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

HORIZONTAL & VERTICAL CONTROL REPORT

Type of Survey: Navigable Area

Project Number: OPR-A325-KR-24

Time Frame: August 2024 – June 2025

LOCALITY

State(s): Massachusetts

General Locality: Massachusetts Bay, Boston Harbor

2024

CHIEF OF PARTY

John R. Bean

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Date:

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A. TIME BASIS

Coordinated Universal Time (UTC) was used to annotate the tide records and all other data obtained for this project.

B. VERTICAL CONTROL

In nearly all project areas, soundings are referenced to Mean Lower Low Water (MLLW) using Ellipsoidally Referenced Survey (ERS) methods per the Project Instructions and baring features are reported in Mean High Water (MHW). There are two project areas above lock and dam structures (the Charles River and the Mystic and Malden Rivers), which are referenced to Normal Pool Level (NPL).

B.1 ERS Water Level Source Data

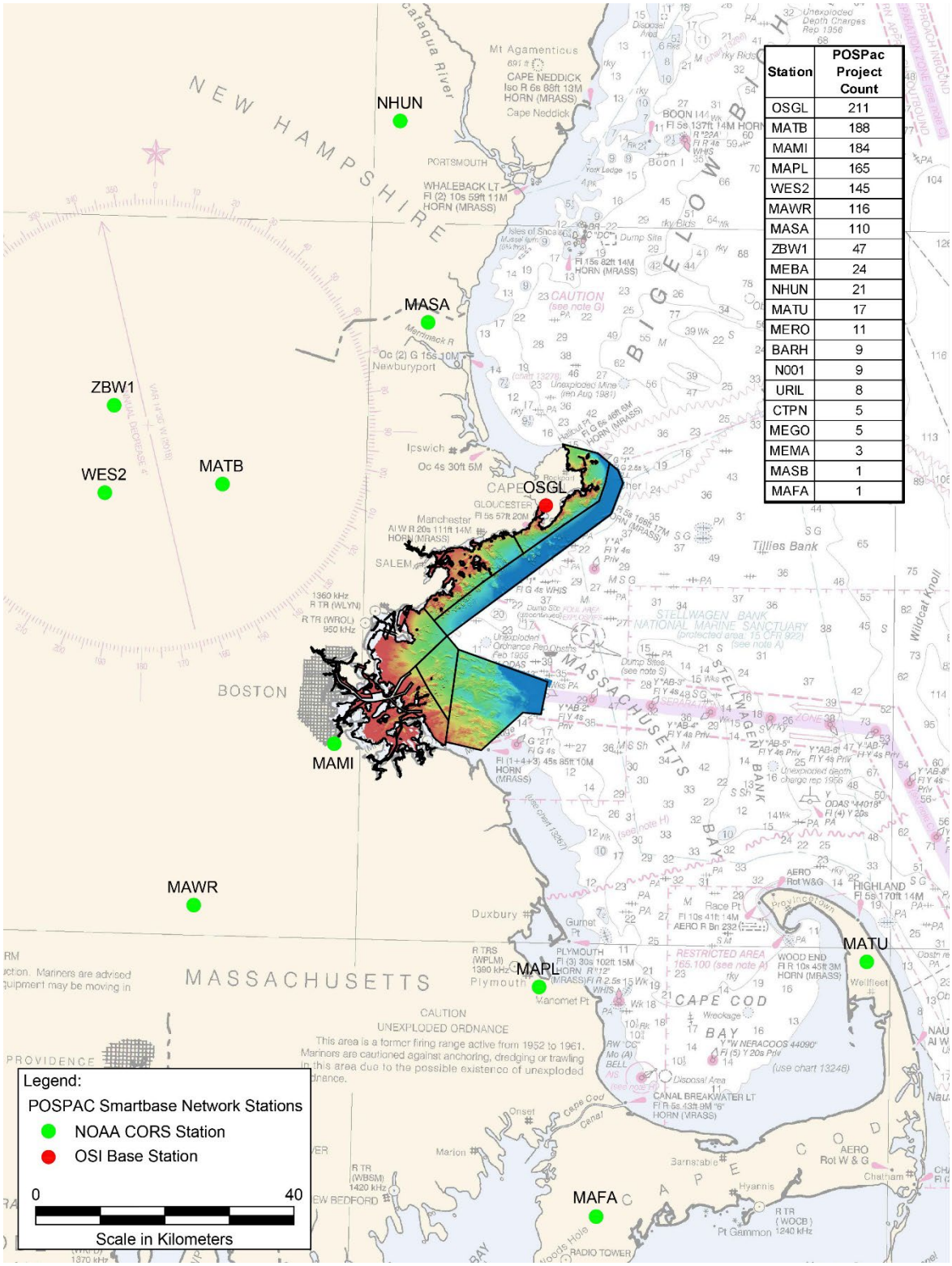
Inertially Aided Post Processed Kinematic (IAPPK) ellipsoid heights were computed using POSPac MMS, Applanix SmartBase (ASB) or single base processing. The ellipsoid heights in the resulting Smoothed Best Estimate Trajectory (SBET) data were used as the basis for the development of ERS Water Level.

