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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

Data Acquisition & Processing Report

Type of Survey Hydrographic

Project No. 2011 *Rainier* field season

Time frame June - October 2011

LOCALITY

State Washington/Alaska

General Locality Strait of Georgia, WA
and West of Prince of Wales Island, AK

2011

CHIEF OF PARTY

Captain Donald W. Haines, NOAA

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Data Acquisition and Processing Report

NOAA Ship *Rainier* (s221)

2011 Field Season

Chief of Party: Captain Donald W. Haines, NOAA

A. EQUIPMENT

This Data Acquisition and Processing Report describes both the survey equipment used and the standard methods for acquisition applied to the equipment used. Not necessarily all equipment described within this report was used during data acquisition for all projects and/or sheets. Data were acquired by the following *Rainier* survey vessels:

<u>Hull Number</u>	<u>Vessel type</u>
2801	28 foot Jensen survey launch
2802	28 foot Jensen survey launch
2803	28 foot Jensen survey launch
2804	28 foot Jensen survey launch
S221	231 foot steel hydrographic ship

Vessels S221, 2801, 2802, 2803, and 2804 are used to acquire shallow-water multibeam (SWMB) data and sound velocity profiles. Any vessel may be utilized for collecting bottom samples and detached positions (DPs). Vessel descriptions and offset measurements are included in the *2011 NOAA Ship Rainier Hydrographic Readiness Review Package*.

Three different categories of echosounder systems are available for use by *Rainier* survey vessels. The individual system(s) chosen for use in a given area were decided at the discretion of the Hydrographer using the guidance stated in the Hydrographic Survey Project Instructions, the Hydrographic Surveys Specifications and Deliverables Manual (HSSDM), and the Field Procedures Manual, and depended upon the limitations of each system, the bottom topography, the water depth, and the ability of the platform vessel to safely navigate the area. These systems are described in the following section.

A complete description of all echosounder systems, positioning, and attitude sensors in addition to a complete inventory and list of serial numbers is located in the *2011 NOAA Ship Rainier Hydrographic Readiness Review Package*.

Sounding Equipment:

1. RESON 8125 Launch Shallow Water Multibeam (SWMB)

Vessel 1103 was originally intended as the platform for the Reson SeaBat 8125 but an internal battery explosion and subsequent acid erosion of the hull rendered that launch unusable for the entire field season. The decision was then made to hull mount the Reson SeaBat 8125 on vessel 2803.

The SeaBat 8125, with Option 033, Angle-Independent Imagery, is a 455 kHz multibeam system that uses high frequency focused near-field beam forming to measure relative water depths across a 120° swath. Each swath consists of 240 individual 0.5° x 1.0° beams. This system is capable of operating in depths from 4 meters to 60 meters, with varying range scale values dependent upon the depth of water and across-track slope. Surface sound velocity was measured using an Reson SVP 71 velocimeter and digitally input into the Seabat 8125 during acquisition.

In order to simplify SWMB surveying in the near-shore areas, the SeaBat 8125 is mounted with a 34° angle looking towards starboard. The transducer is attached with a custom made aluminum bracket bolted to the forward hull hardpoint on the starboard side. Unfortunately this exposed position subjects the 8125 transducer to both high drag during transit and potential rock strikes during shoreline verification. To reduce this risk, a maximum transit speed of 12kts was established for launch 2803 while the SeaBat 8125 was mounted. Under optimal conditions, 2803 can be run along the 30-foot contour parallel to shore during periods of high tide and produce near complete SWMB coverage between the 8 and 4 meter depth curves.



Figure 1 Reson Seabat 8125 mounted on survey launch 2803

2. RESON 7125 Launch Shallow Water Multibeam (SWMB)

Vessels 2801, 2802, 2803 and 2804 are equipped with a hull-mounted Reson SeaBat 7125-B, which is a dual frequency (200/400 kHz), high-resolution multibeam echo sounder system for shallow-water depths. The recommended maximum range at 200kHz is 500m resulting in a theoretical 220 m depth limit for full swath coverage. The 400kHz setting maximum range is 200m resulting in a theoretical 87m depth limit for full swath coverage. The transducer assembly consists of single flat-faced receiver array and two projectors, one for each frequency. These systems included the optional Reson SVP 71 surface sound velocity probe.

The SeaBat 7125 measures relative water depths across a 128° swath in both high and low frequency. Beamforming is conducted in either equi-angle or equidistant mode. Equidistant mode is useful to produce soundings at a uniform distance apart across the entire swath-width of a ping at the cost of less sounding density near nadir. Equi-angle mode is good for maximum ensonification of the bottom directly under the launch at the cost of sparse sounding density in the outer beams. *Rainier* launches typically acquire data in equidistant mode unless running development lines directly over a feature of interest.

In the 200kHz mode the system has a beamwidth of 1° x 2° and in the 400kHz mode has a beamwidth of 0.5° x 1°. At 200kHz, the SeaBat 7125 generates 256 bathymetry soundings per ping. At 400kHz, the system generates 256 or 512 bathymetry soundings per ping. Typical settings used aboard *Rainier* are 256 sounding, equidistant in LF mode and 512 sounding, equidistant in HF mode.

3. Kongsberg EM 710 multibeam echo sounder

S221 (RAINIER) is equipped with a hull-mounted Kongsberg EM 710, which operates at sonar frequencies in the 70 to 100 kHz range. The across-track swath width is up to 5.5 times water depth with a published maximum depth of more than 2000 m. The alongtrack beamwidth of *Rainier*'s configuration is $\frac{1}{2}^\circ$ with a receive beamwidth of 1° . The number of beams is 256 or 128 respectively, with dynamic focusing employed in the near field. A high density beam processing mode provides up to 400 or 200 soundings per swath by using a limited range window for the detections. The beamspace may be set to be either equiangular or equidistant. *Rainier* typically collects 256 beams per ping in equidistant mode.

The transmit fan is divided into three sectors to maximize range capability but also to suppress interference from multiples of strong bottom echoes. The sectors are transmitted sequentially within each ping, and uses distinct frequencies or waveforms. By default, the transmit fan is electronically stabilized for roll, pitch and yaw but *Rainier* experience has shown that yaw stabilization often caused a noticeable "step" between the three sectors of the transmit fan. Due to this problem, *Rainier* typically disables yaw stabilization.



Figure 2 Kongsberg EM 710 sonar transducer housing on Rainier (S221)

4. Lead Line

During shoreline verification, lead lines were used to acquire depths over rocks and other features too shallow to acquire soundings using echo sounders. *Rainier* personnel calibrated lead lines in March and April of 2011. Calibration reports are included in the *2011 NOAA Ship Rainier Hydrographic Readiness Review Package*.

Side Scan Sonar:

1. Multibeam Echosounder Backscatter

Option 033 of the Reson 8125 SWMB system used aboard 2803 provides angle-independent imagery similar to fixed-mount side scan sonar (SSS). The Reson 7125 systems aboard 2801, 2802, 2803 and 2804 also acquired angle-independent pseudo SSS imagery. This SSS imagery is primarily used during processing of the multibeam sounding data to aid in determining whether anomalous soundings are true features or noise. It generally does not have sufficient resolution for small object detection, but the shape of objects and their strength of return can greatly increase the confidence in processing results.

Current guidance from the Field Procedures Manual calls for field units to acquire and submit multibeam backscatter data in snippet mode whenever feasible. Reson “snippets” imagery are recorded at acquisition and are present in the raw data, but not processed or analyzed. Snippet data contains the amplitude data of each individual sonar beam in a swath, but there are problems, well-documented in the hydrographic literature, that reduces the efficacy of processing these data.

Backscatter data are collected by default for the EM710.

Due to problems encountered with the installation and configuration of the tilted Reson 8125 system, backscatter data for this system were not collected for the 2011 field season.

Although no formal processing of backscatter data were performed, backscatter data were periodically converted solely to spot check and ensure that it was being properly logged. No processed backscatter data is included with the data submission but all raw backscatter data are submitted directly to NGDC for archival purposes.

Positioning Equipment:

1. Applanix POS MV 320

Vessels 2801, 2802, 2803, 2804 and *Rainier* are equipped with Applanix POS/MV 320 (version 4) Position and Orientation Sensors to measure and calculate position. The POS/MV is a GPS-aided inertial navigation system, which provides a blended position solution derived from both an Inertial Motion Unit (IMU) and an integrated GPS receiver. The IMU and GPS receiver are complementary sensors, and data from one are used to filter and constrain errors from the other. This inter-dependence results in higher position accuracy and fewer errors than either system could produce by itself.

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

2. Horicon shore-side base stations

During hydrographic operations, *Rainier* maintains at least one GPS base station near the project area. Base station sites are chosen for both clear lines of site to either survey launches or the ship for easy data downloads in addition to a clear horizon to maximize the number of GPS satellites observed. Base station sites are also selected to fall within 20 kilometers of all data within the project area.

Each stations consist of either a Trimble NetR5 or Trimble NetR9 GNSS reference receiver interfaced with a Freewave HTP-900RE 900 MHz Ethernet radio all sealed in a watertight Pelican plastic case. A Zephyr Goedetic 2 GPS antenna is secured atop a Seco fixed-height GPS antenna tripod and connected to the Trimble receiver through a watertight connection fitted in the side of the Pelican case. A UHF antenna on top of an extending pole supported by a standard survey tripod is connected to the Freewave Ethernet radio and provides for remote daily download of the Trimble data. Batteries and solar panels provide power.

