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

# HORIZONTAL & VERTICAL CONTROL REPORT

| | |
|---|---|
| Type of Survey: | Hydrographic Survey |
| Project Number: | OPR-K354-KR-18 |
| Time Frame: | May - September 2018 |

**LOCALITY**

| | |
|---|---|
| State: | Louisiana |
| General Locality: | Gulf of Mexico |
| Sub-locality: | Louisiana Coast |

**2018**

CHIEF OF PARTY

George G. Reynolds

| NOAA FORM 77-28 (11-72) U.S. DEPARTMENT OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION | REGISTRY NUMBERS: |
|---|---|
| **HYDROGRAPHIC TITLE SHEET** | H13100, H13101 H13102, H13103, H13200 |

| | |
|---|---|
| State: | **Louisiana** |
| General Locality: | **Gulf of Mexico** |
| Sub-Locality: | **Louisiana Coast** |
| Scale: | **1:40,000** |
| Date of Survey: | **May 28 to September 24, 2018** |
| Instructions Dated: | **Initial: March 23, 2018, Expanded Area: August 6, 2018** |
| Project No.: | **OPR-K354-KR-18** |
| Vessels: | **R/V Ocean Explorer- Official Number 905425** |
| Chief of Party: | **George G. Reynolds** |
| Surveyed By: | **Ocean Surveys, Inc.** |
| Soundings by: | **Multibeam Echosounder** |
| Imagery by: | **Side Scan Sonar, Multibeam Echosounder Backscatter** |
| Verification by: | **Atlantic Hydrographic Branch** |
| Soundings Acquired in: | **Meters at MLLW** |
| H-Cell Compilation Units: | |

Remarks: The purpose of this project is to provide contemporary surveys to update National Ocean Service (NOS) nautical charting products. All times are recorded in UTC. Data recorded and presented relative to UTM Zone 15 North.

Contractor: Ocean Surveys, Inc.
129 Mill Rock Rd E
Old Saybrook, CT 06475

THE INFORMATION PRESENTED IN THIS REPORT AND THE ACCOMPANYING DIGITAL DATA REPRESENTS THE RESULTS OF SURVEYS PERFORMED BY OCEAN SURVEYS, INC. DURING THE PERIOD OF 28 MAY 2018 TO 24 SEPTEMBER 2018 AND CAN ONLY BE CONSIDERED AS INDICATING THE CONDITIONS EXISTING AT THAT TIME. REUSE OF THIS INFORMATION BY CLIENT OR OTHERS BEYOND THE SPECIFIC SCOPE OF WORK FOR WHICH IT WAS ACQUIRED SHALL BE AT THE SOLE RISK OF THE USER AND WITHOUT LIABILITY TO OSI.

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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

Per the Project Instructions the contemporary surveys were controlled vertically employing ERS tides relative to mean lower low water (MLLW).

## B.1 ERS Tide Source Data

OSI's proposal for this survey suggested surveying to the ellipsoid using Fugro's Marinestar GNSS corrector service integrated with an Applanix POS MV. With the exception of certain calibrations, all field data were recorded utilizing Marinestar correctors. The manufacturer's stated horizontal and vertical accuracy using Marinestar correctors with an Applanix POS MV is 10 centimeters (95%) and 15 centimeters (95%) respectively. However, Marinestar-derived ellipsoid data (including Marinestar data processed using POSPac MMS) were found to be consistently inferior to Inertially Aided Post Processed Kinematic (IAPPK) ellipsoid data. Consequently, Applanix SmartBase (ASB)-derived ellipsoid records were used as the basis for the development of MLLW tides. This change in approach, i.e. using ASB Smoothed Best Estimate of Trajectory (SBET) solutions instead of Marinestar-derived X, Y, Z data, was approved by the COR in an e-mail dated June 28, 2018.

## B.2 VDatum Separation Model (SEP)

A VDatum Separation Model (SEP) with a vertical uncertainty of 17.166 centimeters was provided by NOAA with the original project files. However, the original SEP was superseded on July 22, 2018 with an updated SEP as a result of events described below. The updated SEP was ultimately used in creating MLLW ERS tides. Per wording in the July 22, 2018 e-mail transmitting the updated SEP it was stated that "*MLLW SEP uncertainty in the OPR-K354-KR-2018 project area remains the same [as] previously indicated: 17.2 cm.*" OSI used the unrounded original value of 17.166 centimeters moving forward.

The updated SEP was provided after a bias in the original SEP was detected and brought to the attention of the COR for subsequent discussion during initial data processing.

The updated SEP contained 3 important changes:

1) GEOID 2012B was replaced with xGEOID17B in VDatum.
2) A 10.2 cm scalar was applied to account for a residual error in VDatum TSS (topography of the sea surface) which remained after the change in GEOID model.

3) SEP coverage was extended to include NWLON gauges 876-6072 and 876-4227 (Freshwater Canal Lock), the entire OPR-K354-KR-18 project area, and 2 BMPG sites from Project OPR-K354-KR-16.

The following discussion provides background information which instigated the request for an updated SEP.

Applanix Smart Base processing of the first few weeks of field data revealed a spatialy variable offset between ERS-derived tides and a QA/QC tide dataset derived using alternate methods. The QA/QC tides dataset included local NOAA tides from Station 876-6072 and zoned tides using the data from NOAA tide Station 876-4227 and the .ZDF file provided with OSI's 2017 Project OPR-K354-KR-17.

Graphical comparison of the three tide sources showed that the ERS MLLW tide curve (using the original SEP) was consistently lower than the gauge-derived data with differences on the order of 0.2-0.3 meters offshore at the project site. The magnitude of the difference was less when the vessel was closer to land and greater at the offshore survey extent.

VDatum version (3.6.1), used in creating the original SEP, used Geoid 2012B to calculate TSS. Use of Geoid 2012B appeared to be the primary factor contributing to the detected bias in the original SEP once a comparison was made using xGEOID2017B. This issue was brought to the attention of the COR with a recommendation to shift to xGEOID2017B.

During correspondence on this subject, OSI and NOAA personnel also considered a tide dataset derived during a nearby survey performed by OSI in 2016 (see OPR-K354-KR-16 - HVCR). Specifically, NOAA requested the ellipsoid-MLLW SEP and position values from two bottom mounted pressure gauges (BMPG) deployed to support the 2016 survey. The 2016 Tidal Computation Report (included in the 2016 HVCR) revealed a similar bias, i.e. a total magnitude of 0.23 meters, when using VDatum and GEOID 2012B to correct ERS "boat float" data to MLLW.