Both ASB and single base processing was organized into POSPac projects by vessel and day. Figure 1 illustrates the locations of Continuously Operating Reference Stations (CORS) stations and OSI's installed base station, OSGL, which all contributed to ASB processing. The total number of stations occasionally varied from one POSPac project to the next (i.e. vessel-day) based on CORS data availability and solution quality. The table inset in Figure 1 shows the POSPac IAPPK project count for each station. The final coordinates of OSGL were determined using the NGS' Online Positioning User Service (OPUS).

ERS water levels ("GPS Vertical Adjustments") were derived from SBET altitude. SBET altitude corrected for heave, dynamic draft, and static draft were reviewed graphically in MATLAB and compared to the local NOAA tide gauge water levels. When apparent invalid altitude was present in the daily SBET, additional CORS stations were added to the ASB network. For any remaining daily SBETs with invalid altitude data, NOAA's POSPacAutoQC application was used to interpolate through and replace the invalid data.

B.2 VDatum Separation Models (SEP)

A VDatum Separation Model (SEP) was provided by NOAA with the original project files and described in the Project Instructions (Table 1). A SEP coverage gap was identified in a small area of the Mystic Channel. Following a request to the NOAA Project Manager, this coverage gap was remedied by an updated SEP provided by NOAA.



Station	POSPac Project Count
OSGL	211
MATB	188
MAMI	184
MAPL	165
WES2	145
MAWR	116
MASA	110
ZBW1	47
MEBA	24
NHUN	21
MATU	17
MERO	11
BARH	9
N001	9
URIL	8
CTPN	5
MEGO	5
MEMA	3
MASB	1
MAFA	1

Figure 1. Local NOAA CORS and "OSGL" in relation to the project site with corresponding station POSPac project counts.

Table 1

Ellipsoid Referenced Survey via VDATUM				
This project has a requirement to acquire survey data vertically referenced to the ellipsoid. Separation models for referencing data to MLLW and MHW are included with the project instruction package.				
MHW VDATUM Model				
VDatum Version	Geoid	Area	Area Version	Separation Uncertainty
4.1.2	geoid18	MENHMAgome23_8301		13 cm
MLLW VDATUM Model				
VDatum Version	Geoid	Area	Area Version	Separation Uncertainty
4.1.2	geoid18	MENHMAgome23_8301		13 cm

An additional SEP was developed to reference soundings to NPL in the Charles River above the Charles River Dam and in the Malden and Mystic Rivers above the Amelia Earhart Dam. A preliminary NPL SEP was provided by NOAA citing NPL to MLLW relationships derived from values listed in the Coast Pilot and in a datum note on RNC 13272:

> Above Charles River Dam: NPL-MLLW = 7.2 ft = 2.29 m (NOAA via Coast Pilot)
> Above Amelia Earhart Dam: NPL-MLLW = 6.2 ft = 1.89 m (NOAA via note on RNC 13272)

Subsequent on-site investigation revealed that the value for the NPL to MLLW relationship in the Malden and Mystic Rivers above the Amelia Earhart Dam as reported on recent USACE channel condition surveys is the correct value. This was confirmed with an analysis of ERS water level data and tide board observations at the Amelia Earhart Lock (Table 2 and Figure 2).