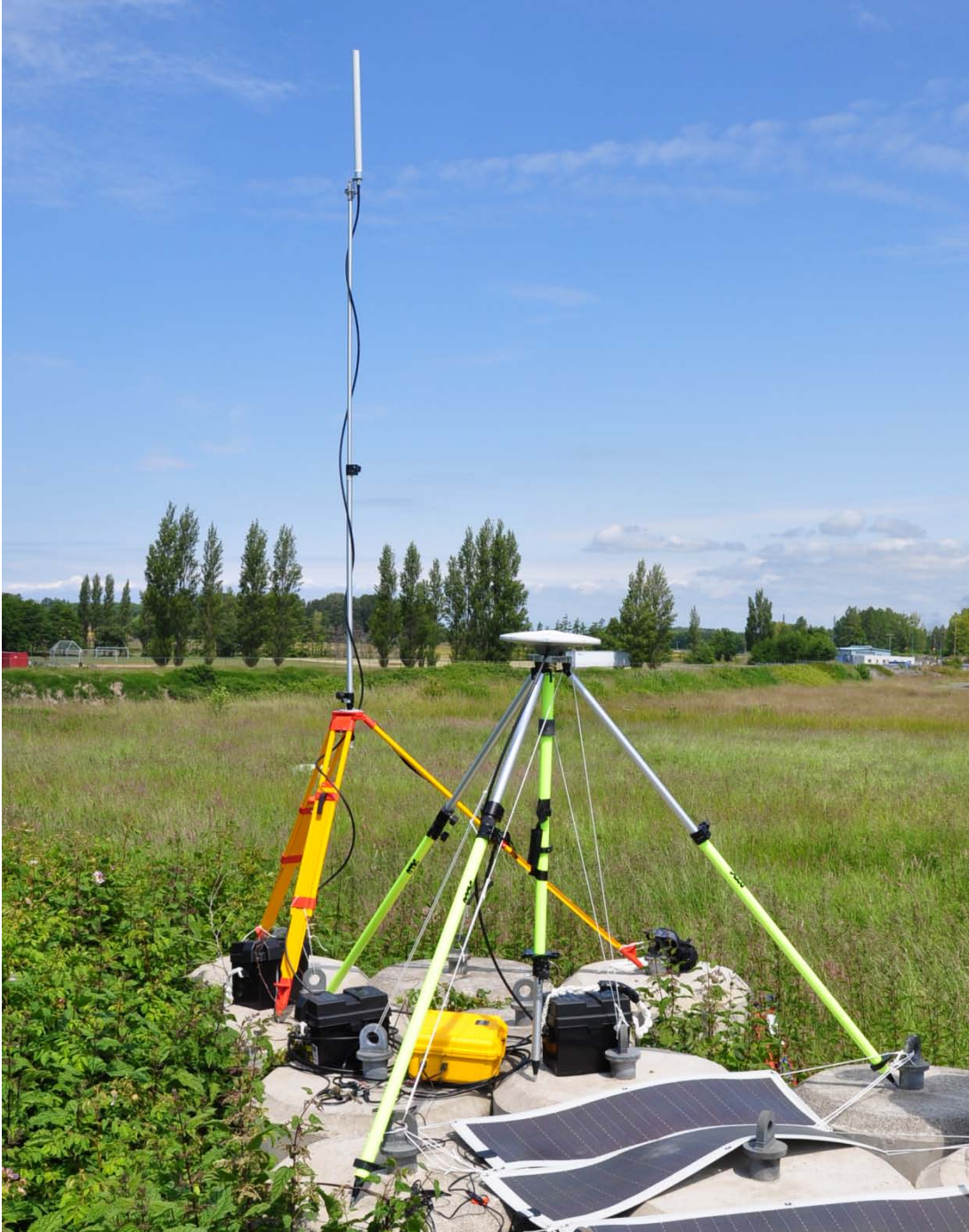


Figure 3 An example of a horizontal control base station consisting of a fixed height GPS tripod, a UHF transmission antenna and a NetR9 receiver with associated batteries and solar panels.

Attitude Measurement Equipment:

1. Applanix POS MV

Rainier's SWMB launches (1101, 2801, 2802, 2803 and 2804) are equipped with Applanix POS/MV Model 320 version 4 Position and Orientation System – Marine Vessel (POS/MV) sensors, which provide accurate navigation and attitude data to correct for the effects of heave, pitch, roll and heading. The POS

generates attitude data in three axes (roll, pitch and heading) to an accuracy of 0.05° or better. Heave measurements supplied by the POS/MV maintain an accuracy of 5% of the measured vertical displacement for movements that have a period of up to 20 seconds. The Heave Bandwidth filter was configured with a damping coefficient of 0.707. The cutoff period of the high pass filter was determined by estimating the swell period encountered on the survey grounds. These values ranged from 8 s (flat water) to 20 s (long period ocean swell), with values of 8 or 12 s typical.

Intermittent problems with the heading accuracy climbing above the ideal cutoff of 0.05° were observed, particularly with launches 2801 and 2802. The root cause of this problem has been hypothesized as a faulty antenna configuration on these launches. The POS/MV manual requires an antenna separation distance of at least 1m and recommends a distance between 2-5m. Unfortunately the first two new launches received by *Rainier* don't fully meet this requirement with 2801 having a separation of 1m and 2802 having a separation of 0.988m. This problem was addressed in the design of the next two new launches (2803 & 2804) which have an antenna separation of ~1.36m each. Heading accuracy was monitored by the launch crew and survey operations were temporarily suspended in the event that the error rose above 0.08° .

Applanix "TrueHeave" values were also recorded. The TrueHeave algorithm uses a delayed filtering technique to eliminate many of the artifacts present in real time heave data. The TrueHeave data were applied to Reson bathymetry in CARIS HIPS post processing.

Full POSpac data were also recorded on vessels S221, 2801, 2802, 2803 and 2804. These data are used to post process POS/MV data to produce superior position and attitude data and can be used to produce a Post-Processed Kinematic (PPK) GPS solution, (see section B for more information).

Sound Speed Measurement Equipment:

Rainier is equipped with a Rolls-Royce Group ODIM Brooke Ocean MVP200 Moving Vessel Profiler (MVP). This system consist of a sensor fish, a conductor cable, a computer controlled high speed hydraulic winch, and a cable metering system. In the underway mode, the sensor fish is towed behind the ship and periodically is allowed to freefall near vertical through the water column recording sound velocity profiles. This enables *Rainier* to take SV casts without stopping the ship at the cost of not being able to collect casts with depths equal to the available cable length. To take deeper SV casts and take full advantage of all the cable on the drum, the ship must come to a stop. While stationary, 600 meter deep SV casts may be collected as opposed to a maximum of 235 meters deep when the ship is in typical survey mode and underway at 10 knots.

Vessel 2801 is equipped with a Rolls-Royce Group ODIM Brooke Ocean MVP30 MVP. This system consist of a sensor fish, a conductor cable, a computer controlled high speed hydraulic winch, and a cable metering system. In the underway mode the sensor fish is towed behind the launch and periodically is allowed to freefall near vertical through the water column recording sound velocity profiles. This enables the launch to take SV casts without stopping the vessel at the cost of not being able to collect casts with depths equal to the available cable length. To take deeper SV casts and take full advantage of all the cable on the drum, the launch must stop. While stationary, 125 meter deep SV casts may be collected as opposed to a maximum of 50 meters deep when the launch is in typical survey mode and underway at 7 knots.

All *Rainier* launches (2801, 2802, 2803, and 2804) are equipped with 24-volt electric winches attached to small swing-arm davits to deploy and recover SV profilers while the vessel is at rest. See section C, Corrections to Echo Soundings, of this report for more information on the actual sound velocity profilers used.



Figure 4 The ODIM Brooke Ocean MVP200 Moving Vessel Profiler mounted aboard *Rainier*

Software:

All multibeam launches (2801, 2802, 2803 and 2804) recorded Reson shallow-water multibeam (SWMB) echosounder data, along with position and attitude data from the POS/MV using HYPACK, Inc.'s HYSWEEP®, an optional add-on module to HYPACK® 2010 hydrographic survey software. Data were logged in the ASCII (HSX Format) which includes full support for HYSWEEP survey features.

All SWMB data were processed using the 64-bit version of CARIS Hydrographic Information Processing System (HIPS) and Hydrographic Data Cleaning System (HDCS) software version 7.1 for the Microsoft Windows 7 environment.

For both the individual SeaCat profilers and *Rainier's* MVP, sound velocity profiles were computed from raw pressure, temperature, and conductivity measurements using the program Velocipy, supplied by the NOS Hydrographic Systems and Technology Programs N/CS11 (HSTP).

A complete list of software and versions is included in the *2011 NOAA Ship Rainier Hydrographic Readiness Review Package*. Software updates were applied throughout the project to improve productivity and data quality. As software patches became available, they were tested by the Field Operations Officer, Chief Survey Technician, or other designated crew member. If tests resulted in satisfactory performance, the updates were installed on all affected workstations and tracked in a version control spreadsheet.

B. DATA PROCESSING AND QUALITY CONTROL

Project Management Overview

Rainier's data processing and quality control procedures are described in detail in the flow diagrams included in Appendix I. Roles, responsibilities, and the generalized project accomplishment procedure are summarized in this section.

Project Planning

Project Instructions received from Hydrographic Surveys Division (HSD) are reviewed by the Chief of Party (Commanding Officer), Field Operations Officer (FOO), and Chief Survey Technician (CST). Preliminary questions are addressed to HSD/OPS for clarification. The FOO then develops survey limits for each assigned sheet, and in consultation with the CO and CST, assigns each survey to a sheet team.

The sheet team is composed of as many as three people: The **Survey Manager** has responsibility for completion of the survey, including planning, data acquisition and processing, quality control, and creation of deliverables. Depending on the complexity of the survey, the Survey Manager is typically a commissioned officer, survey technician, or physical scientist with 6 months or more experience. **Survey Assistants** and/or **Survey Mentors** may also be assigned if required. **Survey Mentors** are assigned to particularly difficult survey areas or in the case of a less experienced Survey Manager. Mentors serve as intermediaries between the survey manager and the FOO, advising the Manager on survey planning and reviewing data and deliverables. Mentors generally have at least a year and a half of experience, and have demonstrated proficiency as Survey Managers themselves. **Survey Assistants** are junior commissioned or civilian personnel with less than one year's experience. They assist the Survey Manager with planning and data processing, and receive training from the Manager and Mentor. Notwithstanding the delegation of this authority to junior personnel, the FOO remains responsible to the Chief of Party for efficient, accurate, and thorough completion of all projects assigned to *Rainier*.

The Sheet Team reviews the Project Instructions, all other relevant guidance¹, and all available prior survey and source data. Prior survey bathymetry, if available, is used as a guide for planning survey acquisition to achieve the coverage required by the letter instructions. If shoreline verification is required for the survey, prior source data (Remote Sensing Division source, prior hydrographic

¹ "NOS Hydrographic Surveys Specifications and Deliverables", "OCS Field Procedures Manual", and Hydrographic Surveys Technical Directives.

survey data, lidar if available, and charted items) are compiled and deconflicted. The resulting survey data acquisition plan is reviewed by the FOO prior to implementation.

Data Acquisition

Field operations are planned by the FOO to utilize the appropriate platforms and sensors to meet the requirements of the survey team's acquisition plan. In the case of launch-based hydrography, actual data acquisition and field quality control is accomplished by a qualified **Launch Team**. At a minimum, this team will include a **Coxswain** (Person-In-Charge) and **Hydrographer-In-Charge** (HIC). The Coxswain is a member of the ship's crew who has met all requirements of coxswain certification for the vessel in use, and has been qualified by the Commanding Officer (CO) in consultation with the Chief Boatswain. The coxswain is responsible for the safe operation of the launch and the safety of the embarked personnel and equipment. The Hydrographer-In-Charge is a member of the ship's crew who has met the requirements for HIC qualification for the surveying techniques to be employed, and has been so qualified by the FOO in consultation with the CST and Chief of Party. The HIC is responsible for directing survey operations and operating survey equipment to efficiently complete the vessel's assigned mission and ensure data quality. Both Coxswains and HICs will generally have at least one year's experience prior to qualification for these positions. Additional qualified **Launch Crewmembers** may be assigned to a vessel as required for training purposes and/or to assist the HIC and Coxswain with survey operations.²

Each survey day begins and ends with a short meeting of personnel involved in that day's operations. Prior to deploying launches, the Commanding Officer and FOO brief the launch crews to ensure that they are aware of all safety issues, operational considerations, and mission for the day. The launch HICs are debriefed by the FOO in the evening to provide a firsthand account of the day's activities, any unusual features discovered, and any problems with data acquisition or launch systems.

Data Processing

Initial data processing at the end of each survey day is the responsibility of the **Night Processing Team**, or launch crew if no night processing team is assigned. The Night Processing Team is typically composed of two crewmembers, one with at least a year's experience, and one junior member in training. Daily processing produces a preliminary product in which all gross data problems have been identified and/or removed, and thus can be used by the Survey Team to plan the next day's operations. The Night Processors complete a data pass down log to inform the survey manager and FOO of any notable features or systematic problems in the day's data.

In addition, night processing crew may be assigned to processing and QC checks of POSPac data. Final application of the POSPac data is the responsibility of the HorCon project manager and/or assistants. The HorCon project manager and the sheet manager work together to ensure SBETs were properly applying to the survey after post acquisition tasks are complete.

