Determining Elevations of Rod Surface Elevation Table Benchmarks at Coastal Wetland Elevation Monitoring Sites

Baseline Report

November 2019

U.S. Department of the Interior
U.S. Fish and Wildlife Service
Inventory & Monitoring Branch, South Atlantic - Gulf and Mississippi Basins

Determining Elevation of Rod Surface Elevation Table Benchmarks at Coastal Wetland Elevation Monitoring Sites: Baseline Report

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Cover photo: Global navigation satellite system (GNSS) occupation of a rod surface elevation table (RSET) benchmark at Cedar Island National Wildlife Refuge (credit: Allie Stewart/USFWS).

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EXECUTIVE SUMMARY

Between 2015 and 2019, 54 rod surface elevation tables (RSETs) installed by the US Fish and Wildlife Service at 17 National Wildlife Refuges (NWRs) were surveyed using Global Navigation Satellite System (GNSS) Trimble R10 receivers. The purpose of these surveys was to establish an elevation for each benchmark. A benchmark elevation is required to compare wetland elevation change rates to rates of relative-sea level rise. Additionally, a survey-grade location and elevation solution for each RSET benchmark, from which vertical displacement can be identified and corrected, is desired. Three RSET benchmarks at each site were simultaneously surveyed for at least 4-6 hours on two to three consecutive days. To provide a more representative and reproducible solution, these GNSS data were processed using Online Positioning User Service-Static (OPUS-S) and the more robust OPUS Projects (OP) processing interfaces.

While OP allows for a lot of flexibility in the way that the data can be processed, this flexibility also creates a situation where there is an almost infinite number of ways to process the data and get horizontal/vertical location solutions. In order to provide consistent and repeatable results, the methods described in McDonald and Cooper (2018) were used to process the data. A brief explanation of these methods is provided in this document. The GNSS data collected between 2015 and 2019 and their OPUS-S and OP solutions from 17 NWRs are summarized in this report. These data represent the baseline elevations for the Coastal Wetland Elevation Monitoring Protocol (CWEM).

The data provided in this report allow users to assess the accuracy of the GNSS solutions. A final benchmark elevation is published for the 48 stations where we were able to calculate a benchmark elevation. These orthometric heights correspond to the elevations (published in millimeters) in the CWEM project's RSET database. Accurate elevation solutions could not be obtained on stations at Roanoke River (RRV013) and Alligator River (ALL030) because these sites are in forested wetlands with dense canopies that prevented adequate GNSS signal acquisition. While an OP solution could not be obtained for Alligator River NWR saltmarsh (Station ALL005B) due to the inclement weather that occurred during one day of the survey, an OPUS-S solution was able to be obtained for the benchmarks surveyed at this refuge.

It should be noted that it was very difficult to achieve sub-centimeter accuracy of benchmark elevations using the GNSS survey methods outlined in this report. Replicate surveys conducted at Pinckney Island NWR suggests the benchmark elevation survey solutions should not assume sub-centimeter accuracy and results may have a confidence interval of +/-1-2 cm or greater. For the purpose of the CWEM program, benchmark elevation accuracies of 1-2 cm provide an adequate reference for the site to the North American Vertical Datum of 1988 (NAVD88) datum and relative sea-level rise, but may not be adequate for detecting small shifts in the vertical elevation of the benchmark through time.

Contents

1. Introduction

1.1 Overview

Sea-level rise and its potential impacts to habitats and species are a concern for the US Fish and Wildlife Service (USFWS) National Wildlife Refuges (NWRs) within the region served by the South Atlantic Landscape Conservation Cooperative (SALCC). Recent sea-level models suggest the rate of sea-level rise along the Mid-Atlantic coast will be greater than the global average due to the characteristics of the continental shelf in this region (Boon 2012; CCSP 2009; Titus et al. 2009). Existing National Oceanic and Atmospheric Administration water level gauges in the Atlantic region have measured relative sea-level rise rates ranging from 1.75 to 4.4 mm per year (CCSP 2009). Rising sea level can lead to wetland loss, saltwater intrusion, habitat conversion, and inland migration of marsh and forested ecosystems. Salt marsh and coastal wetland habitats are especially at risk, as the mean elevation of these coastal systems must increase to not only keep pace with sea level rise, but also the subsidence of organic substrates (Cahoon et al. 2009; Webb et al. 2013). Understanding rates of elevation change within coastal wetlands in relation to sea-level rise (Figure 1) is vitally important to help refuge managers answer critical questions and adjust management techniques for conserving these complex systems.

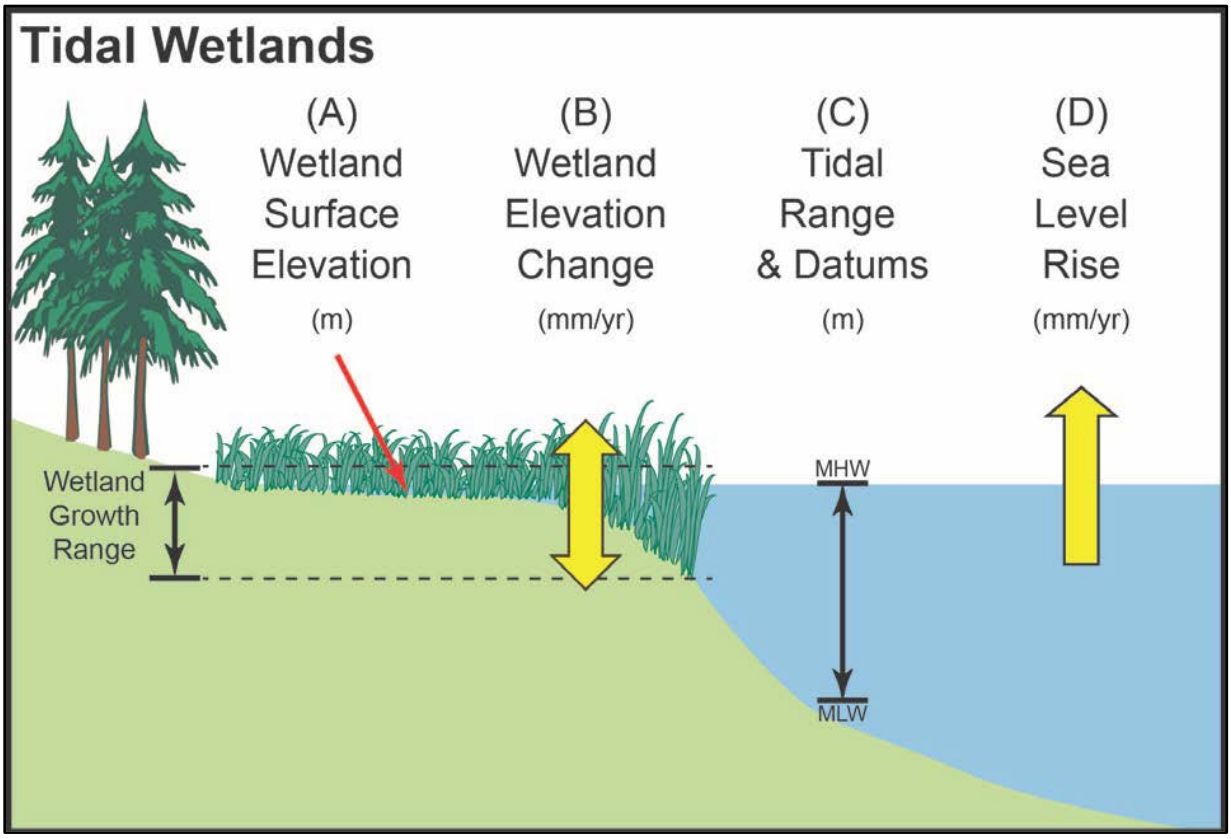

Figure 1. Diagram depicting the relationships between wetland surface elevation (A), wetland elevation change (B), tidal range between Mean High Water (MHW) and Mean Low Water (MLW) (C), and sea level rise (D) (from Lynch et al. 2015).

In 2012, the USFWS Southeast Region Inventory and Monitoring (I&M) Branch initiated a Coastal Wetland Elevation Monitoring (CWEM) effort on 18 NWRs within the SALCC region

(Figure 2). The overarching objectives of the CWEM effort are to: (1) observe impacts of sea level rise and change in priority habitats; (2) determine rates of wetland elevation change and relative sea level rise; and (3) forecast the longevity of these monitored habitats. This monitoring effort involves surveying coastal wetland surface elevations (using rod surface elevation tables [RSETs]), recording accretion/deflation rates, monitoring pore water salinity, and recording vegetation community data at permanent sites within the 18 NWRs. This monitoring effort will provide vital information to refuge managers concerning the status of, and trends in, wetland conditions within their refuge, and help managers make ecologically-informed decisions with respect to conservation and management of wetlands on NWRs.

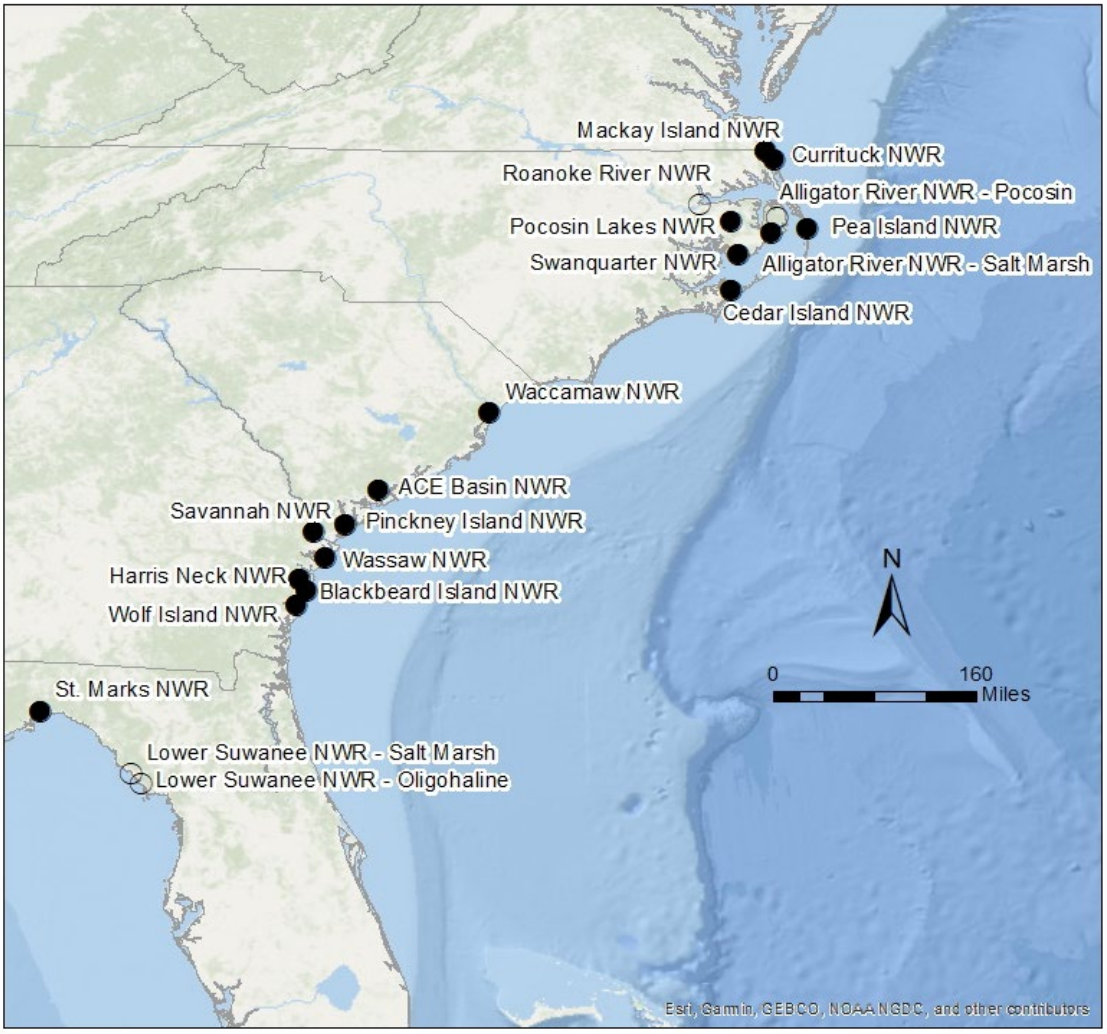

Figure 2. Location of the Coastal Wetland Elevation Monitoring Sites on the National Wildlife Refuges in the South Atlantic Landscape Conservation Cooperative geography. Black circles indicate the sites were surveyed and a benchmark elevation was obtained; hollow circles indicate that no benchmark elevation solution was obtained.

In order to determine wetland elevation change in relation to relative sea-level rise, accurate and precise connections between the wetland surface and a vertical control must be made (Geoghegan et al. 2009; Lynch et al. 2015). This relationship between the wetland surface and a vertical control is achieved by obtaining a precise elevation on each RSET benchmark.

Due to the remoteness of CWEM sites and constraints on other survey methods, GNSS technology was determined to be the most efficient method to establish vertical control at CWEM sites. Data collected during static GNSS campaigns can be post-processed using the Continuously Operating Reference Stations (CORS) network. The Online Positioning User Service – Static (OPUS-S) can be used to post-process data from a single receiver using the CORS network. If simultaneous static GNSS occupations on multiple benchmarks occur, additional post-processing of the data together using the OPUS Projects (OP) online service can further reduce the uncertainty of the GNSS solutions (Lynch et al. 2015; McDonald and Cooper 2018). For this reason, simultaneous static GNSS surveys were used to calculate the baseline elevations for RSET benchmarks at CWEM sites.

1.2 Objectives

This report presents the results of RSET baseline elevation surveys conducted at 18 NWR CWEM sites between 2015 and 2019. These surveys used static GNSS receivers to simultaneously survey the RSETs at each refuge. The objective of the survey was to compute a baseline vertical height referenced to the National Spatial Reference System for each RSET benchmark. This information will allow the project to 1) report wetland elevation change at each plot relative to the NAVD88 datum and 2) to measure benchmark stability over time.

2. Methods

2.1 Study Area

During the winter of 2011-2012, Southeast Region I&M staff, NWR biologists and managers, and partners met to determine priority habitat types for monitoring the effects of sea-level rise. A total of 18 coastal NWRs within the SALCC region were chosen to be monitored using RSET benchmarks and associated monitoring stations. In 2012, a total of 20 CWEM sites were established within 18 NWRs. These sites were established within previously identified 'priority' habitats through a spatially balanced random sampling design (Moorman and Rankin *In Review*). The priority habitats that were identified included: salt and brackish marsh (Pea Island, Alligator River, Swanquarter, Cedar Island, Pinckney Island, Wassaw, Harris Neck, Blackbeard, Wolf Island, St. Marks, and Lower Suwannee NWRs); freshwater and oligohaline marsh (Mackay Island, Currituck, Waccamaw, Ernest F. Hollings ACE Basin (ACE Basin), Savannah, and Lower Suwannee NWRs); pocosin (Alligator River and Pocosin Lakes NWRs); and forested wetland (Roanoke River NWR, Figure 3). At each CWEM site, three RSET benchmarks were installed to track changes in surface elevations. The RSET benchmarks are stable, deep rod benchmarks and were installed using methods outlined by the National Geodetic Survey (NGS) (Floyd 1978; Smith 2007).