> Above Amelia Earhart Dam: NPL-MLLW = 4.9 ft = 1.49 m (USACE tideboard).

Table 2

Mystic and Malden Rivers Normal Pool Level			
Description	meters	feet	Notes
RP Ellipsoid height (NAD83)	-28.170	-92.421	per POSPac for RV South Cove
WL Ellipsoid height (NAD83)	-27.917	-91.591	RV South Cove RP to Waterline = 0.253m (RP is above WL))
MLLW SEP	29.310	96.161	middle of river value
WL MLLW	1.393	4.570	Ellip ht minus MLLW SEP
WL USACE tide board in NPL	1.728	5.670	per USACE, MLLW 4.9ft = 6.0ft on tide board (adjust MLLW by +1.1ft)
Tide board reading	1.753	5.750	11/16/2024 RV South Cove photo
Tide board to South Cove WL	0.024	0.080	
Conclusion: NPL is 4.9ft (1.49m) MLLW			

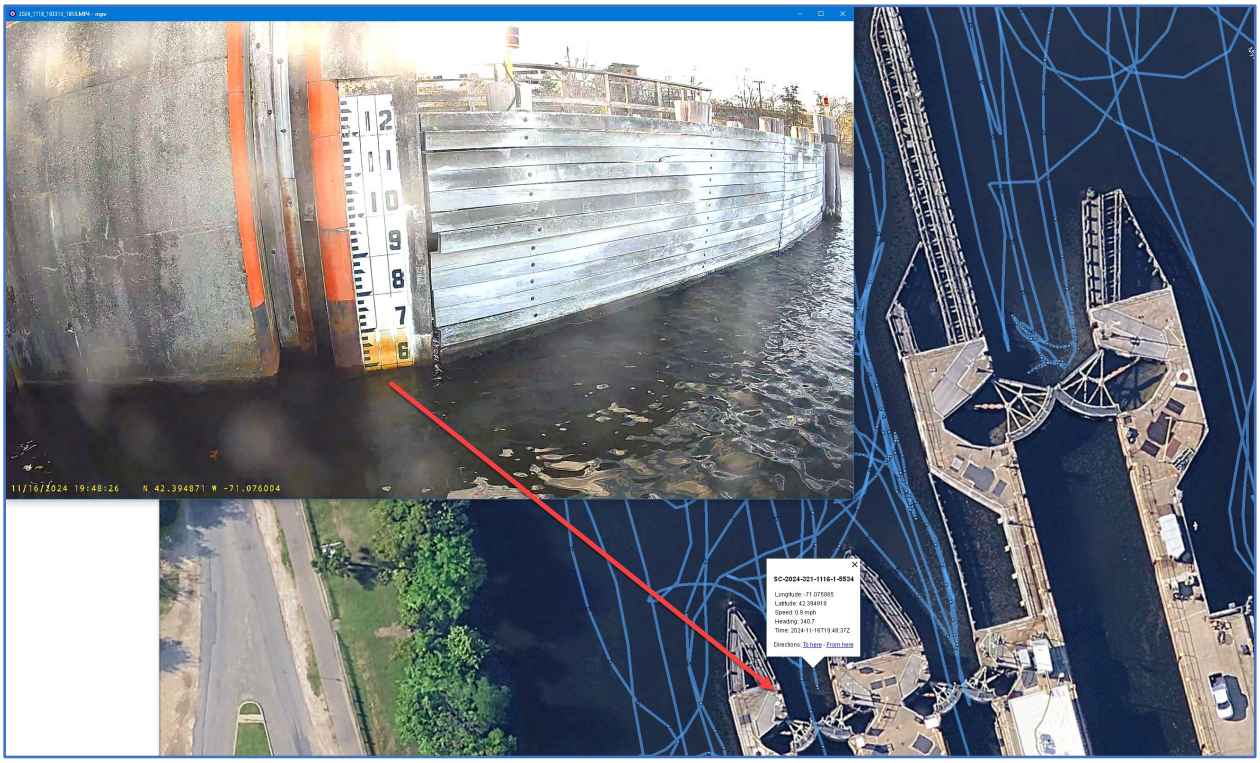


Figure 2. USACE installed tide board observation at Amelia Earhart Lock coincident with RV South Cove ERS water level on 11/16/2024

B.3 ERS SBET Altitude Smoothing

ASB derived ERS SBET altitudes were smoothed prior to inclusion in the data reduction process.

I. ERS SBET Altitude Smoothing Steps:

1) Create and export final SBETs
2) Interpolate invalid altitude spikes with POSPacAutoQC
3) Smooth resultant SBETs using MATLAB
    - Convert SBET altitude to an isolated NAVD88 tide by removing the following components of the SBET altitude:
        - Static draft based on time
        - Dynamic draft based on speed
        - Delayed heave based on time
        - SEP based on position
    - Smooth NAVD88 tide with a 4th order Butterworth low-pass filter
    - Export smoothed SBETs after re-applying the above components
4) Import smoothed SBETs in CARIS HIPS
5) Run CARIS HIPS “Compute GPS Tides” with the NOAA-provided SEP to create tide correctors.

II. ERS Smoothed Tide Curve QA/QC:

Graphical analysis was the primary QA/QC tool used during the development phase of the ERS smoothing routine described above. MATLAB graphs were generated for all conversion and correction steps to identify erroneous source data or MATLAB program code.