The replacement of the GEOID removed most of the observed bias, but not all. A residual bias remained both offshore and inshore which was on the order of 0.1 m. During transits to/from the vessel's local shore base, the survey vessel stopped near NOAA's Freshwater Bayou Canal Lock tide gauge (876-4227) to perform "boat floats" for a period of three NOAA tide gauge readings.

It should be noted that the current, local VDatum model (and the original SEP) did not extend northward all the way to the Freshwater Bayou Canal lock. The model stopped approximately 1 km south of the lock. The absolute difference between MLLW and NAVD88 at the VDatum (3.6.1) node closest to the lock is 0.28 meters. For the boat float/tide gauge QA/QC comparisons, OSI initially chose to use the VDatum node value of 0.28 meters when adjusting ERS tides to MLLW. However, numerous comparisons indicated a bias of approximately 0.1 meters between the boat float ERS MLLW water levels and the tide gauge MLLW water levels when using the 0.28 meter corrector.

The respective NOAA and NGS benchmark descriptions for the primary benchmark at the Freshwater Bayou Lock station (876-6072-A) suggests a difference of 0.38 meters between MLLW and NAVD88. In investigating the bias described above, OSI acquired physical measurements of the water surface relative to the primary benchmark (NAVD88) and compared these data to preliminary NOAA tide gauge data for the same period (relative to MLLW). In this case a difference of approximately 0.38 meters was derived which is in keeping with the NOAA/NGS-published difference. When OSI shifted to using a corrector of 0.38 meters instead of 0.28 meters to convert NAVD88 ERS water levels to MLLW ERS water levels the boat float comparison data compared favorably to NOAA tide gauge-recorded values. This information and the GEOID comparisons contributed to the discussion which resulted in the updated SEP.

## B.3 ERS Tide Smoothing

ASB processing and the relative improvement in SBET ellipsoid heights as (compared to Applanix Single Base or Marinestar results) yielded ASB SBET ellipsoid records which were still too "noisy" in the opinion of OSI data analysts. Consequently, final ERS MLLW tides were smoothed prior to inclusion in the data reduction process. ERS tide smoothing was approved by the COR in a July 5, 2015 e-mail.

### I. ERS Tide Smoothing Steps:

1) Create and export ASB SBETs.
2) Smooth SBETs using MATLAB,
    - Convert SBET altitude to a MLLW 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 MLLW tide with a 4$^{th}$ order low pass filter
    - Export smoothed SBETs after re-applying the above components.
3) Import smoothed SBETs in CARIS HIPS
4) Run CARIS HIPS "Compute GPS Tides" with the updated SEP.

### II. ERS Smoothed Tide Curve QA/QC:

Graphical analysis was the primary QA/QC tool 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:

Daily SBETs were grouped by vessel trip, starting and ending with passage through Freshwater Lock. 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.

When choosing the "best" smoothing filter settings for this project OSI considered a number of filtering approaches including: 1) those used by OSI on a prior NOAA contract survey, 2) those used by JOA Surveys (on behalf of OSI for a prior NOAA contract survey), 3) those suggested by third party sources, and 4) new approaches developed by OSI data analysts.

Based on the above information the following candidate smoothing parameters were compared:

- 1, 5, and 10, minute averages
- 0.5, 1, 2, 3, 4, 5, and 6, hour low pass filters

Both quantitative and qualitative comparative analyses were performed. Statistical assessments were made with EXCEL histograms of crossline and mainscheme difference data generated by CARIS HIPS. Data from all 5 survey sheets composed of all the crosslines and a subset of mainscheme lines equal to the crossline spacing were used. The qualitative analysis consisted of observing the CARIS HIPS standard deviation surface (at intersections) using each version of the smoothed ERS MLLW tides.

As a result of the comparative analysis, a 4$^{th}$ order Butterworth low pass filter with a 3-hour cutoff frequency (i.e. 8-cycles per day) was chosen. The cutoff frequency of 5 hours was the statistical winner, however, the 3, 4, and 5, hour cutoff frequencies' statistics were nearly equal, therefore, the 3-hour cutoff frequency was chosen to better model any shorter period tide undulations.

B.4 GNSS Base Station "OSFL"

To supplement IAPPK SBET processing, OSI installed a temporary GNSS station at the U.S. Army Corps of Engineers Freshwater Bayou Canal Lock, which is the closest improved location (having power, structure, and security) near to the survey area. Specifically, a Trimble NetR9 GNSS receiver was installed on the roof of the lock house located at the southeastern corner of the lock (Figure 1). 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. With two exceptions (described below), there were no outages of the base station record during survey operations. The exceptions include base station outages which occurred on September 2-3, 2018 and September 24, 2018 (DNs 245-246 and DN 268 respectively). The unexplained DNs 245-246 outage lasted from 16:02 (DN 245) to 08:09 (DN 246) UTC and coincided with a weather delay period and therefore did not impact data acquisition. The DN 268 "outage" was not really an outage. Rather, the field team recovered

the base station at the end of operations (after all survey data and post-survey calibration data were acquired) which resulted in a daily file with less than 24 hours of observables data.

The configuration of the NetR9 was based on UNAVCO standard configuration settings for this device. GNSS observables were recorded on removable media as well as on the NetR9's internal storage. 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 at the Freshwater Bayou Canal Lock for this purpose. The Trimble NetR9 was included in IAPPK processing and designated as Ocean Surveys Freshwater Lock or "OSFL." The antenna reference point (ARP) is located at the following OPUS-averaged position (Table 1).

**Table 1**
**121-Day OPUS-Averaged Position of OSFL**

| Latitude (NAD83-2011) | Longitude (NAD83-2011) | Ellipsoid Height (GRS80) |
|---|---|---|
| 29° 33' 09.22889" N | 092° 18' 17.04326 W | -17.223 |

The Freshwater Bayou Canal Lock was an ideal location for the GNSS station as the Lock is also the site of NOAA tide gauge 876-6072 and associated tidal benchmarks. This proximity allowed for an optical leveling tie between the GNSS antenna and the tide station's primary benchmark, 876-6072-A, as well as benchmark 876-6072-C. Leveling results served as a QA/QC check of the ellipsoid value ultimately assigned to the OSFL base station during ASB processing. Pertinent details for the NOAA benchmarks referenced above and leveling results are included below (Figures 2,3,4).

