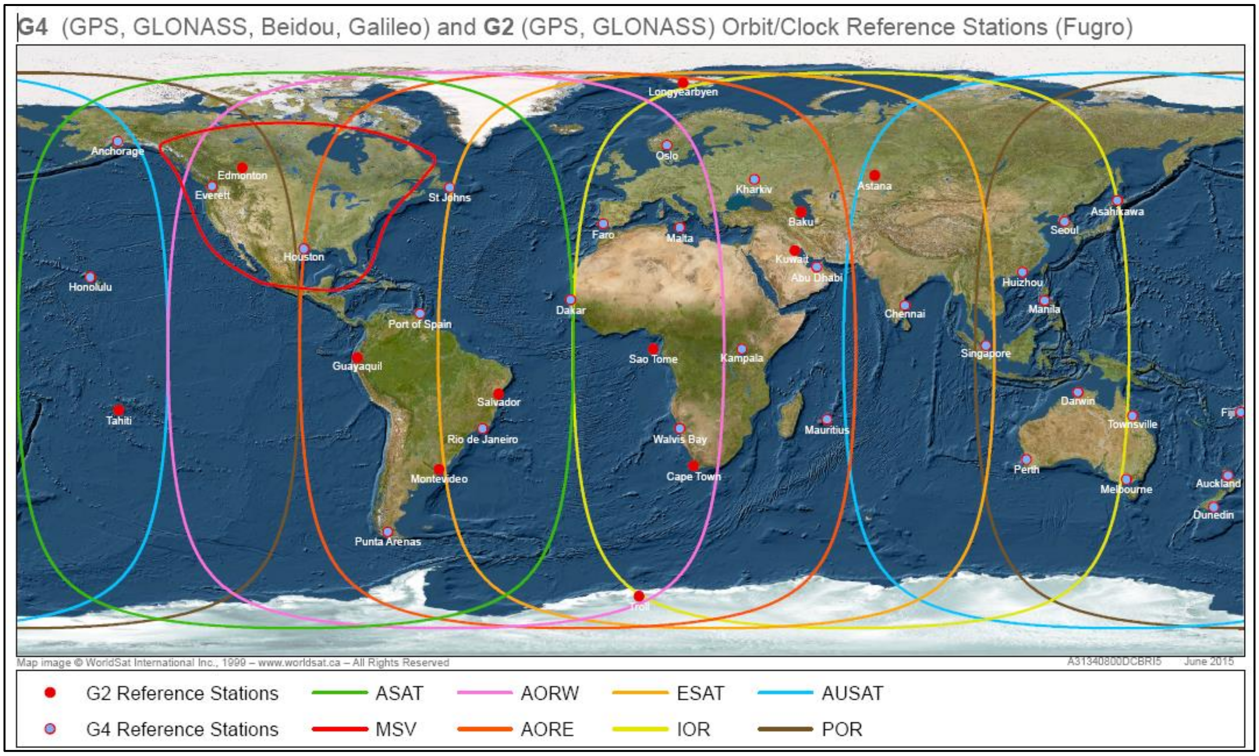


Figure 3 GNSS/IMU Positioning System

The POS/AV data streams are recorded on removable solid-state drives with high input and download data rates. The main technical specifications of the Applanix POS/AV are:

- Logging: Time tag, status, position, attitude, velocity, track and speed, dynamics, performance metrics, raw IMU data and raw GNSS data all at up to 200 Hz
- Media External: Removable 4 GB USB stick. Internal: Embedded 4 GB memory for redundant logging
- Accuracies: 0.05 – 0.3 m position, 0.005 m/s velocity, 0.005° roll/pitch, 0.008° heading and 0.10°/hr drift when post-processed

The main technical specifications of the Aero Antenna Technology AERAT1675_180 GNSS antenna are:

- Airborne Antenna – Iridium Protected
- GNSS L1 1565 – 1607 MHz frequency
- GNSS L2 1217 – 1260 MHz frequency

Processed LiDAR point positions were derived relative to the WGS84 ellipsoid using a Post Processed Kinematic solution (PPK) during GNSS post-processing, which used aircraft positioning data and. Final LiDAR point positions were then reduced to MLLW using a VDatum model created for the survey area by Fugro.

Following all dynamic and static GPS data processing with Applanix POSPac MMS 7.1, the following quality factors were assessed to determine if the final GPS solutions adhered to the project accuracy specifications:

- Dilution of Precision – PDOP, HDOP, and VDOP
- Position Accuracy – RMS for Easting, Northing and Height
- Float / Fixed Ambiguity Status – ambiguity status for each epoch
- Number of Satellites

Imagery Equipment

The SHOALS system incorporates an Allied Prosilica GX3300 down-look camera (**Error! Reference source not found.**) configured to acquire RGB image frames at a rate of 1 Hz with an image size of 3296 x 2472 resolution and a potential image resolution (ground sample distance, variable with altitude) of 0.19 m. The camera employs a high-quality 8-megapixel OnSemi KAI-08051 sensor and APO-XenoPlan lens that provides superior image quality and low noise. This combination provides sharp imagery under a variety of lighting conditions.

Figure 4 Prosilica GX3300 Camera

The camera and lens system have been metrically calibrated using a rigorous camera model that explains the mapping between the 3D coordinates and the image coordinates. This distortion model was first introduced by Brown in 1966 and is called the Plumb Bob model (radial polynomial + thin prism).
During calibration the best fit model of the following are determined:

- Focal length: The focal length in pixels
- Principal point: The principal point coordinates
- Skew coefficient: The skew coefficient defining the angle between the x and y pixel axes.
- Distortions: The image distortion coefficients (radial and tangential distortions).

Figure 5 illustrates the results of the distortion calibration. The resultant model is used as the correction inputs for ortho-rectification on the composite mosaic.

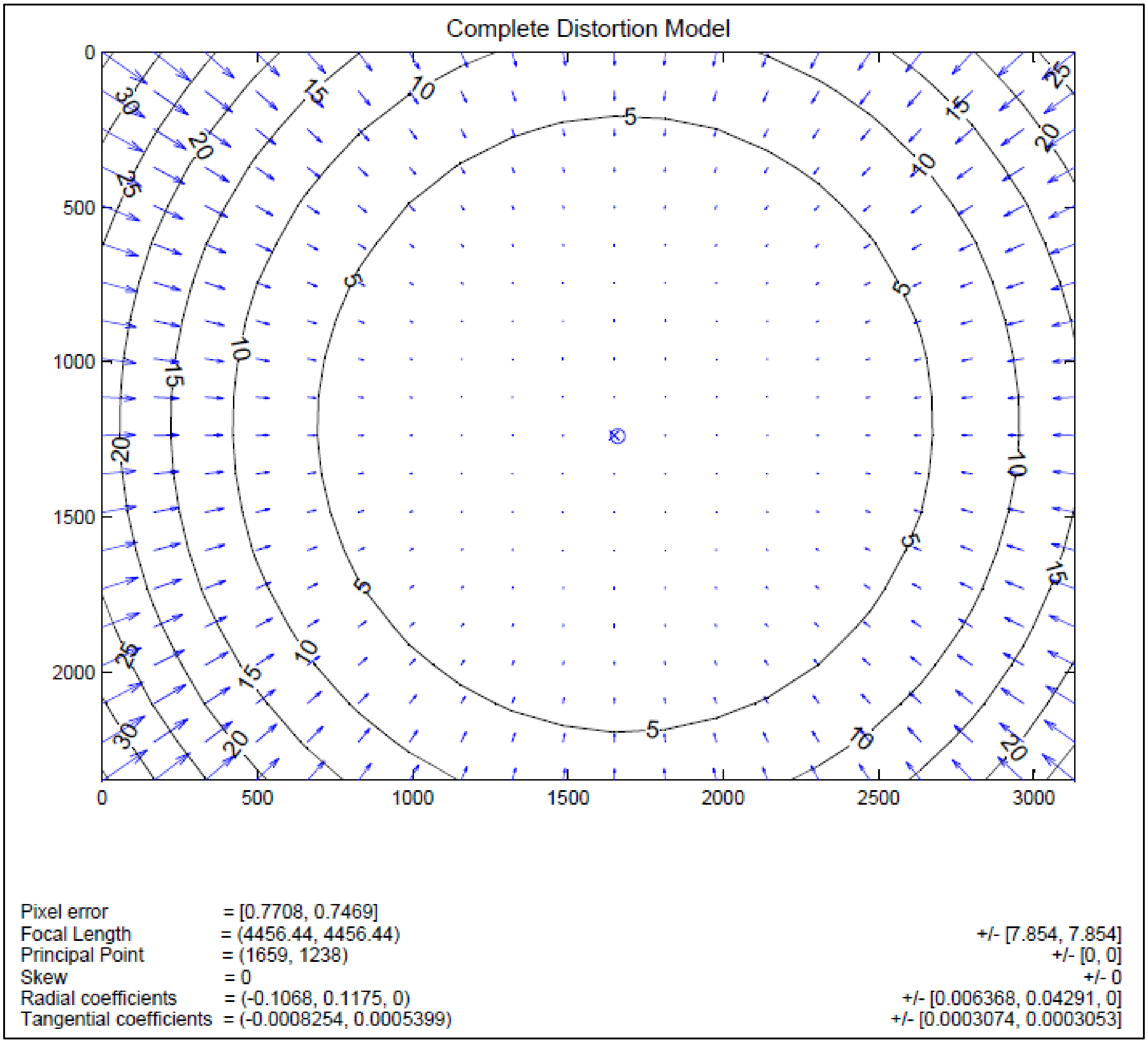


Figure 5 Sample Camera Lens Calibration Results

Once installed on the aircraft, the camera underwent a boresight calibration to eliminate misalignments between the POS/AV and the camera reference point. The procedure involves the analysis of reciprocal lines' imagery and the adjustment of pitch, roll, and heading angle correctors that would align the images to the reference targets on the ground. The angle adjustments sequence iterates for as many times necessary to reduce horizontal misalignment of features to less than 0.5 m 1σ.

Raw digital images were exported with the SHOALS-GCS processing software, which also created the external orientation (EO) image index file that includes the aircraft position and orientation information for each image. The images and EO parameters were input into ERDAS (Leica Photogrammetry Suite) LPS software to generate the ortho-rectified images with the aid of a preliminary Digital Elevation Model (DEM) derived from the data. See **Figure 6** for a sample picture from the SHOALS camera. The rectified images were output at 2.0 m resolution. Spatial accuracy of the rectified imagery has been reported to be within ±2 m at 95 % c.l. when compared to ground control points (GCP) or to high resolution features depicted by topographic LiDAR (< 1 m in horizontal dimensions).

Figure 6 Sample Picture from SHOALS Camera

Static Draft Measurement

Static draft was measured from a tab on the stern of the vessel directly above the IMU and sonar mount and then the correction to the common reference point (IMU) was applied. Refer to the offset diagrams Appendix I for additional information.

Bottom Sampling

The R/V JAB and R/V Westerly were equipped with a 2.4L Van Veen Grab bottom sampler and 100 meters of line. The sampler was hand deployed, and retrieved via a davit that was installed on the port side of the vessel. All samples were discarded after the sample information was recorded.

Software

MBES Acquisition

All raw multibeam data was collected with WFMB v3.10.15.3. WFMB ran on a Windows 7 PC with a quad-core Intel processor. Data from the Reson 7125 sonars were logged in the s7k file format. The s7k files contain all multibeam bathymetry, position, attitude, heading, and UTC time stamp data required by CARIS to process the soundings. A separate WFMB module (PosMVLogger) on the same PC logged all raw POS/MV data for the post-processing of vessel positions in Applanix POSPac MMS software. WFMB also provided a coverage display for real-time QC and data coverage estimation.

WFMB offers the following display windows for operators to monitor data quality:

1. Devices: The Devices window shows the operator which hardware is attached to the PC. It also allows the operator to configure the devices, determine whether they are functioning properly, and to view received data.

2. Graphic: The Graphics window shows navigation information in plan view. This includes vessel position, survey lines, background vector plots, and raster charts.

3. Vehicle: The Vehicle window can be configured to show any tabular navigation information required. Typically, this window displays position, time, line name, heading, HDOP, speed over ground, distance to start of line, distance to end of line, and distance off line. Many other data items are selectable.

4. Calculation: The Calculations window is used to look at specific data items in tabular or graphical format. Operators look here to view the status of the GPS satellite constellation and position solutions, real-time SV, tidal values, etc.

5. MBES Coverage Map: The Coverage Map provides a real time graphical representation of the multibeam data. This allows the user to make judgments and corrections to the data collection procedure based on current conditions.
6. MBES QC View: The QC View contains four configurable windows for real-time display of any of the following: 2D or 3D multibeam data, snippets, pseudo sidescan, or backscatter amplitude. In addition to this, it contains a surface sound speed utility that is configurable for real-time SV monitoring at the sonar head.

Applanix POS/MV V4 and V5 controller software was used to monitor the POS/MV systems. The software has various displays that allow the operator to check real-time position, attitude and heading accuracies, and GPS status. POS/MV configuration and calibration, when necessary, was also done using this program.

Fugro’s PosMvLogger v2.0 was used to provide uninterrupted logging of all Inertial Motion Unit (IMU), dual frequency GPS, and diagnostic data. Additionally, the Delayed Heave data applied in post-processing was collected concurrently in the same file. The program also provided real-time QC and alarms for excessive HDOP, PDOP, and DGPS outages.

Fugro’s MB Survey Tools v3.1.7 was used to aid in file administration and reporting during data acquisition. This program created a daily file that contained survey line, SVP, and static draft records. These logs were stored digitally in a database format and later used to create the log sheets in PDF format located in the Descriptive Report Separate 1.

CARIS Onboard was used to increase efficiency with the daily processing effort. This program ran during data acquisition; converting lines, and applying SVP and Total Propagated Uncertainty (TPU) values. A daily DTM was also updated as each line was processed. The CARIS Onboard daily project was copied to the server at the end of each shift along with the raw data.

Fugro's Bck2Base software is a package that facilitated the transfer of large data sets from the survey location back to the Fugro datacenter. Bck2Base was used to send the daily CARIS Onboard projects to our San Diego datacenter where processing operations took place.

LiDAR Acquisition

Raw LiDAR data was collected using Optech SHOALS v1.2 Airborne System Operator GUI. This interface allows the airborne operator to control the SHOALS sensor and monitor quality indicators, such as PDOP, laser power, satellites tracked, and error messages in real-time during flight. Acquisition software was installed on a ruggedized PowerBook laptop well-suited for the airborne environment. In addition to the interface used by the operator, the SHOALS acquisition software outputs navigation and track guidance information to the flight crew via a separate pilot console that mounts on the dashboard of the aircraft.

Applanix POS/AV data is logged directly to a USB flash drive attached to the POS unit.

Fugro's LiDARSurvey Tools v3.1.7 was used to aid in file administration and reporting during data acquisition. These logs were stored digitally in a database format and later used to create the log sheets in PDF format located in the Descriptive Report Separate 1.

MBES Processing

All lines were converted with CARIS Onboard v1.0.3 during data acquisition.

All Soundings were processed using CARIS HIPS v9.1.4. HIPS converted the s7k files to HIPS format, corrected soundings for sound velocity, motion, tide, dynamic draft, and vessel offset, and was used to examine and reject noisy soundings. HIPS also produced the final Bathymetry Associated with Statistical Error (BASE) surfaces.

CARIS HIPS and SIPS v9.1.8 with Caris_Support_Files_5_4 was used to generate the S-57 Feature Files.

ESRI ArcMap v10.3 was used for survey planning, reviewing coverage plots, creating infills & crosslines, and creating graphics.
MB Survey Tools v3.1.7 was used to extract Delayed Heave from POS files and put data into a text format acceptable to the CARIS Generic Data Parser. This was only needed when the CARIS Load Delayed Heave routine in HIPS failed to import.

MB Survey Tools v3.1.7 allowed processors to track changes and add comments while processing. MB Survey Tools was also used to process all sound velocity profiles and to convert them into a CARIS format.

A complete list of software and versions used on this project is included in Appendix I.

LiDAR Processing

Raw SHOALS data was taken directly into SHOALS GCS v6.32 (Ground Control System) once data was securely copied to the field server. GCS converts raw INH data first into ABH and INH files during download. The next step is an auto-process which creates Hydrographic Output Files (HOF) format data, and filters data based on predetermined parameter values. It is also at this stage that the Smooth Best Estimate and Trajectory (SBET) is applied.

QPS Fledermaus v7.3.3c is the main visualization tool used in the ALB workflow. Surfaces used for cleaning data are built via SHOALS GCS using Fledermaus. This software package also works in conjunction with GCS to allow for reprocessing in GCS whilst visualizing in Fledermaus 3D Editor.

NovAtel Convert 4 v3.9.0.7 was used, when necessary, to convert data from base station's native PDC format to RINEX format.

Applanix POSPac MMS 7.1 was used for the post-processing of airborne GPS data. A SmartBase network was created using downloaded Continually Operating Reference Station (CORS) data, this network was then processed with the airborne POS data to calculate higher accuracy positions than those calculated in real-time.

All Soundings were imported into CARIS HIPS v9.1.4. HIPS converted the HOF data to HIPS formatted HOF, corrected soundings for TPU and reduced data to MLLW using a VDatum model. HIPS also produced the final BASE surfaces.

NOAA's VDatum v3.6 was used to transform data from the ellipsoid to MLLW using a separation model.

CARIS HIPS and SIPS v9.1.8 with Caris_Support_Files_5_4 was used to generate the S-57 Feature Files.

ESRI ArcMap v10.3 was used for survey planning, reviewing coverage plots, creating re-flight & crosslines, and creating graphics.

LiDAR Survey Tools v1.03.06 was used for data management and logging. Airborne logs, processing tasks and daily project information was tracked using this Fugro, Inc. created software.

Workbench, another Fugro software package, was used at various stages. Version 6.01.04 was used for data validation tasks during acquisition and again during the deliverables stage in order to facilitate creation of ortho mosaics.

A complete list of software and versions used on this project is included in Appendix I.

B – Quality Control

MBES

Error estimates for all MBES survey sensors were entered in the CARIS Hips Vessel File (HVF). Additionally, measured uncertainty values were applied to the data where possible. These measured values included delayed heave RMS from the raw POS/MV files, positioning and attitude uncertainties from the Applanix POSPac MMS RMS files, and calculated surface sound velocity values. These error estimates were used in CARIS to calculate the TPU at the 95% confidence level for the horizontal and vertical components of each individual sounding.