III. Choice of Smoothing Parameters:

Combined SBETs were smoothed with a 4th order Butterworth low-pass filter using MATLAB's "filtfilt" function, which runs the filter in forward and reverse, resulting in a zero-lag solution.

OSI has demonstrated the effectiveness of this smoothing method on select prior NOAA contract surveys since 2018.

To determine the best smoothing parameter settings for this survey site, the final SBETs were smoothed and applied to the soundings using each of the following smoothing methods:

- 0.5, 1, 2, 3, 4-hour low pass filters

Statistical comparisons were made of crossline and main scheme difference data generated by CARIS HIPS. Standard deviation surfaces at intersections were reviewed, and the smoothed ERS SBET altitude was compared to local NOAA tide gauges and evaluated for trends and general agreement.

As a result of this iterative comparative analysis, a 4th order Butterworth low pass filter with the following settings were selected to smooth ERS tides:

- 1-hour cutoff frequency: *RV North Cove*, *RV South Cove, RV West Cove II, RV Twister,* and *MV Northstar Challenger*

B.4 Final Application of ERS Water Levels

For the final application of ERS water levels, the final processed SBET ellipsoid record was imported to CARIS. The CARIS "Compute GPS Vertical Adjustment" function was used in conjunction with the NOAA-provided SEP to apply MLLW or NPL correctors to the soundings and MHW heights to baring features:

OPR-A325-KR-24_NAD83(2011)-MLLW.csar
OPR-A325-KR-24_NAD83(2011)-MHW.csar
OPR-A325-KR-24_NAD83(2011)-NPL.csar

Qualitative and quantitative crossline analysis, as well as junction analysis, indicated that the final ERS correctors applied to reduce soundings to MLLW or NPL were adequate for the purpose. The results of crossline and junction analysis are presented in the Descriptive Report (DR) for each survey.