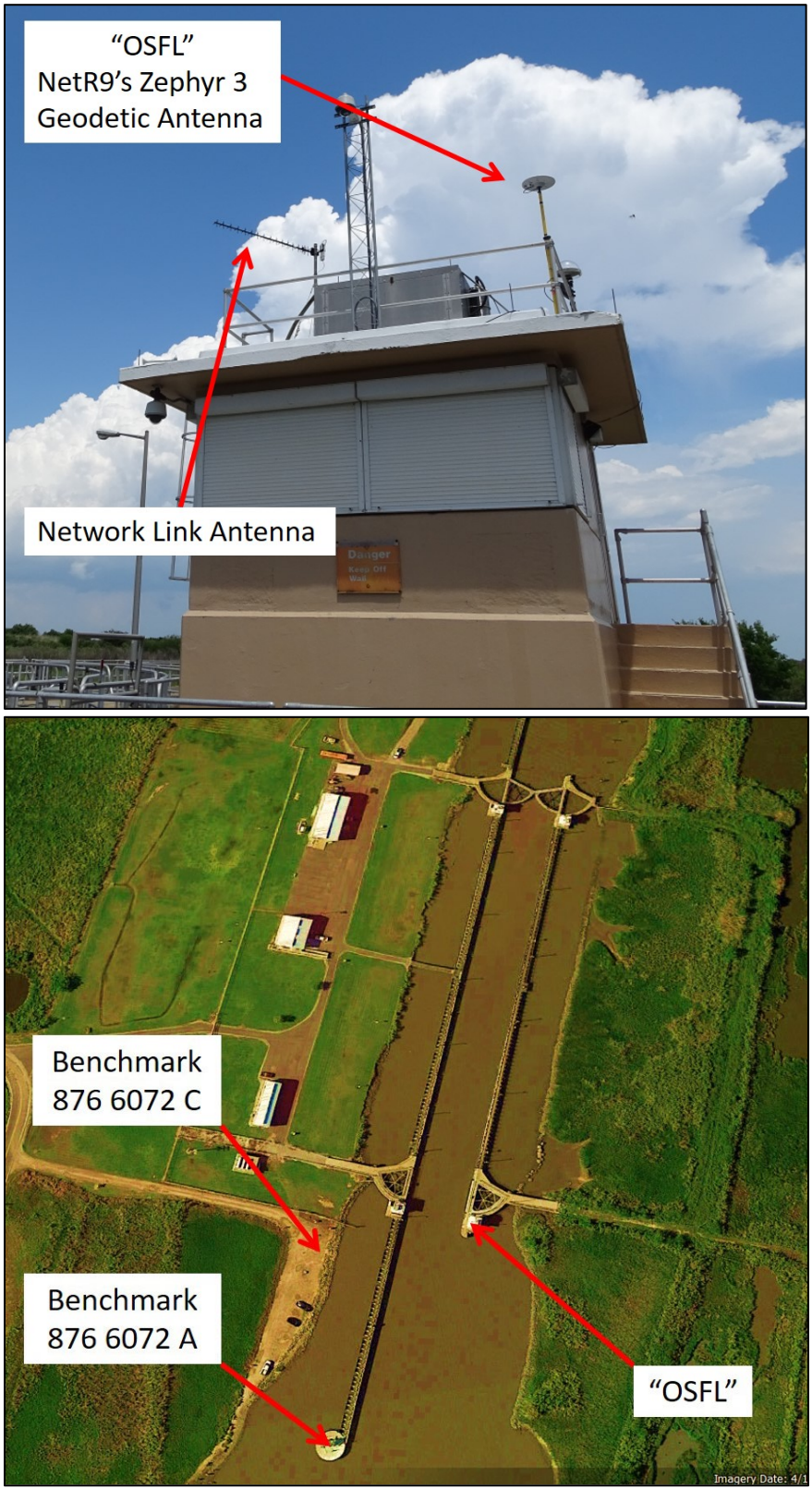


Figure 1. The local setting of OSI's temporary GNSS base station "OSFL."

```
PROGRAM = datasheet95, VERSION = 8.12.4.1
1         National Geodetic Survey,   Retrieval Date = MAY 16, 2018
 DJ9334 ***********************************************************************
 DJ9334  HT_MOD      -  This is a Height Modernization Survey Station.
 DJ9334  TIDAL BM    -  This is a Tidal Bench Mark.
 DJ9334  DESIGNATION -  876 6072 A
 DJ9334  PID         -  DJ9334
 DJ9334  STATE/COUNTY-  LA/VERMILION
 DJ9334  COUNTRY     -  US
 DJ9334  USGS QUAD   -  MULBERRY ISLAND EAST (1979)
 DJ9334
 DJ9334                        *CURRENT SURVEY CONTROL
 DJ9334  ___________________________________________________________________
 DJ9334* NAD 83(2011) POSITION- 29 33 06.35545(N) 092 18 18.87878(W)   ADJUSTED
 DJ9334* NAD 83(2011) ELLIP HT-   -23.283 (meters)        (06/27/12)   ADJUSTED
 DJ9334* NAD 83(2011) EPOCH   -  2010.00
 DJ9334* NAVD 88 ORTHO HEIGHT -     2.12  (meters)        7.0   (feet) GPS OBS
 DJ9334* NAVD 88 EPOCH        -  2009.55
 DJ9334  **This station is located in a suspected subsidence area (see below).
 DJ9334  ___________________________________________________________________
 DJ9334  NAVD 88 orthometric height was determined with geoid model    GEOID12A
 DJ9334  GEOID HEIGHT    -        -25.406 (meters)                     GEOID12A
 DJ9334  GEOID HEIGHT    -        -25.406 (meters)                     GEOID12B
```