The values that were entered in the CARIS HVF for the survey sensors are the specified manufacturer accuracy values and were downloaded from the CARIS website **http://www.caris.com/tpu/**. The following is a breakdown and explanation on the manufacturer and Fugro derived values used in the error model:

- Navigation – A value of 0.10 m was entered for the positional accuracy. This value was selected since all positions were post-processed, with X, Y, and standard deviation values better than 0.10 m.
- Gyro/Heading – Vessel was equipped with a (POS/MV) 320 V4 and had a baseline < 4 m, therefore, a value of 0.020 was entered in the HVF as per manufacturer specifications.
- Heave – The heave percentage of amplitude was set to 5% and the Heave was set to 0.05 m, as per manufacturer specifications.
- Pitch and Roll - As per the manufacturer accuracy values, both were set to 0.02 degrees.
- Timing – All data were time stamped when created (not when logged) using a single clock/epoch (Pelagos Precise Timing method). Position, attitude (including True Heave), and heading were all time stamped in the POS/MV. A ZDA+1 PPS string was also sent to the Reson 7125 processor, yielding timing accuracies on the order of 1 millisecond. Therefore a timing error of 0.001 seconds was entered for all sensors on all vessels.
- All vessel and sensor offsets were derived via conventional survey techniques (total station), while the vessel was dry docked. The results yielded standard deviations of 0.005 m to 0.010 m, vessel and survey dependent.
- Vessel speed – set to 0.10 m/s since a POS/MV with a 50 Hz output rate was in use.
- Loading – estimated vessel loading error set to 0.05 m. This was the best estimate of how the measured static draft changed through the survey day.
- Draft – it was estimated that draft could be measured to within 0.01 m to 0.03 m; therefore values in this range were entered.
- Tide error was computed and set by the TCARI GUI provided by NOAA.
- Sound Speed Values were determined in MB Survey Tools, via the SVP Statistics utility. This utility calculated the Mean, Variance, Standard Deviation, and Min/Max values at a user specified depth interval. A separate value was also taken from the manufacturers specifications.
- MRU Align Standard Deviation for the Gyro and Roll/Pitch were set to 0.10° since this is the estimated misalignment between the IMU and the vessel reference frame.

The calculated vertical and horizontal error or TPU values were then used to create finalized CUBE (Combined Uncertainty Bathymetry Estimator) surfaces; only soundings meeting or exceeding project accuracy specifications were included in this process.

An overview of the data processing flow follows:

During Acquisition the s7k files collected by WFMB were processed by CARIS Onboard. CARIS Onboard converted the s7k files, applied a predicted tide, SVP corrected, applied TPU values, and added lines to a daily CUBE surface. This whole process was automated and ran in the background during data collection.

Once the data arrived at the field office, a review was done to confirm all lines collected had been processed by CARIS Onboard. Once this was complete both the Preliminary Tide and Delayed Heave data were applied to all lines.

The CARIS Onboard projects were then copied to Back2Base to be compressed and sent to our processing center in San Diego for the main processing efforts to be done.

In order for the s7k files to be collected by WFMB and used by CARIS, they must be converted to HDCS format using the CARIS ResonPDS converter routine. Prior to the files being converted, vessel offsets, patch test calibration values, TPU values, and static draft were entered into the HVF.

Once converted, the Preliminary Tide, Dynamic Draft, and Delayed Heave data were loaded into each line and the line was SVP corrected in CARIS HIPS. Prior to sound speed correction, the dynamic draft was loaded into each line via the load Delta draft routine. The TPU was then computed for each sounding and attitude. Bathymetry data for each individual line were examined for noise as well as to ensure the completeness and correctness of the data set.

The data was filtered using a swath angle filter and a Reson quality flag filter (**Table 4**). The swath angle filter rejected all soundings falling farther from a specified angle from nadir. The Reson quality flag filter rejected soundings based on the collinearity and brightness of each ping. Note that "rejected" does not mean the sounding was deleted – it was instead flagged as bad so not be included in subsequent processing such as surface creation. Data flagged as rejected contained valid data but were flagged to remove noise and to speed the processing flow. Valid data were manually reaccepted into the data set occasionally during line and subset editing as required.

Table 4 Reson Quality Flags

Quality Flag	Brightness	Collinearity
0	Failed	Failed
1	Pass	Failed
2	Failed	Pass
3	Pass	Pass

Multiple CARIS filter files were used during the project. The most utilized filters are shown in **Table 5**. The processor selected the appropriate filter file based on a brief review of the data for environmental noise and bottom topography. Filter settings were sometimes modified based on data quality, but all filter settings used were noted on each corresponding line log found in the Descriptive Report Separate 1.

Table 5 CARIS Filter File Definitions

File name	Angle from Nadir	Quality Flag
Port_68_Stbd_68_01.hff	68˚	0&1
Port_65_Stbd_65_01.hff	65˚	0&1
Port_55_Stbd_55_01.hff	55˚	0&1

Because of the high accuracies realized from using Fugro's Marinestar G2 corrections, there was no need to post-process any of the positioning data.

CUBE surfaces were then created at each required resolution for the Sheet or Block (**Table 6**). Each CUBE resolution surface was then finalized using the depth thresholds for that specific resolution. The finalized CUBE surfaces were used for subset cleaning so only the surface relating to the specific resolutions' depth range would be reviewed. CUBE parameters were derived from NOS HSSD March 2016. The following depth threshold and CUBE parameter settings were used on this project.

Table 6 CUBE Surface Parameters

Surface Resolution	Depth Range	IHO S-44 Specification	Surface Creation				Disambiguation			
			Estimate Offset	Capture Distance Scale	Capture Distance Minimum	Horizontal Error Scalar	Method	Density Strength Limit	Locale Strength Maximum	Locale Search Radius
1m	0-20m	Order 1a	4	0.50%	0.71m	1.96	Density & Local	2	2.5	1 pixel
2m	18-40m	Order 1a	4	0.50%	1.41m	1.96	Density & Local	2	2.5	1 pixel
4m	36-80m	Order 1a	4	0.50%	2.83m	1.96	Density & Local	2	2.5	1 pixel
8m	72-160m	Order 1a	4	0.50%	5.66m	1.96	Density & Local	2	2.5	1 pixel
16m	144-320m	Order 1a	4	0.50%	11.31m	1.96	Density & Local	2	2.5	1 pixel

Deviations from these thresholds, if any, are detailed in the appropriate Descriptive Report.

Subsets Tiles (to track areas examined) were created in CARIS HIPS. Adjacent lines of data were examined to identify tidal busts, sound velocity and roll errors, as well as to reject any remaining noise in the data set that adversely affected the CUBE surface.

While examining the data in subset mode, soundings were designated wherever the CUBE surface did not adequately depict the shoalest point of a feature. Soundings were designated when they met or exceeded the criteria for designation set forth in the Specifications and Deliverables. Designation ensured that soundings were carried through to the finalized BASE surface.

A statistical analysis of the sounding data was conducted via the CARIS Quality Control Report (QCR) routine. Crosslines were run in each survey and compared with CUBE surfaces created from the main scheme lines. The IHO S-44 criteria for an Order 1a survey, as specified in the

Project Letter, were used in the CARIS QCR comparison on a beam by beam basis. Quality Control results are found in Separate 4 of each survey's Descriptive Report directory.

CARIS HIPS and SIPS v9.1.8 with Caris_Support_Files_5_4 was used to produce the S-57 final feature file (FFF). Seabed Area (SBDARE) polygon objects were picked from areas with obvious rocky bottom topography from the BASE surfaces. Meta-Coverage (M_COV) and Meta-Quality (M_QUAL) objects were defined as required using the extents of the multibeam BASE surfaces. All additional features that could not be depicted in the CARIS BASE surfaces, such as rocks and bottom samples, were logged in the S-57 assigned feature file.

In preparation for shoreline verification, the project composite source file (CSF.000) was copied and cropped it to include only items contained on the specific survey. This cropped file was then saved as a HOB file named HXXXXX_FFF.hob. Edits were then saved to this HOB file. De-confliction of the composite source shoreline was conducted only on items assigned while conducting shoreline verification.

Primary and secondary flagged features are correlated using the NOAA custom attributes prkyid (Primary Key ID).

Investigation methods and results are described in CARIS HIPS under the S-57 attributes acronym “remrks”. Specific recommendations are described under the S-57 attributes acronym “recomd”.

FFF features that do not exist or were determined to be a duplicate were given a “delete”value in the “descrp” attribute. Features that were positioned incorrectly were also given the “delete” value in the “descrp” attribute, and a new feature with a “new” value in the “descrp” attribute was added in its correct location. The “primsec” field was used to distinguish deleted features from newly positioned features. Most of the assigned features were verified or identified in the LiDAR bathy data or ortho-mosaic. These items were labelled with “LiDAR investigations” in the “Special Feature Type” attribute. The TECSOU field was populated with the “found by multi-beam attribute” for any feature verified by multibeam.

If an assigned feature was not submerged and within 2 mm at survey scale, the position of that assigned feature was retained and only the VALSOU or ELEVAT attributes were updated. To determine the VALSOU or ELEVAT for features investigated by LiDAR, the National VDatum software developed by NOAA was used to reduce LiDAR data to MLLW. LiDAR data was then clipped to the extents of each of the survey priorities and overlaid with Fugro-acquired ortho-imagery and assigned CSF features. The LiDAR grid was then used to determine the VALSOU attribute using the height or depth on the actual features and not the height or depth of the corresponding assigned CSF features (methodology approved by COR and PHB). In order to determine which features should be considered islets, a difference surface corresponding to mean high water (MHW) was created for all survey priorities. Islet elevations were derived by taking the difference between the highest SHOALS topo point and the MHW grid. See the NOS HSSD 2016, Appendix F. WATLEV Attribution encoding guidelines were used for determining points above and below MHW.

To the reviewer: some automated routines that check grid agreement to a feature file (such as HydrOffice QC Tools VALSOU Check) may reveal flags suggesting a positional error; this is because some of the charted features in this survey have depths with little or no height off the bottom, and so automated routines may not be able to distinguish the node-match from the surrounding seafloor.

All shoreline data was submitted in the edited FFF in S-57 format (.000). The SORDAT and SORIND fields were filled in for any objects added or modified in the FFF.

LiDAR - Processing

Conversion of raw sounding data from the airborne system to final depth data was accomplished on the field Ground Control System (GCS) server. This field server was connected to three operator terminals, with all applicable software installed and a stringent data archival processes in place. At critical points during the data collection phase, full project data saves were conducted and backup media dispatched to the Fugro office in San Diego. At the conclusion of field operations, a full final field-save was conducted and all copied data transferred to the main computer servers at the Fugro office, for in-depth data verification.

All acquired bathymetric LiDAR data went through an in-field *preliminary* review to assure that adequate coverage had been obtained and that there were no gaps between flight lines or errors in the data before the flight crew departed the project site.

Following each sortie, the flight data was run through a complete iteration of processing to ensure that it was complete, uncorrupted, and that the project area has been covered adequately. There are essentially five steps to this in-field data verification.

All SHOALS-1000T data was processed using the Optech SHOALS Ground Control System (GCS) v6.32 on Windows 7 workstations equipped with quad-core processors. GCS includes links to QPS Fledermaus v7 software for data visualization and 3D editing, and Applanix POSPac v7.1 software for KGPS positioning processing.

GCS program's Download, Auto-processing and Visualization Software (DAViS) module was used to download raw SHOALS sensor data, apply the inertially-aided KGPS solution, auto-process waveforms with specialized algorithms for surface/bottom detection and depth determination, perform waveform analysis for reflectance generation, and make an initial assessment of data quality. An example of a SHOALS waveform is shown below in **Figure 7**. KGPS processing mode was initially used to verify data quality and to perform the large majority of data editing. At a later stage, water level information was applied to validated LiDAR depths for final survey datum reduction.

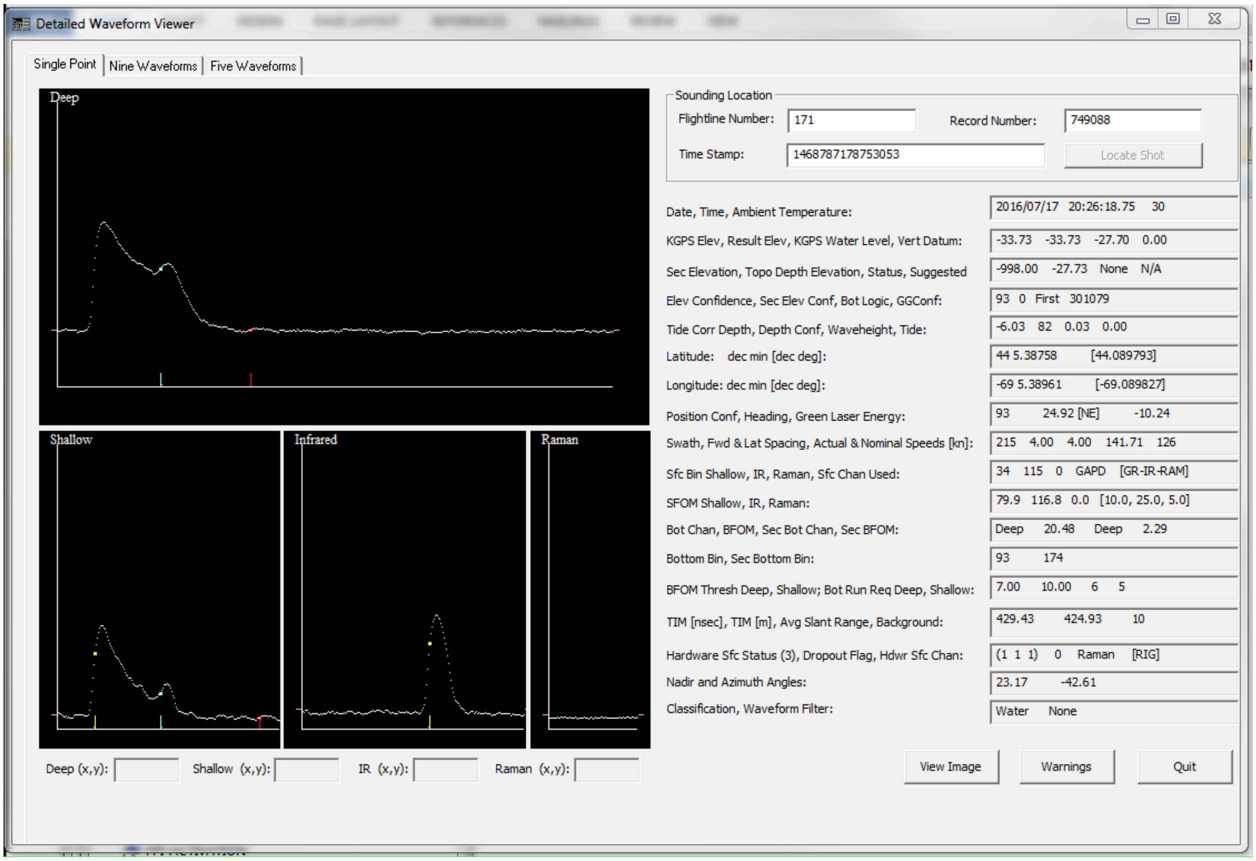


Figure 7 SHOALS GCS Waveform Window

For each flight, a KGPS navigation solution was processed in Applanix POSPac software. GPS data from the airplane and ground control base stations were input in a POSPac project and post-processed to obtain an optimal inertially-aided KGPS navigation solution.

For this project, CORS stations were used as control in the form of a SmartBase network. The network configuration established for ALB field acquisition was held for the duration of the project. Detailed information about this network can be found in the Horizontal and Vertical Control Report (HVCR).

In general, the best possible KGPS solution would present a small separation difference between forward and reverse solutions when combined, ideally <0.10 m RMS and remain fixed throughout the flight period. The final SBET was then used by GCS during LiDAR auto-processing.

The auto-processing operation (AP) is the core of the GCS software. The AP algorithms incorporate the defined calibration parameters, the optimal environmental settings selection, and the KGPS solution (or tides water level). The AP routines contain a waveform analysis algorithm that detects and selects surface and bottom returns from the raw data. In KGPS mode, raw LiDAR depths are referenced as absolute ellipsoidal heights. In Tides mode, depths are the relative range between sea surface and the bottom detection. In both modes, waveforms are analyzed to produce raw reflectance data records.

For this project, sea surface detection method (surface logic) was set as GIR. This means the surface detection occurred using the green channel. If no green surface was found then the IR channel would be used, and then the raman channel as last resource.

The bottom detection mode always used the green channel in the first pulse logic, which takes depth hits that could be flagged as potential targets into account. The alternate choice of *strongest-return* would have resulted in small objects on the seabed going undetected by GCS algorithms.

Prior to AP, all parameter values were confirmed against a list of project parameters which contained the calibration, project, and processing parameters predetermined to meet the scope of work.

After AP was complete for a flight mission, the dataset was prepared for editing and validation in Fledermaus software and its 3D editing capabilities.

A 3D surface was also rendered during auto-processing. The data was reviewed in Fledermaus for preliminary quality and coverage. As part of the QC process, waveform and metadata analysis on a point by point level was reviewed to better determine the quality of the data (refer to **Figure 8**). Also during this phase the downward looking imagery was viewed and used to correlate shallow and drying features in the LiDAR data (refer to **Figure 9**).