B.5 GNSS Base Station "OSGL"

To supplement IAPPK SBET processing, OSI installed a temporary GNSS base station on the roof of US Coast Guard Station Gloucester in Gloucester, Massachusetts (Figure 3). The installed station was designated "OSGL" [**O**cean **S**urveys **Gl**oucester] and consisted of a Trimble NetR9 GNSS receiver equipped with a Zephyr Geodetic 3 antenna (115000-00). OSGL also supplied real-time RTCM RTK correctors to the nearshore survey vessels via a cellular-based NTRIP stream. Real-time correctors provided precise horizontal positioning and allowed for real-time water level monitoring, which aided the survey vessels in mapping the Navigable Area Limit Line (NALL).

Figure 3. Ortho imagery and setup images of OSI's user-installed base station "OSGL" on the roof of US Coast Guard Station Gloucester in Gloucester, Massachusetts.

The configuration of the NetR9 was based on UNAVCO standard configuration settings for this device. The NetR9 was configured to record GNSS observables continuously throughout the period of the survey and parse data observables into daily files for each 24-hour period. Data were delivered to OSI's home office processing center via regular automated FTP and e-mail "pushes." Pushes were transmitted over a network connection that was established on site for this purpose. Data were also saved to the receiver's internal storage as a backup.

The HSSD requires that: "*The integrity of the geodetic tie of non-NOAA CORS installations to the NSRS shall be verified at least once per week while the site is utilized for survey operations. Verification may be achieved by repeated OPUS sessions to demonstrate that the difference between adopted and check positions are within the error budget allotted per THU (Section 3.2).*" OSI submitted all individual days of dual frequency GNSS observables (Rinex files) from OSGL to OPUS. Data were submitted with an ARP height of 0m. OSI used OPUS Projects (https://www.ngs.noaa.gov/OPUS-Projects/OpusProjects.shtml) for OPUS solution management, quality control, and to compute the final network-adjusted coordinates, which were then incorporated into ASB processing (Table 3). Processing steps and parameter selection were in accordance with the NGS-provided OPUS Projects Managers Training (required to obtain access to OPUS projects).

The field effort for this survey was started in late summer and was planned to span several months through the winter, weather permitting, and into spring. Sonar data acquisition was paused for most of the winter season and resumed in early spring to complete remaining fills and investigations. The GNSS base was left operational throughout the entire period. The OPUS project data was split into two separate projects to process 2024 and 2025 data separately. The first

project spanned from 8/2/2024 (DN215) to 12/1/2024 (DN336). The second project spanned from 3/11/2025 (DN070) to 3/28/2025 (DN087). The resulting final network-adjusted coordinates for OSGL from both projects are shown in Table 3.

Table 3
OPUS Projects Network Adjusted Positions of OSGL

Time period	Latitude (NAD83-2011)	Longitude (NAD83-2011)	Ellipsoid Height (GRS80)
DN 215 – 336	42° 36’ 38.24503”	70° 39’ 35.09918”	-12.034 m
DN 070 - 087	42° 36’ 38.24522”	70° 39’ 35.09906”	-12.035 m

Figure 4 shows a summary of the residuals for each of the daily OPUS solutions for both projects, and the improved residuals obtained with OPUS Projects session processing. The residuals are relative to the final network-adjusted position computed by OPUS Projects using all the solutions. The error bars on each point indicate the 1-sigma peak-to-peak root mean square (RMS) error estimate of the 3D position components, namely east, north, and ellipsoid height. The apparent offset in the mean position of the daily residuals and the final network-adjusted positions are due to plate velocities as handled in OPUS Projects for the time span of the project. All processing was done in ITRF 2014, however, final network-adjusted coordinates are also provided by OPUS Projects in NAD 83 (2011) @ 2010.00 (i.e. Table 3).