Figure 2. Excerpt from NGS Datasheet for benchmark 876-6072-A.

```
PROGRAM = datasheet95, VERSION = 8.12.4.1
1         National Geodetic Survey,   Retrieval Date = MAY 16, 2018
 DN4165 ***********************************************************************
 DN4165  HT_MOD      -  This is a Height Modernization Survey Station.
 DN4165  TIDAL BM    -  This is a Tidal Bench Mark.
 DN4165  DESIGNATION -  876 6072 C
 DN4165  PID         -  DN4165
 DN4165  STATE/COUNTY-  LA/VERMILION
 DN4165  COUNTRY     -  US
 DN4165  USGS QUAD   -  MULBERRY ISLAND EAST (1979)
 DN4165
 DN4165                        *CURRENT SURVEY CONTROL
 DN4165  ___________________________________________________________________
 DN4165* NAD 83(2011) POSITION- 29 33 08.62598(N) 092 18 19.23244(W)   ADJUSTED
 DN4165* NAD 83(2011) ELLIP HT-   -24.443 (meters)        (06/27/12)   ADJUSTED
 DN4165* NAD 83(2011) EPOCH   -  2010.00
 DN4165* NAVD 88 ORTHO HEIGHT -     0.96  (meters)        3.1   (feet) GPS OBS
 DN4165* NAVD 88 EPOCH        -  2009.55
 DN4165  **This station is located in a suspected subsidence area (see below).
 DN4165  ___________________________________________________________________
 DN4165  NAVD 88 orthometric height was determined with geoid model    GEOID12A
 DN4165  GEOID HEIGHT    -        -25.408 (meters)                     GEOID12A
 DN4165  GEOID HEIGHT    -        -25.408 (meters)                     GEOID12B
```

Figure 3. Excerpt from NGS Datasheet for benchmark 876-6072-C.

| | |
|---|---|
| Station Name: "OSFL" | Local NOS-NOAA Tide Station Number: 876-6072 |
| Date: 5-24-2018, 18:00:00 UTC | Level Make and SN.: Sokkia B20, SN. QT7438 |
| Party Chief: Robert Wallace | Rod Make: Philadelphia Rod/Chicago Steel Tape W/ target |
| Observer: John Bean | Rod Units: 13 foot rod graduated in 100ths, Sn. T0497 |
| Rodman: Robert Wallace | Units: Feet |
| Weather: Wind Speed: 5 kt Wind Direction: variable | Distances measured by stadia |
| Temp.(F): 80 Sea State: calm Sky: overcast | Leveling Type: Confirmation of GNSS antenna elevation |
| Datum: NAVD88 | |

| Published Elevations in Meters (NAVD88) | | |
|---|---|---|
| 876-6072 A | 2.123 | Per NGS Datasheet (using Geoid 12B) |
| 876-6072 C | 0.965 | Per NGS Datasheet (using Geoid 12B) |

| | Leveling Record (Meters NAVD88) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| BM Designation | BS + | HI | FS - | Elev (NAVD88) | Fwd. Diff. | Diff. | Stadia Distance (m) | Closure Tolerance (m) |
| 876-6072 A | 1.158 | 3.281 | | 2.123 | | | | |
| 876-6072 C | | | 2.332 | 0.950 | -1.173 | 0.000 | 81.686 | 3.4 |
| TP1 (bolt) | 1.487 | 3.447 | 1.321 | 1.960 | -0.163 | 0.000 | 91.135 | 3.6 |
| TP2 (step) | 3.226 | 6.625 | 0.048 | 3.399 | 1.439 | 0.000 | 35.966 | 2.3 |
| R9 Ant. Base (-2m) | 0.414 | 6.611 | 0.428 | 6.197 | 2.798 | 0.000 | 6.401 | 1.0 |
| TP2 (step) | 0.248 | 3.648 | 3.212 | 3.399 | -2.798 | | | |
| TP1 (bolt) | 1.508 | 3.468 | 1.687 | 1.961 | -1.439 | | | |
| 876-6072 C | | | 2.519 | 0.950 | 1.173 | | | |
| 876-6072 A | | | 1.345 | 2.123 | 0.162 | | | |

| | |
|---|---|
| Base of 2.000 meter antenna pole = | 6.197 |
| Therefore, ARP (base) of Trimble R9's Zephyr 3 Geodetic antenna = | 8.197 |
| Geoid 12B Height = | -25.408 |
| Therefore, Ellipsoid Height of ARP = | -17.211 |
| 121-Day OPUS Average Ellipsoid Height = | -17.227 |
| Difference Between Leveled and OPUS-Averaged Ellipsoid Height = | 0.016 |

| Collimation Check | | | | | | |
|---|---|---|---|---|---|---|
| Station | BS + | HI | FS- | Elevation | Delta Elev. | Dist. (Ft.) |
| Peg 1 | 5.332 | 15.332 | | 10.000 | 0.165 | 35 |
| Peg 2 | | | 5.497 | 9.835 | | 35 |
| | | | | | | |
| Peg 1 | 6.350 | 16.350 | | 10.000 | 0.163 | 140 |
| Peg 2 | | | 6.513 | 9.837 | | 70 |

Run 1, level setup between Peg1 and Peg2 (35' to each peg).
Run 2, level setup 140' from Peg1 and 70' from Peg2.

| Closure Tol. |
|---|
| 0.008 |
| Difference |
| 0.002 |

Figure 4. Leveling record tying NOAA benchmarks to OSFL.

OSI submitted 121 individual days of dual frequency GNSS observables to the NGS' Online Positioning Users Service (OPUS) and OPUS returned 121 reports based on "precise" ephemerides. OSFL's 121-day OPUS average of ellipsoid height (and latitude/longitude) was assigned to OSFL for ASB processing.

OSFL was incorporated into ASB processing for all survey days. Due to its proximity to the survey area as well as observed data quality, OSFL was manually selected as the "primary network control" for all days. OSFL was the station against which all other CORS stations utilized in the process were assessed. In fact, after the necessary Z3G antenna ARP adjustments and DEV1 XYZ position adjustments were instituted (discussed in detail below), none of the NGS-CORS stations considered in the SmartBase process required adjustment when using OSFL as control. In other words, the SmartBase process retained the original coordinates of the NGS-CORS stations because the delta between their published and calculated horizontal and vertical coordinates (using OSFL as a reference) were consistently below the threshold necessitating an adjustment.

Station OSFL is considered "certified" in consideration of the information contained in the foregoing paragraph as well as the results of the numerous position verifications discussed below.

To satisfy the HSSD requirement that "*The reference position of non-CORS antenna installations shall be verified at least once per week while the site is utilized for survey operations,"* OSI submitted OSFL RINEX files to OPUS for each of the 121 days that OSFL was in operation. Figure 5 is fashioned after individual NGS-CORS station "Time Series (short term)" statistics display. Specifically, Figure 5 exhibits the horizontal and vertical variability or distance from the accepted position (red line) of the OPUS-derived 3-D position results. The error bars on each point indicate the 1-sigma OPUS-reported peak-to-peak root mean square (RMS) error estimate of the 3-D position components, namely east, north, and ellipsoid height.