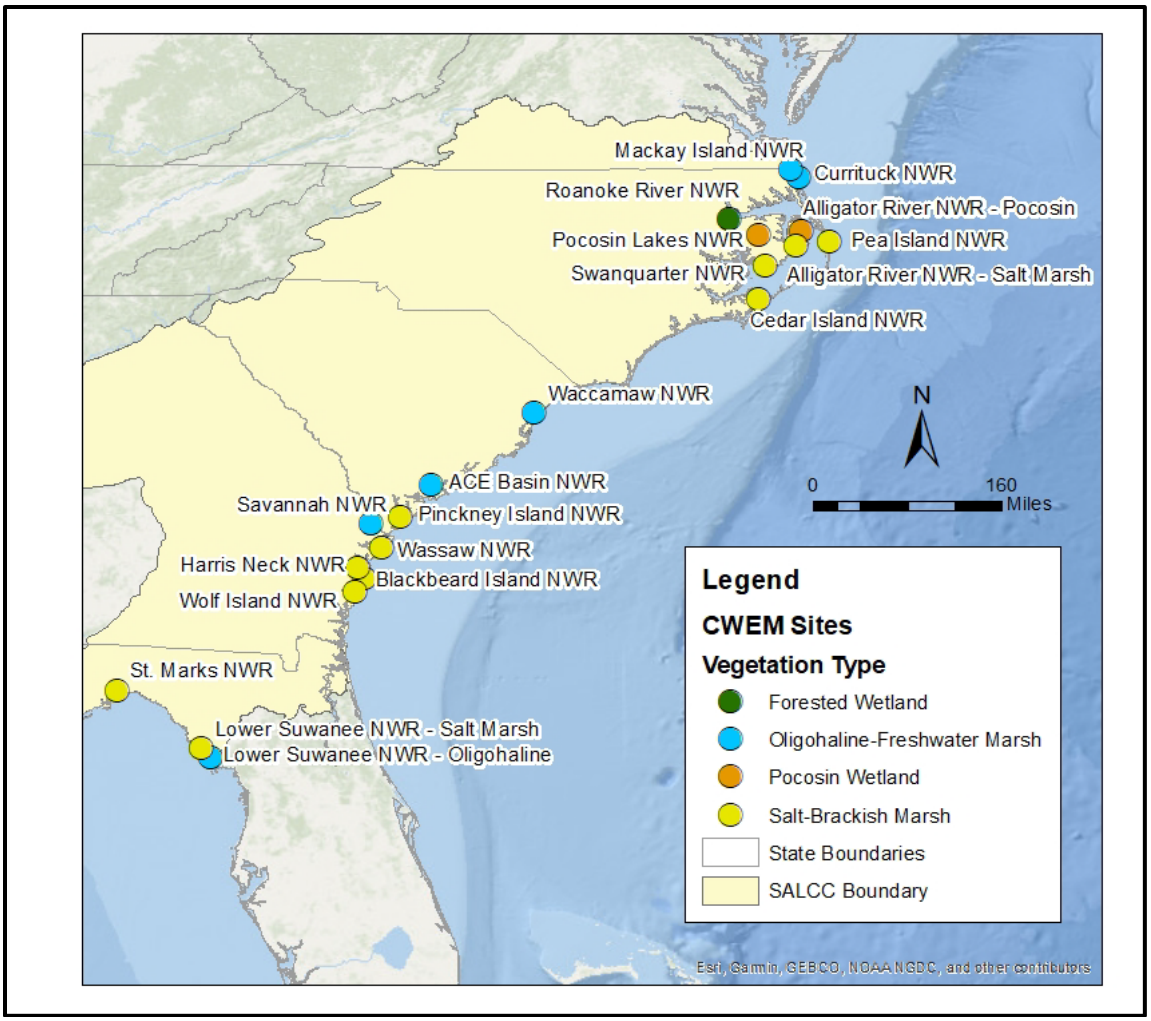

Figure 3. Distribution of the South Atlantic CWEM sites within coastal North Carolina, South Carolina, Georgia, and Florida NWRs.

2.2 Survey Planning

Following guidelines from Mitchell and Crouch (2014), planning was conducted to ensure site logistics and adequate satellite conditions were met for the predicted survey duration prior to deploying GNSS equipment. For tidal CWEM sites (Figure 3), the National Oceanic and Atmospheric Administration (NOAA) Tides and Currents site (http://co-ops.nos.noaa.gov/tide_predictions.html) was used to determine local tide characteristics. To enable GNSS equipment to be safely deployed and retrieved, surveys were planned for days with low tides occurring during late morning to early afternoon. Weather forecasts were checked and monitored, and surveys were not planned for days with heavy rainstorms or approaching storm fronts. At times, weather and tides were not ideal for occupation. Wind speed, 24-hour precipitation, and tidal conditions are summarized for each date of occupation at each site in Appendix A.

No more than three days prior to each survey, the Trimble GNSS Planning Online site (http://www.trimble.com/GNSSPlanningOnline/) was used to check predicted conditions for the number of satellites, dilution of precision (DOPs), and ionosphere total electron content (TEC).

The NOAA Space Weather Prediction Center site (http://www.swpc.noaa.gov/) was used to determine predicted conditions for radio blackouts, solar radiation storms, and geomagnetic storms. If conditions in Table 1 were not met or any space weather warnings were in effect, the survey was postponed to a later date.

Table 1. Recommendation of conditions for dilution of precision (DOPs), ionosphere total electron content (TEC), radio blackouts, solar radiation storms, and geomagnetic storms that should be met for the duration of the static Global Navigation Satellite System (GNSS) occupation (Mitchell and Crouch 2014).

Tool	Condition	Recommendation
Trimble GNSS Planning	DOPs	< 3
	Ionosphere TEC	< 80
NOAA Space Weather	Radio Blackout	R to R2 (Avoid: R3 to R5)
	Solar Radiation Storm	S to S2 (Avoid: S3 to S5)
	Geomagnetic Storm	G to G2 (Avoid: G3 to G5)

2.3 Data Collection

Simultaneous static GNSS observations were conducted at eighteen CWEM sites from June 4th to August 5th, 2015; March 16th to August 25th, 2016; and February 25th, 2019 to March 17th, 2019 to establish baseline elevations for the RSETs located at each refuge (Figure 2). Seven CWEM sites were surveyed in 2015 [Cedar Island (NC), Harris Neck (GA), Pinckney Island (SC), Pea Island (NC), Pocosin Lakes (NC), Swanquarter (NC), and Wassaw (GA) NWRs]. Eight CWEM sites were surveyed in 2016 [Savannah (GA), Pinckney Island (GA, resurvey), St. Marks (FL), Alligator River – salt marsh (NC), Currituck (NC), Waccamaw (SC), Wolf Island (GA), and Blackbeard Island (GA) NWRs]. Five CWEM sites were surveyed in 2019 [Ace Basin (SC), Alligator River – Pocosin (NC), Mackay Island, Pocosin Lakes (NC, resurvey), Roanoke River (NC)]. The two CWEM sites at Lower Suwanee NWR were not surveyed (Table 2).

Static GNSS observations were required to establish National Spatial Reference System (NSRS) connections for each SET benchmark because there are no NSRS benchmarks near the CWEM sites from which total station surveys could be conducted. The GNSS surveys were performed using three GNSS Trimble R10 receivers (Trimble Navigation Ltd, Sunnyvale, California), three US Geological Survey (USGS) fixed-dimension GNSS antenna adapters, and one Trimble TSC3 data collector. The USGS designed the fixed-dimension GNSS antenna adapter (USGS antenna adapter) to attach to the RSET benchmark and provide a stable surface for the GNSS antenna, eliminating the need for a tripod (Geoghegan et al. 2009).

Each USGS antenna adapter was mounted and secured to a RSET benchmark, and a GNSS receiver was placed on the USGS antenna adapter (Figure 4). To insure the GNSS antennas were collecting data directly above each RSET, the USGS antenna adapter was leveled

and the RSET benchmark tilt angle was measured using a digital clinometer. Measurements of the adapter were made in the field and the lab utilizing the methods described in Appendix B. New adapters were purchased in 2018, thus the length of adapters changed between the 2015-2016 surveys and the 2019 surveys. Antenna heights were calculated using angle-based computations outlined by Geoghegan et al. (2009). Antenna height calculations are available in Appendix C. It should be noted that all antenna heights in 2019 were measured from the bottom of the gray cap once it was attached and screwed on to the receiver. In order to account for this measurement discrepancy, a -0.035 m correction needed to be applied to the OPUS-s and OP solutions obtained in 2019.

Each GNSS receiver was configured using Trimble Access software on the Trimble TSC3 data collector following SOP 3 in Moorman and Rankin (*In Review*). The GNSS receiver serial number, USGS antenna adapter identification letter, RSET benchmark code, RSET benchmark tilt angle, angle-based calculations, antenna height, and survey time period were recorded for each session.

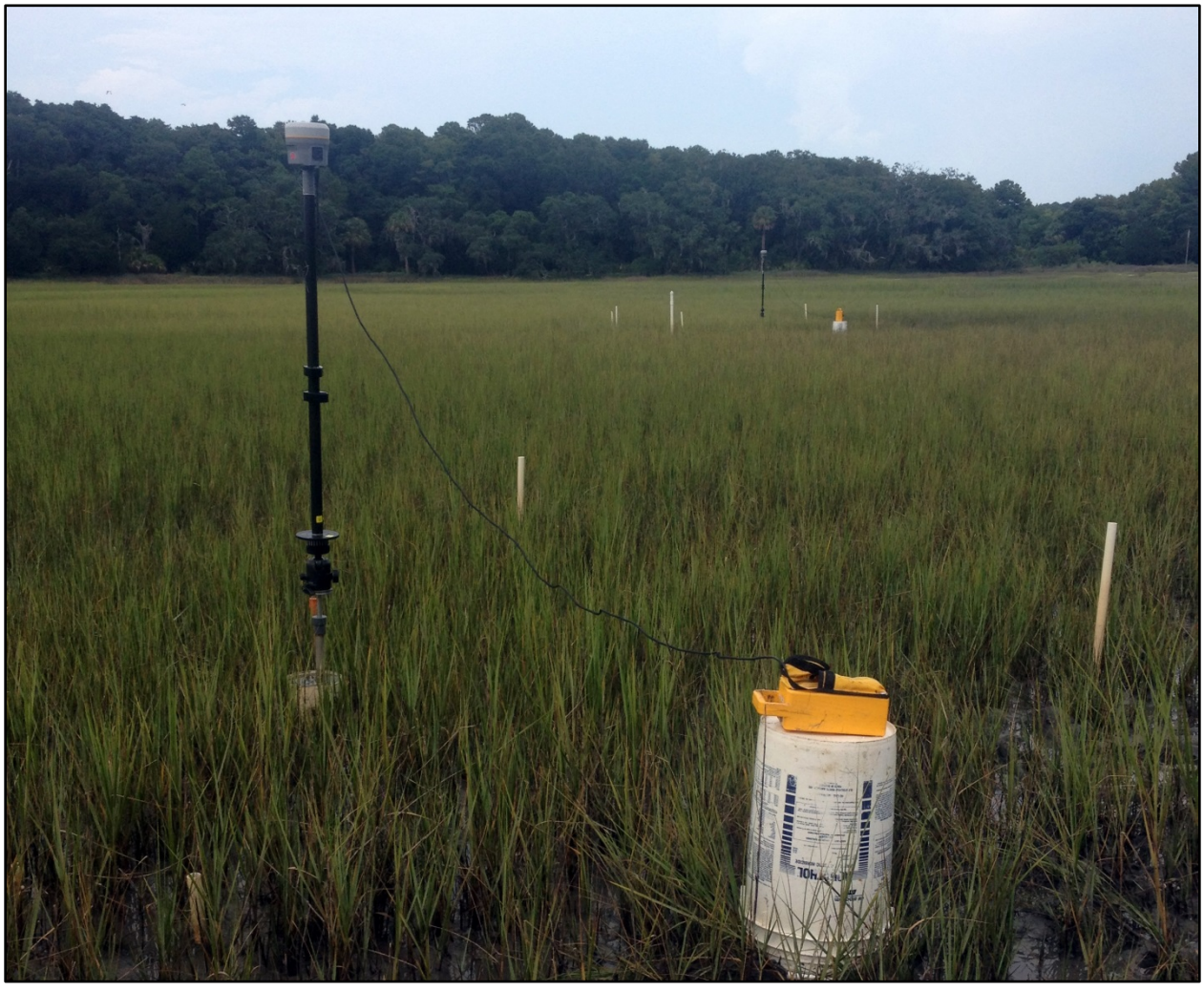

Figure 4. Setup on a RSET benchmark using the USGS antenna adapter, Trimble R10 GNSS receiver, and external battery at Pinckney Island NWR, SC CWEM site.

For each survey, all available GNSS receivers were set up to simultaneously record observations for a minimum of two, 4-6 hour sessions. For all of the sites except Pocosin Lakes NWR, these surveys used three simultaneously recording receivers (Table 2). It is recommended by the NGS to perform at least two GNSS surveys on each survey point on separate days at different times of day (start time at least three hours apart) to ensure different satellite geometry (Zilkoski et al. 1997; Gillins and Eddy 2016). Based on the remoteness of the CWEM sites, tidal fluctuations, need for adequate satellite conditions, in addition to other logistical factors, differing the start time of repeat sessions on subsequent days was not always feasible. While these survey characteristics are not optimal, they were the best that could be done given the difficult survey conditions that are present at the CWEM sites. One replicate survey was conducted at Pinckney Island NWR on all three benchmarks. The RSET sites at Pinckney Island NWR were re-surveyed in 2016 to determine whether the solutions from 2015 could be replicated and to determine whether three sequential days of surveying would provide a better elevation solution. A relative elevation survey also was conducted at this site using a total station to provide a check on the OPUS-S and OP solutions.

2.4 Data Processing

The GNSS data were post-processed using the OPUS-S and OP processing interfaces. OPUS-S and OP use the PAGES (Program for Adjustment of GPS Ephemerides) software to process baselines based on the NGS network's Continuously Operating Reference Stations (CORS) to calculate GNSS solutions for input marks. OPUS-S determines geodetic coordinates for survey points by using the mean of baseline solutions from three CORS sites that observed the same satellites during the survey period as the survey point.

OP allows for multiple sites (that were recording simultaneously) to be processed together in what are called session solutions; (Armstrong et al. 2015). These session solutions greatly increase the consistency of, and decrease the uncertainty in, the baseline solutions. OP also can combine session solutions into a network adjustment that can reduce the uncertainty in, and increase the consistency of, the GNSS solutions.

While OPUS-S projects allow for a lot of flexibility in the way that the data can be processed, this flexibility also creates a situation where there is an almost infinite number of ways to process the data and get horizontal/vertical location solutions. In order to provide consistent and repeatable results, the methods described in McDonald and Cooper (2018) were used to process the data. The methods used to process the GNSS survey data are briefly described below.

Initial OPUS Solutions

The data collected by each GNSS receiver were downloaded in their native .T02 format from each receiver using the TSC3 data collector and converted to the RINEX format using Trimble's Convert to RINEX tool. The Convert to RINEX tool converts the .T02 file into three text files. One of these text files, with extension .YYo (YY = last two digits of current year), is required by OPUS-S to calculate the initial (OPUS-S) solution. The .YYo files for each of the SET sites were uploaded to an OP and an OPUS-S solution was calculated.

Table 2. Site survey information for the GNSS surveys contained in this report.

Refuge Name	OP Group	Benchmark ID	Survey Date	Start Time	Stop Time	Occupation Time	Antenna Height (m)
Pea Island NWR	North	PLD010A	6/4/2015	8:36	16:25	7:49	1.275
Pea Island NWR	North	PLD010B	6/4/2015	9:30	16:15	6:45	1.274
Pea Island NWR	North	PLD010C	6/4/2015	9:45	16:05	6:20	1.275
Pea Island NWR	North	PLD010A	6/5/2015	8:30	15:30	7:00	1.275
Pea Island NWR	North	PLD010B	6/5/2015	8:51	15:18	6:27	1.275
Pea Island NWR	North	PLD010C	6/5/2015	9:07	15:07	6:00	1.275
Cedar Island NWR	North	CDR027A	6/8/2015	10:00	16:02	6:02	1.275
Cedar Island NWR	North	CDR027B	6/8/2015	9:45	16:08	6:23	1.275
Cedar Island NWR	North	CDR027C	6/8/2015	9:20	16:16	6:56	1.275
Cedar Island NWR	North	CDR027A	6/9/2015	8:13	14:15	6:02	1.275
Cedar Island NWR	North	CDR027B	6/9/2015	8:01	14:22	6:21	1.275
Cedar Island NWR	North	CDR027C	6/9/2015	7:47	14:27	6:40	1.275
Swanquarter NWR	North	SWQ000A	6/11/2015	10:00	16:45	6:45	1.275
Swanquarter NWR	North	SWQ000B	6/11/2015	10:16	16:39	6:23	1.275
Swanquarter NWR	North	SWQ000C	6/11/2015	10:30	16:31	6:01	1.275
Swanquarter NWR	North	SWQ000A	6/12/2015	8:44	15:02	6:18	1.275
Swanquarter NWR	North	SWQ000B	6/12/2015	8:25	14:57	6:32	1.275
Swanquarter NWR	North	SWQ000C	6/12/2015	8:38	14:50	6:12	1.275
Pocosin Lakes NWR	North	POC016A	6/23/2015	10:45	16:46	6:01	1.275
Pocosin Lakes NWR	North	POC016B	6/23/2015	10:15	17:00	6:45	1.275
Pocosin Lakes NWR	North	POC016B	6/24/2015	10:00	16:15	6:15	1.276
Pocosin Lakes NWR	North	POC016C	6/24/2015	10:05	16:05	6:00	1.275
Pocosin Lakes NWR	North	POC016A	6/25/2015	9:26	15:47	6:21	1.275
Pocosin Lakes NWR	North	POC016C	6/25/2015	9:39	15:41	6:02	1.275
Pinckney Island NWR	South	PKY008A	7/23/2015	11:09	17:21	6:12	1.275
Pinckney Island NWR	South	PKY008B	7/23/2015	10:57	17:29	6:32	1.275
Pinckney Island NWR	South	PKY008C	7/23/2015	11:15	17:36	6:21	1.275
Pinckney Island NWR	South	PKY008A	7/24/2015	10:25	16:47	6:22	1.275
Pinckney Island NWR	South	PKY008B	7/24/2015	10:08	16:29	6:21	1.275
Pinckney Island NWR	South	PKY008C	7/24/2015	9:55	17:08	7:13	1.275
Harris Neck NWR	South	HSN033A	7/28/2015	9:30	15:45	6:15	1.276
Harris Neck NWR	South	HSN033B	7/28/2015	9:17	16:00	6:43	1.276
Harris Neck NWR	South	HSN033C	7/28/2015	8:56	16:15	7:19	1.275
Harris Neck NWR	South	HSN033A	7/29/2015	8:34	14:34	6:00	1.275
Harris Neck NWR	South	HSN033B	7/29/2015	8:17	14:40	6:23	1.275
Harris Neck NWR	South	HSN033C	7/29/2015	8:00	14:50	6:50	1.275