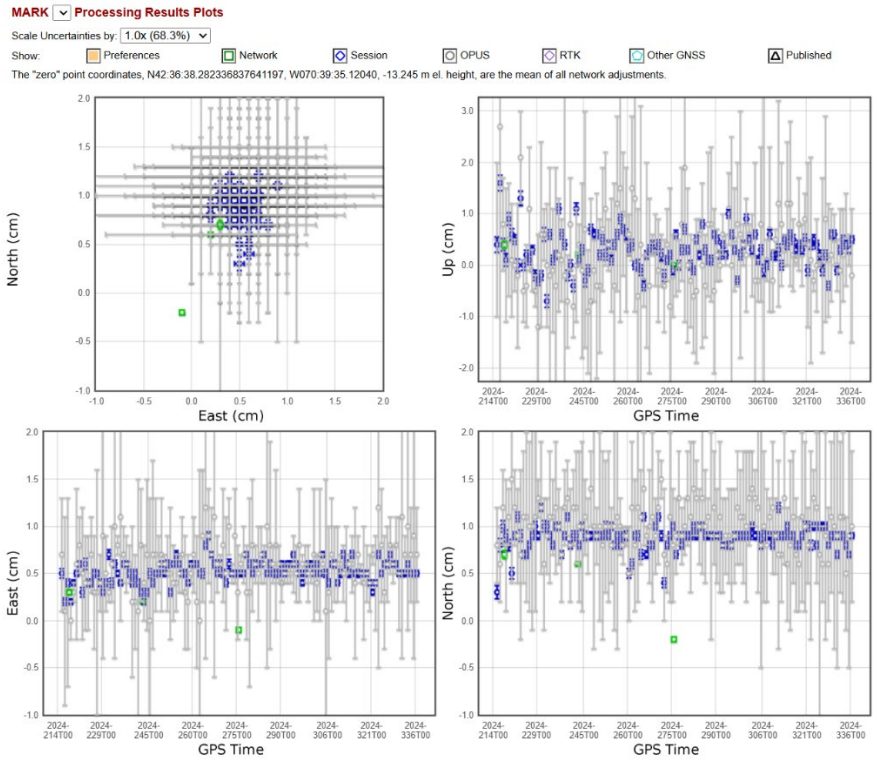


Figure 4a. OPUS project coordinate residuals for GNSS observables at OSGL for the period DN 215-336 2024.