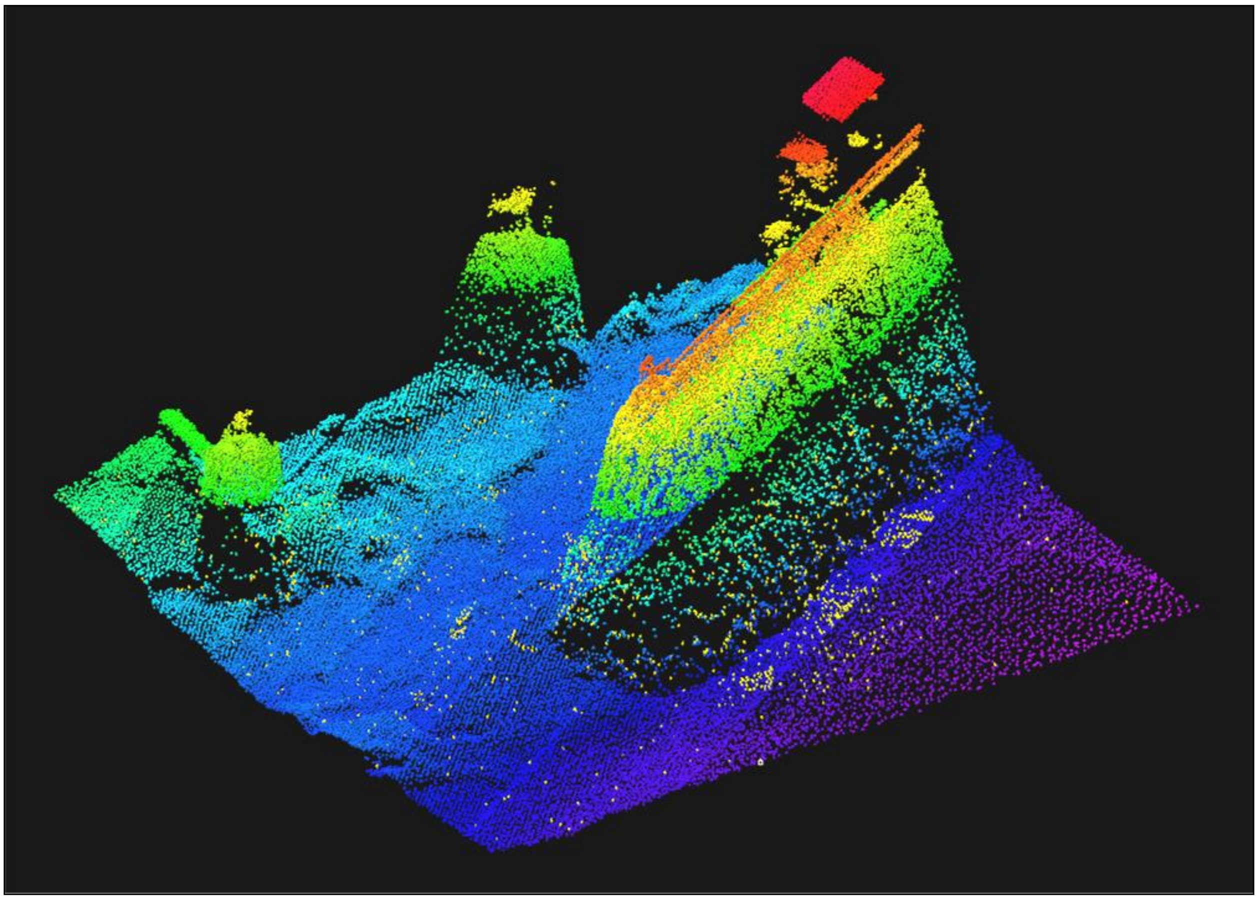


Figure 8 Example of Individual Soundings in 3D Editor

In Fledermaus 3D Editor, erroneous soundings were deleted and shoal soundings verified. Once rendered, the individual datasets were combined with other adjacent data sets for overlap comparisons, cross check comparisons, and continuity checks. The Lead Hydrographer reviewed these larger areas of data to ensure validity and for re-flights plans.

Figure 9 Digital Image Viewer

LiDAR Data Processing -Summary

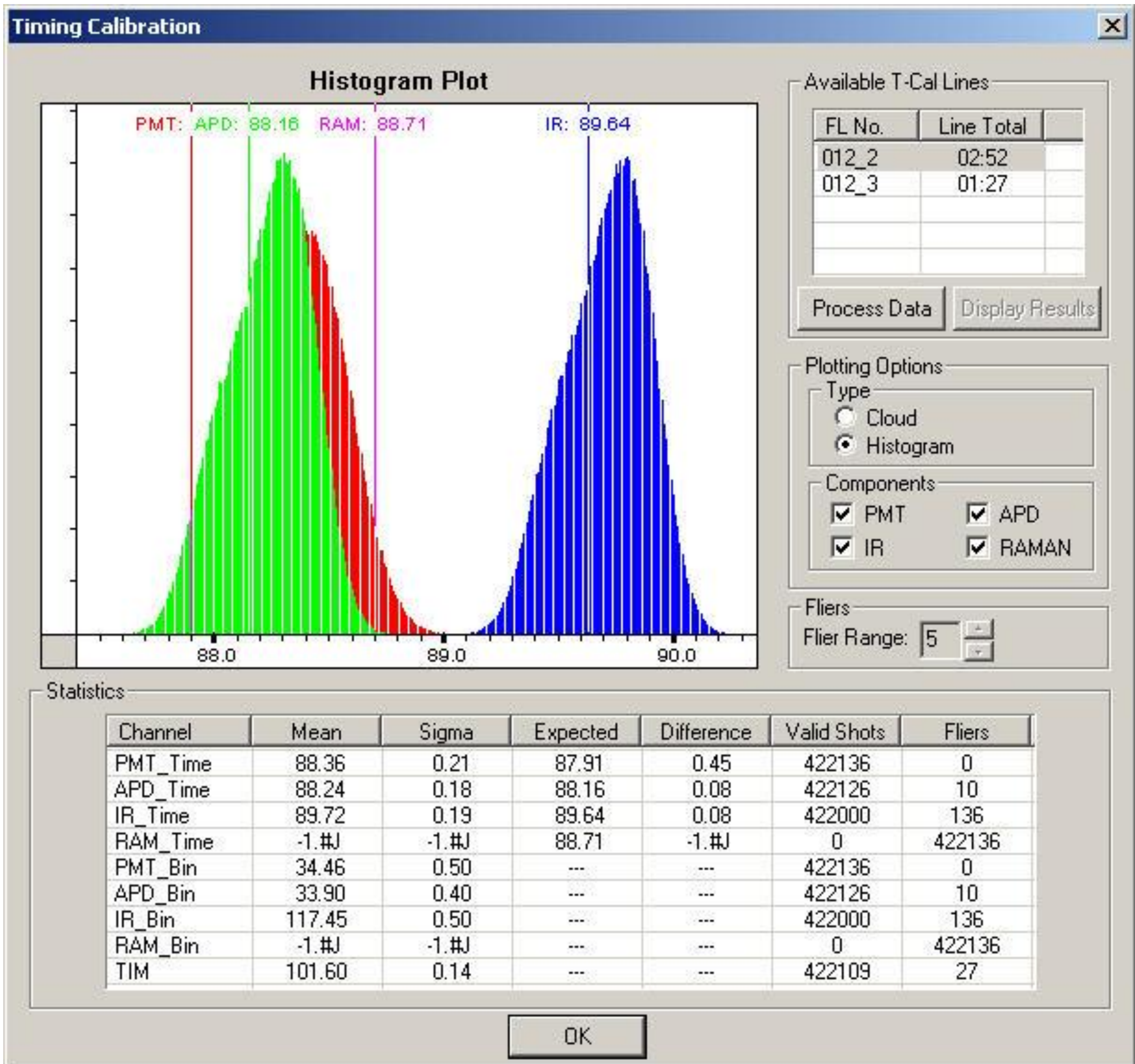
Data processing involves the following stages:

- In-field automatic data processing.
- In-field survey line acceptance by the Senior Data Analyst.
- In-field project wide review by the Lead Hydrographer.
- In-field rough cleaning by Data Analysts.
- Office-based validation of the data by Data Analysts.
- Office-based checking of the data by Senior Data Analysts and the Lead Hydrographer.

- QC of the data by the Lead Hydrographer.
- Approval of the data by the Lead Hydrographer once exported to CARIS.

Laser Power Timing Tests

Each flight during the course of the project collected at least one laser power timing test (LPTT). During this test, the laser is directed through a fiber optic cable of fixed, known length and the timing measured to confirm proper operation of the system. These data were analyzed, see **Figure 10** for an example of the output, and logged after each flight using the GCS software to ensure data was within acceptable thresholds. Results were tracked in LiDAR Survey Tools.



Channel	Mean	Sigma	Expected	Difference	Valid Shots	Fliers
PMT_Time	88.36	0.21	87.91	0.45	422136	0
APD_Time	88.24	0.18	88.16	0.08	422126	10
IR_Time	89.72	0.19	89.64	0.08	422000	136
RAM_Time	-1.#J	-1.#J	88.71	-1.#J	0	422136
PMT_Bin	34.46	0.50	---	---	422136	0
APD_Bin	33.90	0.40	---	---	422126	10
IR_Bin	117.45	0.50	---	---	422000	136
RAM_Bin	-1.#J	-1.#J	---	---	0	422136
TIM	101.60	0.14	---	---	422109	27

Figure 10 Example of Laser Power Timing Test Result

Data Validation

During the field acquisition period, all data were inspected for coverage and overall quality at the field office. Preliminary field processing was conducted to ensure LiDAR measurements, imagery data, and positioning control met the project's quality requirements. Field processing also served to refine mission planning, particularly when external factors such as environmental and weather conditions impacted the daily operations.

At the conclusion of field operations, the survey data package was transferred to the Fugro Datacenter in San Diego, where final processing and product assembly took place. The data processing flow is summarized below and in Figure 1.

- SHOALS data auto-processing with KGPS
- Creation of ortho-mosaic imagery
- Data editing and validation
- Data QC and approval
- Data import in to CARIS HIPS
    - Application of TPU
    - Application of VDatum model
    - Creation of BASE Surface
- Deliverables QC and Approval
- Final Reports

GCS integrates with Fledermaus to create temporary file structures called PFMs, which can be opened as surfaces in Fledermaus for visualization, data review, and editing. Systematic selections of discrete data sections were reviewed using the 3D area-based editor. The 3D Editor opens up a smaller subset of data, displaying point clouds and allows the selection of individual soundings for editing.

In 3D Editor, editing tools like the waveform viewer, digital image viewer, and warning messages were used by the data analyst to flag and validate depths based on quality indicators and metadata available in these windows. GCS re-processing tools are also available in the 3D Editor interface to enhance the data analyst's abilities to edit LiDAR depths. Such tools include, but were not limited to:

- Shallow water algorithm (SWA): recovery of very shallow depths (<1.5 m)
- Depth swaps: false bottom depth swapped in favor of valid bottom picks.
- False land: removal of false land hits caused by high energy returns (e.g. white water).

In large part, manual editing was used to remove gross fliers, obvious anomalies generally caused by poor water clarity and other non-bathymetric returns such as vegetation, boats and other floating objects.

The Lead Hydrographer and Senior Data Analysts performed the final QC of data at various stages during data processing (single flight dataset editing, combined dataset editing, following CARIS import, etc.). Recurrent data editing/QC cycles had to be implemented to maximize editing best practice and minimize involuntary oversight.

Approval

All quality controlled data was exported from GCS for spatial presentation and final approval in CARIS by the Lead Hydrographer. A BASE Surface for each registered sheet was created and the following items were checked for correctness/completeness against the SHOAL layer:

- All applicable flight lines were exported.
- Horizontal and vertical TPU was assigned correctly.
- Data range of minimum and maximum depth values were within project bounds.
- The BASE Surface completely covers the NOAA sheet limits.
- There were no unexplained gaps in the final coverage.
- A standard deviation surface was reviewed to ensure all data meets the accuracy specifications.

Digital Imagery Processing

The SHOALS camera collected digital imagery at 1 Hz and logged alongside the raw LiDAR data. These images were extracted from raw format using Fugro Workbench tools; this included extracting the precise camera position and orientation as determined by the post-processed SBET solution creating an image index. Workbench translated this information through rotation matrices into the exterior orientation (EO) parameters that referenced the sensor's frame to the project's coordinate referenced system.

All extracted images and EO parameters were input in ERDAS LPS v 9.3 photogrammetric software to generate the ortho-rectified images with the aid of a bare earth DEM obtained from USGS National Elevation Dataset (NED).

Ortho-rectified images were processed into tiled mosaics using Trimble's Orthovista v7.0.3 software, applying automated seamlines, feature detection, and tonal color balancing. Final mosaics were produced in 8-bit RGB geoTIFF format at 0.3 meter resolution. A sample of the final ortho mosaic product can be found in **Figure 11**.

Figure 11 Sample Image from Final Ortho mosaic Product

Data Management

Water Clarity

The greatest contributor to depth performance, seabed coverage and data quality with a LiDAR system is water clarity. In order to address this concern, Fugro conducted water clarity assessments across the project area, from the planning phase through the final flight, using a number of different techniques.

Water Clarity Assessment - Remotely Sensed Data

During the planning phase of the project, remotely sensed data was used to estimate the expected water clarity conditions for the Penobscot Bay project area and the likely depth penetration of the SHOALS-1000T, as seen in **Figure 12** & **Figure 13**.

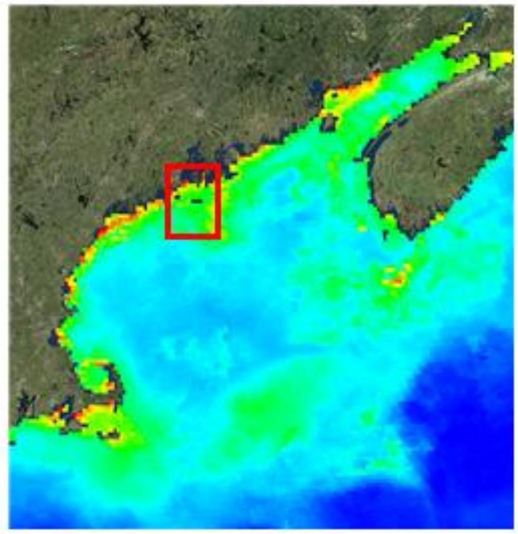
The Diffuse Attenuation Coefficient at Band 3

K490 indicates the turbidity of the water column - how visible light in the blue - green region of the spectrum penetrates within the water column . It is directly related to the presence of scattering particles in the water column.

$$K(490) = K_w(490) + A\left[\frac{L_W(\lambda_1)}{L_W(\lambda_2)}\right]^B.$$

$K_w(490)$ = the diffuse attenuation co for pure water = 0.016 m^{-1}
(From Mueller 2000 and Smith and Baker 1981)

lambda1 = 488/490
lambda2 = 551/555
A = 0.15645
B = -1.5401



Level 2 metadata:
K_490: slope = 0. 0002
K_490: intercept = 0

Figure 12 K490 Equation

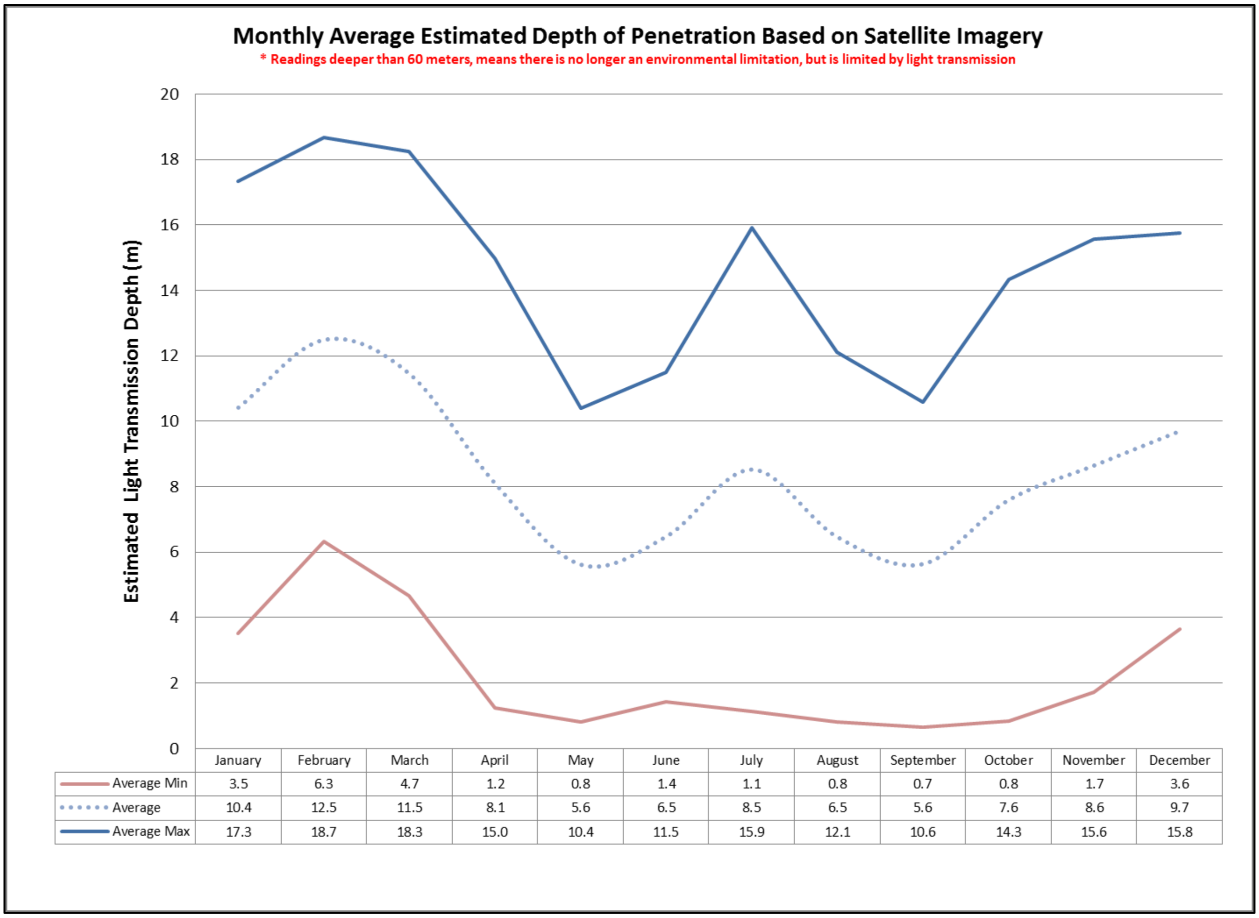


Figure 13 Depth Penetration Estimates from Survey Area

<u>Water Clarity Assessment – Reconnaissance</u>

On 13 June 2016, Fugro staff undertook an aerial reconnaissance mission in the vicinity of Penobscot Bay. Conditions were documented in many photos and water clarity was, on the whole, found to be relatively poor. Water was seen to be clear in the very shallow depths (likely under four meters) and murky in deeper waters.

Figure 14 Image Obtained during Aerial Reconnaissance Mission

<u>Water Clarity Assessment - ALB Data Acquisition</u>

In general, water clarity in the Penobscot Bay survey area was less than ideal for ALB acquisition. Clear water was more common in shallow waters but water in the four to eight-meter range of interest was typically murky. Due to the short duration of the collection period waiting to see improvement over time was not possible.

Conditions were similar in the survey area around Vinalhaven and North Haven Island as well, with shallow depths being clearer than the depth range of interest. The bathymetry in the area tends toward a steep descent into depths outside the range of ALB.