According to NGS' "OPUS-Best Practices" presentation,
(https://www.ngs.noaa.gov/web/science_edu/presentations_archive/files/weston-soler-opusbestpractices.pdf)
"the relationship between peak-to-peak and RMS ($1\sigma$) is peak-to-peak = $1.6929 \times \sigma$."
Individual OSFL OPUS reports are included in the HVCR digital deliverables.

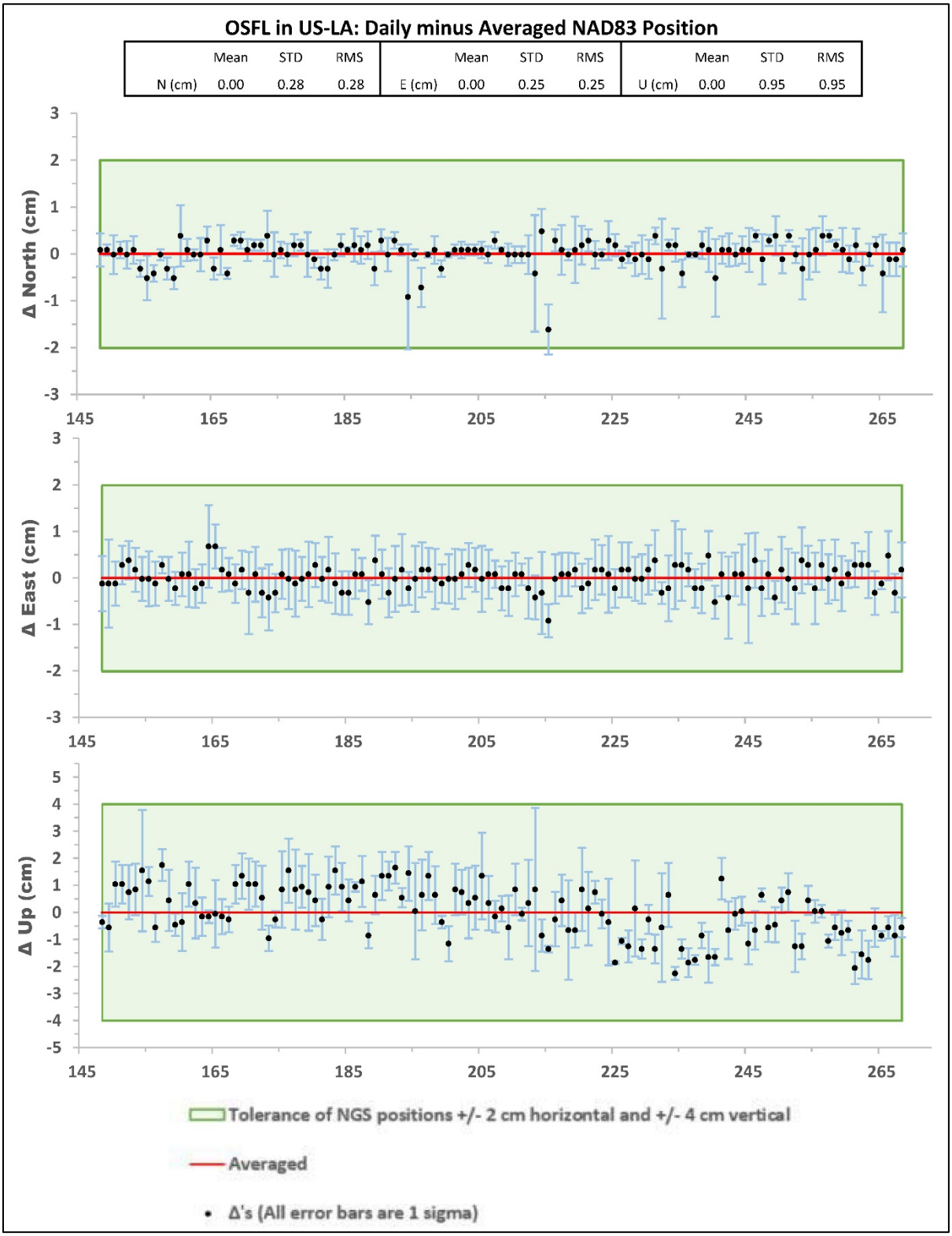


Figure 5. Station OSFL position verification statistics (fashioned after the NGS-CORS default presentation).

## B.5 NGS-CORS Station DEV1 Adjustment

During SBET processing it was discovered that one of the ASB-selected NGS-CORS network stations "DEV1" has an unusually large 3-D position error (accepted position vs. daily observed positions). The resultant ASB processing, as viewed in time series graphs, i.e. as "tide curves," demonstrated to OSI's satisfaction that use of the as-published, uncorrected 3-D position data for DEV1 resulted in degraded SBET ellipsoid height solutions. For this reason, OSI "forced" DEV1 coordinates during the ASB process. The 3-D coordinates employed by OSI for DEV1 during ASB processing are an average of DEV1 OPUS results for the period of the survey, i.e. 121 days of DEV1 dual frequency GNSS observables were submitted to OPUS. Individual DEV1 OPUS reports are included in the HVCR digital deliverables. Figure 6 provides an example of the aforementioned DEV1 3-D position error the period of the survey.