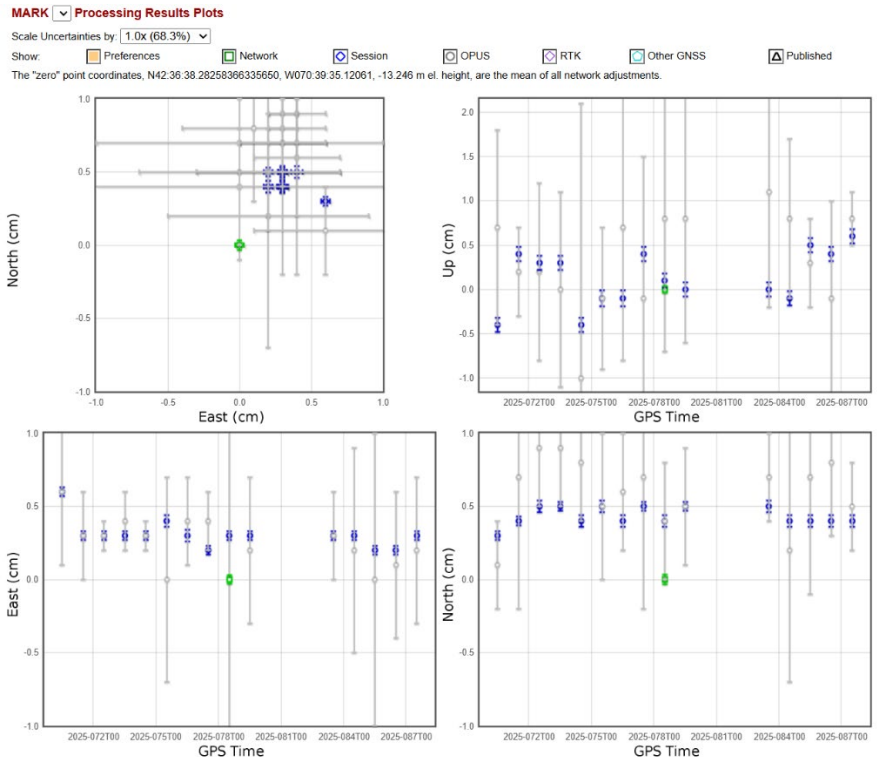


Figure 4b. OPUS project coordinate residuals for GNSS observables at OSGL for the period DN 070-087 2025. OPUS solutions are in grey, improved OPUS Project session solutions are in blue. Error bars represent 1-sigma. Residuals are relative to the final network-adjusted and velocity corrected position (green) from OPUS Projects.

Individual OSGL OPUS Project results (OPUS solutions, sessions, and final network adjustment) are included in the HVCR digital deliverables.

C. HORIZONTAL CONTROL

C.1 Horizontal Datum

The horizontal datum for this project is the North American Datum of 1983 (NAD83). Horizontal coordinates are referenced to Latitude/Longitude and Universal Transverse Mercator (UTM) Zone 19N, in meters.

C.2 Horizontal Control

During the survey, the POSMV on the *RV North Cove, RV South Cove, and RV Twister* received RTCM RTK correctors from the "OSGL" base station via a cellular NTRIP stream, while the *RV West Cove II* and *MV Northstar Challenger* were configured to receive SBAS (FAA WAAS) correctors for real-time positioning. Real-time vessel navigation was replaced during post-

processing with ASB-derived SBET positioning and attitude. Final SBET positioning is referenced to NAD83 (2011).

Positioning system confidence checks for each vessel were accomplished at the start of the survey and periodically thereafter. In practice, the distance between the vessel's reference point (RP) and the dockside horizontal control point, as computed by the navigation system, was compared to the tape-measured distance between the vessel RP and the horizontal control point. The RP of the *MV Northstar Challenger* is not readily accessible, therefore all measurements are referenced from the vessel's tracking point (TP), the sonar reference point of the RESON T50-R instead of the RP.

Temporary navigation confidence check points were installed near each vessel's dock. MBAY 24-MLLW, TBM BEV-MLLW, UTM-19 Mystic Pier 2, and CAM24-MLLW were installed prior to beginning the survey (Figures 5-8).

Temporary points were established using an RTK GNSS system, either a Trimble R8 or Trimble R10 GNSS interfaced with a TSC3 data collector. The rover systems, programmed to receive real-time RTCM RTK corrections from the base station "OSGL", were verified by occupying nearby NGS survey disks. The X,Y coordinates for temporary navigation confidence check points are presented in Table 4.

In all cases, dockside navigation system accuracy checks demonstrated accuracy that was substantially better than 1.0 meter.

Table 4
Temporary Navigation Confidence Check Points

Designation	Easting UTM 19N, NAD83 (meters)	Northing UTM 19N, NAD83 (meters)	Locale	For Survey Vessel
MBAY 24-MLLW	332803.05	4685097.49	Quincy	*RV South Cove* *RV North Cove*
TBM BEV-MLLW	345366.95	4711550.52	Beverly	*RV South Cove* *RV Twister*
CAM24-MLLW	362219.47	4719158.52	Gloucester	*RV South Cove* *RV West Cove II*
UTM-19 Mystic Pier 2	331340.70	4694009.98	Boston	*MV Northstar Challenger*

Figure 5. “MBAY 24 - MLLW” is a pink backed PK Nail in a dock at Safe Harbor Marina Bay in Quincy, Massachusetts.

Figure 6. “TBM BEV-MLLW” is a black X in a noticeable divot at the top of the bulkhead at *Beverly Port Marina* in Beverly, Massachusetts.