Refuge Name	OP Group	Benchmark ID	Survey Date	Start Time	Stop Time	Occupation Time	Antenna Height (m)
Wassaw NWR	South	WSW001A	8/5/2015	9:56	16:57	7:01	1.275
Wassaw NWR	South	WSW001B	8/5/2015	10:17	16:46	6:29	1.275
Wassaw NWR	South	WSW001C	8/5/2015	10:33	16:39	6:06	1.275
Wassaw NWR	South	WSW001A	8/6/2015	8:14	15:30	7:16	1.276
Wassaw NWR	South	WSW001B	8/6/2015	8:32	15:40	7:08	1.275
Wassaw NWR	South	WSW001C	8/6/2015	8:47	15:45	6:58	1.275
Savannah NWR	South	SAV004A	3/16/2016	9:45	15:47	6:02	1.277
Savannah NWR	South	SAV004B	3/16/2016	9:19	15:53	6:34	1.277
Savannah NWR	South	SAV004C	3/16/2016	9:36	15:58	6:22	1.279
Pinckney Island NWR	South	PKY008A	5/3/2016	9:16	15:17	6:01	1.279
Pinckney Island NWR	South	PKY008B	5/3/2016	8:57	15:23	6:26	1.277
Pinckney Island NWR	South	PKY008C	5/3/2016	8:37	15:32	6:55	1.277
Pinckney Island NWR	South	PKY008A	5/4/2016	9:33	15:34	6:01	1.279
Pinckney Island NWR	South	PKY008B	5/4/2016	9:23	15:46	6:23	1.277
Pinckney Island NWR	South	PKY008C	5/4/2016	8:52	15:58	7:06	1.277
Pinckney Island NWR	South	PKY008A	5/5/2016	10:21	16:29	6:08	1.279
Pinckney Island NWR	South	PKY008B	5/5/2016	10:00	17:04	7:04	1.277
Pinckney Island NWR	South	PKY008C	5/5/2016	9:44	16:43	6:59	1.277
Savannah NWR	South	SAV004A	6/28/2016	8:42	15:41	6:59	1.278
Savannah NWR	South	SAV004B	6/28/2016	9:04	15:35	6:31	1.278
Savannah NWR	South	SAV004C	6/28/2016	9:22	15:29	6:07	1.277
St Marks NWR	Down	SMK000A	7/6/2016	10:28	17:46	7:18	1.278
St Marks NWR	Down	SMK000B	7/6/2016	11:01	17:40	6:39	1.278
St Marks NWR	Down	SMK000C	7/6/2016	11:31	17:33	6:02	1.277
St Marks NWR	Down	SMK000A	7/7/2016	9:26	16:31	7:05	1.279
St Marks NWR	Down	SMK000B	7/7/2016	9:55	16:26	6:31	1.276
St Marks NWR	Down	SMK000C	7/7/2016	10:20	16:21	6:01	1.277
Alligator River NWR	North	ALL005A	7/20/2016	10:17	17:59	7:42	1.277
Alligator River NWR	North	ALL005B	7/20/2016	10:03	17:04	7:01	1.276
Alligator River NWR	North	ALL005C	7/20/2016	9:49	17:08	7:19	1.278
Alligator River NWR	North	ALL005A	7/21/2016	10:03	16:04	6:01	1.274
Alligator River NWR	North	ALL005B	7/21/2016	9:52	16:10	6:18	1.275
Alligator River NWR	North	ALL005C	7/21/2016	9:42	16:14	6:32	1.277

Refuge Name	OP Group	Benchmark ID	Survey Date	Start Time	Stop Time	Occupation Time	Antenna Height (m)
Currituck NWR	North	CRT026A	7/26/2016	10:14	7:30	21:15	1.278
Currituck NWR	North	CRT026B	7/26/2016	9:25	7:20	21:55	2.237
Currituck NWR	North	CRT026C	7/26/2016	10:43	16:45	6:02	1.277
Currituck NWR	North	CRT026A	7/28/2016	8:43	15:22	6:39	1.277
Currituck NWR	North	CRT026B	7/28/2016	8:18	15:28	7:10	2.236
Currituck NWR	North	CRT026C	7/28/2016	9:13	15:15	6:02	1.278
Waccamaw NWR	Center	WAW000A	8/9/2016	9:37	16:36	6:59	1.276
Waccamaw NWR	Center	WAW000B	8/9/2016	9:55	16:31	6:36	2.235
Waccamaw NWR	Center	WAW000C	8/9/2016	10:23	16:26	6:03	1.276
Waccamaw NWR	Center	WAW000A	8/10/2016	8:35	15:10	6:35	1.280
Waccamaw NWR	Center	WAW000B	8/10/2016	8:45	15:04	6:19	2.235
Waccamaw NWR	Center	WAW000C	8/10/2016	8:59	15:00	6:01	1.277
Wolf Island NWR	South	WLF035A	8/17/2016	8:48	14:50	6:02	1.281
Wolf Island NWR	South	WLF035B	8/17/2016	8:38	14:54	6:16	1.278
Wolf Island NWR	South	WLF035C	8/17/2016	8:22	14:59	6:37	1.278
Wolf Island NWR	South	WLF035A	8/25/2016	8:33	15:11	6:38	1.279
Wolf Island NWR	South	WLF035B	8/25/2016	8:47	15:02	6:15	1.278
Wolf Island NWR	South	WLF035C	8/25/2016	8:55	14:56	6:01	1.278
Blackbeard Island	South	BLB011A	8/18/2016	11:14	18:53	7:39	1.279
Blackbeard Island	South	BLB011B	8/18/2016	11:34	18:41	7:07	1.277
Blackbeard Island	South	BLB011C	8/18/2016	11:50	18:33	6:43	1.277
Blackbeard Island	South	BLB011A	8/19/2016	7:09	14:06	6:57	1.278
Blackbeard Island	South	BLB011B	8/19/2016	7:32	13:58	6:26	1.278
Blackbeard Island	South	BLB011C	8/19/2016	7:44	13:52	6:08	1.284
Ace Basin NWR	Center	ABS017A	3/12/2019	18:29	1:23	6:54	1.2560*
Ace Basin NWR	Center	ABS017A	3/13/2019	20:08	2:52	6:44	1.2560*
Ace Basin NWR	Center	ABS017B	3/12/2019	18:14	1:28	7:14	1.2556*
Ace Basin NWR	Center	ABS017B	3/13/2019	20:04	3:03	6:59	1.2556*
Ace Basin NWR	Center	ABS017C	3/12/2019	17:59	0:44	6:45	1.2537*
Ace Basin NWR	Center	ABS017C	3/13/2019	19:58	2:46	6:48	1.2566*
Alligator River	North	ALL030A	3/7/2019	13:25	18:25	5:00	1.2532*
Alligator River	North	ALL030A	4/4/2019	16:23	21:13	4:50	1.2550*
Alligator River	North	ALL030B	3/7/2019	13:37	18:01	4:24	1.2529*
Alligator River	North	ALL030B	4/4/2019	16:35	21:06	4:31	1.2551*
Alligator River	North	ALL030C	3/7/2019	13:11	18:28	5:17	1.2521*
Alligator River	North	ALL030C	4/4/2019	16:08	21:03	4:55	1.2544*

*Antenna height measured from bottom of gray cap; a -0.035 m correction was applied to elevation solution.

Refuge Name	OP Group	Benchmark ID	Survey Date	Start Time	Stop Time	Occupation Time	Antenna Height (m)
Mackay Island	North	MCI026A	4/16/2019	17:28	23:22	5:54	1.2535*
Mackay Island	North	MCI026A	4/17/2019	14:17	20:09	5:52	1.2535*
Mackay Island	North	MCI026B	4/16/2019	17:45	0:34	6:49	1.2528*
Mackay Island	North	MCI026B	4/17/2019	14:12	20:05	5:53	1.2528*
Mackay Island	North	MCI026C	4/16/2019	17:55	0:39	6:44	1.2538*
Mackay Island	North	MCI026C	4/17/2019	14:06	20:00	5:54	1.2538*
Roanoke River	North	RRV013A	3/18/2019	18:50	1:25	6:35	1.2553*
Roanoke River	North	RRV013A	3/19/2019	14:42	19:42	5:00	1.2553*
Roanoke River	North	RRV013B	3/18/2019	18:33	23:50	5:17	1.2538*
Roanoke River	North	RRV013B	3/19/2019	14:56	19:59	5:03	1.2543*
Roanoke River	North	RRV013C	3/18/2019	18:16	0:45	6:29	1.2544*
Roanoke River	North	RRV013C	3/19/2019	15:05	20:07	5:02	1.2543*

*Antenna height measured from bottom of gray cap; a -0.035 m (3.5 cm) correction is applied to elevation solution.

OPUS Session and Network Processing

As suggested in Armstrong et al. (2015) and outlined in McDonald and Cooper (2019), the session solutions were created using a hub-style setup. This hub-style setup includes at least five CORS sites within 150 km (one of which is designated as the hub) and three distant (>350 km and less than 800 km distant from each site) CORS sites (Table 3). For each session solution, a CORS site within 150 km of the RSETs being processed was used as the hub to calculate the corrected baselines. Only high quality CORS were used to create the location solutions. Constraint ratios were calculated for each CORS and only those that fluctuated less than 3 standard deviations from their published coordinates were included in the OP solutions (Gillins and Eddy 2016; McDonald and Cooper 2019).

While processing the session solutions, the hub was the only site constrained (normal 3-D constraint). Normal constraints were chosen because there is evidence that TIGHT constraints (which used to be the default) may create baseline solutions that are too rigid and don't take into account the natural variability inherent in GNSS solutions (Gillins and Eddy, 2016). Tropospheric interference was corrected for using a piece-wise linear model with a correction interval of 7,200 seconds as suggested in during the OPUS-S projects training. The distant CORS sites were included to provide additional corrections for any tropospheric interference (Table 3).

Once the session solutions were calculated, network adjustments were created by combining the session solutions. When performing the network adjustments, all of the near CORS stations (including the hub) were constrained horizontally and vertically (normal 3-D constraint) and all of the distant CORS stations were left unconstrained (NONE). For the session solutions and network adjustments, output reference frame and geoid models were chosen by OPUS-S.

Data Security and Archiving

A copy of all field data, raw GNSS files, and OPUS-S Solutions was archived in the FWS Service Catalog (ServCat) under the Coastal Wetland Elevation Monitoring (CWEM) Benchmark Elevation Surveys project: reference code #102976. Raw data and OPUS-S data for each individual refuge site was stored as a unique record in ServCat under this project. This report, an archive of all the code and results from OPUS-S projects and other accompanying files were archived under ServCat reference code #114204. Additionally, the final elevations reported in Table 4 have been entered, in millimeters, into the USFWS RSET database.

Table 3. Continuously Operating Reference Stations (CORS) sites used to create the session solutions and network adjustments in Opus Projects (OP). OP groups are specified in Table 2. See Appendix A for CORS quality analysis.

OP Group	North	Center	South	Down
Hub	NCDU	NCSL	ZJX1	TALH
Near	NCET	COLA	COLA	BRTW
	NCGO	NCCH	GAAT	CRST
	NCJA	NCET	GACR	DLND
	NCJV	NCKN	SCWT	GACR
	NCSF	NCPO	TALH	MCD6
	-	NCWH	ZTL4	PLTK
	-	SCWT	-	XCTY
	-	-	-	ZTL4
Distant	NCSH	NCDU	KYTC	GRIS
	PASS	SCGP	NCDU	NCSL
	SCWT	ZJX1	-	ZMA1

3. Results

A final vertical and horizontal solution was obtained for 16 of the 18 sites surveyed. We accepted the network solution as the final vertical solution for all of the stations sampled. These solutions, along with the computed northing and easting values are reported in Table 4. The Orthometric Heights in millimeters reported are the vertical heights that were reported in the USFWS RSET database. 'NS' indicates that no solution could be acquired.

Table 4. Vertical and horizontal results for all RSET benchmark surveys completed, 2015-2019.

Refuge	Station	Northing (m)	Easting (m)	UTM Zone	Orthometric Height (m)	Orthometric Height (mm)	Year of Survey
Ace Basin	ABS017A	3613453.8	557341.5	17	1.067	1067	2019
Ace Basin	ABS017B	3613447.0	557330.5	17	1.136	1136	2019
Ace Basin	ABS017C	3613443.5	557311.7	17	1.095	1095	2019
Alligator River	ALL005A	3939986.1	419047.6	18	0.451	451	2016
Alligator River	ALL005B	3939986.1	419047.6	18	0.43	430	2016

Refuge	Station	Northing (m)	Easting (m)	UTM Zone	Orthometric Height (m)	Orthometric Height (mm)	Year of Survey
Alligator River	ALL005C	3940004.1	419107.4	18	0.441	441	2016
Alligator River	ALL030A	NS	NS	18	NS	NS	2019
Alligator River	ALL030B	NS	NS	18	NS	NS	2019
Alligator River	ALL030C	NS	NS	18	NS	NS	2019
Blackbeard Island	BLB011A	3485756.0	480281.4	17	0.955	955	2016
Blackbeard Island	BLB011B	3485836.8	480292.4	17	0.976	976	2016
Blackbeard Island	BLB011C	3485867.6	480285.5	17	1.182	1182	2016
Cedar Island	CDR027A	3866865.1	376190.0	18	0.541	541	2015
Cedar Island	CDR027B	3866907.4	376201.5	18	0.565	565	2015
Cedar Island	CDR027C	3866942.3	376209.5	18	0.616	616	2015
Currituck	CRT026A	4032051.1	423665.4	18	0.385	385	2016
Currituck	CRT026B	4032066.4	423701.6	18	0.371	371	2016
Currituck	CRT026C	4032032.5	423647.7	18	0.356	356	2016
Harris Neck	HSN033A	3500121.7	473256.6	17	1.157	1157	2015
Harris Neck	HSN033B	3500103.9	473252.8	17	1.148	1148	2015
Harris Neck	HSN033C	3500038.4	473266.3	17	1.163	1163	2015
Mackay Island	MCI026A	4044227.7	414693.8	18	0.437	437	2019
Mackay Island	MCI026B	4044228.6	414657.4	18	0.359	359	2019
Mackay Island	MCI026C	4044235.1	414632.3	18	0.415	415	2019
Pea Island	PLD010A	3945509.8	456573.6	18	0.635	635	2015
Pea Island	PLD010B	3945546.6	456560.9	18	0.632	632	2015
Pea Island	PLD010C	3945573.4	456550.1	18	0.627	627	2015
Pinckney Island	PKY008A	3569748.4	522450.7	17	1.017	1017	2016
Pinckney Island	PKY008B	3569758.6	522475.1	17	1.047	1047	2016
Pinckney Island	PKY008C	3569762.4	522501.7	17	1.077	1077	2016
Pocosin Lakes	POC016A	3955803.2	377976.0	18	3.325	3325	2015
Pocosin Lakes	POC016B	3955801.2	378010.1	18	3.227	3227	2015
Pocosin Lakes	POC016C	3955808.6	377956.1	18	3.62	3620	2015
Roanoke River	RRV013A	NS	NS	18	NS	NS	2019
Roanoke River	RRV013B	NS	NS	18	NS	NS	2019
Roanoke River	RRV013C	NS	NS	18	NS	NS	2019
Savannah	SAV004A	3559822.5	488313.2	17	1.338	1338	2016
Savannah	SAV004B	3559840.8	488313.7	17	1.327	1327	2016
Savannah	SAV004C	3559863.4	488306.1	17	1.282	1282	2016
St Marks	SMK000A	3334963.7	765170.1	16	0.846	846	2016
St Marks	SMK000B	3335012.6	765198.0	16	0.876	876	2016
St Marks	SMK000C	3335030.7	765161.8	16	0.883	883	2016
Swanquarter	SWQ000A	3913531.4	384999.1	18	0.299	299	2015

Refuge	Station	Northing (m)	Easting (m)	UTM Zone	Orthometric Height (m)	Orthometric Height (mm)	Year of Survey
Swanquarter	SWQ000B	3913554.1	384990.5	18	0.317	317	2015
Swanquarter	SWQ000C	3913583.8	384981.7	18	0.29	290	2015
Waccamaw	WAW000A	3711959.2	675729.4	17	0.808	808	2016
Waccamaw	WAW000B	3711913.7	675708.2	17	0.88	880	2016
Waccamaw	WAW000C	3711889.8	675703.6	17	0.845	845	2016
Wassaw	WSW001A	3526707.4	500477.2	17	1.076	1076	2015
Wassaw	WSW001B	3526725.9	500461.6	17	1.02	1020	2015
Wassaw	WSW001C	3526702.4	500455.8	17	1.002	1002	2015
Wolf Island	WLF035A	3465982.2	470077.3	17	1.345	1345	2016
Wolf Island	WLF035B	3466013.9	470046.7	17	1.272	1272	2016
Wolf Island	WLF035C	3466025.3	470024.2	17	1.28	1280	2016

The results of the OPUS-S and OP solutions for individual stations are presented in the following sections. Each section provides additional details about the results presented in Table 4. Three tables of site-specific data are provided that explain the quality of the solution for the GNSS survey. The **Quality of the solution for the GNSS survey** provides information that will allow the user to assess the quality of the solution provided. **Average Position Solutions** reports position solutions from OPUS-S and OP projects for the stations at each site. **Distances between RSET stations** provides a comparison of the vertical and horizontal distances between a pair of stations computed using OPUS-S and OP solutions. Further explanation of the table headings and variables is included in Appendix D. These site-specific data are provided to allow the user to interpret the quality and consistency of the solutions provided for each of the stations that were surveyed. For example, root mean squared (RMS) errors and the standard error (SE) of the solutions provide an understanding of the relative fit of the solution. A low RMS and a standard error close to 1 suggest higher accuracy and precision of the solution. Although it should be noted that almost invariably the OP solutions will have lower RMS errors. When session solutions have a higher RMS than the OPUS-S solutions, that is because there is a low-precision solution included.