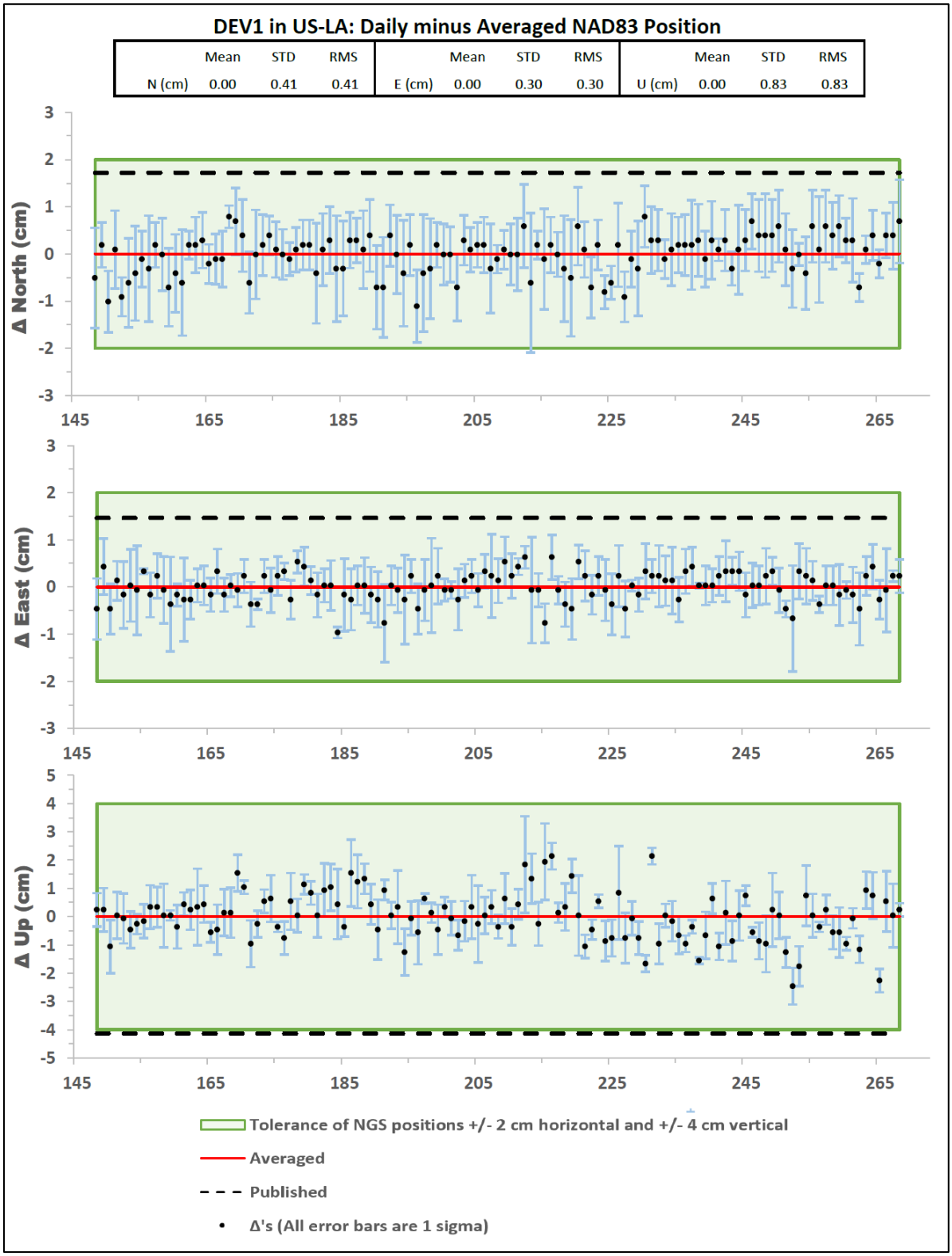


Figure 6. CORS Station DEV1 position error statistics calculated using NGS-CORS-published data and fashioned after the NGS-CORS default presentation.

The CORS-reported and OSI-forced (121 day OPUS-averaged) coordinates of DEV1 are shown in Table 2.

**Table 2**
**Pre- and Post-Adjustment Coordinates used for DEV1**

| Source | Latitude (N) | Longitude (W) | Ellipsoid Hgt (m) |
|---|---|---|---|
| NGS-CORS Reported NAD83 (2011) | 28 10 39.74267 | 091 43 57.51032 | 10.546 |
| OSI ASB-Forced (121 day OPUS Averaged) NAD83 (2011) | 28 10 39.74323 | 091 43 57.50977 | 10.505 |

In many circumstances it may be acceptable to omit a "flawed" CORS station from ASB processing assuming that other local CORS stations allowed for suitable network geometry. In the case of the contemporary survey area, as seen in Figure 7, it is necessary to include DEV1 in ASB processing otherwise the survey area would not fall within the convex hull of a CORS network. For this reason OSI forced the 3-D coordinates shown in the table above.

Figure 7 illustrates the placement of ASB-contributing CORS stations (including OSI's base station OSFL) in relation to the survey area. CORS stations TONY, FSHS, DEV1, CALC, and AMER along with OSI's OSFL were employed in *all* ASB SBET solutions. CORS Stations HOUM and LMCN were included in just a few ASB SBET solutions.