The water clarity had a negative impact on coverage within the four to eight-meter depth range and was of particular interest to this survey. A test flight was conducted during high tide in order to eliminate the low-tide timing as the issues with water clarity due to tidal flushing. Water conditions on this test flight were consistent with those seen on the flights timed around low tide, so it was concluded that the tide level was not the cause of the poor water clarity.

Total Propagated Uncertainty

Fugro has developed methodology to determine vertical and horizontal uncertainty (TPU) for the SHOALS sensor using spatial variance from direct observation of surveyed data, as is laid out in Lockhart et al, 2008[1]. Data collected over a reference bathymetric area within or near the survey area was used to produce the statistical analysis for vertical TPU estimations (**Figure 15**).

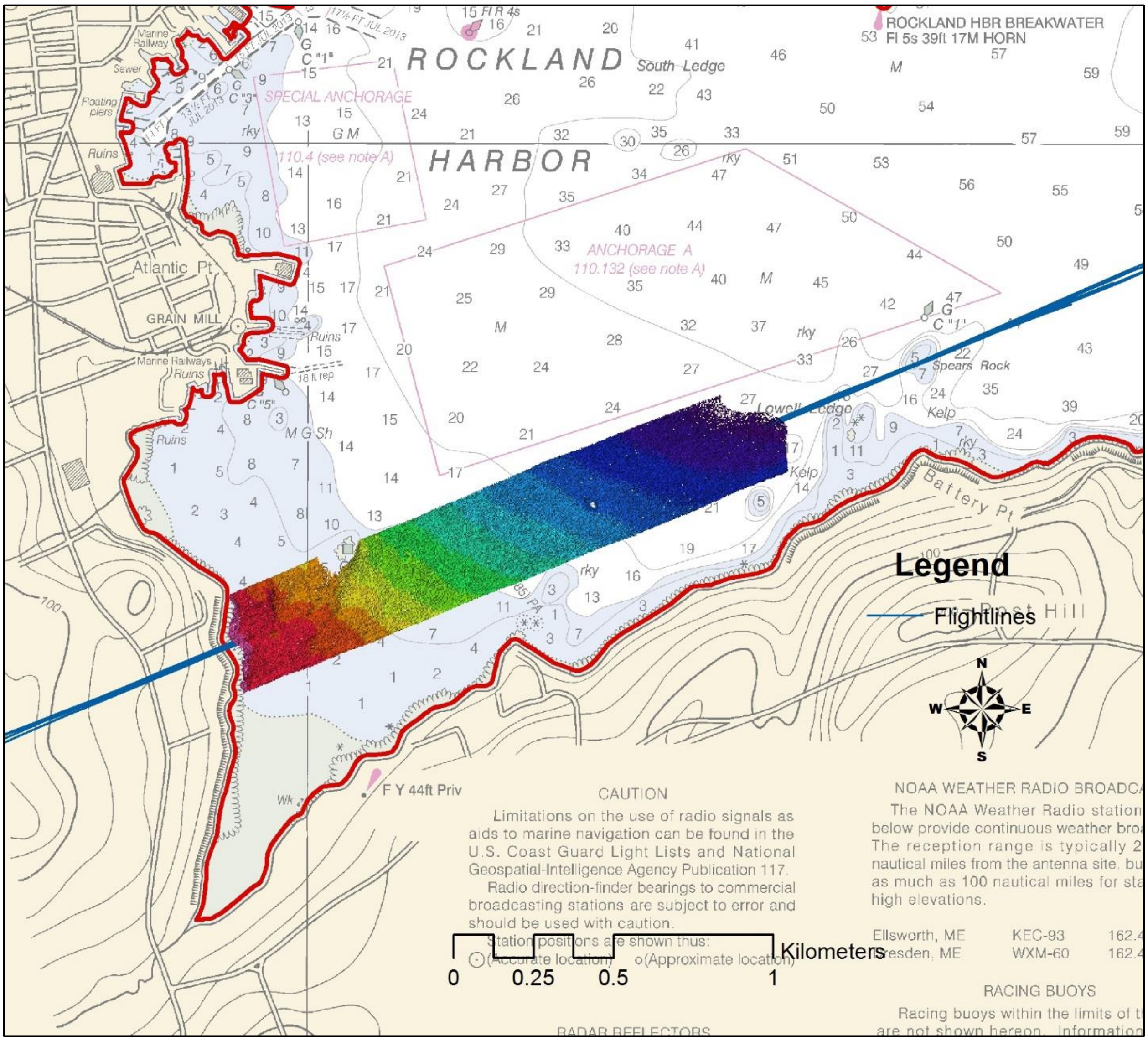


Figure 15 Reference Bathymetric Area for Vertical TPU Analysis

A total of eight lines flown on three different mission flights were evaluated for the vTPU analysis. The regression of vertical depth variances (standard deviation) at cell nodes were recorded for stepped depth intervals (referenced to ellipsoidal heights) in order to estimate the LiDAR

[1] Lockhart, C., D. Lockhart, J. Martinez, 2008. *Comparing LIDAR and Acoustic Bathymetry Using Total Propagated Uncertainty (TPU) and the Combined Uncertainty and Bathymetry Estimator (CUBE) Algorithm*, ILMF 2008. http://www.fugro-pelagos.com/papers.asp

measurement uncertainty with post-processed SmartBase SBET solution applied (**Figure 16**). These values and the regression curve adjusted to them was considered the total vertical uncertainty (1-σ) for the SHOALS depth measurements.

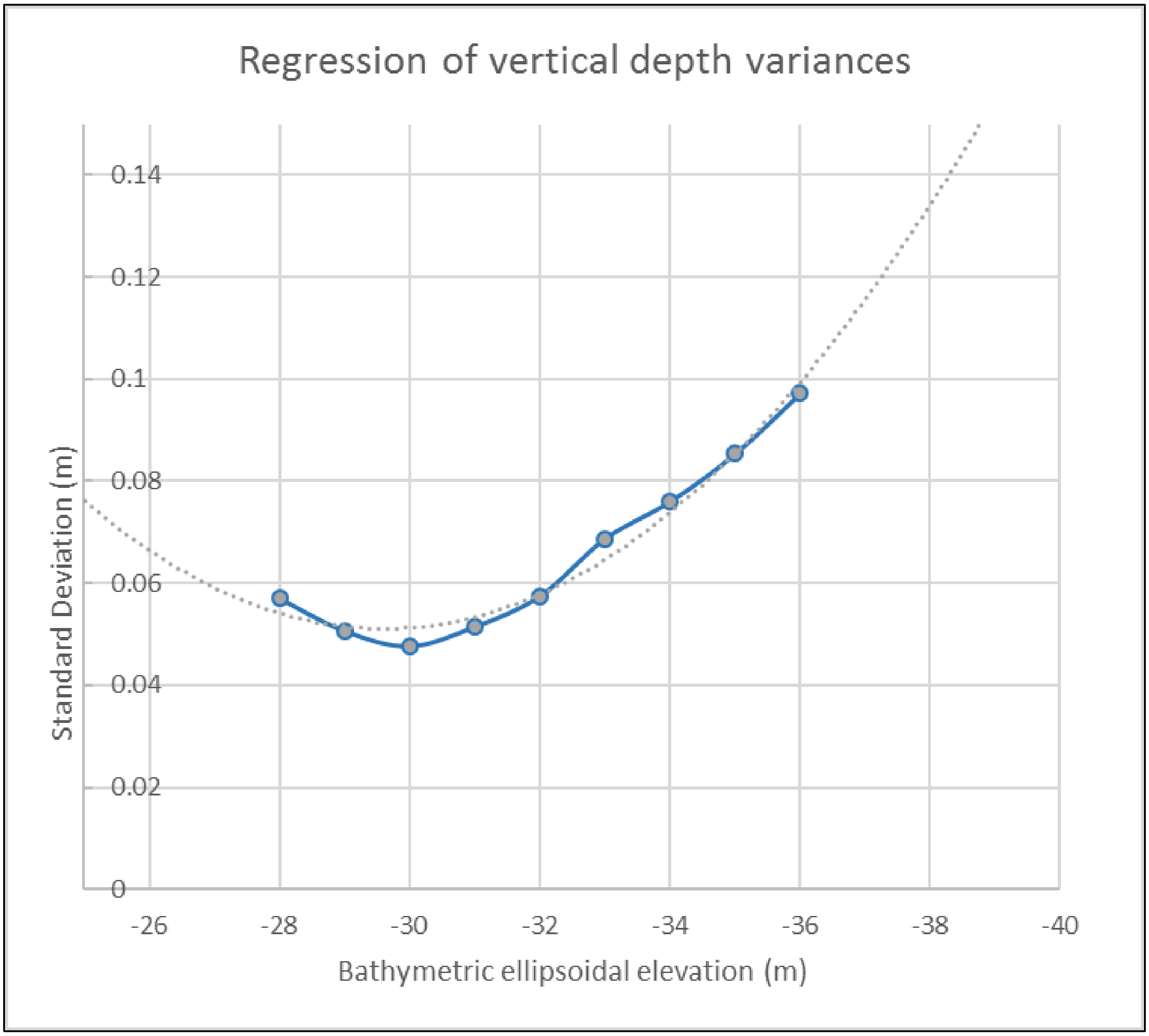


Figure 16 Regression of Vertical Depth Variances for SHOALS Data

Since VDatum was used to reduce depths to chart datum, the uncertainty value associated to this conversion process was added to the SHOALS vertical uncertainty model, in the form:

$$TPU_v = \sqrt{Lidar_U{}^2 + VDatum_U{}^2}$$

The estimated VDatum uncertainty for the Maine region is estimated to be 0.134 m (1-σ), therefore, the final vTPU look up table by depth range to be applied to LiDAR data is shown in **Table 7**.

Table 7 Vertical TPU by Depth (meters)

Depth	LiDAR u	VDatum u	vTPU (1-σ)	vTPU (2-σ)
Land	0.045	0.134	0.141	0.277
-2	0.066	0.134	0.149	0.293
-1.0	0.059	0.134	0.146	0.287
0.0	0.054	0.134	0.144	0.283
1.0	0.051	0.134	0.144	0.281
2.5	0.052	0.134	0.144	0.282
5.0	0.065	0.134	0.149	0.292
7.5	0.093	0.134	0.163	0.320
10.0	0.135	0.134	0.190	0.373
12.5	0.193	0.134	0.235	0.460
15.0	0.265	0.134	0.297	0.581

The horizontal TPU had previously been estimated using dynamic positioning checks over ground truth targets (usually corners of buildings). The standard deviation of the mean difference between the observed and surveyed check point positions was determined to be 2.295 meters at 1 sigma. And 4.499 m at (2-sigma).

The final TPU look-up table used for assigning vertical and horizontal TPU each LiDAR depth shown in Error! Reference source not found..

Table 8 Final TPU Lookup Table at 2-σ

Depth	vTPU	hTPU
Land	0.277	4.499
-2	0.293	4.499
-1	0.287	4.499
0	0.283	4.499
1	0.281	4.499
2.5	0.282	4.499
5	0.292	4.499
7.5	0.320	4.499
10	0.373	4.499
12.5	0.460	4.499
15	0.581	4.499

C – Corrections to Soundings

<u>Sound Velocity Profiles</u>

Sound velocity casts were normally performed every two to three hours on the R/V JAB and R/V Westerly. For each cast, the probes were held at the surface for one to two minutes to achieve temperature equilibrium. The probes were then lowered and raised at a rate of 1 m/s. Between casts, the sound velocity sensors were stored in fresh water to minimize salt-water corrosion and to hold them at an ambient water temperature.

Fugro's MB Survey Tools software was used to check the profiles graphically for spikes or other anomalies, and to produce an SVP file compatible with CARIS HIPS. The WFMB acquisition package also provided QC for surface sound velocity. This was accomplished by creating a real-time plot from the sound velocity probe at the Reson sonar head and notifying the user (via a flashing warning message) if the head sound velocity differed by more than 5m/s from a defined reference sound velocity. This alarm was used as an indication that the frequency of casts may need to be increased. This reference sound velocity was determined by averaging 50 sound velocities produced at the head. The reference sound velocity was reset after each cast and also reset when a cast was performed due to a significant deviation from the reference sound velocity.

Refer to Appendix IV for SVP Calibration Reports.

Settlement Curves

Squat-settlement tests were performed on all vessels to obtain dynamic draft correctors.

The squat-settlement tests were performed by first establishing a 1000-meter line in the direction of the current. The survey vessel sat static at one end of the line for five minutes logging L1/L2 GPS data with the G2 correction. The line was first run at lowest possible engine RPM, then rerun heading the opposite direction at the same RPM, stopping at the end of the line to obtain an additional five minutes of static L1/L2 GPS data. This pattern was repeated for additional lines at incrementing vessel RPMs.

All measurements were corrected for heave, pitch, roll, and reduced to the vessel's common reference point (CRP). Static measurements observed at the end of each line set were used to compute a tide curve for tidal corrections. The settlement curve of dynamic draft correctors was computed via MB Survey Tools directly from the processed PosMV file (SBET). Since the squat and settlement curve was based on the vessel RPMs and not the vessel speed, the results were not entered into the CARIS HVFs. Instead, MBTools was used to create and export these values, which were applied in CARIS using the Load Delta Draft routine prior to sound speed correction.

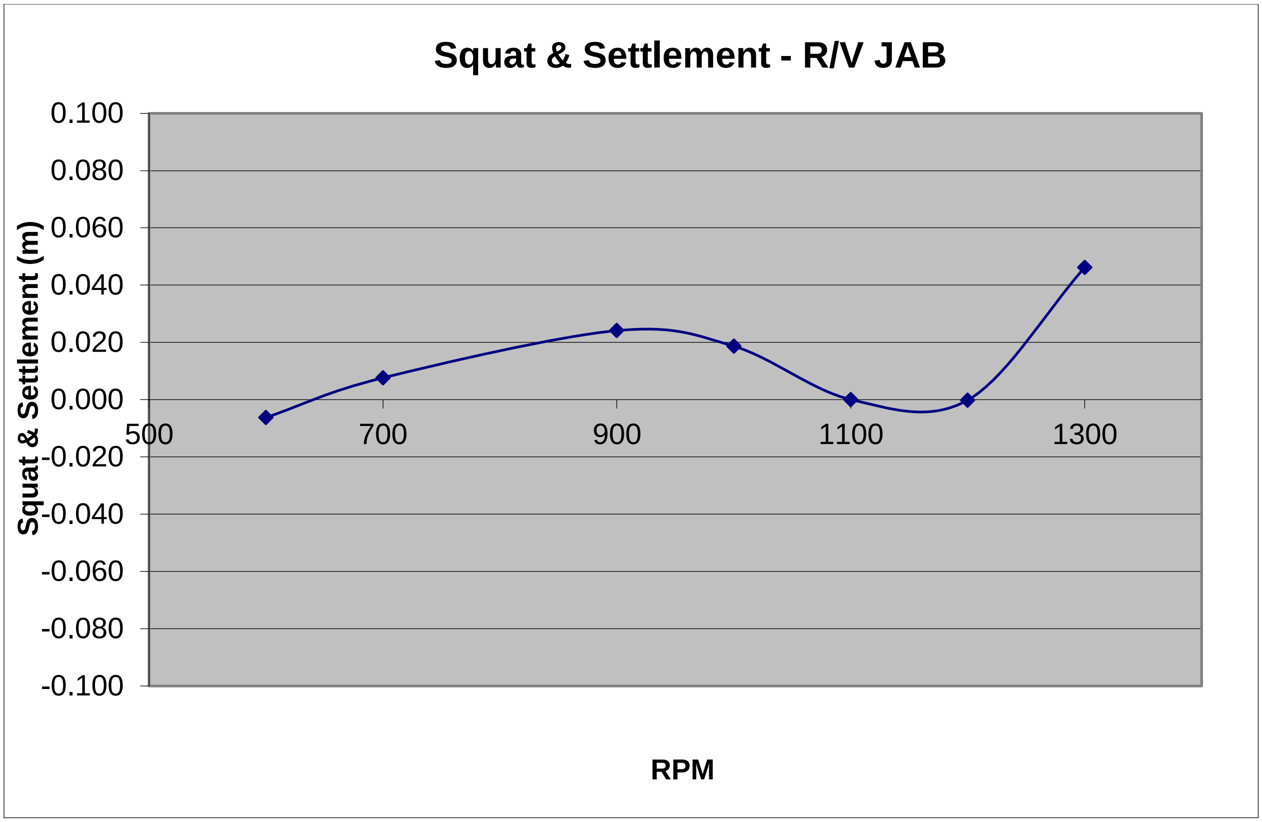


Figure 17 R/V JAB Dynamic Draft

Table 9 R/V JAB Squat Settlement Results

R/V JAB DYNAMIC DRAFT CORRECTORS		
Speed (kts)	**RPM**	**Settlement**
3.4	600	-0.006
3.9	700	0.008
4.4	800	0.016
4.9	900	0.024
5.3	1000	0.019
5.9	1100	0.000
6.2	1200	0.000
6.2	1200	0.000
6.4	1300	0.046

The squat settlement test for the R/V JAB was conducted on September 2, 2016 (Julian Day 246).