The stations at Pinckney Island NWR were surveyed in 2015 and 2016 to provide replicate data. A relative elevation survey also was conducted. The 2015 and 2016 solutions from Pinckney Island were presented separately to provide an understanding of the consistency of the solutions.

3.1 Pea Island NWR: Site POC016 (PLD)

The PLD surveys took place on June 4th and 5th, 2015. The RSET sites were simultaneously surveyed for 6.33 hr on the 4th and for 6 hrs on the 5th. On both survey days, the observed values used (Obs %) were well within the recommended range of values (Table 5). On the second survey day, the percent of observations that were fixed (Fixed %) for PLDc was much lower than the other RSETs. The SE for the second OP-session solution also was low. All solutions had RMS values well within the recommend range of values (< 0.02 m).

The estimated uncertainties for the position northing and easting solutions for PLDc were relatively high for both survey days (Table 6). The northing error for PLDb on the first survey day also was relatively high. The differences between northing, easting, and ellipsoid heights for the averaged OPUS-S versus OP network solutions were all less than 1 cm. The OPUS-S and OP network differences in distances (horizontal and vertical) between benchmarks also were less than 1 cm (Table 7). A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the PLD RSETs.

Table 5. Quality of the solutions for the GNSS survey conducted at PLD.

Id	SET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	plda	6/4/2015	95	94	-	0.019
OPUS-S 2	plda	6/5/2015	96	97	-	0.019
Session 1	plda	PLD1	98	98	1.05	0.016
Session 2	plda	PLD2	99	100	0.72	0.015
Network 1	plda	PLD	99	99	0.91	0.015
OPUS-S 1	pldb	6/4/2015	97	94	-	0.017
OPUS-S 2	pldb	6/5/2015	98	97	-	0.018
Session 1	pldb	PLD1	99	100	1.05	0.016
Session 2	pldb	PLD2	100	100	0.72	0.015
Network 1	pldb	PLD	99	100	0.91	0.016
OPUS-S 1	pldc	6/4/2015	97	98	-	0.018
OPUS-S 2	pldc	6/5/2015	98	76	-	0.017
Session 1	pldc	PLD1	99	100	1.05	0.015
Session 2	pldc	PLD2	99	100	0.72	0.016
Network 1	pldc	PLD	99	100	0.91	0.015

Table 6. Average position solutions for the PLD RSET sites.

Id	SET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	plda	3945509.795	0.005	456573.640	0.008	-38.174	0.011	0.641	0.028
OPUS-S2	plda	3945509.781	0.002	456573.633	0.007	-38.183	0.002	0.632	0.025
aOPUS-S	plda	3945509.788	0.004	456573.637	0.008	-38.179	0.007	0.637	0.027
Network	plda	3945509.791	0.001	456573.642	0.000	-38.180	0.002	0.635	0.015
Range	plda	0.003	-0.003	0.005	-0.008	-0.002	-0.005	-0.002	-0.012
OPUS-S1	pldb	3945546.646	0.020	456560.928	0.009	-38.176	0.007	0.640	0.026
OPUS-S2	pldb	3945546.637	0.000	456560.933	0.009	-38.195	0.007	0.621	0.026
aOPUS-S	pldb	3945546.642	0.010	456560.931	0.009	-38.186	0.007	0.631	0.026
Network	pldb	3945546.637	0.001	456560.933	0.000	-38.184	0.002	0.632	0.015
Range	pldb	-0.004	-0.009	0.003	-0.009	0.002	-0.005	0.001	-0.011
OPUS-S1	pldc	3945573.433	0.019	456550.102	0.008	-38.182	0.011	0.634	0.028
OPUS-S2	pldc	3945573.438	0.024	456550.112	0.030	-38.185	0.006	0.631	0.026
aOPUS-S	pldc	3945573.436	0.022	456550.107	0.019	-38.184	0.009	0.633	0.027
Network	pldc	3945573.434	0.001	456550.103	0.000	-38.189	0.002	0.627	0.015
Range	pldc	-0.002	-0.021	-0.004	-0.019	-0.005	-0.007	-0.006	-0.012

Table 7. Distances between PLD RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	38.982	38.976	-0.006	0.007	0.004	-0.003
a to c	67.858	67.857	-0.001	0.005	0.009	0.004
b to c	28.898	28.903	0.005	-0.002	0.005	0.007

3.2 Cedar Island NWR: Site CDR027 (CDR)

The CDR surveys took place on June 8th and 9th, 2015. The RSET sites were simultaneously surveyed for six hr on the 8th and for six hrs on the 9th. On both survey days, the observed values used (Obs %) and the percent of observations that were fixed (Fixed %) were well within the recommended range of values (Table 8). The SE for the first OP-session solution was slightly lower than optimal but well within the acceptable range of SEs. All solutions, except for CDRa and CDRc's second day, had RMS values within the recommend range of values (< 0.02 m).

The estimated uncertainties for the position elevation solutions for all three RSETs were relatively high on both survey days (Table 9). The northing error for PLDc was relatively high on both survey days on the easting error was relatively high on the second survey day. The northing error for PLDb on the first survey day was also relatively high. The differences between northing, easting, and ellipsoid heights for the averaged OPUS-S versus OP network solutions were all less than 1 cm. The OPUS-S and OP network differences in distances (horizontal and vertical) between benchmarks were less than 1.5 cm (Table 10). A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the CDR RSETs.

Table 8. Quality of the solutions for the GNSS survey conducted at CDR.

Id	SET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	cdra	6/8/2015	97	94	-	0.019
OPUS-S 2	cdra	6/9/2015	98	92	-	0.020
Session 1	cdra	CDR1	99	100	0.82	0.017
Session 2	cdra	CDR2	100	100	1.03	0.019
Network 1	cdra	CDR	100	100	0.93	0.018
OPUS-S 1	cdrb	6/8/2015	96	91	-	0.017
OPUS-S 2	cdrb	6/9/2015	98	88	-	0.018
Session 1	cdrb	CDR1	100	100	0.82	0.015
Session 2	cdrb	CDR2	99	97	1.03	0.016
Network 1	cdrb	CDR	99	99	0.93	0.015
OPUS-S 1	cdrc	6/8/2015	95	92	-	0.018
OPUS-S 2	cdrc	6/9/2015	95	86	-	0.020
Session 1	cdrc	CDR1	99	97	0.82	0.015
Session 2	cdrc	CDR2	99	94	1.03	0.017
Network 1	cdrc	CDR	99	96	0.93	0.016

Table 9. Average position solutions for the CDR RSET sites.

Id	SET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	cdra	3866865.148	0.005	376190.016	0.009	-37.253	0.013	0.537	0.028
OPUS-S2	cdra	3866865.145	0.011	376190.021	0.005	-37.237	0.019	0.553	0.032
aOPUS-S	cdra	3866865.147	0.008	376190.019	0.007	-37.245	0.016	0.545	0.030
Network	cdra	3866865.148	0.001	376190.018	0.000	-37.249	0.002	0.541	0.015
Range	cdra	0.002	-0.007	-0.001	-0.007	-0.004	-0.014	-0.004	-0.015
OPUS-S1	cdrb	3866907.415	0.025	376201.538	0.009	-37.228	0.008	0.562	0.027
OPUS-S2	cdrb	3866907.413	0.006	376201.527	0.001	-37.232	0.018	0.558	0.031
aOPUS-S	cdrb	3866907.414	0.016	376201.533	0.005	-37.230	0.013	0.560	0.029
Network	cdrb	3866907.409	0.001	376201.537	0.000	-37.225	0.002	0.565	0.015
Range	cdrb	-0.005	-0.015	0.005	-0.005	0.005	-0.011	0.005	-0.014
OPUS-S1	cdrc	3866942.353	0.021	376209.516	0.005	-37.175	0.011	0.615	0.028
OPUS-S2	cdrc	3866942.350	0.019	376209.511	0.017	-37.156	0.024	0.634	0.035
aOPUS-S	cdrc	3866942.352	0.020	376209.514	0.011	-37.166	0.018	0.625	0.032
Network	cdrc	3866942.342	0.001	376209.515	0.000	-37.174	0.002	0.616	0.015
Range	cdrc	-0.009	-0.019	0.002	-0.011	-0.009	-0.016	-0.009	-0.017

Table 10. Distances between CDR RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	43.808	43.803	-0.005	-0.015	-0.024	-0.009
a to c	79.628	79.618	-0.010	-0.079	-0.075	0.004
b to c	35.837	35.832	-0.005	-0.064	-0.051	0.013

3.3 Swanquarter NWR: Site SWQ000 (SWQ)

The SWQ surveys took place on June 11th and 12th, 2015. The RSET sites were simultaneously surveyed for 6 hr on the 11th and for 6.1 hrs on the 12th. On both survey days, the observed values used (Obs %) and the percent of observations that were fixed (Fixed %) were well within the recommended range of values (Table 11). The SE for the first OP-session solution was relatively low and all were less than 1.00 +/- 0.10. All solutions had RMS values within the recommend range of values (< 0.02 m).

The estimated uncertainties for the position northing and elevation solutions for all three SETs were relatively high on the second survey day (Table 12). The elevation error for SWQb and SWQc also were relatively high on the first survey day. The differences between northings and eastings for the averaged OPUS-S versus OP network solutions were all less than 0.5 cm. The differences between the OPUS-S and OP network elevation solutions were all greater than 1.5 cm. The OPUS-S and OP network differences in distances (horizontal and vertical) between benchmarks were less than 1 cm (Table 13). A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the SWQ RSETs.

Table 11. Quality of the solutions for the GNSS survey conducted at SWQ.

Id	SET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	swqa	6/11/2015	96	92	-	0.019
OPUS-S 2	swqa	6/12/2015	97	95	-	0.019
Session 1	swqa	SWQ1	100	100	0.79	0.016
Session 2	swqa	SWQ2	100	100	0.89	0.015
Network 1	swqa	SWQ	100	100	0.85	0.016
OPUS-S 1	swqb	6/11/2015	98	95	-	0.018
OPUS-S 2	swqb	6/12/2015	95	95	-	0.018
Session 1	swqb	SWQ1	99	100	0.79	0.016
Session 2	swqb	SWQ2	98	100	0.89	0.016
Network 1	swqb	SWQ	99	100	0.85	0.016
OPUS-S 1	swqc	6/11/2015	99	95	-	0.019
OPUS-S 2	swqc	6/12/2015	97	98	-	0.019
Session 1	swqc	SWQ1	100	100	0.79	0.018
Session 2	swqc	SWQ2	99	100	0.89	0.016
Network 1	swqc	SWQ	99	100	0.85	0.017

Table 12. Average position solutions for the SWQ RSET sites.

Id	RSET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	swqa	3913531.395	0.006	384999.053	0.008	-37.742	0.007	0.314	0.026
OPUS-S2	swqa	3913531.401	0.031	384999.053	0.007	-37.727	0.018	0.329	0.031
aOPUS-S	swqa	3913531.398	0.019	384999.053	0.008	-37.735	0.013	0.322	0.029
Network	swqa	3913531.396	0.000	384999.055	0.000	-37.757	0.001	0.299	0.015
Range	swqa	-0.002	-0.019	0.002	-0.008	-0.023	-0.012	-0.023	-0.014
OPUS-S1	swqb	3913554.101	0.008	384990.536	0.003	-37.712	0.013	0.344	0.028
OPUS-S2	swqb	3913554.094	0.030	384990.545	0.006	-37.717	0.015	0.339	0.029
aOPUS-S	swqb	3913554.098	0.019	384990.541	0.005	-37.715	0.014	0.342	0.029
Network	swqb	3913554.097	0.000	384990.544	0.000	-37.739	0.001	0.317	0.015
Range	swqb	-0.001	-0.019	0.003	-0.005	-0.024	-0.013	-0.025	-0.014
OPUS-S1	swqc	3913583.766	0.004	384981.687	0.009	-37.761	0.012	0.295	0.028
OPUS-S2	swqc	3913583.776	0.029	384981.681	0.006	-37.739	0.023	0.317	0.034
aOPUS-S	swqc	3913583.771	0.017	384981.684	0.008	-37.750	0.018	0.306	0.031
Network	swqc	3913583.769	0.000	384981.686	0.000	-37.766	0.002	0.290	0.015
Range	swqc	-0.002	-0.017	0.002	-0.008	-0.016	-0.016	-0.016	-0.016

Table 13. Distances between SWQ RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	24.243	24.244	0.001	-0.020	-0.018	0.002
a to c	55.178	55.178	0.000	0.016	0.009	-0.007
b to c	30.967	30.966	-0.001	0.035	0.027	-0.008

3.4 Pocosin Lakes NWR: Site POC016 (POC)

The POC surveys took place on June 23rd, 24th, and 25th 2015. Only two R10 receivers were available so only two RSETs were surveyed on each survey day. All of the surveys were for 6 hrs. On the 23rd, POCa and POCb were surveyed, on the 24th, POCb and POCc were surveyed, and on the 25th, POCa and POCc were surveyed. On both survey days, the observed values used (Obs %) and the percent of observations that were fixed (Fixed %) were within the recommended range of values (Table 14). Though the Fixed (%) of POCc were within the recommend range of values, they were quite low and nearly low enough to throw out. The SEs for the OP solutions were relatively good. In addition to the low Fixed (%), POCc also had relatively high RMS values (> 0.02 m).

The estimated uncertainties for the position solutions (northings, eastings, and elevations) for POCc were relatively high on both survey days (Table 15). The elevation errors on both survey days also were high for POCa. POCb, had a high elevation error on the first day, and a high northing error on the second day. The differences between northings and eastings for the averaged OPUS-S versus OP network solutions were all less than 0.5 cm. The differences between the OPUS-S and OP network elevation solutions were all greater than 1 cm and for POCa and POCb were greater than 2.5 m. The OPUS-S and OP network differences in horizontal distances between benchmarks were less than 1 cm (Table 16). The elevation differences were high for “a to c” and “b to c”. A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the POC SETs.