Final data processing and analysis is the responsibility of the Survey Team. While "ping-by-ping" data editing is not required, the Team will review the survey in its entirety to ensure that the final products reflect observed conditions to the standards set by the relevant OCS guidance. Bathymetric surfaces are reviewed with the best available correctors applied to ensure that all data quality problems are identified and resolved if possible, and all submerged features are accurately represented. Shoreline verification (if applicable) and feature data are reviewed in the context of this

² For more information on personnel qualification standards, see NOAA Administrative Order 217-103, NMAO Small Boat Policy, and *Rainier* Standing Orders.

bathymetry. Survey documentation (including the Descriptive Report) is generated in conjunction with this review process.

Review and Quality Control

While quality control reviews are present throughout survey planning, data acquisition, and data processing, the final, complete review is accomplished once acquisition is complete and preliminary deliverables have been produced. Draft survey products are first reviewed by the Survey Mentor (if assigned) to check that *Rainier* standard practice has been followed, all applicable guidance has been observed, and all products meet specifications. Draft surveys are then forwarded to the CST and FOO for data review. The CST's review focuses on features and shoreline verification (if applicable), while the FOO's review focuses on bathymetric products. Feedback is passed back to the Manager, who makes the required changes. This process is repeated until the FOO is satisfied that all products are ready for review by the Chief of Party (CO). The CO reviews all products for consistency with ship and Coast Survey policy, and may also review constituent data to ensure data quality. The CO's comments are passed back through the FOO to the Survey Manager as necessary to address any issues encountered. Finally, once the survey is finalized, the data products are packaged by the CST for submittal to OCS.

Multibeam Echosounder Data

Shallow water multibeam data were monitored in real-time using the 2-D and 3-D data display windows in the on-screen display for the Reson SeaBat 8125. The Reson 7K Control Center online bathymetry data display was monitored in real-time for the Reson SeaBat 7125-B. Adjustable user parameters common for Reson systems are range scale, power, gain, and pulse width. These parameters were adjusted as necessary to ensure the best bathymetric data quality. Additionally, vessel speed was adjusted as necessary, and in accordance with the NOS Specifications and Deliverables and Draft Standing Project Instructions, to ensure the required along-track coverage for object detection.

For the *Rainier's* Kongsberg EM 710 system, shallow water multibeam data were monitored in real-time with the acquisition software, SIS (Seafloor Information System). Data were displayed using 2-D and 3-D data display windows in the real-time screen display.

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

For *Rainier*, traditional line plans are still the norm although real-time coverage tools are used to assess SWMB coverage and find holidays in near real time. Lines are still in use to minimize the number of turns and course adjustments required for the relatively un-maneuverable *Rainier*.

Once the polygons were drawn using MapInfo or Caris Notebook, they were exported as S-57 (.000) files or shape files since Hysweep can handle either format. Hysweep displays these polygons over the chart in addition to plotting the SWMB swath coverage as it is collected. This display of the real-time swath coverage is based upon the matrix file, a polygon with user defined geographic bounds and resolution set up prior to data collection. The resolution of the matrix is selected to match depth range of the polygon currently being used (see table #5). The launch coxswain uses this display to adjust the line as it is driven

so that the swath currently being collected overlaps the grid of previously collected data. Any holidays are immediately evident in the field and can easily be filled in. This method of data acquisition saves time in both the pre-planning stage as well as greatly reducing the need for filling holidays during the subsequent rounds of data acquisition. In the event of any holidays found in post-processing, either traditional holiday lines, small polygons, or exported CARIS BASE surface GeoTIFFs may be used to fill them in.

Rainier's primary bathymetric data review and quality control tool is the CARIS CUBE (Combined Uncertainty and Bathymetry Estimator) surface as implemented in HIPS version 7.1. The CUBE algorithm generates a surface consisting of multiple hypotheses that represent the possible depths at any given position. The CUBE surface is a grid of estimation nodes where depth values are computed based on the horizontal and vertical uncertainty of each contributing sounding as follows:

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

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

Any individual sounding's uncertainty, or Total Propagated Uncertainty (TPU), is derived from the assumed uncertainty in the echosounder measurement itself, as well as the contributing correctors from sound speed, water levels, position, and attitude. TPE values for tide and sound velocity must be entered for each vessel during TPE computation (see table #4).

- **Tide values measured** uncertainty value error ranges from 0.01m to 0.05 m is dependent upon the accuracy of the tide gauges used and the duration of their deployment. *Rainier* is using a value of 0.0 since Tide Component Error Estimation section of the Hydrographic Survey Project Instructions now includes the estimated gauge measurement error in addition to the tidal datum computation error and tidal zoning error.
- **Tide values zoning** is unique for each project area and typically provided in appendix two of the Hydrographic Survey Project Instructions, Water Level Instructions. In section 1.3.1.1 Tide Component Error Estimation, the tidal error contribution to the total survey error budget is given at the 95% confidence level, and includes the estimated gauge measurement error, tidal datum computation error, and tidal zoning error. Since this tidal error value is given for 2 sigma, the value must be divided by 1.96 before it can be entered into CARIS (which expects a 1 sigma value).
- **Sound speed value measured** error ranges from 0.5 to 4 m/s, dependent on temporal/spatial variability. Although Hydrographic the FPM recommends a value of 4 m/s when 1 cast is taken every 4-hours, *Rainier* experience in the field suggests that a value of 3.0 m/s better models this error.
- **Sound speed value surface** is dependent on the manufacturer specifications of the unit utilized to measure surface SV values for refraction corrections to flat-faced transducers. The Reson SVP 71 fixed-mount sound velocity probe is affixed to vessels 2801 2802, 2803 and 2804 to provide correctors for the flat face Reson 7125 and in the case of 2803 the Reson 8125. A Reson SVP 70

is mounted on *Rainier* to provide correctors for the EM710. The Reson SVP 71 velocity probe has a published accuracy of 0.15 m/s while the SVP 70 has a published accuracy of 0.05 m/s.

Vessel	Tide values measured	Tide values zoning	Sound speed values measured	Sound speed values surface
S221_EM710	0.0	Project specific	3.0	0.05
2801_Reson7125	0.0	Project specific	3.0	0.15
2802_Reson7125	0.0	Project specific	3.0	0.15
2803_Reson7125	0.0	Project specific	3.0	0.15
2803_Reson8125	0.0	Project specific	3.0	0.15
2804_Reson7125	0.0	Project specific	3.0	0.15

Table 1: TPE Values for Tide and Sound Velocity

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

After consultation with Kogsberg, *Rainier* modified the base device model file to account for the ½ by 1 degree system installed on the ship. This custom device model is included with the digital data submission of all surveys completed during the 2011 field season.

The exact behavior of CUBE is determined by the values set in the CUBE parameters file, a xml file which can be selected by the user in the CARIS **Tools** → **Options** → **Environment** tab. The Hydrographic Surveys Division (HSD) has created and provided a customized CUBE parameters file (CubeParams_NOAA.xml) with new CUBE parameters that are required for each grid resolution. During the creation of CUBE surfaces the user is given the option to select parameter configurations based upon surface resolution which have been tuned to optimize the performance of the CUBE algorithm. Table #5 illustrates how the advanced options configuration is manipulated based on the grid resolution of the CUBE surface being generated.

Following acquisition, multibeam sonar data were processed using the CARIS HIPS and SIPS Batch Processor. The batch processor runs a user defined script which accomplishes the following standard tasks without user intervention:

1. Convert the “raw” Reson data to the HDCS data format.
2. Load predicted tides.
3. Load and apply sound velocity files.
4. “Merge” data to apply position, attitude, vessel offsets, and dynamic draft correctors to bathymetry and compute the corrected depth and position of each sounding.
5. Compute TPE.
6. Filters may be applied to the data after checking with the sheet manager if specific data issues exist. If used, data is filtered according to the following criteria:
 - Reject soundings with poor quality flags, (0 for Reson).
 - Reject soundings with TPE greater than the horizontal and vertical error limits specified in the NOS Hydrographic Surveys Specifications and Deliverables:

$$\text{Horizontal Error} > \pm(5\text{m} + 5\% \text{ of depth})$$

$$\text{Vertical Error} > \pm \sqrt{a^2 + (b * d)^2}, \text{ where "a" and "b" are defined as}$$

Depth range	Depth a	Depth b
0-100m	0.500	0.013
Greater that 100m	1.000	0.023

7. Add data to the master “QC” field sheet encompassing the entire survey.
 - “QC” Field Sheet naming convention: Hxxxxx_QC (e.g., H12345_QC)
 - Base surface are created in accordance with the depth ranges set forth in table #5.

Depth Range Filtering	CUBE Surface Resolution	BASE surface Advanced Options Configuration
0 – 20 m	1.0 m	NOAA_1m
18 – 40 m	2.0 m	NOAA_2m
36 – 80 m	4.0 m	NOAA_4m
72 – 160 m	8.0 m	NOAA_8m
144-320 m	16.0 m	NOAA_16m

Table 2: Depth range vs. CUBE surface resolution

It has been the experience aboard *Rainier* that CUBE surfaces of differing resolutions that cover the same dataset may produce widely different results. In an effort to eliminate this problem, cube surface resolution values of 1, 2, 4, 8 and 16 meters were chosen. On occasion a 0.5m CUBE surface is utilized in areas of rocky or uneven bottom when the default surface does not well represent all of the shoal points. Since these resolution values are even multiples, all of the surfaces produced for a given field sheet will have the nodes of all surfaces co-located.

The following options are selected when CUBE surfaces were created:

- **Surface Type** – CUBE
- **IHO S-44 Order** – Order 1a
- **Include status** – check Accepted, Examined and Outstanding
- **Disambiguation method** - Density & Locale (this method selects the hypothesis that contains greatest number of soundings and is also consistent with neighboring nodes).
- **Advanced Configuration** – As per table #5 and dependent upon the surface resolution.

After consultation with the sheet manager, preliminary data cleaning may be performed on “QC” field sheet. Each surface is masked to the appropriate depth range for its resolution using the attribute filter found in the “properties” of the depth layer. The Attribute Filter is enabled by selecting the check box. The filter is set by checking on the button and changing the expression to read “Depth >X AND Depth <Y” where X= min depth for the resolution and Y= max depth for the resolution. E.g. a 2 m resolution surface would get the expression: Depth >18 AND Depth <40.

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

- Subset Mode is the default tool selected due to its ability to quickly compare large numbers of soundings with adjacent or overlapping data for confirmation or rejection. Subset mode also excels with the assessment of possible features, disagreement between overlapping lines, and crossline comparison. The image designer can be used to visually enhance patterns and anomalies in CUBE surfaces, especially the standard deviation CUBE surface.
- Swath Editor is useful for burst noise, multipath, and other "gross fliers" which are specific to a particular line or lines, and most easily removed in this mode. Additionally, when it was felt that the quality of the data was reduced due to environmental conditions such as rough seas or extreme variance in sound velocity, data were filtered on a line by line basis to a lesser swath width to ensure data quality. Swath editor is also useful when examining single lines of tilted 8125 data.
- Both modes (but particularly Swath Editor) are used as a training aid to help novices learn how the various sonars operate, and provide feedback to the acquisition process.

With the advent of CUBE-based processing, it has become possible to adjust the final bathymetric surface directly by selecting the correct hypothesis to use. Although this method is available, it is not “allowed” according to HSD and it is standard practice on *Rainier* to clean soundings in the traditional method until the CUBE algorithm selects the correct hypothesis.

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

A coarse 8m resolution “Launch” BASE surface may also be maintained for use in the survey launches during data acquisition. The 8m resolution was selected to maintain smaller, easily transportable GeoTiff files.