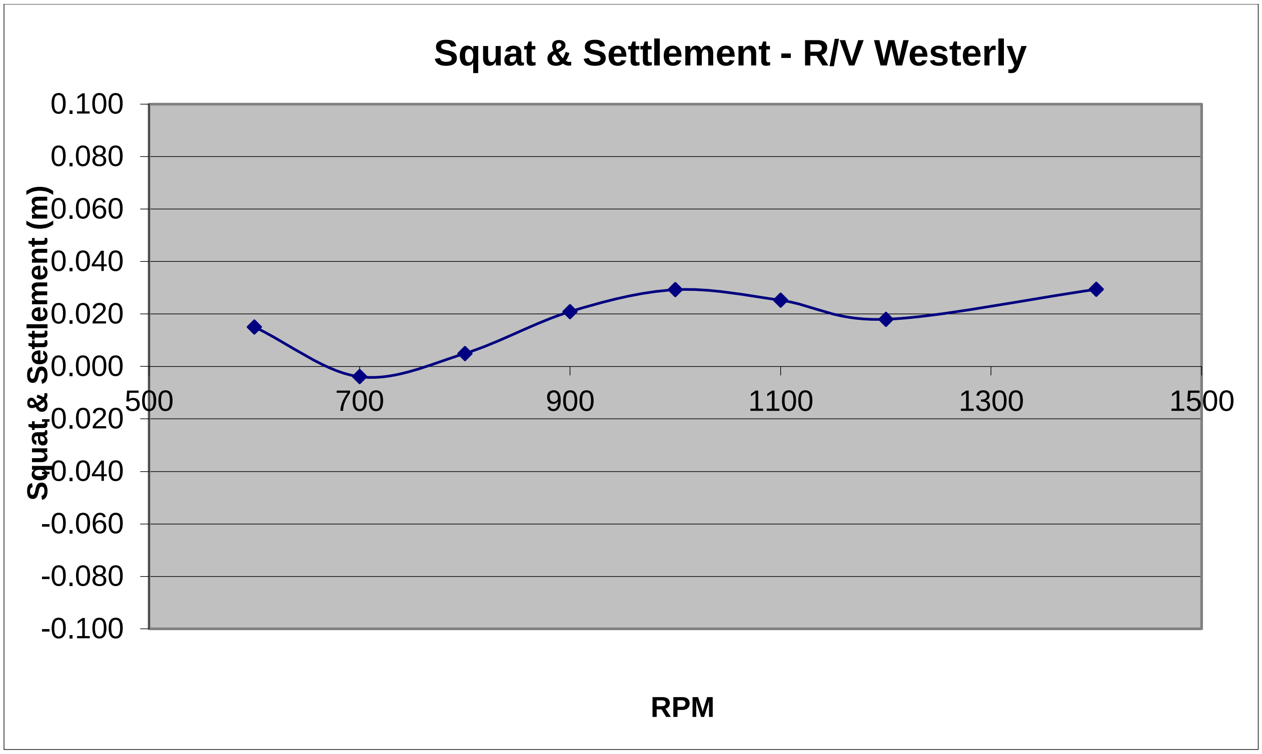


Figure 18 R/V Westerly Dynamic Draft

Table 10 R/V Westerly Squat Settlement Results

R/V Westerly DYNAMIC DRAFT CORRECTORS		
Speed (kts)	**RPM**	**Settlement**
3.6	600	0.015
3.9	700	-0.004
4.5	800	0.005
4.9	900	0.021
5.4	1000	0.029
5.8	1100	0.025
6	1200	0.018
6.35	1300	0.024
6.7	1400	0.029

The squat settlement test for the R/V Westerly was conducted on Sept 1, 2016 (Julian Day 245).

Static Draft

Static draft was measured from a point on the stern of the vessel beside the pole. The tables below show the static draft values measured for all vessels (**Table 11**).

Table 11 Draft Measurements for the R/V JAB (Dual 7125)

Draft#	Julian Day	Date (UTC)	Time (UTC)	Depth (m)
1	202	7/20/2016	10:31:28	-0.46
2	203	7/21/2016	10:30:37	-0.46

Draft#	Julian Day	Date (UTC)	Time (UTC)	Depth (m)
3	204	7/22/2016	11:00:35	-0.46
4	205	7/23/2016	11:04:27	-0.45
5	206	7/24/2016	16:35:00	-0.46
6	207	7/25/2016	10:15:19	-0.46
7	208	7/26/2016	10:49:59	-0.47
8	209	7/27/2016	11:01:18	-0.47
9	210	7/28/2016	11:19:04	-0.45
10	211	7/29/2016	10:18:57	-0.47
11	212	7/30/2016	10:25:11	-0.47
12	213	7/31/2016	10:37:32	-0.47
13	214	8/1/2016	10:08:05	-0.48
14	215	8/2/2016	10:41:01	-0.48
15	216	8/3/2016	10:23:32	-0.47
16	216	8/3/2016	21:55:01	-0.47
17	217	8/4/2016	10:17:19	-0.47
18	217	8/4/2016	21:57:50	-0.47
19	218	8/5/2016	10:32:13	-0.47
20	219	8/6/2016	11:44:01	-0.47
21	219	8/6/2016	22:00:11	-0.47
22	223	8/10/2016	10:14:01	-0.47
23	224	8/11/2016	10:15:16	-0.47
24	225	8/12/2016	11:17:09	-0.47
25	225	8/12/2016	21:52:43	-0.47
26	226	8/13/2016	10:05:05	-0.46
27	227	8/14/2016	10:35:54	-0.47
28	228	8/15/2016	11:47:23	-0.47
29	229	8/16/2016	10:32:38	-0.47
30	230	8/17/2016	13:11:43	-0.46
31	231	8/18/2016	11:39:30	-0.45
32	232	8/19/2016	11:49:08	-0.47
33	233	8/20/2016	11:45:37	-0.46
34	234	8/21/2016	10:00:00	-0.46
35	235	8/22/2016	11:51:17	-0.47
36	236	8/23/2016	10:00:00	-0.46
37	237	8/24/2016	11:39:59	-0.45
38	238	8/25/2016	11:49:42	-0.47
39	239	8/26/2016	10:58:24	-0.46
40	240	8/27/2016	10:27:11	-0.45
41	241	8/28/2016	10:21:00	-0.45
42	242	8/29/2016	10:30:29	-0.45
43	243	8/30/2016	10:20:15	-0.46
44	244	8/31/2016	10:20:02	-0.46
45	245	9/1/2016	10:28:09	-0.46
46	246	9/2/2016	10:31:33	-0.46
47	247	9/3/2016	10:36:28	-0.46

Draft#	Julian Day	Date (UTC)	Time (UTC)	Depth (m)
48	248	9/4/2016	10:49:34	-0.46
49	249	9/5/2016	10:21:23	-0.45
50	250	9/6/2016	11:20:14	-0.46
51	251	9/7/2016	10:28:35	-0.46
52	252	9/8/2016	10:15:22	-0.46
53	253	9/9/2016	10:22:34	-0.46
54	254	9/10/2016	10:24:15	-0.46
55	255	9/11/2016	10:21:26	-0.46
56	256	9/12/2016	10:52:33	-0.46
57	257	9/13/2016	10:24:01	-0.46

Table 12 Draft Measurements for the R/V Westerly (Dual 7125)

Draft#	Julian Day	Date (UTC)	Time (UTC)	Depth (m)
1	210	7/28/2016	20:15:15	-0.62
2	211	7/29/2016	10:31:55	-0.65
3	212	7/30/2016	12:44:44	-0.64
4	213	7/31/2016	14:38:38	-0.61
5	214	8/1/2016	10:44:19	-0.63
6	215	8/2/2016	10:47:36	-0.63
7	216	8/3/2016	9:58:16	-0.61
8	217	8/4/2016	10:04:01	-0.61
9	218	8/5/2016	10:24:35	-0.63
10	219	8/6/2016	10:18:43	-0.63
11	220	8/7/2016	10:35:21	-0.63
12	221	8/8/2016	10:23:37	-0.63
13	222	8/9/2016	10:10:52	-0.62
14	223	8/10/2016	10:10:18	-0.63
15	224	8/11/2016	10:19:22	-0.63
16	225	8/12/2016	10:04:29	-0.63
17	226	8/13/2016	10:08:11	-0.65
18	228	8/15/2016	12:35:47	-0.64
19	229	8/16/2016	10:56:05	-0.63
20	230	8/17/2016	10:50:06	-0.63
21	231	8/18/2016	10:23:24	-0.64
22	232	8/19/2016	10:30:24	-0.63
23	233	8/20/2016	10:11:30	-0.63
24	234	8/21/2016	10:23:25	-0.63
25	235	8/22/2016	10:28:09	-0.63
26	236	8/23/2016	10:51:35	-0.63
27	237	8/24/2016	10:28:58	-0.63
28	238	8/25/2016	10:38:36	-0.64
29	239	8/26/2016	10:45:01	-0.64
30	240	8/27/2016	10:30:51	-0.64
31	241	8/28/2016	10:35:00	-0.63

Draft#	Julian Day	Date (UTC)	Time (UTC)	Depth (m)
32	242	8/29/2016	13:00:23	-0.66
33	243	8/30/2016	10:41:49	-0.63
34	244	8/31/2016	11:00:08	-0.64
35	246	9/2/2016	10:41:59	-0.63
36	247	9/3/2016	10:57:34	-0.64
37	248	9/4/2016	10:28:28	-0.63
38	249	9/5/2016	10:28:02	-0.63
39	250	9/6/2016	10:35:38	-0.63
40	251	9/7/2016	10:40:31	-0.64
41	252	9/8/2016	10:58:38	-0.63
42	254	9/10/2016	10:28:21	-0.63
43	255	9/11/2016	10:48:36	-0.64
44	256	9/12/2016	10:30:25	-0.63
45	257	9/13/2016	10:31:57	-0.64
46	258	9/14/2016	10:30:37	-0.64
47	259	9/15/2016	10:38:57	-0.64
48	260	9/16/2016	10:28:03	-0.64
49	261	9/17/2016	10:03:00	-0.64
50	262	9/18/2016	20:54:35	-0.63
51	263	9/19/2016	10:07:19	-0.63
52	264	9/20/2016	10:12:50	-0.64
53	265	9/21/2016	10:00:54	-0.64
54	266	9/22/2016	10:03:25	-0.63
55	267	9/23/2016	10:13:40	-0.62
56	268	9/24/2016	10:27:24	-0.64
57	269	9/25/2016	10:10:58	-0.63
58	270	9/26/2016	10:15:34	-0.63
59	271	9/27/2016	10:52:41	-0.63
60	273	9/29/2016	10:05:39	-0.63
61	274	9/30/2016	10:10:36	-0.63

Tides

During field operations, the JAB and Westerly sounding data were initially reduced to MLLW using a combination of preliminary and verified tidal data along with a zone definition file (ZDF) that was based on tidal data from the Portland, ME station. This station is owned and operated by NOAA's National Ocean Service (NOS) through the Center for Operational Oceanographic Products and Services (CO-OPS). Preliminary and verified tidal data was assembled by CO-OPS and accessed through NOAA's Tides&Currents website (*http://tidesandcurrents.noaa.gov/*). A cumulative file for the gauge in use was updated daily by appending the new data as it became available. These unverified tides were used in the field for preliminary processing only.

On December 12, 2016, the final TCARI grid was acquired from CO-OPS and applied to all sounding data using the TCARI GUI (version 16.8) and merged in CARIS HIPS. Verified tidal data were used for all final CUBE Surfaces, soundings, and S-57 Feature files.

LiDAR vertical control for OPR-A366-KR-16 was GPS-derived. POS files logged during data acquisition on each flight were post-processed using Applanix POSPac SmartBase routine to create an SBET file. Following creation, the SmartBase SBETs were then applied to the data in SHOALS GCS, replacing the real-time GPS navigation position with a post-processed GPS position. The separation model was created with NOAA's VDatum v3.6. This model also allowed for topographic data to be referenced to MLLW through the use of DTM-derived interpolation.

Data was initially referenced to the ITRF00 (WGS84) ellipsoid using the Applanix SmartBase (ASB) routine. An SBET solution was processed using a network of CORS stations, with MEOW, as control. The LiDAR data was maintained on the ellipsoid during processing.

All depth soundings were eventually reduced to MLLW in CARIS using this Fugro-created VDatum model. Topographic heights detected by LiDAR were also related to MLLW through the same method. The model was applied to the data, using the compute GPS tides utility, and then merged.
For additional information, refer OPR-A366-KR-16 HVCR.

Vessel Attitude: Heading, Heave, Pitch, and Roll

Vessel heading and dynamic motion were measured by the Applanix (POS/MV) V4 on R/V JAB and Applanix (POS/MV) V5 on the R/V Westerly. The system calculated heading by inversing between two Trimble GPS-generated antenna positions. An accelerometer block (the IMU), which measured vessel attitude, was mounted directly above the multibeam transducer.

Calibrations

Multibeam

For all vessel and sonar configurations, patch tests were conducted to identify alignment errors (timing, pitch, heading, and roll) between the motion sensor and the multibeam transducer(s). Patch test calibration values used to correct all soundings for the survey are shown in **Table 13**.

Table 13 Patch Test Results Summary

Patch Test Results						
Vessel	**Patch Test Day**	**MB Sonar**	**Timing Error**	**Pitch Offset**	**Roll Offset**	**Azimuth Offset**
R/V JAB	2016-225	Port 7125 400 kHz	0.000	0.900	14.675	-0.300
	2016-225	Stbd 7125 400 kHz	0.000	0.800	-14.430	1.500
	2016-251	Port 7125 400 kHz	0.000	0.900	14.645	-0.300
	2016-251	Stbd 7125 400 kHz	0.000	0.800	-14.330	1.500
R/V Westerly	2016-210	Port 7125 400 kHz	0.000	-0.500	16.450	-1.200
	2016-210	Stbd 7125 400 kHz	0.000	-0.200	-14.710	0.200
	2016-226	Port 7125 400 kHz	0.000	-0.500	16.350	-1.200
	2016-226	Stbd 7125 400 kHz	0.000	-0.200	-14.625	-0.400

Notes:

- Patch Test Day represents the Julian day the actual test was conducted. May be pre- or post-dated in CARIS HVF to cover lines run before or after patch test.

- Several CARIS HIPS Vessel files (HVF) were used throughout the project; some for calibration purposes (which include PORT or STBD in file name) and others for the project's main line scheme and crosslines. For example, the CARIS HVF named "2Westerly_PORT_7125_7004Record_400kHz" was used to compute the patch test results for the port 400kHz 7125 system on the R/V Westerly using the 7004/7006 bathy record. HVF "1JAB_PORT_7125_7027Record_400kHz" was used to compute the patch test results for the port 400kHz 7125 system on the R/V JAB using the 7027 bathy record.

- Part way through the survey the 7030 record was implemented into the acquisition workflow. The 7030 record is the installation parameter of the sonar, which includes the transmit and receiver offsets. Most of the information stored in the 7030 record is not used by CARIS. To fully utilize the 7027 record in a dual head setup, the 7030 record was essential and written to the raw s7k files during data collection. During the conversion process, if the 7030 record was present in the s7k file, CARIS wrote an "InstallationParameter.XML'' file to the line directory. The HVF was set up in such a way that the sonars' receiver offsets were input under SV1 (Port receiver offsets) and SV2 (STBD receiver offsets) and the transmitter offsets were read from the 7030 record by CARIS. Any HVF with 7030 in its name is using the 7027/7030 records. For example, "2Westerly_Dual_7125_7030Record_400kHz" is for the dual 400kHz 7125 systems on the R/V Westerly using the 7027 bathy record and the 7030 installation parameters record.

<u>Aircraft Offset Survey</u>

The only offset measurement required during system mobilization was from the POS/AV Inertial Measurement Unit (IMU) to the POS/AV GPS antenna. The IMU is completely enclosed within the laser housing. The offsets from the IMU to the common measuring point (CMP) on the outside of the housing are known constants.

Offsets were measured using a total station establishing a base line along the port side of the aircraft. Ranges and bearings are measured from the total station to the CMP on the top of the laser housing. Additional measurements are made to the sides and top of the housing to determine its orientation. A final measurement is made to the center of the POS/AV GPS antenna. The IMU to POS/AV GPS offsets are calculated using the known IMU to CMP offsets. A summary of the offset measurements made during system mobilization are presented in **Figure 19** below. The offsets from the IMU to the POS/AV GPS antenna are entered into the POS/AV console prior to survey.

RESULTS

SENSOR REFERENCE POINT to GPS ANTENNA		SET 1		SET 2		SET 3		SET 4	
	X	-0.046	REJECT DATA ☐	-0.052	REJECT DATA ☐	-0.049	REJECT DATA ☐	-0.049	REJECT DATA ☐
	Y	0.287		0.287		0.291		0.291	
	Z	-0.809		-0.814		-0.812		-0.813	

TAPE MEASUREMENT (SENSOR REF to GPS ANTENNA)	
X	n/a
Y	n/a
Z	n/a

IMU to SENSOR REFERENCE		SENSOR REF to GPS ANTENNA	
X	0.073	X	-0.049
Y	-0.230	Y	0.289
Z	-0.415	Z	-0.812

IMU to GPS ANTENNA		
	X	0.024
	Y	0.059
	Z	-1.227

Checked By: D. Johnson

Figure 19 SHOALS Sensor Offsets

In order to further ensure accuracy and refine values, Offsets were derived again using Applanix POSPac MMS 7.1 inertial post-processing software during sensor verification. A summary of the final derived offset measurements calculated for sensor installation in aircraft N89F are shown in **Figure 20**.

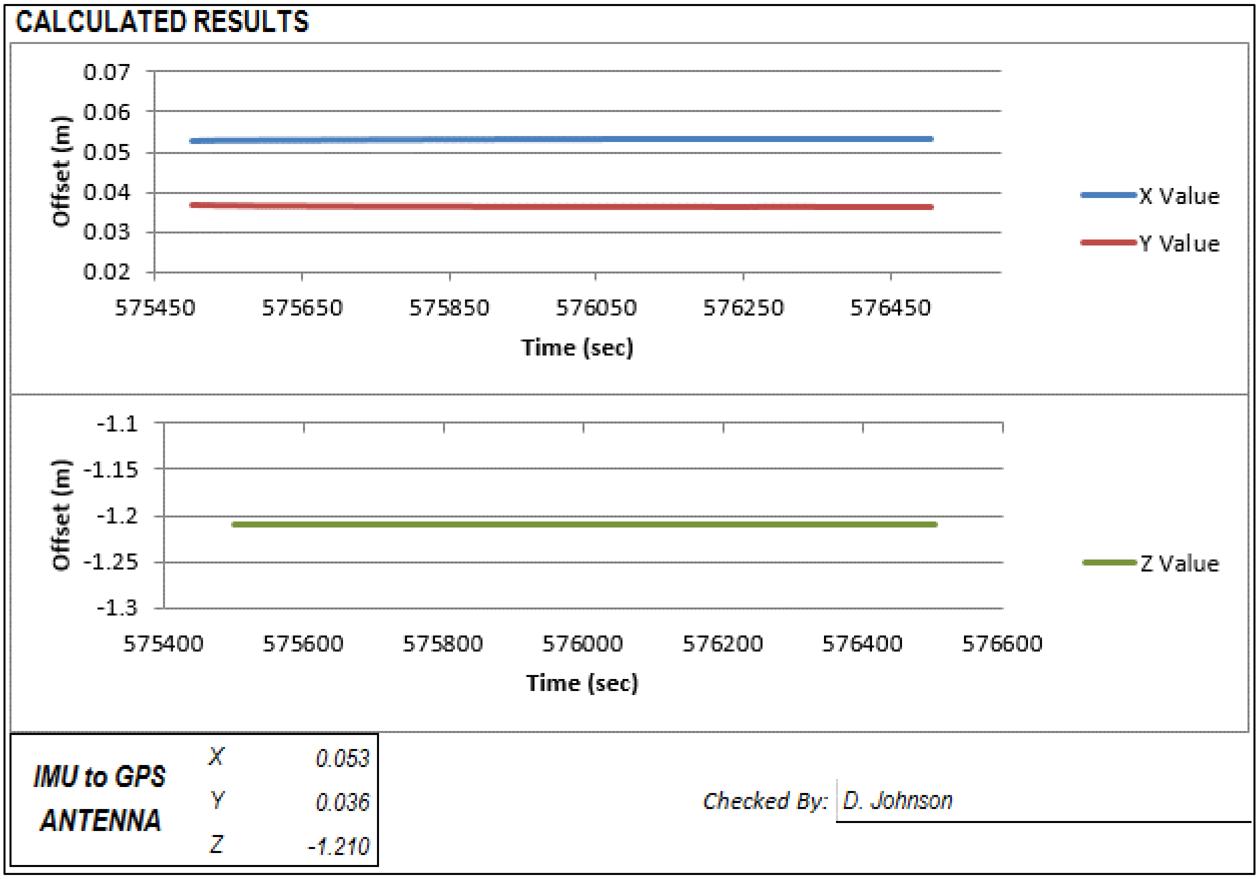


Figure 20 Software-Derived Aircraft Offset Calculations

<u>Shoals Sensor Calibration</u>

A full geometric calibration was carried out in June 2016 in Oxnard, California in preparation for the survey operations in Maine. This rigorous procedure involves several stages intended to characterize the system parameters to allow raw, uncorrected data to be transformed into calibrated data.