Table 14. Quality of the solutions for the GNSS survey conducted at POC.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	poca	6/23/2015	88	84	-	0.019
OPUS-S 2	poca	6/25/2015	93	82	-	0.019
Session 1	poca	POC1	98	100	0.89	0.016
Session 2	poca	POC3	99	92	1.02	0.017
Network 1	poca	POC	98	97	0.99	0.016
OPUS-S 1	pocb	6/23/2015	92	90	-	0.019
OPUS-S 2	pocb	6/24/2015	89	80	-	0.020
Session 1	pocb	POC1	97	98	0.89	0.018
Session 2	pocb	POC2	96	100	1.02	0.018
Network 1	pocb	POC	97	99	0.99	0.018
OPUS-S 1	pocc	6/24/2015	74	79	-	0.026
OPUS-S 2	pocc	6/25/2015	76	83	-	0.025
Session 1	pocc	POC2	96	100	1.02	0.024
Session 2	pocc	POC3	99	92	1.02	0.025
Network 1	pocc	POC	75	95	0.99	0.024

Table 15. Average position solutions for the POC RSET sites.

Id	SET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	poca	3955803.175	0.024	377976.002	0.009	-34.415	0.027	3.354	0.037
OPUS-S2	poca	3955803.168	0.004	377976.006	0.008	-34.401	0.044	3.368	0.051
aOPUS-S	poca	3955803.172	0.014	377976.004	0.009	-34.408	0.036	3.361	0.044
Network	poca	3955803.171	0.001	377976.004	0.000	-34.444	0.002	3.325	0.015
Range	poca	-0.001	-0.013	0.000	-0.009	-0.036	-0.034	-0.036	-0.029
OPUS-S1	pocb	3955801.218	0.009	378010.097	0.004	-34.509	0.021	3.261	0.033
OPUS-S2	pocb	3955801.230	0.021	378010.099	0.012	-34.517	0.004	3.253	0.026
aOPUS-S	pocb	3955801.224	0.015	378010.098	0.008	-34.513	0.013	3.257	0.030
Network	pocb	3955801.225	0.001	378010.100	0.000	-34.543	0.002	3.227	0.015
Range	pocb	0.001	-0.014	0.002	-0.008	-0.030	-0.011	-0.030	-0.015
OPUS-S1	pocc	3955808.630	0.024	377956.113	0.022	-34.157	0.031	3.611	0.040
OPUS-S2	pocc	3955808.632	0.019	377956.136	0.016	-34.112	0.068	3.656	0.072
aOPUS-S	pocc	3955808.631	0.022	377956.125	0.019	-34.135	0.050	3.634	0.056
Network	pocc	3955808.628	0.001	377956.125	0.000	-34.148	0.002	3.620	0.015
Range	pocc	-0.003	-0.021	0.000	-0.019	-0.014	-0.048	-0.014	-0.041

Table 16. Distances between POC SET sites.

SETs	Distance OPUS (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS (m)	Elevation Network (m)	Elevation Difference (m)
a to b	34.150	34.151	0.002	0.105	0.099	-0.006
a to c	20.616	20.614	-0.001	-0.273	-0.296	-0.023
b to c	54.479	54.480	0.001	-0.378	-0.395	-0.017

3.5 Pinckney Island NWR: Site PKY008 (PKY)

The SETs at PKY were surveyed twice. The first survey took place over two days (July 23rd and 24th, 2015) and the second survey was done over the course of three days (May 3rd through 5th, 2016). Additionally, a total station was setup on a high point outside of the salt marsh and was used to determine the relative elevation between the RSETs. On the 23rd, the RSETs were simultaneously surveyed for 6.2 hrs. On the 24th, the RSETs were simultaneously surveyed for 6 hrs. For the 2016 surveys, all of the RSETs were simultaneously surveyed for 6 hrs on all three survey days. On both 2015 survey days, the observed values used (Obs %) and the percent of observations that were fixed (Fixed %) were within the recommended range of values (Table 17). Though the Fixed (%) of PKYb were within the recommend range of values, OP-session 1 had a relatively low value. The SEs for the OP solutions were relatively high; especially OP-session 1. The RMS values for all of the solutions were relatively high. On all three 2016 surveys days, the observed values used (Obs %) were within the recommended range of values (Table 17). Each RSET had at least one day during which the Fixed (%) was relatively low. The OP solution SEs were relatively good, except for OP-session 5. Similar to the 2015 solutions, the RMS values for each RSET and for each solution were relatively high.

The estimated uncertainties for the 2015 position solutions (northings, eastings, and elevations) were relatively high on the first survey day and higher for PKYa and PKYb compared to PKYc (Table 18). The 2016 OPUS-S solutions had a similar pattern and had lower errors relative to the 2015 survey. The differences between the 2015 averaged OPUS-S versus OP network solutions for PKYb were all greater than 2 cm. During 2016, PKYb also had a large difference between averaged OPUS-S versus OP network solutions but the elevation difference was not as great. The largest difference between the 2015 and 2016 solutions was the difference between the northing and easting of PKYb and the elevations of PKYa and PKYb. The OPUS-S and OP network differences in horizontal distances between benchmarks were relatively high for both surveys for “a to b” and “b to c” (Table 19). The elevation differences between OPUS-S and OP network also were relatively high. The elevation differences were high for “a to c” and “b to c”. The relative elevation survey indicated that there was more error than expected based on the low error reported by OP. While the 2016 survey was closer to reality, there was still up to 1.8 cm of disagreement between the OP network elevations and the true relative elevation differences between the RSETs.

Table 17. Quality of the solutions for the GNSS survey conducted at PKY.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	pkya	7/23/2015	95	82	-	0.023
OPUS-S 2	pkya	7/24/2015	97	96	-	0.022
Session 1	pkya	PKY1	93	93	1.47	0.030
Session 2	pkya	PKY2	96	93	1.14	0.023
Network 1	pkya	PKY1	95	93	1.30	0.027
OPUS-S 1	pkyb	7/23/2015	94	93	-	0.024
OPUS-S 2	pkyb	7/24/2015	96	93	-	0.020
Session 1	pkyb	PKY1	96	75	1.47	0.038
Session 2	pkyb	PKY2	93	95	1.14	0.023
Network 1	pkyb	PKY1	94	83	1.30	0.031
OPUS-S 1	pkyc	7/23/2015	95	88	-	0.022
OPUS-S 2	pkyc	7/24/2015	96	98	-	0.020
Session 1	pkyc	PKY1	94	96	1.47	0.032
Session 2	pkyc	PKY2	96	95	1.14	0.021
Network 1	pkyc	PKY1	95	96	1.30	0.027
OPUS-S 3	pkya	5/3/2016	94	97	-	0.020
OPUS-S 4	pkya	5/4/2016	96	85	-	0.027
OPUS-S 5	pkya	5/5/2016	97	82	-	0.023
Session 3	pkya	PKY3	91	92	0.99	0.029
Session 4	pkya	PKY4	95	98	0.97	0.023
Session 5	pkya	PKY5	94	98	0.81	0.021
Network 2	pkya	PKY2	93	96	0.94	0.024
OPUS-S 3	pkyb	5/3/2016	95	96	-	0.019
OPUS-S 4	pkyb	5/4/2016	95	78	-	0.029
OPUS-S 5	pkyb	5/5/2016	93	84	-	0.024
Session 3	pkyb	PKY3	93	89	0.99	0.029
Session 4	pkyb	PKY4	92	100	0.97	0.021
Session 5	pkyb	PKY5	93	100	0.81	0.020
Network 2	pkyb	PKY2	93	96	0.94	0.024
OPUS-S 3	pkyc	5/3/2016	96	98	-	0.020
OPUS-S 4	pkyc	5/4/2016	92	88	-	0.028
OPUS-S 5	pkyc	5/5/2016	96	85	-	0.026
Session 3	pkyc	PKY3	95	84	0.99	0.025
Session 4	pkyc	PKY4	92	95	0.97	0.021
Session 5	pkyc	PKY5	94	100	0.81	0.020
Network 2	pkyc	PKY2	94	93	0.94	0.022

Table 18. Average position solutions for the PKY RSET sites.

Id	RSET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S 1	pkya	3569748.400	0.015	522450.735	0.017	-30.701	0.037	1.033	0.042
OPUS-S 2	pkya	3569748.400	0.010	522450.732	0.015	-30.709	0.010	1.025	0.022
aOPUS-S 1	pkya	3569748.400	0.013	522450.734	0.016	-30.705	0.024	1.029	0.032
Network 1	pkya	3569748.401	0.001	522450.743	0.000	-30.676	0.003	1.058	0.012
Range 1	pkya	0.001	-0.012	0.010	-0.016	0.029	-0.021	0.029	-0.020
OPUS-S 3	pkya	3569748.391	0.009	522450.732	0.012	-30.703	0.025	1.031	0.032
OPUS-S 4	pkya	3569748.399	0.008	522450.735	0.019	-30.718	0.026	1.016	0.033
OPUS-S 5	pkya	3569748.409	0.004	522450.744	0.004	-30.714	0.006	1.020	0.021
aOPUS-S 2	pkya	3569748.400	0.007	522450.737	0.012	-30.712	0.019	1.022	0.029
Network 2	pkya	3569748.396	0.000	522450.738	0.000	-30.717	0.002	1.017	0.012
Range 2	pkya	-0.004	-0.007	0.001	-0.012	-0.005	-0.017	-0.005	-0.017
N2 - N1	pkya	-0.005	-0.001	-0.005	0.000	-0.041	-0.001	-0.041	0.000
OPUS-S 1	pkyb	3569758.582	0.014	522475.043	0.009	-30.675	0.055	1.059	0.059
OPUS-S 2	pkyb	3569758.592	0.010	522475.054	0.016	-30.686	0.008	1.048	0.022
aOPUS-S 1	pkyb	3569758.587	0.012	522475.049	0.013	-30.681	0.032	1.054	0.041
Network 1	pkyb	3569758.554	0.001	522475.025	0.000	-30.709	0.003	1.025	0.012
Range 1	pkyb	-0.033	-0.011	-0.024	-0.013	-0.029	-0.029	-0.029	-0.029
OPUS-S 3	pkyb	3569758.601	0.011	522475.037	0.011	-30.687	0.019	1.047	0.027
OPUS-S 4	pkyb	3569758.533	0.016	522475.013	0.009	-30.695	0.022	1.039	0.030
OPUS-S 5	pkyb	3569758.571	0.004	522475.055	0.012	-30.700	0.011	1.034	0.023
aOPUS-S 2	pkyb	3569758.568	0.010	522475.035	0.011	-30.694	0.017	1.040	0.027
Network 2	pkyb	3569758.594	0.000	522475.050	0.000	-30.687	0.001	1.047	0.012
Range 2	pkyb	0.026	-0.010	0.015	-0.011	0.007	-0.016	0.007	-0.015
N2 - N1	pkyb	0.040	-0.001	0.025	0.000	0.022	-0.002	0.022	0.000

Table 18. cont.

Id	SET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S 1	pkyc	3569762.390	0.016	522501.699	0.016	-30.651	0.033	1.084	0.039
OPUS-S 2	pkyc	3569762.394	0.008	522501.694	0.013	-30.634	0.009	1.101	0.022
aOPUS-S 1	pkyc	3569762.392	0.012	522501.697	0.015	-30.643	0.021	1.093	0.031
Network 1	pkyc	3569762.396	0.001	522501.706	0.000	-30.657	0.003	1.078	0.012
Range 1	pkyc	0.004	-0.011	0.010	-0.015	-0.015	-0.018	-0.015	-0.019
OPUS-S 3	pkyc	3569762.393	0.011	522501.699	0.013	-30.652	0.017	1.083	0.026
OPUS-S 4	pkyc	3569762.395	0.010	522501.686	0.017	-30.650	0.018	1.085	0.027
OPUS-S 5	pkyc	3569762.400	0.008	522501.712	0.007	-30.653	0.010	1.082	0.022
aOPUS-S 2	pkyc	3569762.396	0.010	522501.699	0.012	-30.652	0.015	1.083	0.025
Network 2	pkyc	3569762.393	0.000	522501.703	0.000	-30.658	0.001	1.077	0.012
Range 2	pkyc	-0.003	-0.010	0.004	-0.012	-0.006	-0.014	-0.006	-0.013
N2 - N1	pkyc	-0.003	-0.001	-0.003	0.000	-0.001	-0.002	-0.001	0.000

Table 19. Distances between PKY SET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)	Elevation Difference to Total Station (m)
a to b (2015)	26.363	26.319	-0.044	-0.024	0.033	0.058	0.049
a to c (2015)	52.849	52.850	0.001	-0.063	-0.019	0.044	0.022
b to c (2015)	26.918	26.956	0.038	-0.038	-0.052	-0.014	-0.027
a to b (2016)	26.340	26.364	0.025	-0.018	-0.030	-0.012	-0.014
a to c (2016)	52.849	52.852	0.003	-0.060	-0.059	0.001	-0.018
b to c (2016)	26.937	26.922	-0.015	-0.042	-0.029	0.013	-0.004

3.6 Harris Neck NWR: Site HSN033 (HSN)

The HSN surveys took place on July 28th and 29th, 2015. The RSET sites were simultaneously surveyed for 6.25 hrs on the 28th and for 6 hrs on the 29th. On both survey days, the observed values used (Obs %) and the percent of observations that were fixed (Fixed %) were within the recommended range of values (Table 20). The SE for the all of the OP solutions were very close to 1.0. All solutions had slightly elevated RMS values (close to or > 0.02 m).

The estimated uncertainties for the position elevation solutions for all three RSETs were relatively high on both survey days (Table 21). The northing errors for all three RSETs were also relatively high on the first survey day. The differences between northings and eastings for the averaged OPUS-S versus OP network solutions were all less than 1 cm. The differences between the OPUS-S and OP network elevation solutions were all less than 1.5 cm. The OPUS-S and OP network differences in distances (horizontal and vertical) between benchmarks were less than 1.5 cm (Table 22). A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the HSN RSETs.

Table 20. Quality of the solutions for the GNSS survey conducted at HSN.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	hsna	7/28/2015	95	89	-	0.021
OPUS-S 2	hsna	7/29/2015	92	88	-	0.019
Session 1	hsna	HSN1	95	96	1.06	0.025
Session 2	hsna	HSN2	96	98	1.00	0.019
Network 1	hsna	HSN	96	97	1.04	0.022
OPUS-S 1	hsnb	7/28/2015	94	84	-	0.021
OPUS-S 2	hsnb	7/29/2015	95	90	-	0.019
Session 1	hsnb	HSN1	95	95	1.06	0.023
Session 2	hsnb	HSN2	97	100	1.00	0.020
Network 1	hsnb	HSN	96	97	1.04	0.021
OPUS-S 1	hsnc	7/28/2015	92	85	-	0.020
OPUS-S 2	hsnc	7/29/2015	94	94	-	0.020
Session 1	hsnc	HSN1	93	93	1.06	0.024
Session 2	hsnc	HSN2	95	100	1.00	0.021
Network 1	hsnc	HSN	94	96	1.04	0.022

Table 21. Average position solutions for the HSN RSET sites.

Id	RSET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	hsna	3500121.724	0.022	473256.569	0.014	-29.638	0.016	1.133	0.028
OPUS-S2	hsna	3500121.725	0.016	473256.578	0.014	-29.617	0.047	1.154	0.053
aOPUS-S	hsna	3500121.725	0.019	473256.574	0.014	-29.628	0.032	1.144	0.041
Network	hsna	3500121.717	0.001	473256.583	0.000	-29.614	0.002	1.157	0.014
Range	hsna	-0.007	-0.018	0.009	-0.014	0.014	-0.030	0.014	-0.027
OPUS-S1	hsnb	3500103.885	0.016	473252.837	0.002	-29.635	0.014	1.136	0.027
OPUS-S2	hsnb	3500103.880	0.011	473252.839	0.017	-29.630	0.030	1.141	0.038
aOPUS-S	hsnb	3500103.883	0.014	473252.838	0.010	-29.633	0.022	1.139	0.033
Network	hsnb	3500103.879	0.001	473252.843	0.000	-29.623	0.002	1.148	0.014
Range	hsnb	-0.003	-0.013	0.005	-0.010	0.009	-0.020	0.009	-0.019
OPUS-S1	hsnc	3500038.424	0.015	473266.272	0.010	-29.617	0.040	1.153	0.046
OPUS-S2	hsnc	3500038.433	0.004	473266.256	0.014	-29.602	0.027	1.168	0.035
aOPUS-S	hsnc	3500038.429	0.010	473266.264	0.012	-29.610	0.034	1.161	0.041
Network	hsnc	3500038.431	0.001	473266.265	0.000	-29.607	0.002	1.163	0.014
Range	hsnc	0.002	-0.009	0.001	-0.012	0.003	-0.032	0.003	-0.027

Table 22. Distances between HSN RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	18.229	18.226	-0.003	0.005	0.009	0.004
a to c	83.858	83.847	-0.011	-0.018	-0.007	0.011
b to c	66.817	66.810	-0.007	-0.023	-0.016	0.007

3.7 Wassaw NWR: Site WSW001 (WSW)

The WSW surveys took place on August 5th and 6th, 2015. The RSET sites were simultaneously surveyed for 6 hrs on the 5th and for 6.75 hrs on the 6th. On the first survey day, WSWb had a relatively low Fixed (%), though it was within the recommended range of values (Table 23). The SE for the all of the OP solutions were relatively good. All solutions had elevated RMS values.