- Naming convention is Hxxxxx_LaunchSafety_8m.
- The surface is created as a single resolution CUBE surface at 8m resolution.
- The CUBE surface is colored using a standardized custom *Rainier* generated CARIS *Colour Range* table (see table #6).
- The color pallet selected is intended to aid swift navigation over previously survey areas in addition to highlighting shallow areas.

Depth Range	COLOR (CARIS)
-5 – 1 m	Pink
1 – 2 m	Red
2 – 4 m	Yellow
4 – 8 m	Dark Yellow
8 – 20 m	Lime
20 – 40 m	Turquoise
40 – 80 m	Blue
80 – 160 m	Violet
160 – 500 m	Grey

Table 6: Depth range vs. COLOR in use for launch safety DTMs

Final review of the “QC” field sheet CUBE Surface is left to the Mentor or experienced survey manager who inspects areas with questionable shaded depth models and/or high standard deviation to ensure that no actual features were cleaned out. The use of large tiles is encouraged to track coverage of problems areas.

On occasion, the resolution of the CUBE surface may not be sufficient to capture the high point of a bathy feature. In less than 20m of water, any feature where the most probable accurate sounding was shoaler than the CUBE surface by greater than one half the allowable error under IHO S-44 Order 1 was considered inadequately captured by the CUBE surface. In greater than 20m of water, this allowable error was expanded to the full Order 1 error allowance at that depth. Although this may occur on irregular shoals or rock pinnacles, man-made features such as piles and wrecks are of particular concern. These features have very slender high points that extend far above the surrounding seafloor as well as the CUBE surface. To ensure that these features are properly represented, the shoalest point is flagged “designated” in CARIS. During the “finalization” process, the CUBE surface is forced to honor all soundings which have been flagged “designated”. In the case of a survey where the high points of many features are not being captured by the CUBE surface, (i.e. a boulder field), the hydrographer may decide to produce higher resolution CUBE surfaces to ensure that these features are being honored. Any such deviations from standard procedures will be noted in that survey’s Descriptive Report.

At the time of this report, Coast Survey has not approved multiple resolution BASE surfaces as a final deliverable. Although these surfaces are acceptable for field use, the algorithm produces artifacts at the resolution steps that are unsuitable for a final product. To circumvent this problem, single resolution CUBE surfaces were generated to be “cookie cut” and then reassembled to create the final CUBE surface from which depths are derived. Multiple CUBE surfaces are gridded using different resolutions for different depth ranges (see table #5).

Under ideal circumstances gridding should be done at the finest resolution that the data density will support. This theoretical maximum resolution was historically defined as three times the beam footprint size for a particular echosounder and depth combination. Current guidance (HSSD 5.2.2.2) states that 95% of the nodes in a cube surface shall contain at least 5 soundings per node. This minimum density of 5 soundings per node has experimentally been shown to be adequate to represent the depth of the seafloor while not being strongly influenced by a single erroneous sounding. The percentage of nodes meeting this specification is calculated using a Python script written by ST Weston Renoud of the NOAA Ship *Fairweather* and documented in the appropriate descriptive report.

To meet this sounding density, *Rainier* adheres the table of resolutions and depth ranges as defined in HSSD which are based on practical experience in “typical” survey areas, and a working knowledge of bottom coverage capabilities of each echo sounding system currently in use throughout the fleet. These resolutions are also based on assumed sonar system selections for each depth regime and practical data processing limitations. Deeper areas are gridded at a coarser resolution than shoaler areas where the data density is greater.

With the advent of the CARIS CSAR framework and multi-threaded CUBE processing implemented in CARIS HIPS and SIPS 7.0, it is now practical to create a single field sheet that covers an entire survey. This ability fixes the shortcoming in previous versions of CARIS which limited CUBE surfaces to a maximum of approximately 25 million nodes. All resolution-specific CUBE surfaces are now created in this single sheet wide field sheet. The field sheet layout and CUBE surface resolutions are described for each survey in the Descriptive Report.

Each resolution-specific CUBE surface is named according to the following convention:

H<registry #>_<resolution in meters>m

(EX: “H12345_2m” refers to the two-meter resolution surface of survey H12345)

Once the collection of CUBE surfaces accurately represent the surveyed bottom and it is certain that no further edits will be made, each CUBE surface is finalized using the resolution shown in table #5. All finalized CUBE surfaces are then combined at the coarsest resolution created for the data set to produce the final combined CUBE surface. The final combined CUBE surface is named by the following convention; Hxxxxx_Final_Combined.

The final CUBE surfaces are sun-illuminated from different angles and examined for coverage and as a final check for systematic errors such as tide, sound velocity, or attitude and/or timing errors. The final CUBE surface submitted in the field sheet serves to demonstrate that both SWMB coverage requirements are met and that systematic errors have been examined for quality-assurance purposes.

As a quality control (QC) measure, cross-lines with a linear nautical total of at least 4% of mainscheme multibeam lines were run on each survey and manually compared to the mainscheme lines in CARIS subset mode. This qualitative QC comparison is discussed in the Descriptive Report for each survey.

Feature Data

Source shoreline data is typically supplied by N/CS31 in a single Composite Source file (CSF) in both S-57 .000 and .hob formats. Additionally, a Project Reference file (PRF) is supplied containing sheet limits, AWOIS items, and recommended bottom sample sites. The project-wide CSF file was trimmed to each sheet's individual survey limits and saved as both HOB and S-57 .000 files by the survey managers. The .000 format is used for the real time acquisition display in Hypack on the survey launches. The HOB file was used in CARIS Notebook and printed to create paper boat sheets for reference and note-taking during shoreline verification operations. This process is described in detail in the “CARIS Notebook” section below.

Shoreline verification was conducted during daylight periods near MLLW. A line was run along the shore approximating the position of the Navigational Area Limit Line (NALL). Thick near-shore kelp often dictated the position of the NALL. In the absence of direction to the contrary, the NALL was the furthest offshore of the following:

- The 4m depth contour at MLLW.
- A line seaward of the MHW line by the ground distance equivalent to 0.8mm at the scale of the largest scale raster chart of the area.

This definition of the NALL is subject to modification by the Project Instructions, Chief of Party (Commanding Officer), or (in rare instances) Hydrographer-In-Charge of the survey launch.

Some likely additional reasons for modifying the position of the NALL included:

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

As the approximate NALL line was run along the shore, the hydrographer both annotated the shoreline reference document and scanned the area for features to be addressed. All features with CARIS Notebook custom attribute “asgmt” populated with 'Assigned' offshore of the NALL were fully investigated. 'Assigned' features inshore of the NALL were verified or DP'd for height if exposed but launches did not navigate inshore of the NALL to either disprove or investigate potential submerged 'Assigned' features. Features are addressed in the following manner:

- Seaward of the NALL:
 - A feature found within 20 meters of the composite source position had its height/depth determined.
 - A feature outside 20 meters of the composite source position had its field position revised in addition to a height/depth determination.
 - Features with any linear dimension greater than 0.5mm by 0.65mm at the scale of the largest scale chart were treated as an area and delineated.
 - New features not in the Composite Source file.
 - AWOIS items and other features specifically identified for investigation.
- Inshore of the NALL:
 - Navigationally significant features only, as defined below.

Navigationally Significant features were defined as the following:

- All features within the limits of safe navigation (i.e., offshore of the NALL).
- Features inshore of the NALL which:
 - are sufficiently prominent to provide a visual aid to navigation (landmarks). Note that rocks awash are almost never landmarks, but distinctive islets or other features visible at MHW can be useful for visual navigation.
 - significantly (a ground unit distance equivalent to 0.8mm at the scale of the largest scale chart of the area) deflect this limit. Common examples of these features include foul areas and large reef/ledge structures.
 - are man-made permanent features connected to the natural shoreline (such as piers and other mooring facilities) larger than the resolution specified for the survey. Seasonal features will be evaluated by the Command.
 - are man-made permanent features disconnected from the shoreline, such as stakes, pilings, and platforms, regardless of size.

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

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

“Noted”

- The existence of a feature and its characteristics were confirmed from a distance, and its position appeared to be correct within the scale of the chart or source.
- Appropriate for features inshore of the limit of hydrography and not navigationally significant, significant features that require no further investigation, or features unsafe to approach to verify position within survey scale.

- Noted features were annotated on the shoreline reference document but carried no further forward in the processing pipeline. A "noted" annotation on a feature is not included in the H-Cell and adds little to PHB's current evaluation and verification process.

“Verified ”

- The feature's position and characteristics were acquired and recorded either by directly occupying the site, or by applying a range and bearing offset to a known position. Positioning was generally by DGPS methods.
- Appropriate for navigationally significant features inshore of the limits of hydrography. Also appropriate for existing features that do not require a height (VALSOU or HEIGHT attribute).

“DP for Height”

- The feature's source position is correct, but height (VALSOU or HEIGHT attribute) was either unknown or incorrect. **This position does not supersede that of the source data, so it is only necessary to approach the feature as closely as required to accurately estimate the height.**
- Appropriate for source features found within 20m of their source positions, but with incorrect or missing height or depth data.

“New”

- The feature's position and attributes (including height) were acquired and recorded either by directly occupying the site, or by applying a range and bearing offset to a known position. Positioning was generally by DGPS methods.
- Appropriate for items seaward of the NALL that are not present in the Composite Source.
- Items inshore of the NALL which are navigationally significant and are not present in source data.

“Not Seen”

- The feature was present in source data (chart, DCFF, etc.) but was not visually observed in the field. Full disproval search (see below) was **not** conducted.
- Appropriate for:
 - Features above MHW, the absence of which can be proven visually from a distance.
 - Source features inshore of the limit of hydrography which are not observed, but whose presence on or absence from the survey will not affect safe navigation.
 - Any feature from source which was not seen, but for which full disproval search (see below) is impractical or unsafe.

“Disproved”

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

The primary purpose of detached positions (DPs) is to verify and define shoreline features (ex: rocks, reefs ledges, piles), disprove charted features, position navigational aids and landmarks (ex: buoys, beacons, lights), and mark positions of bottom samples. Point features were captured in the field as attributed S-57 objects in CARIS Notebook. Any line objects, such as small piers or foul areas were digitized directly into CARIS Notebook while in the field. Concurrent with the acquisition of these features, digital photographs were taken of most objects which were exposed above the waterline.