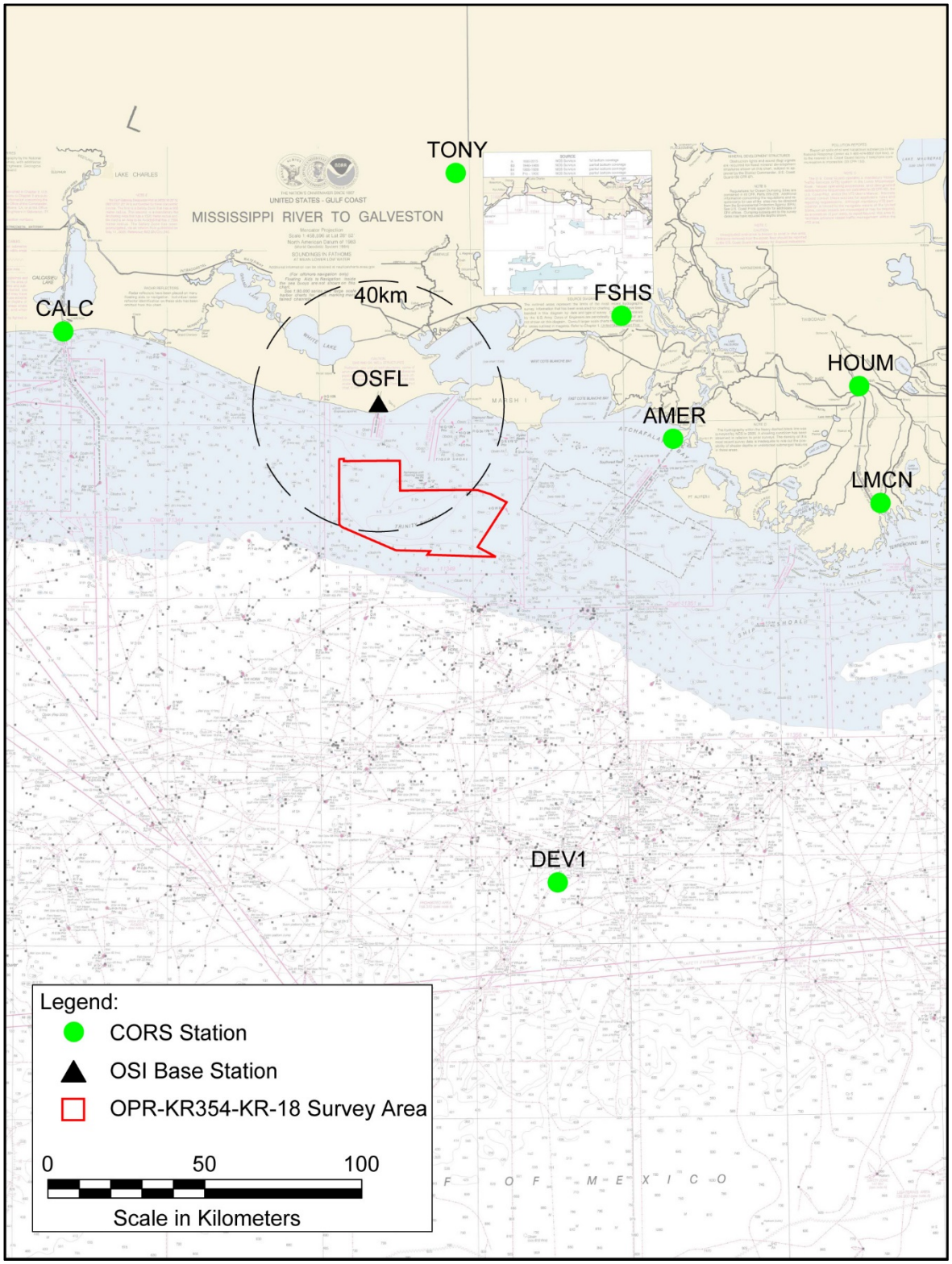


Figure 7. CORS stations (along with OSFL) used in ASB SBET solutions supporting Project OPR-K354-KR-18.

## B.6 OSFL and NGS-CORS Antenna Adjustments

OSI used the current version of POSPac MMS, v. 8.3 w/ SP1, for all ASB processing. During ASB processing it was discovered that the program does not handle the antenna reference point (ARP) to antenna phase center (APC) offset calculation correctly for the newer type of antenna used on OSI's GNSS base station OSFL. The new antenna type is a Trimble Zephyr 3 Geodetic (Z3G) which has an antenna code of "TRM115000.00 NONE." The ARP is 0.065 meters below the APC on a Trimble Z3G antenna. It was also discovered that three of the NGS-CORS base stations used in ASB processing (Figure 9 above) changed to the new antenna type during the period of the survey.

The POSPac MMS processing issue appears to be a misapplication of the ARP-APC offset. Essentially the software behaves as if the ARP of the Z3G is located at the APC. The software issue was raised with Applanix before v.8.3 w/ SP1 was issued. Unfortunately, the offset error has not been corrected in the software (as of the completion of project ASB processing).

OSI determined the start date of antenna changes at NGS-CORS stations contributing to the ASB SBETs from their respective NGS-CORS "Site Logs."

In order to fix the incorrect application of the Z3G antenna offset in POSPac MMS, OSI forced the ellipsoid height for the affected NGS-CORS stations as well as OSI's OSFL.

The affected stations, the date on which the respective antennas were changed to a Z3G, and the pre-/post-change ellipsoid heights are shown in Table 3.

**Table 3**
**SBET-Contributing Stations with Trimble Zephyr 3 Geodetic Antennas**

| Station | Antenna Type @ Start of Survey | Date Changed to Zephyr 3 Geodetic TRM115000.00 NONE | Published ARP Ellipsoid Height | OSI-Forced ARP Ellipsoid Height |
|---|---|---|---|---|
| OSFL | TRM115000.00 NONE | N/A | -17.223 (From 121 Day OPUS Average) | -17.158 |
| FSHS | TRM57971.00 NONE | 2018-08-24T15:18Z | -14.505 | -14.440 |
| TONY | TRM57971.00 NONE | 2018-08-13T18:27Z | -5.557 | -5.492 |
| LMCN | TRM57971.00 NONE | 2018-08-22T17:45Z | -14.743 | -14.678 |

### B.7 Application of ERS Tides

The QA/QC steps used in assessing ERS tide components and the processes employed in creating ERS tides are detailed in earlier sections of this report. In summary, once a "smoothed" IAPPK ellipsoid record was generated the CARIS "Compute GPS Tides" function was used in conjunction with the NOAA-provided SEP in creating MLLW tide correctors.

Qualitative and quantitative crossline analysis as well as junction analysis indicate that the final ERS correctors employed in reducing soundings to MLLW were adequate for the purpose. The results of crossline and junction analysis are presented in the Descriptive Report for each Survey.

## 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 15, in meters. The assigned project boundary falls entirely within UTM Zone 15.

### C.2 Horizontal Control

With the exception of certain calibrations, all survey tasks were executed in real-time employing Fugro's Marinestar-aided Differential GNSS (DGNSS) positioning. Correctors from the U.S. Coast Guard Differential GPS (DGPS) station in English Turn, LA were utilized by the secondary GPS, a Trimble MS750, used as a "position integrity" alarm.

Marinestar correctors are referenced to the 2008 realization of the International Terrestrial Reference Frame (ITRF 2008). In order to operate in real-time within the local reference frame, UTM 15N, NAD83, the time variable transformation function was utilized in the HYPACK acquisition software.

The Marinestar solution was replaced during post processing with Applanix SmartBase (ASB)-derived SBET positioning and attitude. Final SBET positioning is referenced to NAD83.

Positioning system confidence checks of the POS MV were accomplished at the start of survey and during provisioning stops in Intracoastal City, LA. In practice, the distance between the vessel's reference point (RP) and the dockside horizontal control point "SMIC-01," as computed by the navigation system, was compared to the tape-measured distance between the vessel RP and the horizontal control point. The horizontal control point SMIC-01 was established by OSI on August 1, 2017 (DN 212) during Project OPR-K354-KR-17 using OPUS (Figure 8 and Table 4). The 2017 SMIC-01 OPUS report is included in the HVCR digital deliverables.

In all cases, dockside navigation system accuracy testing demonstrated that the POS MV, employing Marinestar correctors and subject to real-time datum transformation, had an accuracy of better than 1.0 meter.

Vessel positions and distance measurements for each "nav check" were recorded in the acquisition log and are included here in Table 5, and in Appendix III of the DAPR.