The estimated uncertainties for the position elevation solutions for all three RSETs were relatively high on the first survey day and also was high for WSWb on the second survey day (Table 24). The easting error for WSWb was relatively high on the first survey day. The differences between northings and eastings for the averaged OPUS-S versus OP network solutions were all less than 1 cm. The differences between the OPUS-S and OP network elevation solutions were very low for WSWa and WSWb; WSWc's elevation differences were higher than the other RSETs but less than 1.5 cm. The OPUS-S and OP network differences in distances (horizontal) between benchmarks were less than 1 cm (Table 25). A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the WSW RSETs.

Table 23. Quality of the solutions for the GNSS survey conducted at WSW.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	wswa	8/5/2015	96	90	-	0.020
OPUS-S 2	wswa	8/6/2015	94	83	-	0.023
Session 1	wswa	WSW1	96	98	1.08	0.024
Session 2	wswa	WSW2	96	92	1.10	0.024
Network 1	wswa	WSW	96	94	1.12	0.024
OPUS-S 1	wswb	8/5/2015	95	80	-	0.022
OPUS-S 2	wswb	8/6/2015	95	84	-	0.022
Session 1	wswb	WSW1	96	97	1.08	0.027
Session 2	wswb	WSW2	97	98	1.10	0.027
Network 1	wswb	WSW	97	98	1.12	0.027
OPUS-S 1	wswc	8/5/2015	96	91	-	0.021
OPUS-S 2	wswc	8/6/2015	96	87	-	0.024
Session 1	wswc	WSW1	98	97	1.08	0.029
Session 2	wswc	WSW2	97	97	1.10	0.024
Network 1	wswc	WSW	97	97	1.12	0.026

Table 24. Average position solutions for the Wassaw NWR RSET sites.

Id	RSET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	wswa	3526707.367	0.011	500477.241	0.012	-30.179	0.016	1.087	0.028
OPUS-S2	wswa	3526707.349	0.012	500477.218	0.014	-30.202	0.007	1.064	0.024
aOPUS-S	wswa	3526707.358	0.012	500477.230	0.013	-30.191	0.012	1.076	0.026
Network	wswa	3526707.357	0.001	500477.238	0.000	-30.190	0.002	1.076	0.014
Range	wswa	-0.001	-0.011	0.008	-0.013	0.000	-0.010	0.001	-0.012
OPUS-S1	wswb	3526725.923	0.009	500461.636	0.019	-30.239	0.028	1.027	0.036
OPUS-S2	wswb	3526725.931	0.008	500461.622	0.011	-30.251	0.020	1.015	0.030
aOPUS-S	wswb	3526725.927	0.009	500461.629	0.015	-30.245	0.024	1.021	0.033
Network	wswb	3526725.927	0.001	500461.634	0.000	-30.246	0.002	1.020	0.014
Range	wswb	0.000	-0.008	0.005	-0.015	-0.001	-0.022	-0.001	-0.019
OPUS-S1	wswc	3526702.417	0.010	500455.801	0.012	-30.248	0.017	1.017	0.029
OPUS-S2	wswc	3526702.405	0.011	500455.821	0.012	-30.252	0.013	1.013	0.027
aOPUS-S	wswc	3526702.411	0.011	500455.811	0.012	-30.250	0.015	1.015	0.028
Network	wswc	3526702.409	0.001	500455.813	0.000	-30.263	0.002	1.002	0.014
Range	wswc	-0.002	-0.010	0.002	-0.012	-0.013	-0.013	-0.013	-0.014

Table 25. Distances between WSW RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	24.252	24.256	0.003	0.055	0.056	0.001
a to c	21.982	21.989	0.007	0.059	0.073	0.014
b to c	24.225	24.228	0.003	0.005	0.017	0.012

3.8 Savannah NWR: Site SAV004 (SAV)

The SAV surveys took place on March 16th and June 28th, 2016. The RSET sites were simultaneously surveyed for 6 hrs on the 16th and for 6hrs on the 28th. On both survey days, the observed values used (Obs %) and the percent of observations that were fixed (Fixed %) were within the recommended range of values (Table 26). The SE for the OP-session solutions was slightly low for the first session and slightly high for the second session. All of the solutions, except for OPUS-S 1 and OP-session 1, had elevated RMS values.

The estimated uncertainties for the position elevation solutions for SAVb and SAVc were relatively high on the second survey day and relatively high for SAVa on the first survey day (Table 27). The northing and easting uncertainties for all OP-S solutions for all RSETS were relatively low (< 1.5 cm). The differences between northings and eastings for the averaged OPUS-S versus OP network solutions were all less than 0.5 cm. The differences between the OPUS-S and OP network elevation solutions were low for SAVb and SAVc. SAVa's elevation differences were slightly higher than the other RSETs but less than 1.5 cm. The OPUS-S and OP network differences in distances (horizontal and vertical) between benchmarks were less than 0.5 cm (Table 28). A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the SAV RSETs.

Table 26. Quality of the solutions for the GNSS survey conducted at SAV.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	sava	3/16/2016	97	92	-	0.019
OPUS-S 2	sava	6/28/2016	93	90	-	0.024
Session 1	sava	SAV1	94	100	0.81	0.019
Session 2	sava	SAV2	96	99	1.17	0.030
Network 1	sava	SAV	95	99	1.03	0.025
OPUS-S 1	savb	3/16/2016	97	93	-	0.018
OPUS-S 2	savb	6/28/2016	95	90	-	0.028
Session 1	savb	SAV1	95	98	0.81	0.018
Session 2	savb	SAV2	98	92	1.17	0.029
Network 1	savb	SAV	96	95	1.03	0.024
OPUS-S 1	savc	3/16/2016	95	93	-	0.018
OPUS-S 2	savc	6/28/2016	94	84	-	0.028
Session 1	savc	SAV1	94	98	0.81	0.019
Session 2	savc	SAV2	97	94	1.17	0.029
Network 1	savc	SAV	95	96	1.03	0.024

Table 27. Average position solutions for the SAV RSET sites.

Id	RSET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	sava	3559822.528	0.012	488313.226	0.013	-29.834	0.019	1.370	0.030
OPUS-S2	sava	3559822.519	0.002	488313.209	0.009	-29.877	0.008	1.327	0.025
aOPUS-S	sava	3559822.524	0.007	488313.218	0.011	-29.856	0.014	1.349	0.028
Network	sava	3559822.522	0.001	488313.219	0.000	-29.866	0.002	1.338	0.014
Range	sava	-0.002	-0.006	0.001	-0.011	-0.011	-0.012	-0.011	-0.014
OPUS-S1	savb	3559840.774	0.012	488313.742	0.009	-29.855	0.010	1.349	0.025
OPUS-S2	savb	3559840.783	0.005	488313.740	0.008	-29.884	0.017	1.320	0.029
aOPUS-S	savb	3559840.779	0.009	488313.741	0.009	-29.870	0.014	1.335	0.027
Network	savb	3559840.780	0.001	488313.743	0.000	-29.877	0.002	1.327	0.014
Range	savb	0.001	-0.008	0.002	-0.009	-0.007	-0.012	-0.008	-0.013
OPUS-S1	savc	3559863.428	0.012	488306.133	0.010	-29.917	0.007	1.287	0.024
OPUS-S2	savc	3559863.431	0.012	488306.140	0.007	-29.908	0.021	1.296	0.031
aOPUS-S	savc	3559863.430	0.012	488306.137	0.009	-29.913	0.014	1.292	0.028
Network	savc	3559863.429	0.001	488306.141	0.000	-29.922	0.002	1.282	0.014
Range	savc	0.000	-0.011	0.004	-0.009	-0.009	-0.012	-0.010	-0.014

Table 28. Distances between SAV RSET sites.

RSETs	Distance OPUS (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	18.263	18.266	0.003	0.014	0.011	-0.003
a to c	41.514	41.515	0.000	0.057	0.056	-0.001
b to c	23.893	23.891	-0.003	0.043	0.045	0.002

3.9 St. Marks NWR: Site SMK000 (SMK)

The SMK surveys took place on July 6th and 7th, 2016. The RSET sites were simultaneously surveyed for 6 hrs on the 6th and for 6 hrs on the 7th. On both survey days, the observed values used (Obs %) and the percent of observations that were fixed (Fixed %) were within the recommended range of values (Table 29). The Fixed (%) were slightly lower on the first day for all three RSETs and low for SMKb and SMKc on the second survey day. The SE for all of the OP solutions were very good. All of the solutions had elevated RMS values.

The estimated uncertainties for the position elevation solutions for SMKa were high on both survey days (Table 30). Elevation errors were high on the first survey day for SMKb, and on the second survey day for SMKc. The northing and easting uncertainties for SMKa were high on both survey days, high for SMKb on the second survey day, and high for SMKc on the first survey day. The differences between northings and eastings for the averaged OPUS-S versus OP network solutions were all less than 1 cm. The differences between the OPUS-S and OP network elevation solutions were low for SMKa and SMKb. SMKc's elevation differences were slightly higher than the other RSETs but less than 2 cm. The OPUS-S and OP network differences in distances (horizontal and vertical) between benchmarks were less than 1.5 cm (Table 31). A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the SMK RSETs.

Table 29. Quality of the solutions for the GNSS survey conducted at SMK.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	smka	7/6/2016	93	83	-	0.023
OPUS-S 2	smka	7/7/2016	93	92	-	0.024
Session 1	smka	SMK1	95	87	1.00	0.029
Session 2	smka	SMK2	98	94	1.02	0.025
Network 1	smka	SMK	96	90	1.01	0.027
OPUS-S 1	smkb	7/6/2016	91	81	-	0.025
OPUS-S 2	smkb	7/7/2016	93	84	-	0.024
Session 1	smkb	SMK1	91	93	1.00	0.029
Session 2	smkb	SMK2	98	90	1.02	0.026
Network 1	smkb	SMK	94	92	1.01	0.028
OPUS-S 1	smkc	7/6/2016	95	88	-	0.023
OPUS-S 2	smkc	7/7/2016	93	80	-	0.026
Session 1	smkc	SMK1	96	94	1.00	0.030
Session 2	smkc	SMK2	95	91	1.02	0.027
Network 1	smkc	SMK	95	92	1.01	0.029

Table 30. Average position solutions for the SMK RSET sites.

Id	RSET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	smka	3334963.678	0.017	765170.123	0.009	-26.691	0.017	0.840	0.028
OPUS-S2	smka	3334963.667	0.019	765170.125	0.013	-26.691	0.015	0.840	0.028
aOPUS-S	smka	3334963.673	0.018	765170.124	0.011	-26.691	0.016	0.840	0.028
Network	smka	3334963.666	0.000	765170.124	0.000	-26.685	0.002	0.846	0.014
Range	smka	-0.006	-0.018	0.000	-0.011	0.006	-0.014	0.006	-0.014
OPUS-S1	smkb	3335012.560	0.006	765198.001	0.003	-26.682	0.015	0.850	0.028
OPUS-S2	smkb	3335012.566	0.017	765198.010	0.015	-26.641	0.008	0.891	0.025
aOPUS-S	smkb	3335012.563	0.012	765198.006	0.009	-26.662	0.012	0.871	0.027
Network	smkb	3335012.562	0.000	765198.008	0.000	-26.656	0.002	0.876	0.014
Range	smkb	-0.001	-0.012	0.003	-0.009	0.005	-0.010	0.005	-0.013
OPUS-S1	smkc	3335030.659	0.018	765161.836	0.010	-26.671	0.008	0.861	0.025
OPUS-S2	smkc	3335030.665	0.004	765161.863	0.009	-26.658	0.027	0.874	0.036
aOPUS-S	smkc	3335030.662	0.011	765161.850	0.010	-26.665	0.018	0.868	0.031
Network	smkc	3335030.659	0.000	765161.849	0.000	-26.649	0.002	0.883	0.014
Range	smkc	-0.003	-0.011	0.000	-0.010	0.015	-0.016	0.016	-0.017

Table 31. Distances between SMK RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	56.282	56.288	0.006	-0.029	-0.029	0.000
a to c	67.499	67.502	0.004	-0.026	-0.036	-0.009
b to c	40.433	40.435	0.002	0.003	-0.007	-0.010

3.10 Alligator River NWR: Site ALL005 (ALL)

The ALL surveys took place on July 20th and 21st, 2016. The RSET sites were simultaneously surveyed for ~7 hrs on the 20th and for 6 hrs on the 21st. Though a receiver was setup on ALLb, the data were not used because the percent of the observations that were fixed were 70% for the first day of survey and 58% on the second day. On both survey days, the observed values used (Obs %) for ALLa and ALLc were within the recommended range of values (Table 32). The Fixed (%) was low for both RSETs on both survey days. Additionally, the Fixed (%) for the second OP-session for ALLa was below the recommended range of values. The SE for the OP-session solutions were very good. The SE for the OP-network solution was slightly elevated. All of the solutions had high RMS values.

The estimated uncertainties for the position northings and eastings for both RSETs were very high on the second survey day (Table 33). Elevation errors were high on both survey days for ALLc. The differences between northings for the averaged OPUS-S versus OP network solutions were all less than 1 cm. The differences between the OPUS-S and OP network easting and elevation solutions were high for both RSETs. The OPUS-S and OP network difference in vertical distance between ALLa and ALLC was greater than 2 cm (Table 34). A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the ALL RSETs.

Table 32. Quality of the solutions for the GNSS survey conducted at ALL.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	alla	7/20/2016	90	86	-	0.026
OPUS-S 2	alla	7/21/2016	92	73	-	0.040
Session 1	alla	ALL1	93	95	1.02	0.026
Session 2	alla	ALL2	97	67	1.05	0.042
Network 1	alla	ALL	95	86	1.22	0.035
OPUS-S 1	allc	7/20/2016	92	80	-	0.026
OPUS-S 2	allc	7/21/2016	96	74	-	0.034
Session 1	allc	ALL1	97	89	1.02	0.026
Session 2	allc	ALL2	98	83	1.05	0.045
Network 1	allc	ALL	97	88	1.22	0.037

Table 33. Average position solutions for the ALL005 RSET sites.

Id	RSET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	alla	3939986.118	0.001	419047.655	0.002	-38.405	0.008	0.433	0.027
OPUS-S2	alla	3939986.138	0.028	419047.603	0.046	-38.451	0.012	0.387	0.028
aOPUS-S	alla	3939986.128	0.015	419047.629	0.024	-38.428	0.010	0.410	0.028
Network	alla	3939986.119	0.001	419047.604	0.000	-38.387	0.002	0.451	0.015
Range	alla	-0.009	-0.014	-0.025	-0.024	0.041	-0.008	0.041	-0.013
OPUS-S1	allc	3940004.108	0.008	419107.454	0.007	-38.403	0.028	0.436	0.038
OPUS-S2	allc	3940004.128	0.029	419107.410	0.052	-38.432	0.085	0.407	0.089
aOPUS-S	allc	3940004.118	0.019	419107.432	0.030	-38.418	0.057	0.422	0.064
Network	allc	3940004.120	0.001	419107.395	0.000	-38.398	0.002	0.441	0.015
Range	allc	0.002	-0.018	-0.037	-0.030	0.020	-0.055	0.020	-0.049

Table 34. Distances between CDR RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	-	-	-	-	-	-
a to c	62.450	62.442	-0.008	-0.011	0.011	0.022
b to c	-	-	-	-	-	-

3.11 Currituck NWR: Site CRT026 (CRT)

The CRT surveys took place on July 26th and 28th, 2016. The RSETs were simultaneously surveyed for 6 hrs on the 26th, and 6 hrs on the 28th. A storm blew into the area on the 26th and the receivers on CRTa and CRTb were left out and on until the following morning. On both survey days, the observed values used (Obs %) and percent Fixed were within the recommended range of values (Table 35). Though the SEs for the OP solutions were within the recommended range of values, the second OP-session's SE was relatively low. The RMS values for all RSETs were elevated on the first survey day and for the first OP-session solution. The RMS value for CRTa and CRTb also were high in the OP-network solution.