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

In addition to the traditional shoreline techniques, RA3 (2803) may also be used to delineate the NALL with her ~34-degree tilted Reson 8125. During periods of high tide, 2803 acquired data while running parallel to shore. While running along the 30-foot curve was found to nicely fill in between the 4 and 8 meter curves with complete coverage, it also produced coverage far inside the NALL line (typically the 4-meter curve). Areas of kelp often prevented 2803 from reaching the 30-foot curve. Any additional soundings collected inshore of the NALL line were processed as follows:

- “Good” seafloor is not rejected anywhere. Any bad soundings are cleaned out to make the surface represent the seafloor, but there is no cut-off of soundings shoaler than the 4-meter or 0-meter curves. Negative soundings are fine so long as they accurately represent the bottom.
- No launch is to go inside the NALL line trying for the 0-meter curve, or developing items that are found outside the survey limits (i.e. NALL line)
- For cultural features (pilings, piers, buoy's and buoy chains, etc.) that are above MLLW (i.e. negative sounding) AND on the CSF HOB layer, all soundings on the cultural item are deleted. This technique will prevent the BASE surface from being pulled up on features already charted above MLLW in the HOB file.
- For cultural features that are below MLLW, the shoalest sounding is designated (which the BASE surface will honor) AND the feature is included on the field verified HOB file.
- For cultural features that are above MLLW and are not on the field verified HOB file, the least depth is flagged as "outstanding," but not include it in the BASE surface and all other data on the object is rejected. In this case the "outstanding" sounding is used as a basis for creating a new feature in the field verified HOB, but it will not affect the BASE surface. This is accomplished by using the option in BASE surface creation to not include outstanding soundings. Alternatively in the case of area-type cultural features, all depths may be temporarily retained ant the resultant DTM used to digitize the feature. Once digitization is complete, all soundings on the cultural item are deleted.
- Rocks and reefs are treated as "seafloor." No data is rejected on rocks, reefs or ledges, even above MLLW. The primary method of getting heights on rocks will remain "leveling" (aka eyeballing) during traditional shoreline, but if a least depth of a rock is obtained with SWMB, it will be designated and the height/depth will be used as the VALSOU in the CSF HOB. As previously stated, launches will not go inshore of the NALL line trying to get these data, but it will not be discarded if they are obtained. In cases where the echosounder data does not get the least depth, the soundings obtained will be left in the surface and a DP (or previously acquired comp source data) will be used for the feature.

Following acquisition, digital photos were renamed with an unique ID and moved into a single folder. Any required application of tide and SV corrections are performed in CARIS Notebook.

S-57 Attribution

With the advent of custom CARIS support files supplied by HSTP, Caris Notebook, Bathy DataBase,

and Plot Composer now supports feature flags previously available only in Pydro. All feature flagging can now be accomplished in CARIS Notebook while Pydro is relegated to generating reports.

Features are selected for investigation by HSD OPS based on distance from MHW. Project instructions require that “All features with attribute *asnmt* populated with 'Assigned' shall be verified even if they are inshore of NALL.” Contrary to the project instructions, OPR-N161-RA-11 had the attribute *NINFOM* populated with 'Assigned' instead of *asnmt*.

In the event that an investigation inshore of NALL is called for, due to safety and potential equipment damage concerns, no *Rainier* launches ventured inshore of the NALL. If the feature in question was exposed, time and height attributes were assigned while driving past. If the feature was not evident while driving the NALL during shoreline verification, a remark of “inshore of NALL not investigated” was made with a recommendation of retain as charted.

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

Submerged features, such as wrecks and submerged piles designated in CARIS may also be brought into Notebook for attribution.

All features marked as “primary” were edited to have their object/attribute instances describe each feature as completely as possible. Object attributes assigned to each feature conform to direction located within both the Field & Processing Branch Features Encoding Guide v1.3 and the CARIS “IHO S-57/ENC Object and Attribute Catalogue”. S-57 attribution is not required for those features flagged as "secondary" nor for unassigned features.

NOAA specific attribution in Notebook includes “*descrp*” with a drop-down menu which is edited to reflect the hydrographer recommendations as follows:

- ***descrp* - new** -- A new feature was identified during survey operations. The hydrographer recommends adding the feature to the chart.
- ***descrp* - update** -- The feature was found to be portrayed incorrectly on the chart. Update is also used in the case where the feature was found to be attributed incorrectly or insufficiently and is modified to reflect the additional or corrected attribution.
- ***descrp* - delete** -- The feature was disproved using approved search methods and guidelines. The hydrographer recommends removing it from the chart.
- ***descrp* - retain** -- The feature was found during survey operations to be positioned correctly or was not investigated. The hydrographer recommends retaining the feature as charted.

CARIS Notebook

The composite source shoreline feature file created at HSD and delivered with the project instructions is to be used as the only shoreline data for use in the field. The composite source file is compiled from all available source shoreline files (i.e. ENC, Geographic Cells, lidar, RNC, and Prior Surveys) into a single file in an S-57 .000 format.

In preparation for shoreline verification, the Survey Manager copied the project wide composite source file and cropped it to include only items contained on their assigned sheet. This cropped file is then saved as a HOB file named **HXXXXXX_Composite_Source.hob**. At this point, no further edits are ever made to this HOB file and it is retained as the “starting point” to any subsequent changes discovered during shoreline verification. A copy of the original source HOB file is created and called **HXXXXXX_**

Final_Features_File.hob. It is to this final features HOB file that any edits are performed.

The Survey Manager next creates a composite shoreline reference document, the paper representation of the shoreline that will be used to write observations in the field. The **HXXXXX_Composite_Source.hob** file may be color coding to highlight any assigned features by using the NINFOM=Assigned field. The resultant color coded shoreline is then sent directly to the plotter from Notebook. The **HXXXXX_Composite_Source.hob** is also saved in an S-57 .000 format which can be directly opened in Hypack for field reference and verification where necessary.

In the field, CARIS Notebook was used to acquire DPs and/or modify S-57 attribution of existing features. Edits and DPs were collected on the most current version of the **HXXXXX_Final_Features_File.hob** file. An archival copy of the final features file is saved for each day of feature verification. Daily copies are produced in order to aid feature tracking and the eventual compilation of all features in the submission **HXXXXX_Final_Features_File.hob**.

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

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

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

For surveys where limited shoreline verification was performed, DP/GPs and/or CARIS VBES/SWMB CUBE surfaces were used to help define kelp and foul areas. Any new line features were digitized in the **HXXXXX_Final_Features_File.hob** file. Deleted sections of line features and/or any items fully deleted are flagged “delete”. When objects were added or modified the SORDAT and SORIND fields were updated. Disproved features always maintain their original SORDAT and SORIND.

Investigation methods and results are described in CARIS Notebook under the S-57 attributes acronym “remrks”. In the event that charting confusion could result from just the “remrks” field, specific recommendations are described under the S-57 attributes acronym “recomd”. Any composite source features or shoreline not addressed during shoreline verification are left untouched.

All shoreline data is submitted in CARIS Notebook HOB file **HXXXXX_Final_Features_File.hob**. The SORDAT and SORIND fields were filled in for any objects added to or modified in the Final Features HOB file.

Pydro Feature Extraction & Reports

Although feature attribution acquired in the field is typically entered directly into CARIS Notebook bypassing attribution in Pydro completely, Pydro is still used to generate reports on features. Typically after all edits have been completed in CARIS Notebook, the entire hob file is exported by **File → Export**

→ to S57... The resulting file is then loaded into Pydro **Data → (Re)insert → to S57 Feature Data (ENC_GPs)**. A report is then generated **Reports → For Descriptive Report → DR via HSSD Extended S-57 Attributes**.

Soundings designated as DTONs are imported into Pydro from CARIS in order to generate the DTON report. AWOIS items are also tracked and resolved in Notebook in addition to generating the shoreline report which includes these items. Submerged features, such as rocks, wrecks and submerged piles designated in CARIS may also be brought into Pydro for attribution and eventual export to Notebook.

In addition to the Feature Report, Pydro was used to generate, Danger to Navigation Reports, and Requests for Approved Water Levels included with each survey.

Raw GPS and BASE station OPUS data

POSPac 000 and BASE station data processing conforms to the Ellipsoidally Referenced Surveys Standard Operating Procedure document in the FPM appendices. By post processing the POSPac 000, GNSS and base station data, POSPac creates SBET files which are used by CARIS along with the corresponding POSPac 000 file to improve the data collected. Applying SBETs (smoothed best estimate trajectory) in CARIS HIPS increase the accuracies of attitude and navigation related data. Currently it is the responsibility of the HorCon project manager and the sheet manager to work together applying SBETs to the survey after post acquisition tasks are complete.

Initial processing requires:

- **Processing RAW GPS BASE station data** – Raw GPS data is downloaded daily from shore stations as (.T01/.T02) files. These files are converted into RINEX format using Trimble utility program “Convert to RINEX – TBC utility” v2.1.1.0. Three files are produced, files .YYg, .YYn, and .YYo.
- **Obtaining Base Station OPUS Solution** -- After creating RINEX files from the base station receiver raw file, the .YYo file is then submitted to OPUS in order to get a precise position solution. If bandwidth is an issue, as it usually is aboard the ship, the RINEX file may need to be decimated and zipped to get the file size smaller and achieve a reasonable upload time. A 3 mb file usually takes about 3-5 minutes to upload on the ship’s Vsat.
- **OPUS reference frame and format** -- Once the RINEX file size is reasonable (under 7mb), go to the OPUS website at: <http://www.ngs.noaa.gov/OPUS>. At the OPUS site the user is given the option to choose the new IGS08 reference from or the old ITRF00 reference frame. Until further testing and verification is done, *Rainier* continues to use the old ITRF00 reference frame. For Solution Formats, the extended solution + XML (DRAFT) is selected.
- **Single Base Station Processing** –
 - 1) Open Applanix POSPac™ Mobile Mapping Suite and set up the project
 - 2) Load the “true heave” POSPac 000 file (recorded on the launch)
 - 3) Bringing in the base station OPUS solution (the .YYo file that corresponds to the day number being processed).
 - 4) Once the coordinate manager window opens, the true ITRF coordinates from the OPUS report is input.

5) Both the SBET (in ITRF format) and smrmsg error data files are created.

- **Batch Processing** -- Batch processing allows processing of multiple POS/MV .000 files from multiple vessels on a once per day per survey sheet basis.
- **PosPac SBET Quality Control** -- Once the POSPac project has completed processing successfully, quality control of the SBETs (Smoothed Best Estimated Trajectories) is performed.
- **Exporting Custom SBET** -- Once the QC is complete and the processing log updated, the next step is to export a custom SBET in NAD83. A custom SBET in NAD 83 is created since the DGPS beacons broadcast in NAD83 and the default SBET created by POSPac is in ITRF.

SBETs are applied in CARIS by loading both the SBET files and error data files in smrmsg format. Every SBET file generated during single base station processing there is an associated smrmsg file.

- 1) **Process → Load Attitude/Navigation data...** Load the custom SBET files (NAD83). Import data for Navigation, Gyro, Pitch, Roll, and GPS Height are all selected for loading.
- 2) **Process → Load Error data...** Loads the smrmsg error data file. Import data for Position RMS, Roll RMS, Pitch RMS, and Gyro RMS are all selected for loading. Vertical RMS is not selected since HIPS will default to using the trueheave RMS values.

At this point the HIPS data must be remerged and the TPE recomputed. When computing TPE, “Error Data” should be checked in the “Uncertainly Source” window to ensures that *.smrmsg error data are used for the TPU computation.

For the 2011 field season, all surveys had their elevations referenced to the MLLW. No surveys are submitted with elevations referenced to the ellipsoid.

C. CORRECTIONS TO ECHO SOUNDINGS

Sound Velocity

Sound velocity profiles for *Rainier* survey launches were acquired with SeaBird Electronics SeaCat SBE19 and SBE 19Plus Conductivity, Temperature, and Depth (CTD) profilers (S/N 219, 281, 4039, 4114, 4343, and 4443) or with the Brooke Ocean Moving Vessel Profiler MVP-30 (S/N 007510 and 007511, main and spare). For ship acquisition, sound velocity profiles the Brooke Ocean Moving Vessel Profiler MVP-200 (S/N 007761)

Raw conductivity, temperature, and pressure data were processed using the program Velocipy which generated sound velocity profiles for CARIS in the .SVP format. Calibration reports and dates of the SeaCat profilers and MVPs are included in the *2011 NOAA Ship Rainier Hydrographic Readiness Review Package*. SeaCat profilers were last calibrated in the winter of 2009 and, due to budget constraints, were not recalibrated in 2011. Seabird states the calibrations are good until the instruments are placed in the water, and with permission from Hydrographic Surveys Division Operations branch, a sound speed profile comparison was conducted between a calibrated Fairweather SeaCat (SN 6122) and all of *Rainier*'s SeaCat instruments. It was determined that sound speed profiles acquired by all *Rainier* SBE19 and SBE19Plus instruments were consistent with *Fairweather*'s SBE 19Plus sound speed profiles.