Figure 7. “CAM24-MLLW” is a nail in the decking adjacent to the northward metal gangway leading down to the docks at Cape Ann Marina in Gloucester, Massachusetts.

Figure 8. “UTM-19 Mystic Pier 2” is a marked ‘x’ along the northward bulkhead at the entrance to the Little Mystic Channel in Boston, Massachusetts.

Navigation system confidence checks for each vessel are included below in Table 5 through Table 9.

Table 5
***MV Northstar Challenger* Tabulation of Navigation System Confidence Checks**

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 19N, NAD83 (meters)	Observed Northing UTM 19N, NAD83 (meters)	Calculated Distance TP to Nav. Checkpoint (meters)	Tape Measure RP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
9/4/2024	19:32	UTM-19 Mystic Pier 2	WAAS	331350.02	4693998.41	14.86	14.82	0.04
9/12/2024	21:51	UTM-19 Mystic Pier 2	WAAS	331347.71	4694000.39	11.88	13.61	1.73
9/12/2024	23:38	UTM-19 Mystic Pier 2	WAAS	331348.57	4694000.44	12.37	12.98	0.61

Table 6
***RV North Cove* Tabulation of Navigation System Confidence Checks**

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 19N, NAD83 (meters)	Observed Northing UTM 19N, NAD83 (meters)	Calculated Distance RP to Nav. Checkpoint (meters)	Tape Measure TP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
9/30/2024	21:01	MBAY 24-MLLW	RTCM	332804.52	4685107.60	10.16	10.22	0.06

Table 7
***RV South Cove* Tabulation of Navigation System Confidence Checks**

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 19N, NAD83 (meters)	Observed Northing UTM 19N, NAD83 (meters)	Calculated Distance RP to Nav. Checkpoint (meters)	Tape Measure RP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
8/2/2024	15:04	CAM24-MLLW	RTCM	362219.47	4719158.52	9.67	9.64	-0.03
9/3/2024	19:09	TBM BEV-MLLW	RTCM	345366.95	4711550.52	9.24	9.28	0.04
11/19/2024	20:32	MBAY 24 - MLLW	RTCM	332803.05	4685097.49	17.72	17.75	0.03
11/20/2024	12:58	TBM BEV - MLLW	RTCM	345366.95	4711550.52	11.36	11.32	-0.04
3/10/2025	12:58	CAM24-MLLW	RTCM	362226.35	4719160.21	7.08	7.00	-0.08

Table 8
***RV West Cove II* Tabulation of Navigation System Confidence Checks**

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 19N, NAD83 (meters)	Observed Northing UTM 19N, NAD83 (meters)	Calculated Distance RP to Nav. Checkpoint (meters)	Tape Measure RP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
8/8/2024	9:58	CAM24 - MLLW	WAAS	362219.47	4719158.52	12.21	13.15	0.94

Table 9
***RV Twister* Tabulation of Navigation System Confidence Checks**

Date	Time UTC	Nav. Check-point	DGNSS Corr. Source	Observed Easting UTM 19N, NAD83 (meters)	Observed Northing UTM 19N, NAD83 (meters)	Calculated Distance RP to Nav. Checkpoint (meters)	Tape Measure RP to Nav. Checkpoint (meters)	Difference Calculated vs. Tape Measured (meters)
3/12/2025	12:35	TBM Bev-MLLW	RTCM	345369.48	4711543.01	7.92	7.95	0.03

D. APPROVAL SHEET

This report and the accompanying data are respectfully submitted.

Field operations contributing to the accomplishment of Surveys H13990, H13991, H13992, H13993, H13994, H13995, H13996, and H13997 were conducted under my direct supervision with frequent personal checks of progress and adequacy. This report and associated data have been closely reviewed and are considered complete and adequate as per the Statement of Work.

Approver Name	Approver Title	Approval Date	Signature
John R. Bean	Chief of Party	6/5/2025	Digitally signed by John R. Bean
David T. Somers	Data Processing Manager	6/5/2025	Digitally signed by David T. Somers