Calibration data used is collected over a variety of environments outlined below.

- Bathymetric lines over a flat, calm surface
- Opposing flight lines over pitched roof buildings – both parallel and perpendicular to the flight path. Additionally, lines that are offset from the peak are collected to capture the edges of the swath.
- Lines of varying altitudes over a topographic ground truth surface – both centered and offset to capture all areas of the swath.
- Bathymetric data over a previously collected MBES ground truth surface. This data should include data in the 8 to 13-meter range.

An overview of the calibration process is detailed below.

The first step is the angular calibration, a minimum of two lines of approximately five-minute duration are collected over a flat, calm body of water. These lines are downloaded and auto-processed in SHOALS GCS, after which they are loaded into an Optech calibration Utility, AutoCalib. This utility analyzes the line data and determines a set of angular offset equations that generate offset values to flatten the water surface when applied to data.

Following the derivation of angular equations, the offset values are further refined using the lines flown on the pitched roof building(s). These lines are examined and reprocessed with different values iteratively until all passes are found to align the building peak with minimal offset from one another.

Once angular values are finalized, the residual vertical error of the system is addressed. This portion uses the topographic ground truth lines and involves comparing the observed elevations to a previously surveyed ground truth surface. Small offset values are then derived for each altitude to correct any existing vertical topographic bias in the system.

The final step derives the remaining bias values using the bathymetric data collected. Bias values for the deep green channel are automatically calculated by SHOALS GCS during the auto-process stage. Apriori depth values are calculated by comparing the data collected by the LiDAR to the bathymetric ground truth surface.

Derived offset values are then used to populate a file referred to as the system parameters file, which is loaded into the mission plans used for flights. Values are again verified before auto-processing to ensure resulting data will be fully calibrated.

D – Approval Sheet

Approval Sheet

For

H12884, H12885, H12886 & H12887

As Chief of Party, Field operations for this hydrographic survey were conducted under my direct supervision, with frequent personal checks of progress and adequacy. I have reviewed the attached survey data and reports.

All field sheets, this Data Acquisition and Processing Report, and all accompanying records and data are approved. All records are forwarded for final review and processing to the Processing Branch.

The survey data meets or exceeds requirements as set forth in the NOS Hydrographic Surveys and Specifications Deliverables Manual, Standing and Letter Instructions, and all HSD Technical Directives. These data are adequate to supersede charted data in their common areas. This survey is complete and no additional work is required.

Approved and forwarded,

Dean Moyles, (ACSM Cert. No. 226)
Senior Hydrographer
Fugro
February 7, 2017

X Moyles, Dean

Digitally signed by Moyles, Dean
DN: dc=com, dc=fugro, l=america, ou=fpi, ou=people_fpi, 0.9.2342.19200300.100.1.1=moylesd, cn=Moyles, Dean, email=dmoyles@fugro.com
Date: 2017.02.07 07:45:43 -08'00'

Dean Moyles (ACSM Cert. No. 226)
Senior Hydrographer

Appendix I – Vessel Reports

<u>R/V JAB</u>

The R/V JAB **(Figure 21),** is owned and operated by Theory Marine and accommodated a survey crew for day operations and acquisition hardware. Dual Reson SeaBat 7125 multibeam sonars were installed on an over the side pole mount on the stern. The Reson systems and IMU were installed on a special mounting plate, where each Reson 7125 was rotated approximately 15 degrees. The Reson systems were installed in their normal SV2 bracket which included an SV70 probe (located in the nose cone) and were attached to the mounting plate by a flange. The inertial measurement unit (IMU) for the POS/MV was an underwater unit that was installed directly above the Reson 7125s (**Figure 22**).

All 7125 multibeam data files were logged in the s7k format using WFMB v3.10.15.3. The bathy data from each Reson 7125 (records 7027) were stitched together in WFMB to create one s7k file with each ping containing 1024 beams.

Table 14 Vessel Specifications (R/V JAB)

SURVEY VESSEL R/V JAB	
Owner	Theory Marine Services
Official Number	1229272
Length	44’
Breadth	15.5’
Max Draft	2’
BHP Main Engines	500 HP (Cummins QSC 8.3 liter x 2)
Propulsión	Hamilton 322 Jet Drive x 2
Fresh Water Capacity	30 Gallons
Fuel Capacity	600 Gallons

Figure 21 R/V JAB

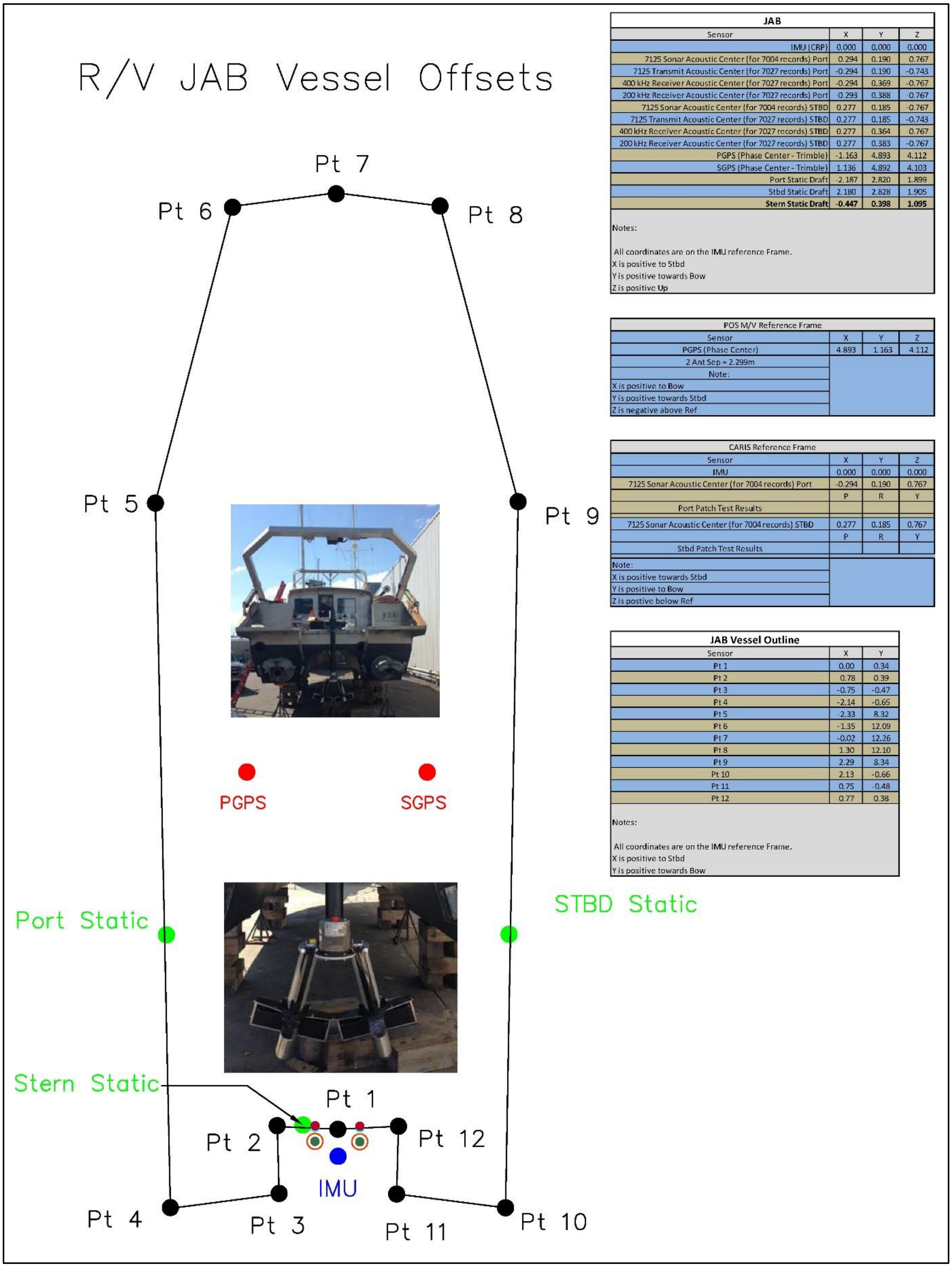
Figure 22 R/V JAB Dual 7125 with Underwater IMU

Two Trimble L1/L2 antennas were mounted above and forward from the sonar. Offset 2.299 meters port-starboard from each other, the L1/L2 antennas provided GPS data to the POS/MV for position, attitude, and heading computations. The port side antenna functioned as the POS/MV master antenna, the starboard side antenna functioned as the POS/MV secondary.

The AML Smart probes were deployed from the stern using a hydraulic winch.

A Draft measurement point was located on the stern alongside the pole. The Draft measurement point being located so close to the CRP (IMU) and Reson 7125 allowed us to obtain a precise static draft measurement.

Offset values for the CRP to the sonar and waterline were applied to the data in CARIS HIPS as specified in the HIPS vessel file (HVF). Offsets between the GPS antennas and the CRP were applied internally by the POS/MV by entering a GPS lever arm offset. Note that the HVF does not contain navigation offsets, because the position provided by the POS/MV is already corrected to the CRP. Vessel offsets used are shown in the offset diagram (**Figure 23**).



JAB			
Sensor	X	Y	Z
IMU (CRP)	0.000	0.000	0.000
7125 Sonar Acoustic Center (for 7004 records) Port	0.294	0.190	0.767
7125 Transmit Acoustic Center (for 7027 records) Port	-0.294	0.190	-0.743
400 kHz Receiver Acoustic Center (for 7027 records) Port	-0.294	0.369	-0.767
200 kHz Receiver Acoustic Center (for 7027 records) Port	-0.293	0.388	-0.767
7125 Sonar Acoustic Center (for 7004 records) STBD	0.277	0.185	-0.767
7125 Transmit Acoustic Center (for 7027 records) STBD	0.277	0.185	-0.743
400 kHz Receiver Acoustic Center (for 7027 records) STBD	0.277	0.364	0.767
200 kHz Receiver Acoustic Center (for 7027 records) STBD	0.277	0.383	-0.767
PGPS (Phase Center - Trimble)	-1.163	4.893	4.112
SGPS (Phase Center - Trimble)	1.136	4.892	4.103
Port Static Draft	-2.187	2.820	1.899
Stbd Static Draft	2.180	2.828	1.905
Stern Static Draft	**-0.447**	**0.398**	**1.095**

Notes:

All coordinates are on the IMU reference Frame.
X is positive to Stbd
Y is positive towards Bow
Z is positive Up

POS M/V Reference Frame			
Sensor	X	Y	Z
PGPS (Phase Center)	4.893	1.163	4.112
2 Ant Sep = 2.299m			
Note:			
X is positive to Bow			
Y is positive towards Stbd			
Z is negative above Ref			

CARIS Reference Frame			
Sensor	X	Y	Z
IMU	0.000	0.000	0.000
7125 Sonar Acoustic Center (for 7004 records) Port	-0.294	0.190	0.767
	P	R	Y
Port Patch Test Results			
7125 Sonar Acoustic Center (for 7004 records) STBD	0.277	0.185	0.767
	P	R	Y
Stbd Patch Test Results			
Note:			
X is positive towards Stbd			
Y is positive to Bow			
Z is postive below Ref			

JAB Vessel Outline		
Sensor	X	Y
Pt 1	0.00	0.34
Pt 2	0.78	0.39
Pt 3	-0.75	-0.47
Pt 4	-2.14	-0.65
Pt 5	-2.33	8.32
Pt 6	-1.35	12.09
Pt 7	-0.02	12.26
Pt 8	1.30	12.10
Pt 9	2.29	8.34
Pt 10	2.13	-0.66
Pt 11	0.75	-0.48
Pt 12	0.77	0.38

Notes:

All coordinates are on the IMU reference Frame.
X is positive to Stbd
Y is positive towards Bow

Figure 23 R/V JAB Offset Diagram

R/V Westerly

The R/V Westerly **(Figure 24),** is owned and operated by Zephyr Marine, accommodated a survey crew for day operations and acquisition hardware. Dual Reson SeaBat 7125 multibeam sonars were installed on an over the side pole mount located on the stern. The Reson systems and IMU were installed on a special mounting plate, where each Reson 7125 was rotated approximately 15 degrees. The Reson systems were installed in their normal SV2 bracket which included an SV70 probe (located in the nose cone) and were attached to the mounting plate by a flange. The inertial measurement unit (IMU) for the POS/MV was an underwater unit that was installed directly above the Reson 7125's (**Figure 25**).

All 7125 multibeam data files were logged in the s7k format using WFMB v3.10.15.3. The bathy data from each Reson 7125 (records 7004/7006, 7027) were stitched together in WFMB to create one s7k file with each ping containing 1024 beams.

Table 15 Vessel Specifications (R/V Westerly)

SURVEY VESSEL R/V Westerly	
Owner	Zephyr Marine
Official Number	1231991
Length	44'
Breadth	15.5'
Max Draft	2'
BHP Main Engines	500 HP (Cummins QSC 8.3 liter x 2)
Propulsión	Hamilton 322 Jet Drive x 2
Fresh Water Capacity	30 Gallons
Fuel Capacity	600 Gallons

Figure 24 R/V Westerly

Figure 25 R/V Westerly Dual 7125 with Underwater IMU

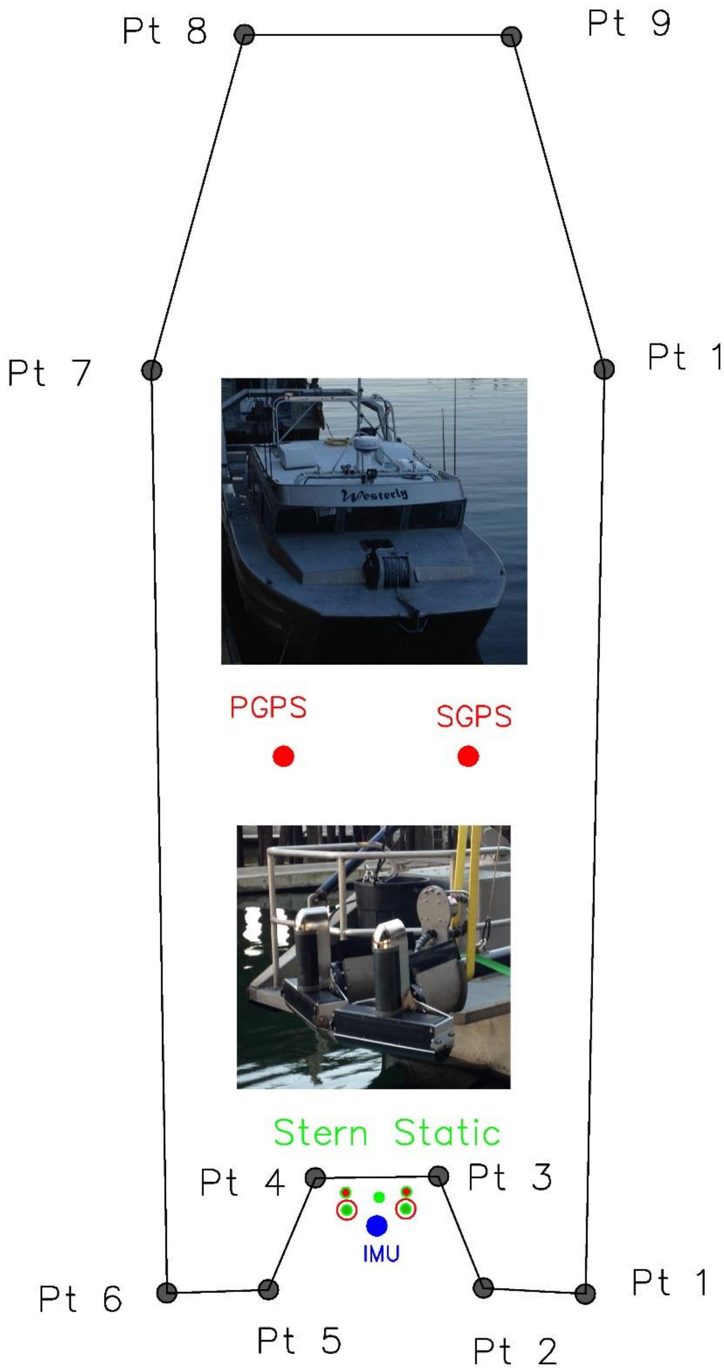
Two Trimble L1/L2 antennas were mounted above and forward from the sonar. Offset 1.873 meters port-starboard from each other, the L1/L2 antennas provided GPS data to the POS/MV for position, attitude, and heading computations. The port side antenna functioned as the POS/MV master antenna; the starboard side antenna functioned as the POS/MV secondary.

The AML Smart probes were deployed from the stern using a hydraulic winch.

A Draft measurement point was located on the stern alongside the pole. The Draft measurement point being located so close to the CRP (IMU) and Reson 7125 allowed us to obtain a precise static draft measurement.

Offset values for the CRP to the sonar and waterline were applied to the data in CARIS HIPS as specified in the HIPS vessel file (HVF). Offsets between the GPS antennas and the CRP were applied internally by the POS/MV by entering a GPS lever arm offset. The HVF does not contain navigation offsets, because the position provided by the POS/MV is already corrected to the CRP. Vessel offsets used are shown in the offset diagram (**Figure 26**).