For survey launches, the speed of sound through the water was determined by a minimum of one cast for every four hours of SWMB acquisition as strongly recommended in the NOS Hydrographic Surveys Specifications and Deliverables manual. Casts were conducted more frequently when changing survey areas, or when it was felt that conditions, such as a change in weather, tide, or current, would warrant additional sound velocity profiles. Additionally, drastic changes in the surface sound velocity indicative of the need for a new cast were determined by observation of the real-time display of the Reson SVP 71 mounted on all *Rainier* SWMB launches.

The Reson 7125 SWMB systems utilized on vessels 2801, 2802, 2803 and 2804 require a sound velocity probe to be interfaced with the sonar processor for use in projector steering computations. A Reson SVP 71 surface sound velocity probe is utilized to feed real time SV values directly into the 7-P Sonar Processing Unit.

The Reson 8125 SWMB system utilized on vessel 2803 also requires a sound velocity probe to be interfaced with the sonar processor for use in projector steering computations. A Reson SVP 71 surface sound velocity probe already in place for use by the Reson 7125 SWMB system on 2803 was also used to feed real time SV values for the Reson 8125 SWMB system via the 81-P Sonar Processor unit.

The Kongsberg EM 710 multibeam systems utilized on aboard *Rainier* requires a sound velocity probe to be interfaced with the sonar acquisition unit for use in projector steering computations. A Reson SVP 70 surface sound velocity probe is utilized to feed real time SV values directly into the acquisition computer for use in beam steering calculations. *Rainier's* MVP is also interfaced to send cast information directly to the SIS acquisition computer. Casts are collected every 15 to 30 minutes dependent on local conditions. SIS also monitors changes in the surface sound speed vs. the value obtained with the last cast in real-time. The user is then warned for the need of a new cast by highlighting both the "SV Profile" and "SV Used" numerical displays in yellow with a difference greater than 3 m/s and red for a difference greater than 5 m/s.

MVP casts sent directly to the Kongsberg EM 710 are processed in SIS and are applied to all subsequent SWMB data. This method has the drawback that the MVP cast taken prior to the collection SWMB data will always be applied rather than the SV cast that is closest. This shortcoming is circumvented by post applying SV data to all EM 710 data in CARIS HIPS/SIPS.

All sound velocity profiles for CARIS, both CTD and MVP, are concatenated into a sheet-wide file in order of ascending time/date and saved in the root directory of each sheet's SVP directory. This concatenated file is then applied to all HDCS data acquired, including that of the EM710, with the option **Nearest in distance within time (4 Hours)** selected under the **Profile Selection Method**.

Vessel Offsets and Dynamic Draft Correctors

The table below shows when the vessel offsets and dynamic draft correctors used for this project were last determined. A full description of the methods and results employed for each vessel is included in the *2011 NOAA Ship Rainier Hydrographic Readiness Review Package*.

Vessel Hull Number	Date of Static Draft and Transducer Offset Measurements	Method of Settlement and Squat Measurement	Date of Settlement and Squat Measurement	Location of Settlement and Squat Measurement
S221	October 2010	Ellipsoidal Reference	June 7, 2011	Lake Washington, WA
2801	May 2011	Ellipsoidal Reference	April 25, 2011	Lake Washington, WA
2802	May 2011	Ellipsoidal Reference	April 25, 2011	Lake Washington, WA

2803	May 2011	Ellipsoidal Reference	April 27, 2011	Lake Washington, WA
2803 Reson 8125	September 2011	Ellipsoidal Reference	April 27, 2011	Lake Washington, WA
2804	May 2011	Ellipsoidal Reference	May 11, 2011	Lake Washington, WA

Table 8: Dates of measurements (transducer offsets and settlement – squat)

Settlement and squat observations were conducted for *Rainier* (S221) and launches 2801, 2802, 2803 and 2804 using the ellipsoidal referenced method. *Rainier* followed the procedure as outlined in section 1.4.2.1.2.1 of the FPM. Data were analyzed using the Pydro macro ProcSBETDynamicDraft.py as detailed in the NOAA Ellipsoidally Referenced Survey (ERS) SOP in the chapter 4 of the FPM appendices to produce delta draft vs. speed curves.

For the ellipsoidally referenced dynamic draft measurement method as utilized by *Rainier*, the launch was run with a constant line heading while speed was increased in two-knot increments from clutch ahead to fourteen knots in two-minute intervals. A five minute rest period was placed between the runs. POSPac data was recorded as soon as the system was brought up and throughout the entire duration of the dynamic draft measurement. The same procedure was utilized for the *Rainier* herself.

Following acquisition, the POSPac data recorded by the POS/MV was imported into the POSPac MMS software suite and processed using Single Base processing. Data from the national Geodetic Survey CORS station SEAI, operated at Sand Point, was selected as the Base Station. The resulting SBET was exported as an ASCII file, which was processed using the python processing script developed by ENS Glen Rice. Dynamic draft curves and delta draft value tables were then generated and entered into the CARIS dynamic draft table.

During the 2007-2008 winter repair period, National Geodetic Survey's Geodetic Services Division personnel conduct spatial relationship surveys on two *Rainier* launches (2801 and 2802). These measurements, in addition to dimensional blueprints and technical schematics from sonar manuals were used to determine each vessels' offsets. Following *Rainier's* MRP in 2010 - 2011 spot checks of these vessel offsets and static drafts were measured using steel tapes and a LEICA laser distance meter but no significant differences were observed. These results were not unexpected since no significant changes were made to vessels 2801 or 2802 during the winter repair period.

Rainier acquired two more new launches (2803 and 2804) for the 2009 field season and arrangements were made for personnel from the National Geodetic Survey's Geodetic Services Division to return and conduct spatial relationship surveys. Vessels 2803 and 2804 were pulled out of the water and put up on blocks in order to determine the spatial relationship of various sensors, the multibeam transducers, and reference points in relation to the POS/MV IMU. Unfortunately at the time this survey was conducted, the transducer arrays of the SWMB systems were not yet installed on these two launches due to the need for some additional grinding and welding on the hulls. Two reference points (FORE and AFT) were positioned adjacent to the sonar rack assembly well in anticipation of the sonar installation at a later date. *Rainier* personnel used these reference points and steel tapes to position the SWMB transducers once they were installed in their final position. These measurements, in addition to dimensional blueprints and technical schematics from sonar manuals were used to determine each vessels' offsets. Assuming that there has been no major change to configuration, offset measurements are spot checked on an annual basis as part of the system readiness/hydrographic systems readiness review.

During the *Rainier's* 2010-2011 major repair period, in conjunction with the installation of the new Kongsberg EM 710 multibeam system, Westlake Consultants, Inc. was contracted to conduct a measurement and alignment report. The spatial relationship between the ship's granite block, IMU mounting plate, transducer array, POS/MV antennae, and multiple ship reference points were all

determined. Using these ship reference points *Rainier* crew determined two additional reference points atwartship of the IMU, to port and starboard. These two points and a weighted tape were used to determine the waterline of the ship prior to acquiring ship hydro.

For the 2011 field season an aluminum mounting bracket was commissioned to affix a Reson 8125 to RA3 (2803) at a ~34° angle to starboard. This mounting bracket utilized the pre-existing hard mounting points built into the hull for instrument sleds. Offsets to the Reson 8125 for vessel 2803 were measured from the FORE and AFT reference points on the keel using both steel tapes and a LEICA laser distance meter. The mounting angle of the transducer was checked with a Brunton clinometer.

Dynamic draft and vessel offsets corrector values are stored in the HIPS Vessel Files (HVF's). Survey platforms which mount more than one acquisition system or use sonar systems with multiple frequencies have a separate HVF associated with each individual acquisition method available. Each of these HVF's contains sensor offset and dynamic draft correctors that pertain to this single acquisition system. Sensor offset and dynamic draft correctors were applied to bathymetric data in CARIS during post-processing. Vessel offset diagrams and dynamic draft tables are included in the *2011 NOAA Ship Rainier Hydrographic Readiness Review Package*. The HVF's themselves are submitted with the digital HDCS data.

The following table lists the HIPS Vessel File used for each available sonar system:

HVF name	Survey Vessel & System Type
S221_Simrad-EM710.hvf	NOAA Ship Rainier, SWMB using Simrad EM 710
2801_Reson7125_HF_512	Jensen hull 2801, SWMB using Reson 7125, 400kHz, 512 beams
2801_Reson7125_LF_256	Jensen hull 2801, SWMB using Reson 7125, 200kHz, 256 beams
2802_Reson7125_HF_512	Jensen hull 2802, SWMB using Reson 7125, 400kHz, 512 beams
2802_Reson7125_LF_256	Jensen hull 2802, SWMB using Reson 7125, 200kHz, 256 beams
2803_Reson7125_HF_512	Jensen hull 2803, SWMB using Reson 7125, 400kHz, 512 beams
2803_Reson7125_LF_256	Jensen hull 2803, SWMB using Reson 7125, 200kHz, 256 beams
2803_Reson8125	Jensen hull 2803, SWMB using hull mounted Reson 8125
2804_Reson7125_HF_512	Jensen hull 2804, SWMB using Reson 7125, 400kHz, 512 beams
2804_Reson7125_LF_256	Jensen hull 2804, SWMB using Reson 7125, 200kHz, 256 beams

Table 9: List of HVF's used for the 2011 field season.

Heave, Pitch, Roll and Heading, Including Biases and Navigation Timing Errors

Attitude and Heave data were measured with the sensors described in Section A, and applied in post-processing during SVP Correct and Merge in CARIS HIPS.

Rainier's SWMB equipped survey launches utilize a data time synchronization method known as “precise timing” as described in Section 3 of the OCS Field Procedures Manual. This synchronization significantly reduces latency magnitude and variability, producing data which is both horizontally and vertically more accurate.

Rainier's SWMB equipped survey launches utilize a heave filter integration method known as “TrueHeave” as described in Section 3 of the OCS Field Procedures Manual. This dramatically reduces the filter settling time as compared to the traditional heave filter, almost completely eliminating the need for steadying up on lines before logging can begin.

TrueHeave data were logged throughout the survey day, independent of line changes. A new POS file need be created only in the event that the acquisition computer crashes. Every "POS" file is named in such a manner to be easily identifiable with the applicable year, DN and VN (ex: 2011_285_2801.000). TrueHeave files are transferred to the "POSMV" folder of the CARIS preprocessed data drive (ex: H:\OPR-O190-A-11\H12289\POSMV\2801(RA-4)\DN265 contains TrueHeave data acquired by vessel 2801 on day number 265 for sheet H12289) for later submission to the PHB. In the event of computer crashes, multiple POS files have their names appended with "A", "B", and so on so that the order they were collected. After regular CARIS data conversion this TrueHeave file was separately loaded into HIPS, replacing the unfiltered heave values recorded in the raw data.

It is standard procedure to start TrueHeave logging at least 5 minutes before starting bathymetric data acquisition and letting it run for at least 5 minutes afterward. This is required because the filter which produces the true heave values looks at a long series of data before and after the actual acquisition time of bathymetric data to create the baseline for the appropriate true heave calculation. If there is a problem with the TrueHeave data, the utility "fixTrueHeave" was run from the command line with the following context: "**fixTrueHeave <trueheave filename> -trim**". This produces a new file with the same base name, but with the suffix "fixed" appended. This new ".fixed" file is then applied to the appropriate lines in HIPS.