The estimated uncertainties for the position northings and eastings for all RSETs were relatively high on both survey days (Table 36). Elevation errors were high on both survey days for CRTb. Elevation errors also were high for one of the survey days for CRTa and CRTc. The differences between northings and eastings for the averaged OPUS-S versus OP network solutions were all less than 1 cm. The difference between the OPUS-S and OP network elevation solutions were high for CRTa. The OPUS-S and OP network difference in horizontal distances between the RSETs was less than 0.5 cm (Table 37). The difference in elevation distances were relatively high for "a to b" and "a to c". A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the CRT RSETs.

Table 35. Quality of the solutions for the GNSS survey conducted at CRT.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	crta	7/26/2016	96	84	-	0.026
OPUS-S 2	crta	7/28/2016	97	94	-	0.017
Session 1	crta	CRT1	98	98	1.01	0.027
Session 2	crta	CRT2	100	94	0.83	0.013
Network 1	crta	CRT	99	97	0.96	0.024
OPUS-S 1	crtb	7/26/2016	95	88	-	0.025
OPUS-S 2	crtb	7/28/2016	96	95	-	0.019
Session 1	crtb	CRT1	97	94	1.01	0.033
Session 2	crtb	CRT2	100	100	0.83	0.017
Network 1	crtb	CRT	98	95	0.96	0.029
OPUS-S 1	crtc	7/26/2016	93	87	-	0.020
OPUS-S 2	crtc	7/28/2016	97	94	-	0.016
Session 1	crtc	CRT1	99	94	1.01	0.019
Session 2	crtc	CRT2	100	97	0.83	0.015
Network 1	crtc	CRT	99	95	0.96	0.017

Table 36. Average position solutions for the CRT RSET sites.

Id	RSET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	crta	4032051.068	0.019	423665.363	0.019	-38.143	0.029	0.404	0.038
OPUS-S2	crta	4032051.077	0.025	423665.365	0.020	-38.148	0.008	0.399	0.027
aOPUS-S	crta	4032051.073	0.022	423665.364	0.020	-38.146	0.019	0.402	0.033
Network	crta	4032051.066	0.001	423665.362	0.000	-38.162	0.001	0.385	0.015
Range	crta	-0.006	-0.021	-0.002	-0.020	-0.017	-0.018	-0.017	-0.018
OPUS-S1	crtb	4032066.423	0.011	423701.567	0.014	-38.166	0.020	0.381	0.032
OPUS-S2	crtb	4032066.422	0.020	423701.572	0.024	-38.184	0.042	0.363	0.049
aOPUS-S	crtb	4032066.423	0.016	423701.570	0.019	-38.175	0.031	0.372	0.041
Network	crtb	4032066.424	0.001	423701.560	0.000	-38.176	0.001	0.371	0.015
Range	crtb	0.002	-0.015	-0.009	-0.019	-0.001	-0.030	-0.001	-0.026
OPUS-S1	crtc	4032032.517	0.023	423647.710	0.013	-38.182	0.003	0.364	0.026
OPUS-S2	crtc	4032032.553	0.019	423647.709	0.011	-38.192	0.024	0.354	0.035
aOPUS-S	crtc	4032032.535	0.021	423647.710	0.012	-38.187	0.014	0.359	0.031
Network	crtc	4032032.530	0.001	423647.702	0.000	-38.190	0.002	0.356	0.015
Range	crtc	-0.005	-0.020	-0.008	-0.012	-0.003	-0.012	-0.003	-0.016

Table 37. Distances between CRT RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	39.325	39.321	-0.004	0.029	0.014	-0.015
a to c	25.599	25.602	0.003	0.041	0.028	-0.014
b to c	63.634	63.636	0.002	0.012	0.014	0.002

3.12 Waccamaw NWR: Site WAW000 (WAW)

The WAW surveys took place on August 9th and 10th, 2016. The RSETs were simultaneously surveyed for 6 hrs on the 9th and for 6 hrs on the 10th. On both survey days, the observed values used (Obs %) and percent Fixed were within the recommended range of values (Table 38). Though the SEs for the OP solutions were within the recommended range of values, the first OP-session's SE was relatively high. The RMS values for all RSETs were relatively high. Surprisingly, the RMS values for the OP solutions were worse than the OPUS-S RMS values.

The estimated uncertainties for the position solutions (northings, eastings, and elevations) for all RSETs were relatively low (less than 1.5 cm) on both survey days (Table 39). The differences between northings, eastings, and elevations for the averaged OPUS-S versus OP network solutions were all less than 1 cm. The OPUS-S and OP network difference in horizontal distances between the RSETs was less than 0.5 cm (Table 40). The difference in elevation distances were relatively high for "a to c" and "b to c". A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the WAW RSETs.

Table 38. Quality of the solutions for the GNSS survey conducted at WAW.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	wawa	8/9/2016	91	85	-	0.019
OPUS-S 2	wawa	8/10/2016	90	93	-	0.019
Session 1	wawa	WAW1	95	84	1.13	0.024
Session 2	wawa	WAW2	92	96	0.97	0.020
Network 1	wawa	WAW	94	91	1.06	0.022
OPUS-S 1	wawb	8/9/2016	93	85	-	0.021
OPUS-S 2	wawb	8/10/2016	94	85	-	0.018
Session 1	wawb	WAW1	94	92	1.13	0.025
Session 2	wawb	WAW2	97	94	0.97	0.020
Network 1	wawb	WAW	95	93	1.06	0.023
OPUS-S 1	wawc	8/9/2016	94	89	-	0.019
OPUS-S 2	wawc	8/10/2016	92	84	-	0.020
Session 1	wawc	WAW1	97	92	1.13	0.021
Session 2	wawc	WAW2	97	95	0.97	0.020
Network 1	wawc	WAW	97	93	1.06	0.020

Table 39. Average position solutions for the WAW RSET sites.

Id	RSET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	wawa	3711959.247	0.005	675729.365	0.008	-33.939	0.014	0.818	0.024
OPUS-S2	wawa	3711959.243	0.002	675729.363	0.001	-33.947	0.011	0.810	0.023
aOPUS-S	wawa	3711959.245	0.004	675729.364	0.005	-33.943	0.013	0.814	0.024
Network	wawa	3711959.247	0.001	675729.366	0.000	-33.949	0.002	0.808	0.012
Range	wawa	0.002	-0.003	0.002	-0.005	-0.006	-0.011	-0.006	-0.012
OPUS-S1	wawb	3711913.726	0.007	675708.194	0.010	-33.871	0.013	0.886	0.024
OPUS-S2	wawb	3711913.717	0.005	675708.178	0.002	-33.869	0.012	0.888	0.024
aOPUS-S	wawb	3711913.722	0.006	675708.186	0.006	-33.870	0.013	0.887	0.024
Network	wawb	3711913.724	0.001	675708.190	0.000	-33.877	0.002	0.880	0.012
Range	wawb	0.002	-0.005	0.004	-0.006	-0.007	-0.011	-0.007	-0.012
OPUS-S1	wawc	3711889.841	0.002	675703.619	0.009	-33.925	0.003	0.832	0.020
OPUS-S2	wawc	3711889.849	0.004	675703.606	0.004	-33.917	0.011	0.840	0.023
aOPUS-S	wawc	3711889.845	0.003	675703.613	0.007	-33.921	0.007	0.836	0.022
Network	wawc	3711889.849	0.001	675703.616	0.000	-33.912	0.002	0.845	0.012
Range	wawc	0.004	-0.002	0.003	-0.007	0.009	-0.005	0.009	-0.010

Table 40. Distances between WAW RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	50.209	50.207	-0.001	-0.073	-0.072	0.001
a to c	74.024	74.021	-0.002	-0.022	-0.037	-0.015
b to c	24.311	24.309	-0.001	0.051	0.035	-0.016

3.13 Wolf Island NWR: Site WLF035 (WLF)

The WLF surveys took place on August 17th and 25th, 2016. The RSETs were simultaneously surveyed for 6 hrs on the 17th and 6 hrs on the 25th. On both survey days, the observed values used (Obs %) were within the recommended range of values (Table 41). The percent of observations that were fixed [Fixed (%)] were relatively low on both survey days for all of the RSETs. The SEs for the OP solutions were well within the recommended range of values. The RMS values for all RSETs were relatively high for all solutions.

The estimated uncertainties for the position solutions (northings, eastings, and elevations) for all RSETs were relatively high to very high on both survey days (Table 42). The differences between northings and eastings for the averaged OPUS-S versus OP network solutions were all less than 1 cm. The elevation differences between the averaged OPUS-S solutions and the OP network solutions for WLFa and WLFc were greater than 1 cm. The OPUS-S and OP network difference in horizontal distances between the RSETs was less than 0.5 cm (Table 43). The difference in elevation distances were high for "a to b" and "a to c". A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the WLF RSETs.

Table 41. Quality of the solutions for the GNSS survey conducted at WLF.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	wlfa	8/17/2016	97	79	-	0.025
OPUS-S 2	wlfa	8/25/2016	96	89	-	0.021
Session 1	wlfa	WLF1	98	89	1.05	0.027
Session 2	wlfa	WLF2	98	93	0.92	0.023
Network 1	wlfa	WLF	98	91	1.02	0.025
OPUS-S 1	wlfb	8/17/2016	97	77	-	0.024
OPUS-S 2	wlfb	8/25/2016	98	84	-	0.023
Session 1	wlfb	WLF1	96	94	1.05	0.025
Session 2	wlfb	WLF2	96	98	0.92	0.025
Network 1	wlfb	WLF	96	96	1.02	0.025
OPUS-S 1	wlfc	8/17/2016	95	86	-	0.025
OPUS-S 2	wlfc	8/25/2016	96	82	-	0.025
Session 1	wlfc	WLF1	96	92	1.05	0.024
Session 2	wlfc	WLF2	98	94	0.92	0.027
Network 1	wlfc	WLF	97	93	1.02	0.025

Table 42. Average position solutions for the WLF RSET sites.

Id	RSET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	wlfa	3465982.233	0.008	470077.318	0.024	-28.657	0.018	1.296	0.029
OPUS-S2	wlfa	3465982.216	0.014	470077.352	0.011	-28.609	0.009	1.344	0.025
aOPUS-S	wlfa	3465982.225	0.011	470077.335	0.018	-28.633	0.014	1.320	0.027
Network	wlfa	3465982.221	0.001	470077.341	0.000	-28.608	0.002	1.345	0.014
Range	wlfa	-0.004	-0.010	0.006	-0.018	0.025	-0.012	0.025	-0.013
OPUS-S1	wlfb	3466013.863	0.024	470046.731	0.015	-28.678	0.041	1.275	0.047
OPUS-S2	wlfb	3466013.858	0.014	470046.725	0.013	-28.675	0.031	1.278	0.039
aOPUS-S	wlfb	3466013.861	0.019	470046.728	0.014	-28.677	0.036	1.277	0.043
Network	wlfb	3466013.863	0.001	470046.737	0.000	-28.681	0.002	1.272	0.014
Range	wlfb	0.002	-0.018	0.009	-0.014	-0.005	-0.034	-0.004	-0.029
OPUS-S1	wlfc	3466025.271	0.015	470024.128	0.023	-28.690	0.015	1.264	0.028
OPUS-S2	wlfc	3466025.292	0.018	470024.171	0.043	-28.636	0.054	1.318	0.059
aOPUS-S	wlfc	3466025.282	0.017	470024.150	0.033	-28.663	0.035	1.291	0.044
Network	wlfc	3466025.278	0.001	470024.151	0.000	-28.674	0.002	1.280	0.014
Range	wlfc	-0.004	-0.016	0.002	-0.033	-0.011	-0.033	-0.011	-0.030

Table 43. Distances between WLF RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	44.018	44.021	0.002	0.044	0.073	0.029
a to c	68.430	68.433	0.003	0.030	0.066	0.036
b to c	25.303	25.307	0.004	-0.014	-0.007	0.006

3.14 Blackbeard Island NWR: Site BLB001 (BLB)

The BLB surveys took place on August 18th and 19th, 2016. The RSETs were simultaneously surveyed for 6.75 hrs on the 18th and 6 hrs on the 19th. On both survey days, the observed values used (Obs %) and percent of observations that were fixed (Fixed %) were within the recommended range of values (Table 44). Though the SEs for the OP solutions were within the recommended range of values, the first OP-session SE was slightly elevated. The RMS values for all RSETs were relatively high for all solutions.

The estimated uncertainties for the position elevation solutions for all RSETs were relatively high to very high on both survey days (Table 45). The differences between northings, eastings, and elevations for the averaged OPUS-S versus OP network solutions were all less than 1 cm. The OPUS-S and OP network difference in horizontal distances between the RSETs was less than 0.5 cm (Table 46). The difference in elevation distances were higher for "a to b". A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the BLB RSETs.

Table 44. Quality of the solutions for the GNSS survey conducted at BLB.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	blba	8/18/2016	94	94	-	0.024
OPUS-S 2	blba	8/19/2016	95	95	-	0.022
Session 1	blba	BLB1	96	92	1.16	0.023
Session 2	blba	BLB2	96	96	1.07	0.023
Network 1	blba	BLB	96	94	1.13	0.023
OPUS-S 1	blbb	8/18/2016	95	97	-	0.024
OPUS-S 2	blbb	8/19/2016	97	87	-	0.022
Session 1	blbb	BLB1	96	96	1.16	0.024
Session 2	blbb	BLB2	98	100	1.07	0.022
Network 1	blbb	BLB	97	97	1.13	0.023
OPUS-S 1	blbc	8/18/2016	95	89	-	0.022
OPUS-S 2	blbc	8/19/2016	97	93	-	0.020
Session 1	blbc	BLB1	95	99	1.16	0.023
Session 2	blbc	BLB2	98	95	1.07	0.020
Network 1	blbc	BLB	96	97	1.13	0.022

Table 45. Average position solutions for the BLB RSET sites.

Id	RSET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S1	blba	3485755.967	0.003	480281.426	0.015	-29.689	0.011	0.942	0.025
OPUS-S2	blba	3485755.960	0.009	480281.432	0.013	-29.657	0.042	0.974	0.048
aOPUS-S	blba	3485755.964	0.006	480281.429	0.014	-29.673	0.027	0.958	0.037
Network	blba	3485755.960	0.001	480281.432	0.000	-29.676	0.002	0.955	0.014
Range	blba	-0.004	-0.005	0.003	-0.014	-0.003	-0.025	-0.003	-0.023
OPUS-S1	blbb	3485836.762	0.011	480292.359	0.006	-29.654	0.035	0.979	0.042
OPUS-S2	blbb	3485836.766	0.017	480292.362	0.013	-29.677	0.016	0.956	0.028
aOPUS-S	blbb	3485836.764	0.014	480292.361	0.010	-29.666	0.026	0.968	0.035
Network	blbb	3485836.763	0.001	480292.365	0.000	-29.657	0.002	0.976	0.014
Range	blbb	-0.001	-0.013	0.004	-0.010	0.009	-0.024	0.008	-0.021
OPUS-S1	blbc	3485867.632	0.010	480285.450	0.007	-29.455	0.020	1.179	0.031
OPUS-S2	blbc	3485867.625	0.011	480285.446	0.013	-29.451	0.032	1.183	0.040
aOPUS-S	blbc	3485867.629	0.011	480285.448	0.010	-29.453	0.026	1.181	0.036
Network	blbc	3485867.627	0.001	480285.452	0.000	-29.452	0.002	1.182	0.014
Range	blbc	-0.002	-0.010	0.004	-0.010	0.001	-0.024	0.001	-0.022

Table 46. Distances between BLB RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	81.537	81.539	0.003	-0.007	-0.019	-0.012
a to c	111.737	111.739	0.002	-0.220	-0.224	-0.004
b to c	31.629	31.629	0.000	-0.213	-0.205	0.008

3.15 Ace Basin: Site ABS017 (ABS)

The ABS surveys took place on March 12th and 13th, 2019. The RSETs were simultaneously surveyed for 6.25 hrs on the 12th and for 6.6 hrs on the 13th. On both survey days, the observed values used (Obs %) and percent of observations that were fixed (Fixed %) were within the recommended range of values (Table 44). The SEs for the OP solutions were within the recommended range of values though were relatively low. The RMS values for all RSETs were relatively low for all solutions.

The estimated uncertainties for the position elevation solutions for all RSETs were low on both survey days (Table 48). The differences between northings, eastings, and elevations for the averaged OPUS-S versus OP network solutions were all less than 0.5 cm. The OPUS-S and OP network difference in horizontal distances between the RSETs was less than 0.2 cm (Table 49). A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the ABS SETs.