R/V Westerly Vessel Offsets



Westerly			
Sensor	X	Y	Z
IMU (CRP)	0.000	0.000	0.000
7125 Sonar Acoustic Center (for 7004 records) Port	-0.305	0.160	-0.694
7125 Transmit Acoustic Center (for 7027 records) Port	-0.305	0.160	-0.670
400 kHz Receiver Acoustic Center (for 7027 records) Port	-0.317	0.338	-0.703
200 kHz Receiver Acoustic Center (for 7027 records) Port	-0.316	0.357	-0.703
7125 Sonar Acoustic Center (for 7004 records) STBD	0.296	0.173	-0.694
7125 Transmit Acoustic Center (for 7027 records) STBD	0.296	0.173	-0.670
400 kHz Receiver Acoustic Center (for 7027 records) STBD	0.302	0.345	-0.702
200 kHz Receiver Acoustic Center (for 7027 records) STBD	0.302	0.364	-0.702
PGPS (Phase Center - Trimble)	-0.947	4.769	4.228
SGPS (Phase Center - Trimble)	0.930	4.769	4.228
Stern Static Draft	**0.023**	**0.289**	**1.260**

Notes:

All coordinates are on the IMU reference Frame.
X is positive to Stbd
Y is positive towards Bow
Z is positive Up

POS M/V Reference Frame			
Sensor	X	Y	Z
PGPS (Phase Center)	4.769	-0.947	-4.228
2 Ant Sep = 1.873m			
Note:			
X is positive to Bow			
Y is positive towards Stbd			
Z is negative above Ref			

CARIS Reference Frame			
Sensor	X	Y	Z
IMU	0.000	0.000	0.000
7125 Sonar Acoustic Center (for 7004 records) Port	-0.305	0.160	0.694
	P	R	Y
Port Patch Test Results			
7125 Sonar Acoustic Center (for 7004 records) STBD	0.296	0.173	0.694
	P	R	Y
Stbd Patch Test Results			
Note:			
X is positive towards Stbd			
Y is positive to Bow			
Z is postive below Ref			

Westerly Vessel Outline		
Sensor	X	Y
Pt 1	2.12	-0.69
Pt 2	1.08	-0.63
Pt 3	0.63	0.50
Pt 4	-0.63	0.49
Pt 5	-1.10	-0.65
Pt 6	-2.14	-0.68
Pt 7	-2.29	8.69
Pt 8	-1.35	12.10
Pt 9	1.37	12.08
Pt 10	2.31	8.70

Notes:

All coordinates are on the IMU reference Frame.
X is positive to Stbd
Y is positive towards Bow

Figure 26 R/V Westerly Offset Diagram

SHOALS-1000T

The Optech SHOALS-1000T ALB system, serial number 004, is capable of acquiring 2500 soundings per second in bathymetric mode. SHOALS soundings are acquired by the transmission of laser pulses from the aircraft through a scanning system and detecting return signals from land, the sea surface, water column, and the seabed. The scanning (transmitting) occurs on a stabilized platform that compensates for aircraft pitch and roll. The return signals are electronically amplified and conditioned prior to being digitized and logged.

Figure 27 SHOALS-1000T ALB System

Figure 28 SHOALS-1000T ALB System

The SHOALS-1000T can be configured to operate at many different sounding densities, namely 2 m x 2 m, 3 m x 3 m, 4 m x 4 m and 5 m x 5 m spot spacing. A 2 m x 2 m sounding density is typically used for engineering applications where higher resolution may be required, whereas a 5 m x 5 m sounding density is typically used for larger scale, lower-resolution mapping requirements, such as resource planning. All sounding densities meet the IHO Order 1 Depth and Position accuracy requirements. For OPR-A366-KR-16 the 3 m x 3 m sounding density was utilized and data was acquired at a survey altitude of 400 meters.

The survey platform for the SHOALS-1000T ABS throughout this project was a Beechcraft King Air A90, call sign N87Q, owned and operated by Dynamic Aviation of Bridgewater, Virginia.

Figure 29 Beechcraft King Air A90

This aircraft and supplier have been used previously by Fugro on numerous projects with the SHOALS-1000T. Technical information relating to this aircraft can be found in **Table 16**. Fugro is able to quickly and easily mobilize this platform using specially engineered and FAA approved mounting plates. On this particular job the RIEGL 820 was installed alongside the SHOALS in order to provide ultra-high density topographic point data for feature verification; Fugro used specialized mounting plates to facilitate the dual installation of the RIEGL 820 with the SHOALS.

Table 16 Aircraft Technical Specifications

AIRCRAFT	BEECHCRAFT KING AIR A90/E90
Registration Number	N87Q
Owner	Dynamic Aviation
Wing Span	14.6 m
Length	10.8 m
Gross Weight	4377 kg
Typical Empty Weight	2336 kg
Engines	PT6A-20 (Turboprop)

The airborne components of the SHOALS-1000T consist of two separate modules. The laser and camera sources are contained in a single housing bolted to a flange above the aircraft camera door. An equipment rack, containing the system cooler and power supplies was installed aft of the laser. All hardware was located on the starboard side of the King Air aircraft. The system is controlled through a laptop by the Airborne Operator and a separate pilot console provides navigation and track guidance information to the flight crew. **Figure 30** shows the SHOALS system installed in the project aircraft.

Figure 30 SHOALS and RIEGL 820 Installation in N87Q

All project data was acquired at an altitude of 400 meters with a planned speed of 140 knots; Spot spacing was planned as 3 m x 3 m with 100 % seabed coverage. Swath width was approximately 300 meters with a center-to-center line spacing of 250 meters allowing 50 meters of swath overlap. Crosslines were planned, in accordance with HSSD guidelines, to equal 4 % of the main scheme line kilometers with collection being dispersed both spatially and temporally. Additional information relating to the operational capacities of the SHOALS-1000T and aircraft can be found below in **Table 17**.

Table 17 Aircraft and SHOALS Operating Specifications

Aircraft Type	Beechcraft King Air A90
Average Aircraft Endurance	4.5 hours
Aircraft Range	Up to 1000 nautical miles
Aircraft Transit Speed	175 knots
Aircraft Transit Altitude	2300 to 2900 m
Survey Altitude	300 to 500 m
Airborne System	• Independent sensor cooling • Gyro-stabilized scanner bed • Single operator console • Integrated pilot display
Operational Capability	Full day or night operation in all weather (VFR, IFR)
Airborne Survey Crew	One operator and two pilots
Depth Sounding Rate	2500 kHz
Depth Range	50 m in very clear water
Topographic Range	150 m above sea level
Sounding Density	2 x 2 m, 3 x 3 m, 4 x 4 m and 5 x 5 m
Swath Width	Variable swath, up to 0.58 x altitude
Digital Imagery Capability	Allied Prosilica GX3300
Integrated Inertial System	Applanix POS/AV 510 v6
Differential Corrections	Marinestar G2 (GPS/GLONASS) service
Horizontal Accuracy	IHO Order 1b
Vertical Accuracy	IHO Order 1b
Area Coverage	50.4 km^2 per hour, 5 x 5m

Equipment

Table 18 R/V JAB Acquisition Equipment

Description	Serial Number
Applanix IMU LN200	64
Applanix POS/MV Processor L1/L2 (RTK)	4032
GPS Antenna L1/L2 (Primary)	1441036287
GPS Antenna L1/L2 (Secondary)	1441045035
Reson NAVISOUND SVP 70	1008130
Reson NAVISOUND SVP 70 (Spare)	1016096
Reson 71-P Processor-7125 SV2 (FP3)	18340714124
Reson 71-P Processor-7125 SV2 (FP3)	18243512030
Reson SeaBat 7125 400kHz/200Khz Projector	1612100
Reson SeaBat 7125 400kHz/200Khz Projector	3313039
Reson SeaBat 7125 Receive Array	4107007
Reson SeaBat 7125 Receive Array	4013021
Fugro Acquisition PC	BGR 602604
WinFrog Multibeam Dongle	3100441U
WinFrog Multibeam Dongle	3100442U
AML SV Plus Velocity Probe	5283
AML SV Plus Velocity Probe	5354

Table 19 R/V Westerly Acquisition Equipment

Description	Serial Number
Applanix IMU LN200	
Applanix POS/MV Processor L1/L2 (RTK)	7821
GPS Antenna L1/L2 (Primary)	1441021131
GPS Antenna L1/L2 (Secondary)	1441045154
Reson NAVISOUND SVP 70 (Primary)	4506001
Reson 71-P Processor-7125 SV2 (FP3)	18341114131
Reson 71-P Processor-7125 SV2 (FP3)	18340313024
Reson SeaBat 7125 400kHz/200Khz Projector	2710017
Reson SeaBat 7125 400kHz/200Khz Projector	1012060
Reson SeaBat 7125 Receive Array	2411051
Reson SeaBat 7125 Receive Array	4715040
Fugro Acquisition PC	BGR 602832
WinFrog Multibeam Dongle	3100443U
AML SV Plus Velocity Probe	4431
AML SV Plus Velocity Probe	5353

Table 20 LiDAR Acquisition Equipment

Description	Serial Number
SHOALS	004
Applanix POS/AV	6152
GPS Antenna L1/L2 (Irridium filtered)	5594
Applanix IMU LN200	407154
GPS BASESTATION L1/L2 (STARFIX XP/HP)	NBV07120004
GNSS ANTENNA LBAND	NCL14140041
GPS BASESTATION L1/L2 (STARFIX XP/HP)	NBVO7080003
GNSS ANTENNA LBAND	NCL14140040
GPS BASESTATION L1/L2 (STARFIX XP/HP)	NBV07120002
GNSS ANTENNA LBAND	NCL09220003

Software

Table 21 MBES Software List (Acquisition& Processing Center)

Software Package	Version	Service Pack	Hotfix
Fugro WinFrog Multibeam	3.10.15.3	N/A	N/A
Fugro MB Survey Tools	3.1.7	N/A	N/A
Fugro POSMVLogger	2	N/A	N/A
CARIS HIPS/SIPS	9.1.4	N/A	N/A
CARIS Notebook	3.1	1	2
CARIS Bathy DataBASE	4.1.17	N/A	N/A
CARIS Onboard	1.0.3	N/A	N/A
CARIS Easy View	4.1.16	N/A	N/A
ESRI ArcGIS	10.3	10.3	N/A
Applanix POS/MV V4 Controller	5.8.0.0	N/A	N/A
Applanix POS/MV V5 Controller	8.46	N/A	N/A
Nobeltec Tides and Currents	3.5.107	N/A	N/A
Microsoft Office	2013	N/A	N/A
Microsoft Windows (64-bit)	7 Enterprise	1	N/A
Helios Software Solutions TextPad	5.2.0	N/A	N/A
NOAA Extended Attribute Files	5.4	N/A	N/A
IrfanView	4.25	N/A	N/A
IrfanView	5.25	N/A	N/A
IrfanView	6.25	N/A	N/A
IrfanView	7.25	N/A	N/A

Table 22: LiDAR Software List (Acquisition& Processing Center)

Software Package	Version	Service Pack	Hotfix
Fugro LiDAR Survey Tools	1.03.06	N/A	N/A
Optech SHOALS	1.2	N/A	N/A
SHOALS (GCS)	6.32	N/A	N/A
Optech Auto Cal	N/A	N/A	N/A
CARIS HIPS/SIPS	9.1.4	N/A	N/A
CARIS Base Editor	4.1.17	N/A	N/A
QPS Fledermaus	7.3.3c	N/A	N/A
Workbench	6.01.04	N/A	N/A
NovAtel Convert 4	3.9.0.7	N/A	N/A
ESRI ArcGIS	10.3	N/A	N/A
Applanix POS Pac MMS	7.1	N/A	N/A
NOAA’s VDatum	3.6	N/A	N/A
ERDAS LPS	9.3	N/A	N/A
Ortho Vista	7.0.3	N/A	N/A
Microsoft Office	2013	N/A	N/A
Microsoft Windows (64-bit)	7 Enterprise	1	N/A
Helios Software Solutions TextPad	5.2.0	N/A	N/A
RiAcquire ALS - Regal	2.0.0	N/A	N/A
SDCImport - Regal	1.6.4	N/A	N/A
RiPROCESS - Regal	1.7.2	N/A	N/A
GeoSysManager (64 bits) - Regal	2.0.5	N/A	N/A
IrfanView	4.25	N/A	N/A
IrfanView	5.25	N/A	N/A
IrfanView	6.25	N/A	N/A
IrfanView	7.25	N/A	N/A
IrfanView	8.25	N/A	N/A

Appendix II – Echosounder Reports

Multibeam Echosounder Calibration

A patch test was completed for the MBES using seafloor topology for data to be corrected for navigation timing, pitch, azimuth, and roll offsets, which may exist between the MBES transducer and the Motion Reference Unit (MRU).

Patch tests were performed independently on each sonar and were run at various stages of survey operations to calibrate the MBES and MRU for different vessel configurations.

No adjustment was required for navigation timing error. Fugro has implemented a specific timing protocol for multibeam data acquisition. In this method, UTC time tags generated within the POS/MV are applied to all position, heading, and attitude data. The POS/MV ZDA+1 PPS (pulse per second) string is also sent to the Reson SeaBat sonar system, where the ping data are tagged. The architecture of the POS/MV ensures that there is zero latency between the position, heading, and attitude strings. The only latency possible is in the ping time. In addition, the navigation-to-ping latency will be identical to the attitude-to-ping and heading-to-ping latencies.

Navigation latency is generally difficult to measure using standard timing and patch testing techniques. However, using Fugro's timing protocol, the navigation latency will be the same as the roll latency. Fortunately, roll latencies are very easy to identify. Data with a roll timing latency will have a rippled appearance along the edge of the swath. During patch test analysis, the roll latency is adjusted until the ripple is gone. This latency value is then applied to the ping time, synchronizing it with the position, attitude, and heading data.

The pitch error adjustment was performed on sets of two coincident lines, run at the same velocity, over a conspicuous object, in opposite directions. The nadir beams from each line were compared and brought into alignment, by adjusting the pitch error value.

The azimuth error adjustment was performed on sets of two lines, run over a conspicuous topographic feature. Lines were run in opposite directions, at the same velocity with the same outer beams crossing the feature. Since the pitch error has already been identified, data from the same outer beams for each line were compared and brought into alignment, by adjusting the azimuth error value.

The roll error adjustment was performed on sets of two coincident lines, run over flat terrain, at the same velocity, in opposite directions. The pitch error and azimuth error were already identified. Data across a swath were compared for each line and brought into agreement by adjusting the roll error value.

Patch test data were then corrected using the identified values, and the process repeated to check their validity. Patch test values were obtained in CARIS HIPS calibration mode. Calculated values were then entered into the HVF so that data could be corrected during routine processing.

Multibeam Echosounder Calibration Results

Table 23 Patch Test Results for Each Vessel

Patch Test Results						
Vessel	**Patch Test Day**	**MB Sonar**	**Timing Error**	**Pitch Offset**	**Roll Offset**	**Azimuth Offset**
R/V JAB	2016-225	Port 7125 400 kHz	0.000	0.900	14.675	-0.300
	2016-225	Stbd 7125 400 kHz	0.000	0.800	-14.430	1.500
	2016-251	Port 7125 400 kHz	0.000	0.900	14.645	-0.300
	2016-251	Stbd 7125 400 kHz	0.000	0.800	-14.330	1.500
R/V Westerly	2016-210	Port 7125 400 kHz	0.000	-0.500	16.450	-1.200
	2016-210	Stbd 7125 400 kHz	0.000	-0.200	-14.710	0.200
	2016-226	Port 7125 400 kHz	0.000	-0.500	16.350	-1.200
	2016-226	Stbd 7125 400 kHz	0.000	-0.200	-14.625	-0.400

Notes:

- Patch Test Day represents the Julian day the actual test was conducted. May be pre- or post-dated in CARIS HVF to cover lines run before or after patch test.

- Several CARIS HIPS Vessel (HVF) files were used throughout the project; some for calibration purposes (which include PORT or STBD in file name) and others for the project's main line scheme and crosslines. For example, the CARIS HVF named "2Westerly_PORT_7125_7004Record_400kHz" was used to compute the patch test results for the port 400kHz 7125 system on the R/V Westerly using the 7004/7006 bathy record. HVF "1JAB_PORT_7125_7027Record_400kHz" was used to compute the patch test results for the port 400kHz 7125 system on the R/V JAB using the 7027 bathy record.

- Part way through the survey the 7030 record was implemented into the acquisition workflow. The 7030 record is the installation parameters of the sonar, which include the transmit and receiver offsets. Most of the information stored in the 7030 record is not used by CARIS. To fully utilize the 7027 record in a dual head setup, the 7030 record was essential and written to the raw s7k files during data collection. During the conversion process, if the 7030 record was present in the s7k file, CARIS wrote an "InstallationParameter.XML'' file to the line directory. The HVF was set up in such a way that the sonars' receiver offsets were input under SV1 (Port receiver offsets) and SV2 (STBD receiver offsets) and the transmitter offsets were read from the 7030 record by CARIS. Any HVF with 7030 in its name is using the 7027/7030 records. For example, "2Westerly_Dual_7125_7030Record_400kHz" is for the dual 400kHz 7125 systems on the R/V Westerly using the 7027 bathy record and the 7030 installation parameters record.

Multibeam Bar Check

A bar check calibration of multibeam sonar systems is performed to accurately relate observed (recorded) depths to the true depth of water. Therefore, the calibration determines any error in the system's raw depth readings (as well as verifying the accuracy of the vessel offset survey).

A bar check calibration is performed by lowering a horizontal metal plate to a known depth below the waterline. Then, data at that known depth is acquired using the multibeam sonar system and processed using the CARIS HIPS and SIPS Swath Editor routine.

By processing the data in the CARIS Swath Editor routine, the vessel's equipment offsets measured during the offset survey, the sound velocity profile taken at the time of the bar check, the survey's static draft measurement procedure, and the data cleaning routine used during the survey are all applied to the data to calculate the difference between the sonar's measurement of the horizontal bar and the actual, known depth below the waterline.

Any difference in the measured depth versus the known depth can be attributed to error in the sound velocity profile, the static draft measurement procedure, the vessel offset survey, and/or the sonar system's internal capabilities.

On 8 September 2016, hydrographers onboard the R/V JAB and the R/V Westerly performed bar check calibrations for the respective Reson 7125 multibeam sonar systems.

Prior to performing the bar check calibrations, accurate static draft measurements were performed. Then, a flat, metal plate was lowered to a specific depth below the waterline, using lowering lines of metal chain on both sides to have the plate horizontal at 4.0 meters of water depth.