Timing and attitude biases were determined in accordance with Section 1 of the Field Procedures Manual, and are described in the *2011 NOAA Ship Rainier Hydrographic Readiness Review Package*.

All vessel offsets, dynamic draft correctors, and system bias values are contained in CARIS HIPS Vessel Files (HVF's) and were created using the program Vessel Editor in CARIS. These offsets and biases are applied to the sounding data during processing in CARIS.

Water Level Correctors

For daily processing, soundings were reduced to Mean Lower-Low Water (MLLW) using predicted water levels files supplied with the project instructions. The predicted water level data were applied to the survey depths in CARIS using height ratio and time correctors from a preliminary CO-OPS provided zone definition file.

After the conclusion of data acquisition, water levels are applied to the soundings using one of two methods, verified observed water levels using height ratio and time correctors from a CO-OPS supplied zone definition file or TCARI tides. TCARI tides are the preferred method but zoned tides using verified observed water levels may be used if the required TCARI grid is unavailable for the project.

Refer to individual Descriptive Reports for further information regarding water level correctors specific to each survey.

D. APPROVAL

As Chief of Party, I have ensured that standard field surveying and processing procedures were followed during this project. All operations were conducted in accordance with the Office of Coast Survey Field Procedures Manual (May 2011 edition), NOS Hydrographic Surveys Specifications and Deliverables (April 2011 edition), and all Hydrographic Technical Directives issued through the dates of data acquisition. All departures from these standard practices are described in this Data Acquisition and Processing Report and/or the relevant Descriptive Reports.

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

Approved and Forwarded:

Donald W. Haines, CAPT/NOAA
Commanding Officer
NOAA Ship *Rainier*

In addition, the following individual was also responsible for overseeing data acquisition and processing of this project:

Chief Survey Technician:

James B. Jacobson
Chief Survey Technician
NOAA Ship *Rainier*

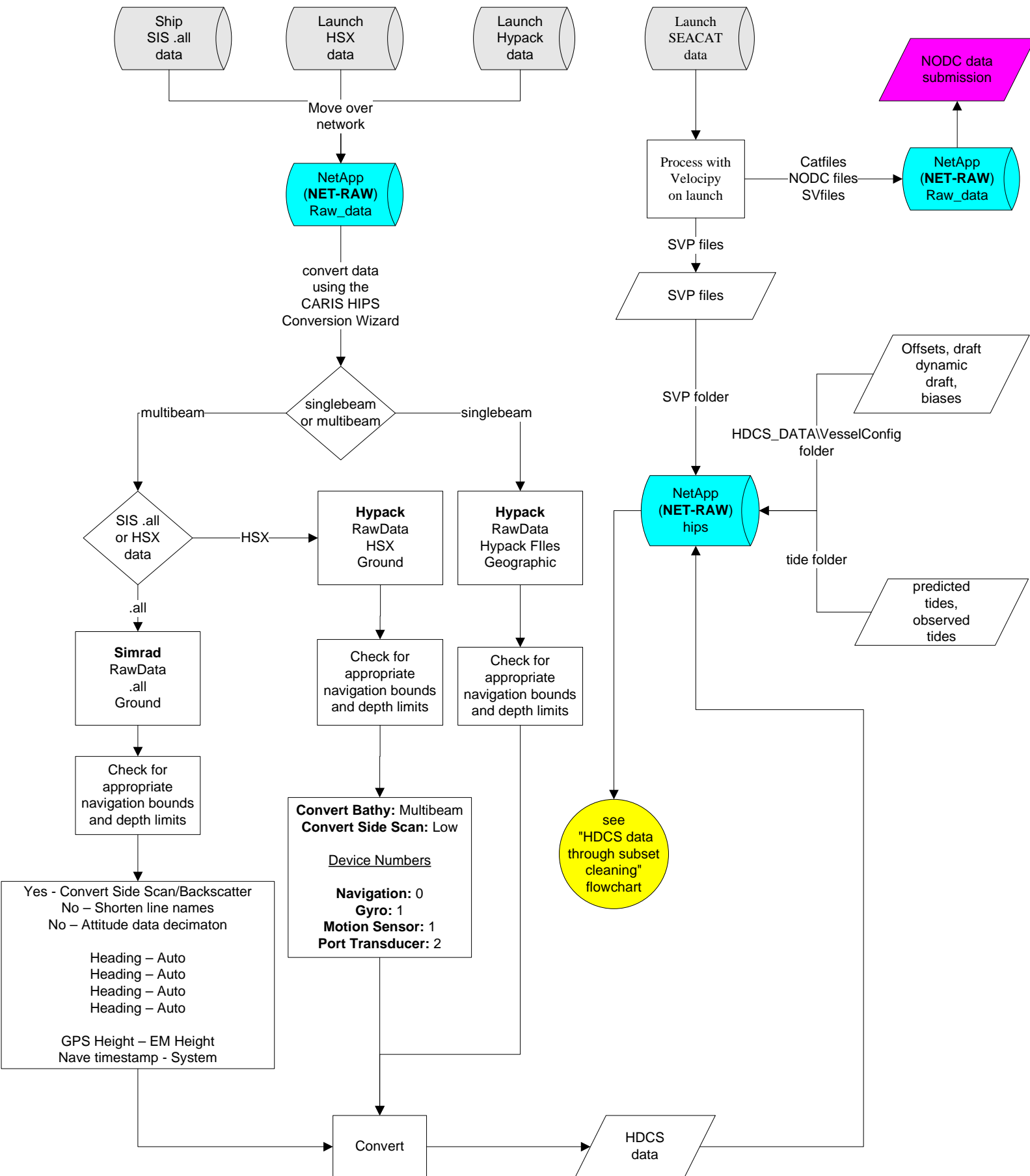
Field Operations Officer:

Olivia A. Hauser, LT/NOAA
Field Operations Officer
NOAA Ship *Rainier*

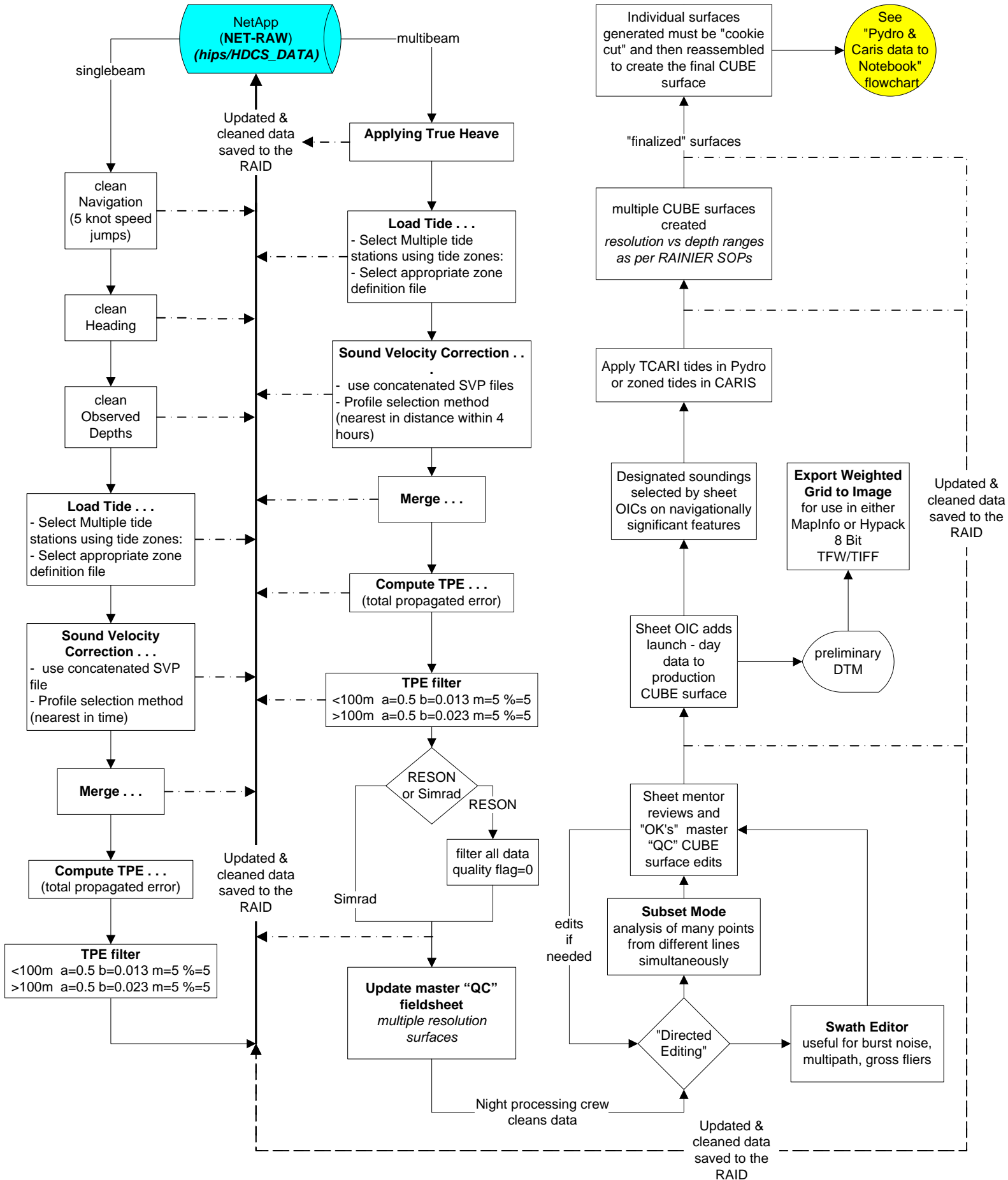
APPENDIX I

Data Processing Flow Diagrams

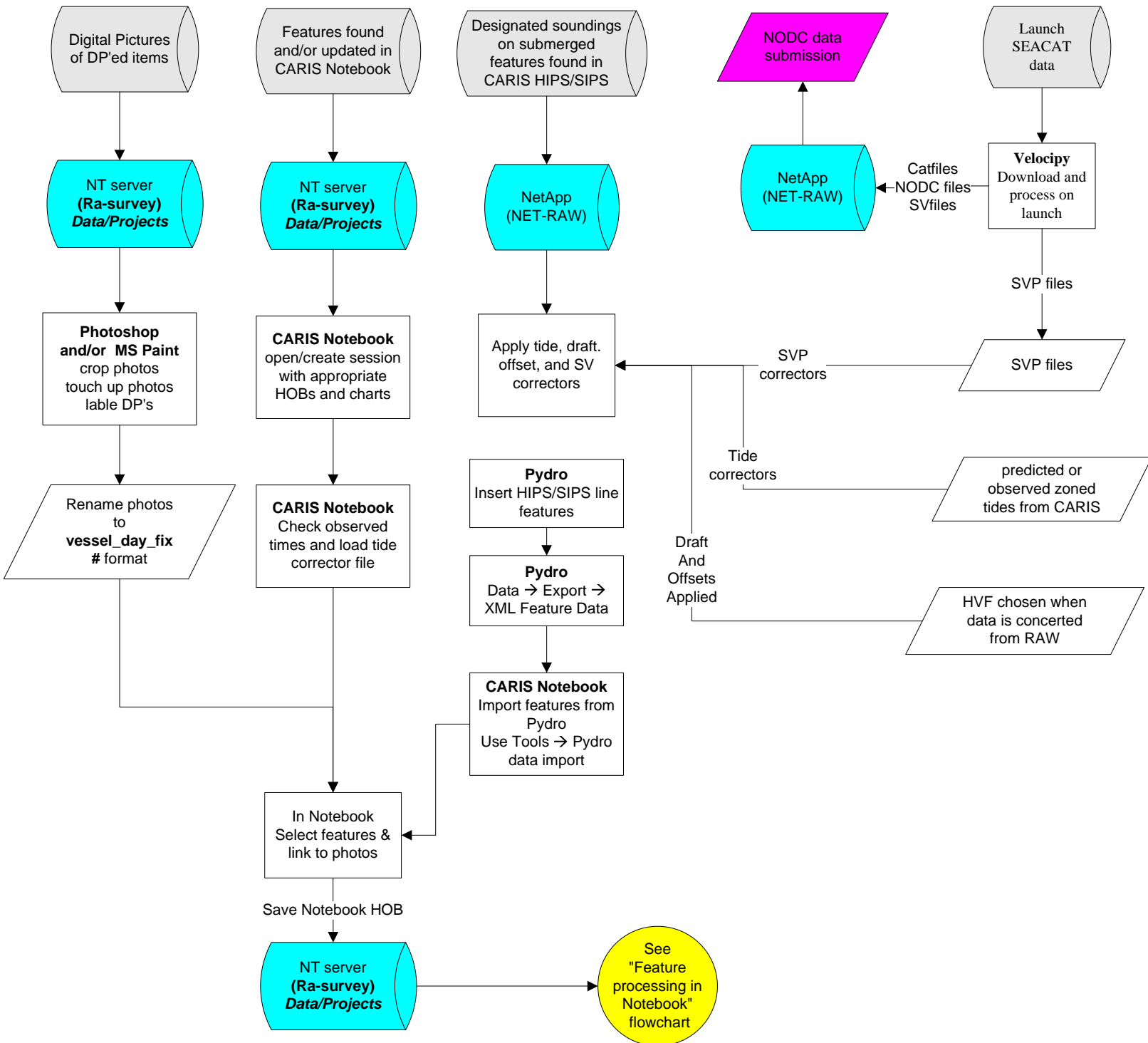
Raw sounding data to HDCS



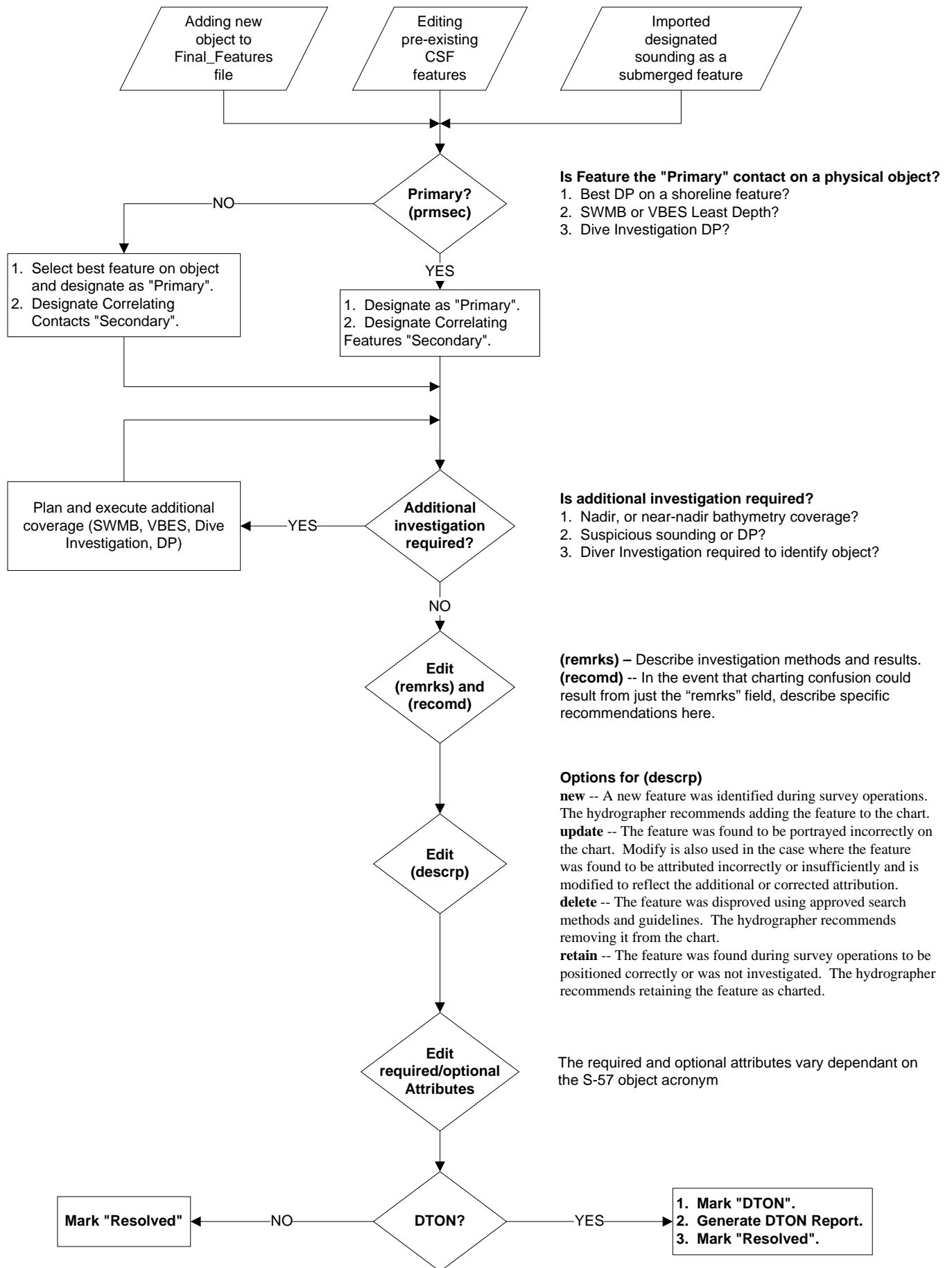
HDCS data through subset cleaning



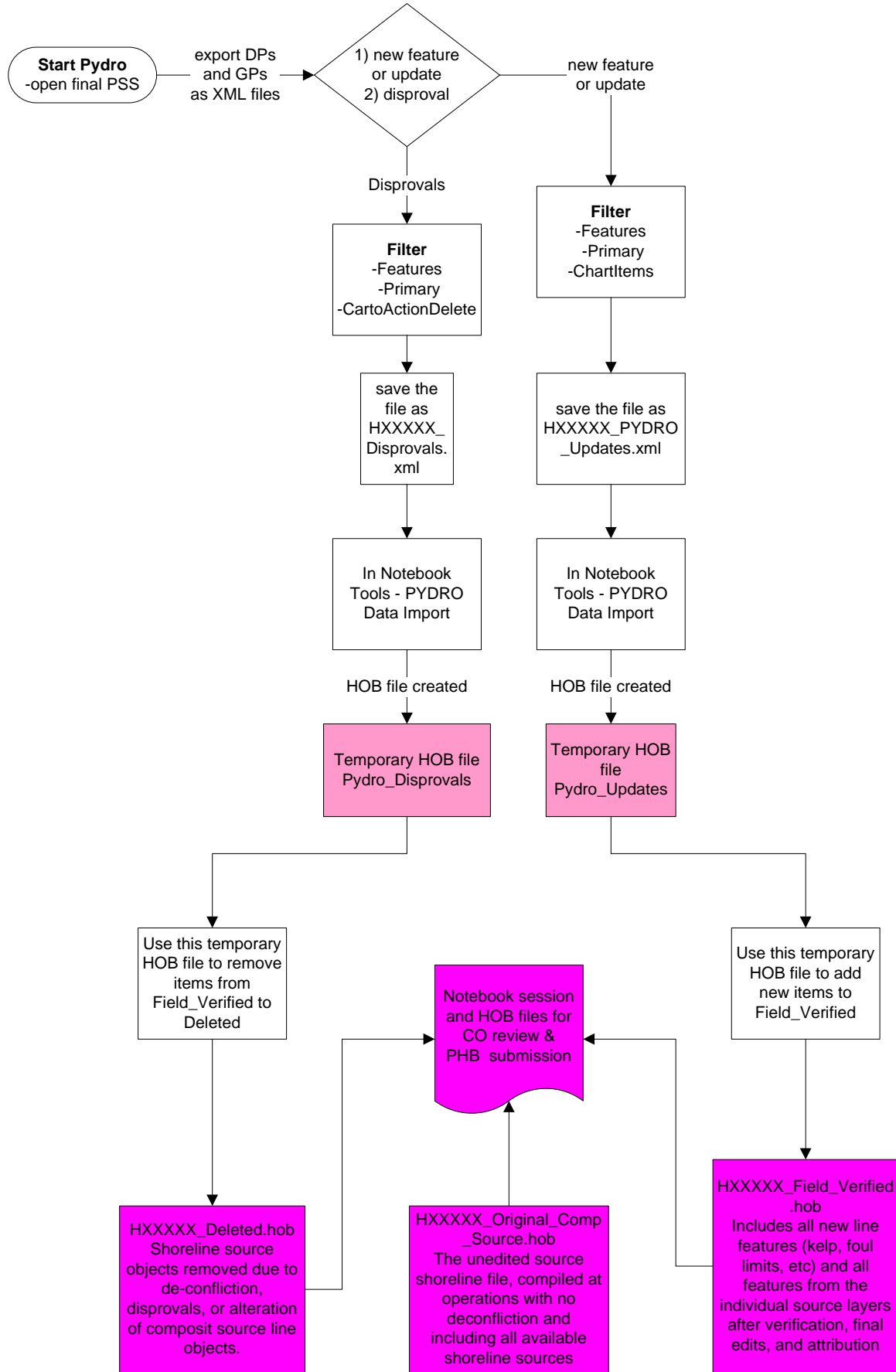
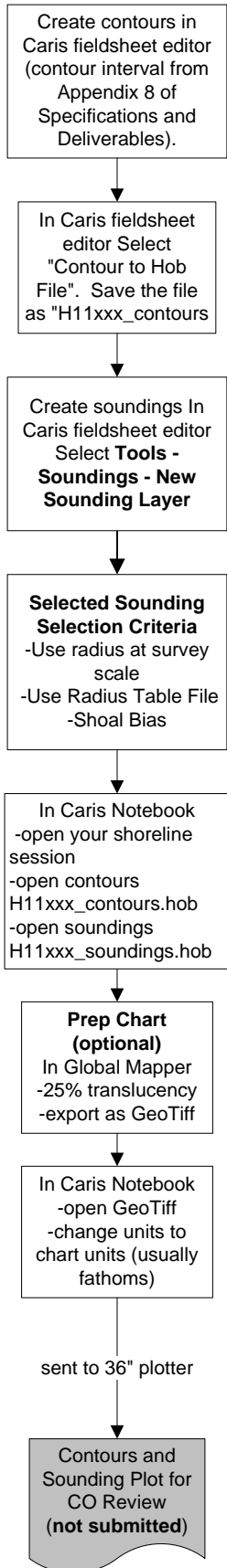
Shoreline processing (Raw DP's to Pydro)



Feature processing in Notebook



Pydro & Caris data to Notebook



APPENDIX I

Data Processing Flow Diagrams