Position information from the vessel's primary and secondary GPS receivers (POS MV w/Marinestar and Trimble MS750 DGPS) were continuously compared in HYPACK SURVEY and status indicators were monitored in real time. By means of a "positioning integrity" utility in the HYPACK SURVEY program, a position disparity between the primary and secondary positioning systems that exceeded two (2) meters would be reported by means of a visual alarm on the data acquisition screen. In one case, August 30, 2018 (DN242) @ ~21:56 the position integrity alarm detected an unexplained, substantial POS MV positioning (and heading) fault. The fault was remedied by rebooting the POS MV. In this case, the affected survey line was abandoned and re-surveyed. As a conservative measure, the preceding survey line was also abandoned and re-surveyed.


Figure 8. SMIC-01 NAIL is a pink flagged PK Nail in a Shell Morgan Landing dock piling shown here from three perspectives (antenna pole on point). This point was used exclusively by the *R/V Ocean Explorer*.

**Table 4**
**Navigation System Checkpoint**
**OPUS "Precise" Solution Coordinates**

| Nav. Check Point | Reference Easting UTM 15N, NAD83 (meters) | Reference Northing UTM 15N, NAD83 (meters) | Description of Position |
|---|---|---|---|
| SMIC-01 NAIL | 581,615.52 | 3,295,068.34 | PK nail in dock piling at Shell Morgan Landing, Intracoastal City, LA |

**Table 5**
***R/V Ocean Explorer* - Tabulation of Navigation System Performance Checks**

| Date | Time UTC | Nav. Check-point | DGNSS Beacon | Observed Easting UTM 15N, NAD83 (meters) | Observed Northing UTM 15N, NAD83 (meters) | Calculated Distance RP to Nav. Checkpoint (meters) | Tape Measure RP to Nav. Checkpoint (meters) | Difference Calculated vs. Tape Measured (meters) |
|---|---|---|---|---|---|---|---|---|
| 05/26/18 (DN 146) | 21:39 | SMIC Nail | Marine-star | 581,622.2 | 3,295,070.2 | 6.9 | 6.9 | 0.0 |
| 06/04/18 (DN 155) | 4:21 | SMIC Nail | Marine-star | 581,625.9 | 3,295,065.1 | 10.8 | 10.7 | 0.1 |
| 06/10/18 (DN 161) | 3:55 | SMIC Nail | Marine-star | 581,623.7 | 3,295,067.9 | 8.2 | 8.3 | 0.1 |
| 06/17/18 (DN 168) | 3:59 | SMIC Nail | Marine-star | 581,625.1 | 3,295,065.8 | 9.9 | 10.1 | 0.2 |
| 06/23/18 (DN 174) | 20:25 | SMIC Nail | Marine-star | 581,625.3 | 3,295,065.8 | 10.1 | 9.8 | 0.3 |
| 07/01/18 (DN 182) | 13:03 | SMIC Nail | Marine-star | 581,625.0 | 3,295,065.9 | 9.8 | 9.6 | 0.2 |
| 07/08/18 (DN 189) | 11:33 | SMIC Nail | Marine-star | 581,624.9 | 3,295,065.9 | 9.7 | 9.8 | 0.1 |
| 07/14/18 (DN 195) | 12:33 | SMIC Nail | Marine-star | 581,624.5 | 3,295,066.8 | 9.1 | 9.2 | 0.1 |
| 07/20/18 (DN 201) | 3:38 | SMIC Nail | Marine-star | 581,625.0 | 3,295,066.0 | 9.8 | 10.0 | 0.2 |
| 07/24/18 (DN 205) | 4:25 | SMIC Nail | Marine-star | 581,623.6 | 3,295,068.1 | 8.1 | 8.5 | 0.4 |
| 07/30/18 (DN 211) | 1:48 | SMIC Nail | Marine-star | 581,624.0 | 3,295,067.5 | 8.6 | 8.9 | 0.3 |
| 08/05/18 (DN 217) | 4:07 | SMIC Nail | Marine-star | 581,626.9 | 3,295,068.6 | 11.3 | 11.4 | 0.1 |
| 08/11/18 (DN 223) | 11:25 | SMIC Nail | Marine-star | 581,624.9 | 3,295,066.1 | 9.7 | 9.8 | 0.1 |
| 08/17/18 (DN229) | 7:22 | SMIC Nail | Marine-star | 581,624.7 | 3,295,066.7 | 9.4 | 9.7 | 0.3 |
| 08/23/18 (DN 235) | 8:53 | SMIC Nail | Marine-star | 581,625.1 | 3,295,066.1 | 9.8 | 10.0 | 0.1 |

| Date | Time UTC | Nav. Check-point | DGNSS Beacon | Observed Easting UTM 15N, NAD83 (meters) | Observed Northing UTM 15N, NAD83 (meters) | Calculated Distance RP to Nav. Checkpoint (meters) | Tape Measure RP to Nav. Checkpoint (meters) | Difference Calculated vs. Tape Measured (meters) |
|---|---|---|---|---|---|---|---|---|
| 08/29/18 (DN 241) | 7:02 | SMIC Nail | Marine-star | 581,624.9 | 3,295,066.5 | 9.5 | 9.7 | 0.1 |
| 09/04/18 (DN 247) | 8:39 | SMIC Nail | Marine-star | 581,624.4 | 3,295,066.5 | 9.0 | 9.1 | 0.1 |
| 09/10/18 (DN 253) | 15:10 | SMIC Nail | Marine-star | 581,630.1 | 3,295,058.3 | 17.8 | 18.1 | 0.3 |
| 09/20/18 (DN 263) | 10:58 | SMIC Nail | Marine-star | 581,630.5 | 3,295,057.6 | 18.4 | 18.7 | 0.3 |
| 09/25/18 (DN 268) | 2:12 | SMIC Nail | Marine-star | 581,630.4 | 3,295,057.8 | 18.2 | 18.4 | 0.2 |

## D. APPROVAL SHEET

# LETTER OF APPROVAL

# REGISTRY NOS.
# H13100, H13101, H13102, H13103, AND H13200

This report and the accompanying data are respectfully submitted.

Field operations contributing to the accomplishment of Surveys H131000, H13101, H13102, H13103, and H13200 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 |
|---|---|---|---|
| George G. Reynolds | Chief of Party | 01/25/2019 | George G. Reynolds 2019.01.25 16:06:42 -05'00' |
| John R. Bean | Lead Hydrographer | 01/25/2019 | John R. Bean 2019.01.25 16:07:06 -05'00' |
| David T. Somers | Data Processing Manager | 01/25/2019 | David T. Somers 2019.01.25 16:07:31 -05'00' |