The Reson 7125 systems were energized independently and data was acquired to measure the plate's depth. During data acquisition, the vessels' navigation and motion sensors, a POS/MV (v. 4) on the R/V JAB and POS/MV (v. 5) on the Westerly were also energized to record the vessels' attitude in the water at the time of measurement. Data were acquired for a period of 1-2 minutes to provide data samples large enough to calculate an average observed depth for each system.

An SVP cast was performed to create sound velocity profiles of the water column in the vicinity of the vessels.

The data was then processed in CARIS HIPS to reduce the observed depths to the waterline and compare them to the known depths of the horizontal plate. The processing procedure that was followed, parallels the standard data processing procedures as detailed in the report of survey. The static draft measurement, the vessel equipment offsets, the vessel attitude data, and the sound velocity corrections were all applied to the raw depth observations.

The data were then further processed in the CARIS HIPS Swath Editor routine.

The acquired observed plate's depths were exported from CARIS to Microsoft Excel to calculate an average observed depth over a 1-minute period for each system. The results of the bar check calibrations are detailed below.

<u>Multibeam Bar Check Results</u>

R/V JAB Reson 7125 (4m Bar Depth)

The image below shows a CARIS HIPS Swath Editor display screen with the horizontal plate ensonified at a depth of 4.0 meters below the waterline (the value of 4.02 meters is the average depth calculated over a 1-minute period of data acquisition).

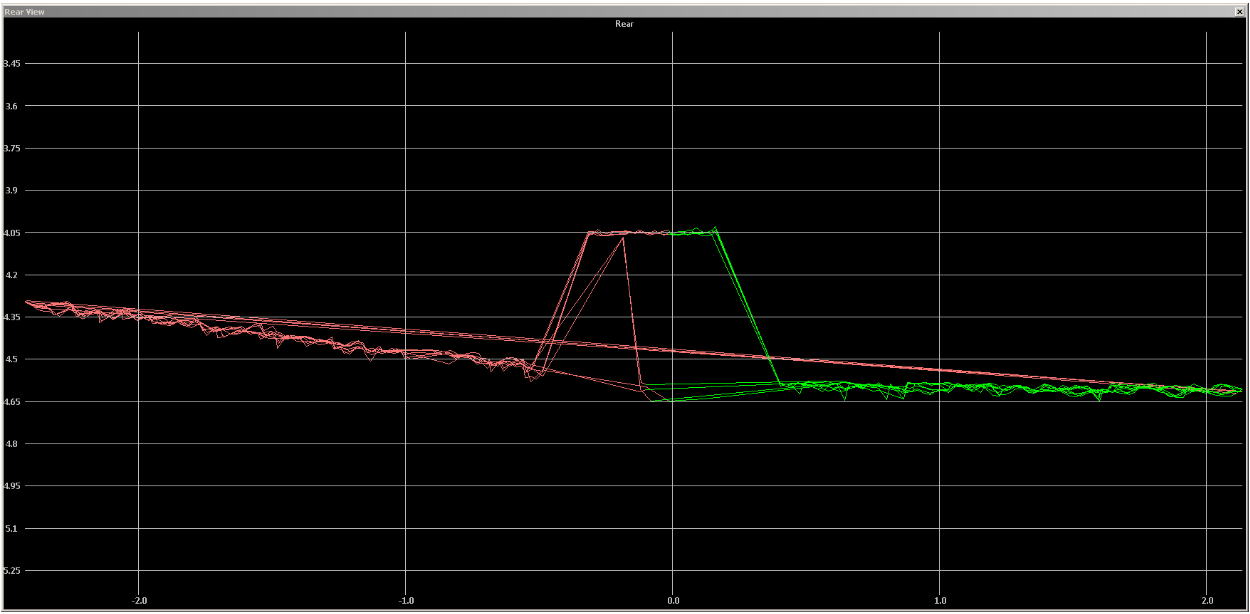


Figure 31 R/V JAB 4m Bar Check Showing the Bar Relative to Seafloor

R/V Westerly Reson 7125 (4m Bar Depth)

The image below shows a CARIS HIPS Swath Editor display screen with the horizontal plate ensonified at a depth of 4.0 meters below the waterline (the value of 3.99 meters is the average depth calculated over a 1-minute period of data acquisition).

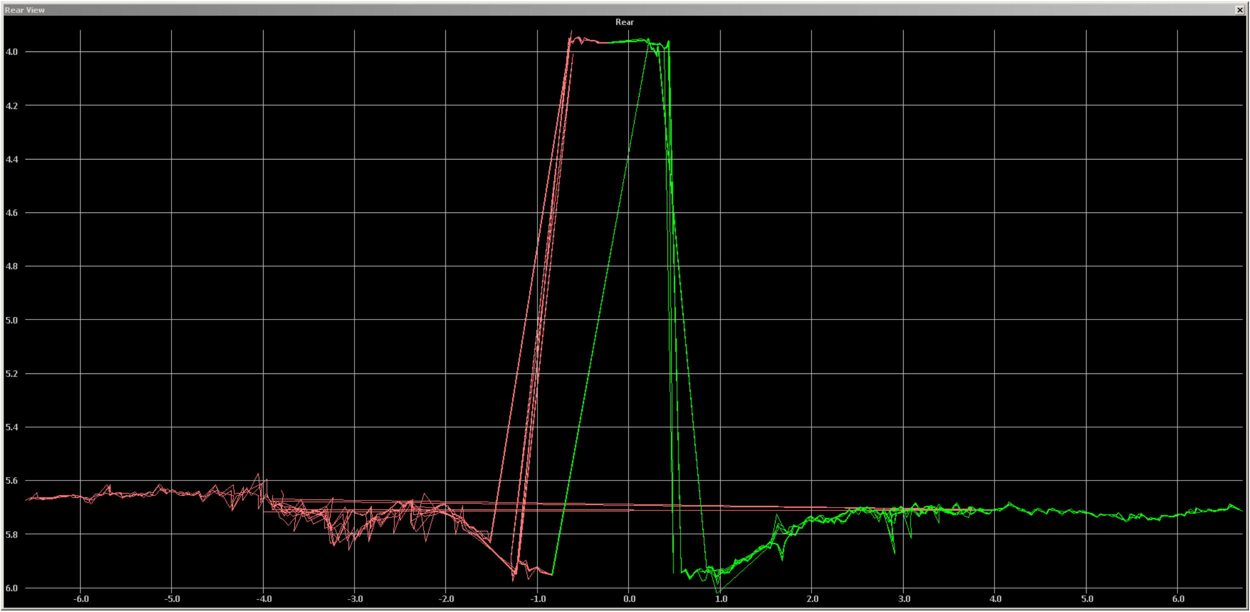


Figure 32 R/V Westerly 4m Bar Check Showing the Bar Relative to Seafloor

Multibeam Confidence Checks

Sonar system confidence checks, as outlined in Section 5.2.3.1 of the HSSD, were performed by comparing post processed depth information collected over a common area by each vessel. The confidence check results are outlined in the table below. In addition to this, checks were performed on overlapping main scheme and crossline data collected from different vessels on different days.

Multibeam Confidence Check Results

Table 24 Confidence Check Results

Surface Vessels	Mean Difference (m)	Standard Deviation (m)
JAB vs. Westerly	0.03	0.04
Westerly vs. LiDAR	+/-0.1	+/-0.3

The above results were computed from difference surfaces that were created from overlapping data collected by the R/V JAB and the R/V Westerly during field operations. See **Table 24** and **Figure 33**. The same or better results were noticed in additional checks that were performed using crossline data.

Overlapping data between the LiDAR and MBES systems was also compared and results are shown in the table above and in the images in **Figure 34** and **Figure 35**.

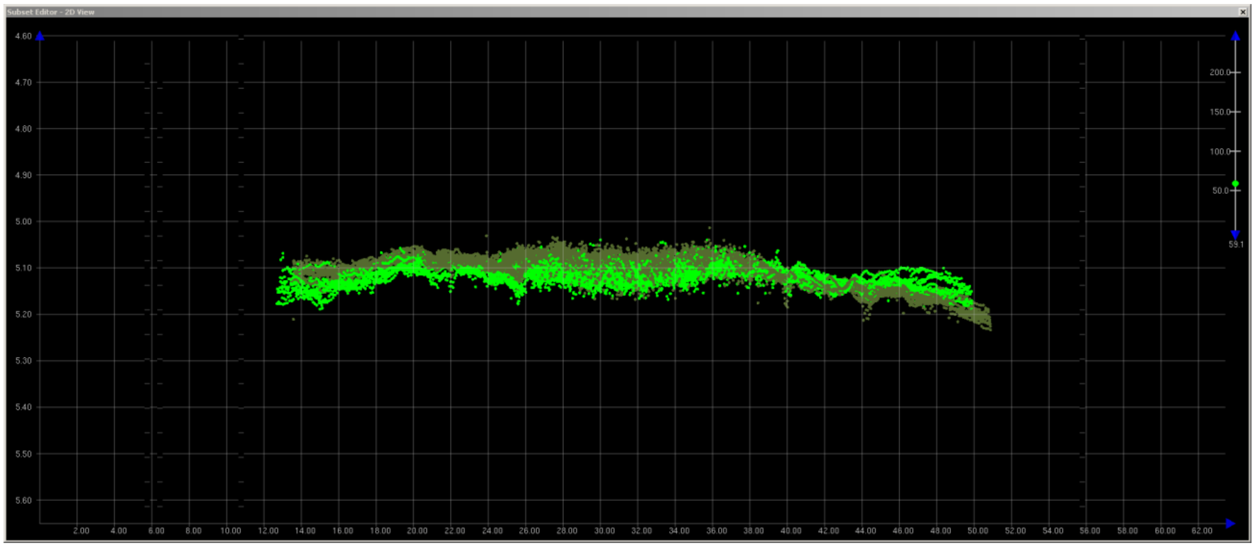


Figure 33 JAB vs Westerly Comparison

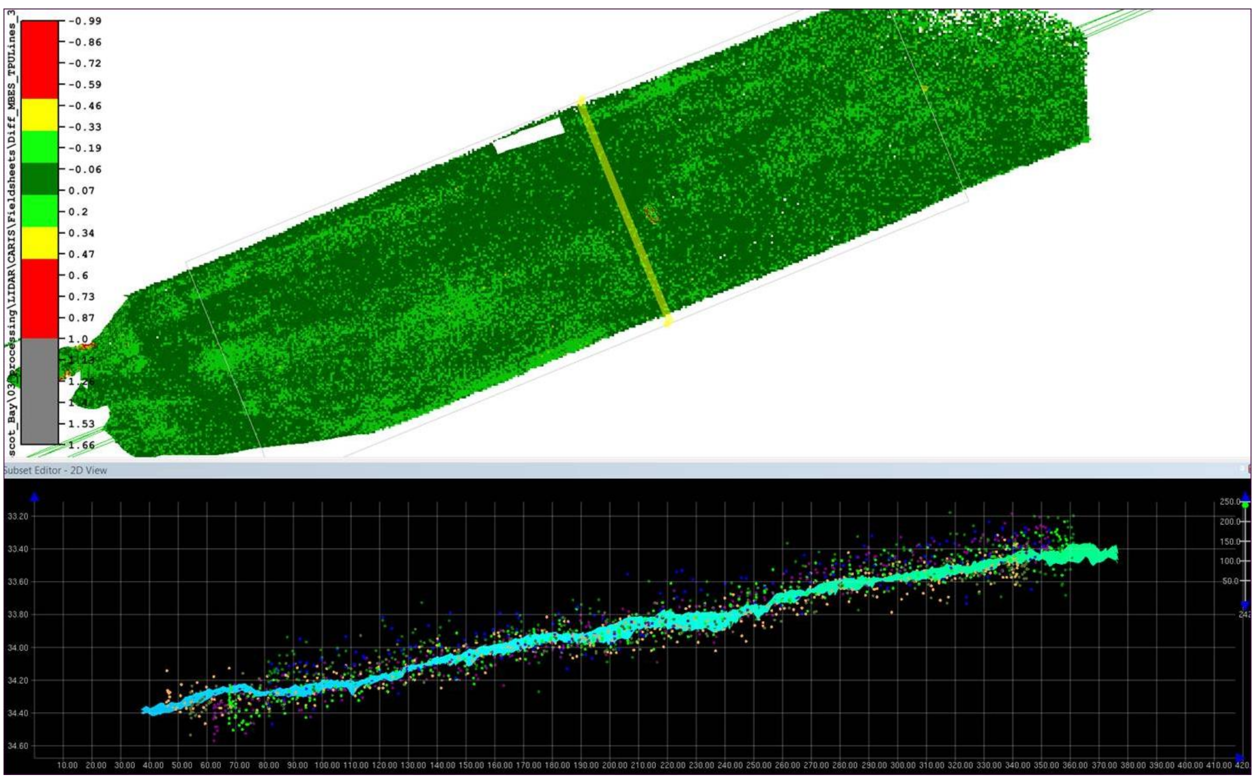


Figure 34 Westerly vs LiDAR

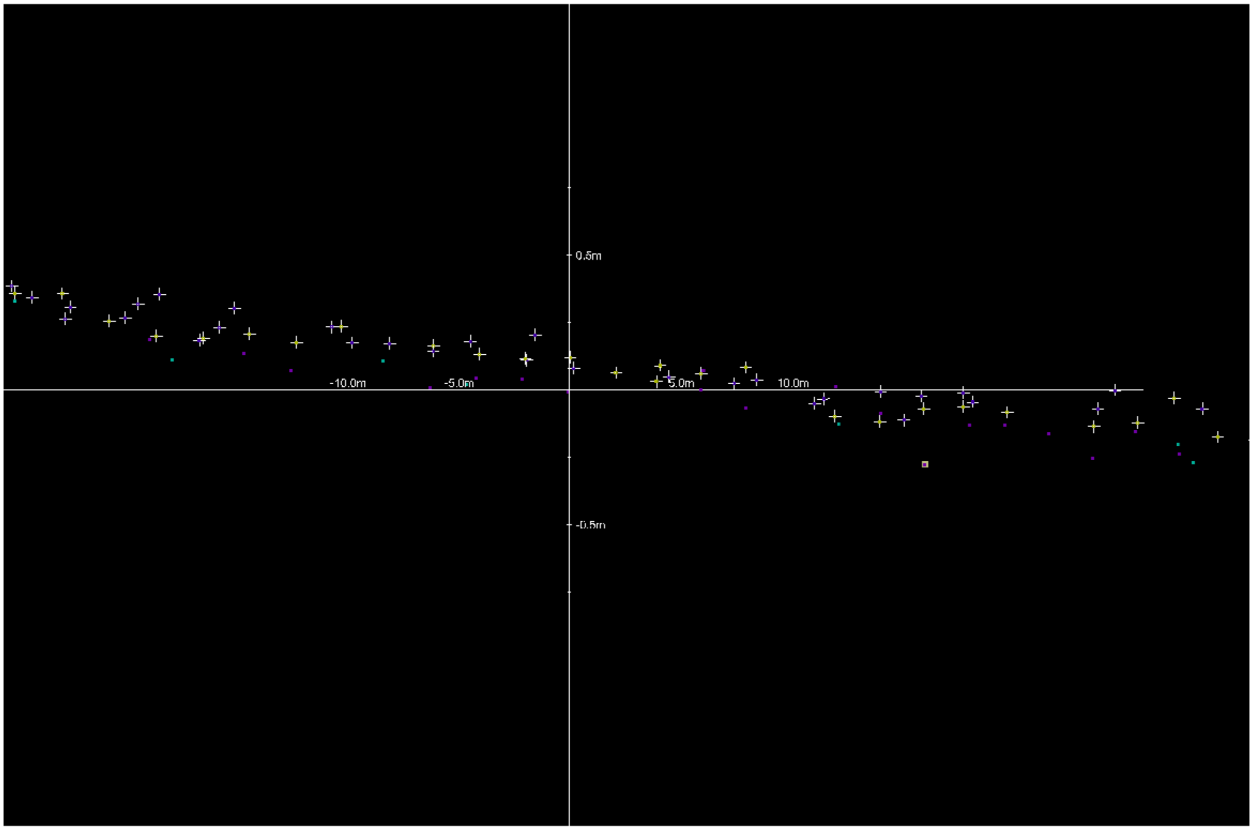


Figure 35 Westerly/JAB vs LiDAR

Appendix III – Positioning and Attitude System Reports

GAMS Calibration

Vessel headings are measured by the Applanix POS/MV V4/V5, by way of a GPS Azimuth Measurement Subsystem (GAMS). GAMS computes a carrier-phase differential GPS position solution of a Slave antenna with respect to a Master antenna position, thereby computing the heading between the two. In order for this subsystem to provide a heading accuracy of 0.01º, the system needs to know and resolve the spatial relationship between the two antennas. During the GAMS calibration, since the offset from the IMU to the Master antenna is known (from the vessel offset survey), the location of the Slave antenna is calculated by computing the baseline between the two antennas with respect to the IMU axes.

To calibrate the heading data received from the POS/MV GAMS subsystem, the POS Viewer software is used to run the GAMS Calibration routine. First, an accurate and precise separation distance between the two GNSS antennas is entered into the POS Viewer's GAMS Parameter Setup window. Once this known offset is entered into the system, the vessel begins maneuvering with turns to port and starboard (preferably figure-eight maneuvers) to allow the system to refine its heading accuracy.

Once the heading data falls to within an allowable accuracy, the vessel ends the figure-eight maneuvers and maintains a steady course and speed. The GAMS Calibration routine is started, and the POS/MV completes the calibration. The results can be viewed in the GAMS Parameter Setup window of the POS Viewer software.

The GAMS subsystem should be calibrated only one time at the start of the survey. An additional calibration should be completed and logged any time the IMU or antennas are moved.

GAMS Calibration Results

The calculations give the following results:

Table 25 Vessel Heading Calibration (GAMS Calibration)

Vessel	R/V JAB	R/V Westerly
Two Antenna Separation (m)	2.298	1.873
Heading Calibration Threshold (deg)	0.5	0.5
Heading Correction (deg)	0.000	0.000
Baseline Vector X axis	-0.013	-0.006
Baseline Vector Y axis	2.298	1.873
Baseline Vector Z axis	0.008	0.005

Appendix IV – Sound Speed Sensor Report

All SVP Calibration Reports can be found under the Appendix_IV_(SVP_Calibrations) directory.

Appendix V – Swapped Transmit and Receiver Report

A full report can be found under the Appendix_V_(TxRx_Report) directory.