Table 47. Quality of the solutions for the GNSS survey conducted at ABS.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	absa	3/12/2019	97	96	-	0.020
OPUS-S 2	absa	3/13/2019	98	98	-	0.019
Session 1	absa	ABS1	98	100	0.77	0.020
Session 2	absa	ABS2	97	100	0.81	0.019
Network 1	absa	ABS	98	100	0.79	0.020
OPUS-S 1	absb	3/12/2019	97	95	-	0.020
OPUS-S 2	absb	3/13/2019	97	98	-	0.019
Session 1	absb	ABS1	97	95	0.77	0.021
Session 2	absb	ABS2	98	100	0.81	0.019
Network 1	absb	ABS	98	98	0.79	0.020
OPUS-S 1	absc	3/12/2019	98	96	-	0.020
OPUS-S 2	absc	3/13/2019	98	95	-	0.020
Session 1	absc	ABS1	99	100	0.77	0.021
Session 2	absc	ABS2	97	100	0.81	0.020
Network 1	absc	ABS	98	100	0.79	0.021

Table 48. Average position solutions for the ABS RSET sites. Due to differences in antenna adapter, a -0.035 m correction was applied to all elevation solutions (Table 4).

Id	RSET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S	absa	3613453.764	0.011	557341.503	0.007	-31.119	0.009	1.106	0.023
Network	absa	3613453.762	0.000	557341.503	0.000	-31.122	0.001	1.102	0.012
Range	absa	-0.002	-0.011	0.000	-0.007	-0.004	-0.008	-0.004	-0.011
OPUS-S	absb	3613447.018	0.014	557330.476	0.007	-31.049	0.011	1.174	0.024
Network	absb	3613447.018	0.000	557330.475	0.000	-31.052	0.001	1.171	0.012
Range	absb	0.001	-0.014	0.000	-0.007	-0.003	-0.010	-0.003	-0.012
OPUS-S	absc	3613443.484	0.012	557311.672	0.006	-31.090	0.015	1.133	0.026
Network	absc	3613443.482	0.000	557311.672	0.000	-31.093	0.001	1.130	0.012
Range	absc	-0.002	-0.012	0.000	-0.006	-0.003	-0.014	-0.003	-0.014

Table 49. Distances between ABS RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	12.928	12.927	-0.001	-0.070	-0.070	0.000
a to c	31.553	31.553	0.000	-0.029	-0.029	0.000
b to c	19.133	19.133	0.000	0.041	0.041	0.000

3.16 Roanoke River: Site RRV013 (RRV)

The RRV surveys took place on March 18th and 19th, 2019. The RSETs were simultaneously surveyed for 5 hrs on the 18th and for 4.6 hrs on the 19th. On both survey days, the observed values used (Obs %) and percent of observations that were fixed (Fixed %) were extremely poor (Table 47). Due to these poor readings, no further processing was conducted. Additionally, due to the poor Obs (%), the solutions were not acceptable and were not provided. If absolute elevations are needed for this site, an alternate form of survey will be needed to get accurate x, y, and z values.

Table 50. Quality of the solutions for the GNSS survey conducted at ABS.

Id	Site	Date	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	rrva	3/18/2019	6	78	-	0.020
OPUS-S 2	rrva	3/19/2019	6	75	-	0.021
OPUS-S 1	rrvb	3/18/2019	8	74	-	0.024
OPUS-S 2	rrvb	3/19/2019	7	83	-	0.021
OPUS-S 1	rrvc	3/18/2019	9	66	-	0.024
OPUS-S 2	rrvc	3/19/2019	8	78	-	0.023

3.17 Alligator River: Site ALL030 (ALL030)

The ALL030 surveys took place on March 7th and April 4th, 2019. The RSETs were simultaneously surveyed for 4.4 hrs on the 7th and for 4.5 hrs on the 4th. On both survey days, the observed values used (Obs %) and percent of observations that were fixed (Fixed %) were extremely poor (Table 47). Due to these poor readings, no further processing was conducted. Additionally, due to the poor Obs (%), the solutions were not acceptable and were not provided. If absolute elevations are needed for this site, an alternate form of survey will be needed to get accurate x, y, and z values.

Table 51. Quality of the solutions for the GNSS survey conducted at ABS.

Id	Site	Date	Obs (%)	Fixed (%)	SE (m)	RMS (m)
OPUS-S 1	All030	3/7/2019	20	72	-	0.024
OPUS-S 2	All030	4/4/2019	17	80	-	0.025
OPUS-S 1	All030	3/7/2019	25	76	-	0.030
OPUS-S 2	All030	4/4/2019	25	68	-	0.304
OPUS-S 1	All030	3/7/2019	19	73	-	0.023
OPUS-S 2	All030	4/4/2019	18	74	-	0.024

3.18 Mackay Island: Site MCI026 (MCI)

The MCI surveys took place on April 16th and 17th, 2019. The RSETs were simultaneously surveyed for 5.5 hrs on the 16th and 5.75 hrs on the 17th. On both survey days, the observed values used (Obs %) and percent of observations that were fixed (Fixed %) were within the recommended range of values (Table 51). The SEs for the OP solutions were relatively low. The RMS values for all RSETs were acceptable for all solutions.

The estimated uncertainties for the position northing and elevation solutions for all RSETs were relatively high on both survey days (Table 52). The differences between northings, eastings, and elevations for the averaged OPUS-S versus OP network solutions were all less than 0.7 cm. The OPUS-S and OP network difference in horizontal and vertical distances between the RSETs was less than 0.5 cm (Table 53). A relative elevation survey is needed to determine if the elevation solutions (along with error envelopes) provided a reasonable estimate of the elevations of the ABS SETs.

Table 52. Quality of the solutions for the GNSS survey conducted at MCI.

Id	RSET	Solution	Obs (%)	Fixed (%)	SE	RMS (m)
OPUS-S 1	mcia	4/16/2019	97	97	-	0.021
OPUS-S 2	mcia	4/17/2019	97	96	-	0.020
Session 1	mcia	MCI1	98.2	100	0.65	0.021
Session 2	mcia	MCI2	98.8	100	0.68	0.019
Network 1	mcia	MCI	98.5	100	0.66	0.020
OPUS-S 1	mcib	4/16/2019	96	97	-	0.021
OPUS-S 2	mcib	4/17/2019	97	95	-	0.018
Session 1	mcib	MCI1	99	100	0.65	0.020
Session 2	mcib	MCI2	98.5	100	0.68	0.018
Network 1	mcib	MCI	98.8	100	0.66	0.019
OPUS-S 1	mcic	4/16/2019	97	96	-	0.020
OPUS-S 2	mcic	4/17/2019	98	94	-	0.020
Session 1	mcic	MCI1	98.2	100	0.65	0.019
Session 2	mcic	MCI2	98.7	100	0.68	0.021
Network 1	mcic	MCI	98.4	100	0.66	0.020

Table 53. Average position solutions for the MCI RSET sites. Due to differences in antenna adapter, a -0.035 m correction is applied to all elevation solutions (Table 4).

Id	SET	Northing (m)	Northing Error (m)	Easting (m)	Easting Error (m)	Ellipsoid Height (m)	Ellipsoid Error (m)	Orthometric Height (m)	Orthometric Error (m)
OPUS-S	mcia	4044227.752	0.024	414693.792	0.009	-37.775	0.038	0.470	0.046
Network	mcia	4044227.746	0.000	414693.789	0.000	-37.773	0.001	0.472	0.015
Range	mcia	-0.006	-0.024	-0.003	-0.009	0.002	-0.037	0.002	-0.031
OPUS-S	mcib	4044228.654	0.025	414657.387	0.010	-37.847	0.045	0.397	0.052
Network	mcib	4044228.648	0.000	414657.386	0.000	-37.849	0.001	0.394	0.015
Range	mcib	-0.006	-0.025	-0.001	-0.010	-0.002	-0.044	-0.003	-0.037
OPUS-S	mcic	4044235.071	0.027	414632.346	0.013	-37.795	0.043	0.449	0.050
Network	mcic	4044235.065	0.000	414632.346	0.000	-37.793	0.001	0.450	0.015
Range	mcic	-0.006	-0.027	0.000	-0.013	0.002	-0.042	0.002	-0.035

Table 53. Distances between MCI RSET sites.

RSETs	Distance OPUS-S (m)	Distance Network (m)	Distance Difference (m)	Elevation OPUS-S (m)	Elevation Network (m)	Elevation Difference (m)
a to b	36.417	36.414	-0.002	0.072	0.076	0.004
a to c	61.880	61.877	-0.003	0.020	0.020	0.000
b to c	25.850	25.849	0.000	-0.052	-0.056	-0.004

Discussion

This report presents and summarizes results from CWEM RSET benchmark elevation surveys completed between 2015 and 2019. During this period, 54 of the 60 RSETs at the18 of the 20 CWEM sites installed by the U.S. Fish and Wildlife Service's CWEM network were surveyed using GNSS receivers. The purpose of these surveys was to establish a survey-grade location for each RSET benchmark, from which any horizontal or vertical displacement can be identified and corrected. Additionally, a benchmark elevation is required in order to compare rates of marsh elevation change at each plot to rates of relative sea-level rise.

Benchmark elevation solutions were obtained for the RSETs at 16 of the 18 sites that were surveyed. Two of the sites, Roanoke River (RRV013) and Alligator River (ALL030) are located within forested wetlands. Multiple surveys were conducted at these sites during the leaf-off period, but the tree canopy (branch density) prevented the R10 units from obtaining sufficient data to calculate accurate solutions. Alternative methods (e.g., transiting with a total station from an established benchmark) will be needed to obtain a baseline elevation for these benchmarks.

This report provides the results of each GNSS survey and includes information on the OPUS-S and OP (network) solutions for all of the sites that were surveyed between 2015 and 2019. These data are provided so that the user can assess the accuracy of the location (x, y, z) solutions that are provided in this report. A final benchmark elevation (orthometric height) is provided in Table 4 for the 48 stations where sufficient data were collected to obtain a reliable location solution. These orthometric heights correspond to the elevations (published in millimeters) in the RSET database. These elevations will be used for subsequent calculations in the CWEM project.

It should be noted that it was very difficult to achieve sub-centimeter accuracy of benchmark elevations using the GNSS survey. Replicate surveys were conducted at Pinckney Island NWR stations in both 2015 and 2016. Additionally, a relative elevation survey was completed using a total station. The results from these replicate surveys suggest there is more error/uncertainty in the OP network solutions than suggested by their low reported uncertainties. For example, in 2016, there was up to 1.8 cm of disagreement between the OP network elevations and the true relative elevation differences between the RSETs. As a result, users of the benchmark elevation survey data should not assume sub-centimeter accuracy and account for the fact that benchmark GNSS survey results may have confidence interval of +/-1-2 cm or greater. Activities such as using a total station to obtain the relative elevation difference between stations at a single site would provide a better understanding of the accuracy of the GNSS solutions provided in this report.

Due to the results of the Pinckney Island resurvey and a cost-benefit analysis of the accuracy of the solutions versus the time required to achieve the accuracy, we suggest a one-day deployment of the GNSS. Sub-centimeter accuracy is not needed for the CWEM project so OPUS-S will be used and will provide the needed (sub-decimeter) accuracy. While this method would provide less accurate elevations, data collection, which includes a vegetation survey (Boyle et al. 2018), would be much more efficient. Additionally, a survey of the benchmarks to each other would allow us to attain a relative elevation difference between the benchmarks that could be used to assess the accuracy of the survey. A standardized antenna height should also be

used because antenna heights calculated from field measurements only varied +/- 1 mm. Using a standardized antenna height will not only reduce the amount of time needed to set up the survey, but also, it will greatly reduce the amount of time it takes to process the data. These changes will make the collection of elevation data much more efficient and reduce the number of field days by half.

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Appendix A. Wind Speed, Tidal information, and 24-hour precipitation during each survey.

Refuge	Date of Survey	Max Wind Speed (miles per an hour)	High Tide time (GMT)	24-hour Precip. (inches)	Weather Station Used
Pea Island	6/4/2015	16	1:54	1.19	Norfolk Int'l Airport Station
Pea Island	6/5/2015	16	2:36	0	Norfolk Int'l Airport Station
Cedar Island	6/8/2015	18	4:30	0	Coastal Carolina Regional Airport
Cedar Island	6/9/2015	18	5:12	0.37	Coastal Carolina Regional Airport
Swanquarter	6/11/2015	16	20:18	0	Coastal Carolina Regional Airport
Swanquarter	6/12/2015	16	21:30	0.71	Coastal Carolina Regional Airport
Pocosin Lakes	6/23/2015	14	18:24	0	Pitt-Greenville Airport
Pocosin Lakes	6/24/2015	13	6:54	0	Pitt-Greenville Airport
Pocosin Lakes	6/25/2015	13	20:00	0	Pitt-Greenville Airport
Pinckney Island	7/23/2015	12	18:06	0.15	Hilton Head Airport, SC
Pinckney Island	7/24/2015	9	18:24	0	Hilton Head Airport, SC
Harris Neck	7/28/2015	16	22:42	0	Brunswick Golden Isles Airport, GA
Harris Neck	7/29/2015	13	23:18	0	Brunswick Golden Isles Airport, GA
Wassaw	8/5/2015	18	4:36	0	Savannah/Hilton Head Int'l Airport, GA
Wassaw	8/6/2015	22	17:54	0.1	Savannah/Hilton Head Int'l Airport, GA
Savannah	3/16/2016	15	6:42	0	Savannah/Hilton Head Int'l Airport, GA
Pinckney Island	5/3/2016	7	22:00	0	Hilton Head Airport, SC
Pinckney Island	5/4/2016	15	22:54	0	Hilton Head Airport, SC
Pinckney Island	5/5/2016	15	23:54	0	Hilton Head Airport, SC
Savannah	6/28/2016	23	19:12	0.44	Savannah/Hilton Head Int'l Airport, GA
St Marks	7/6/2016	28	21:06	1.24	Tallahassee Int'l Airport, FL
St Marks	7/7/2016	15	12:00	0	Tallahassee Int'l Airport, FL
Alligator River	7/20/2016	14	0:30	0	Norfolk Int'l Airport, VA
Alligator River	7/21/2016	10	1:48	0	Norfolk Int'l Airport, VA
Currituck	7/26/2016	22	17:06	0	Norfolk Int'l Airport, VA
Currituck	7/28/2016	17	19:18	0	Norfolk Int'l Airport, VA
Waccamaw	8/9/2016	18	17:42	0	Myrtle Beach Int'l Airport, SC
Waccamaw	8/10/2016	14	18:24	0	Myrtle Beach Int'l Airport, SC
Wolf Island	8/17/2016	10	0:18	0	Brunswick Golden Isles Airport, GA

Refuge	Date of Survey	Max Wind Speed (miles per an hour)	High Tide time (GMT)	24-hour Precip. (inches)	Weather Station Used
Wolf Island	8/25/2016	17	19:36	0	Brunswick Golden Isles Airport, GA
Blackbeard Island	8/18/2016	18	0:18	0	Savannah/Hilton Head Int'l Airport, GA
Blackbeard Island	8/19/2016	20	1:00	0.17	Savannah/Hilton Head Int'l Airport, GA
Ace Basin	3/12/2019	18	2:48	0	Charleston Int'l Airport / Charleston AFB, SC
Ace Basin	3/13/2019	17	3:48	0	Charleston Int'l Airport / Charleston AFB, SC
Alligator River	3/7/2019	15	1:00	0	Norfolk Int'l Airport, VA
Alligator River	4/4/2019	16	0:00	0	Norfolk Int'l Airport, VA
Mackay Island	4/16/2019	16	9:24	0	Norfolk Int'l Airport, VA
Mackay Island	4/17/2019	16	23:00	0	Norfolk Int'l Airport, VA
Pocosin Lakes	2/26/2019	13	6:42	0.36	Pitt-Greenville Airport
Roanoke River	3/18/2019	28	22:30	0	Pitt-Greenville Airport
Roanoke River	3/19/2019	15	10:42	0	Pitt-Greenville Airport

Appendix B. SOPs for measuring Antenna Height in the field, 2015-2019.

Standardizing adapter measurements for USFWS South Atlantic Coastal Wetland Elevation Monitoring Network

Michelle Moorman and Nicole Rankin

Surveys, 2015-2016
During the summers of 2015 and 2016, repeated GNSS measurements were made at 42 RSET benchmarks sites located at 14 of the 22 RSET stations in the USFWS South Atlantic Coastal Wetland Elevation Monitoring Network. USGS-designed, fixed-dimension adapters manufactured by Nolan's machine shop were used to secure the GNSS unit to the benchmark during deployment. This document outlines the process used for determining the height of the antenna above the benchmark. This measurement is needed in order to derive benchmark elevations from field surveys.

Parts of the adapter: We calculated the height of the GNSS antenna when attached to the USGS Fixed-Dimension Adapter (Figure 1) using methods from the national geodetic survey (NOAA, Undated Report). Measurements of the tilt of the benchmark and five different parts of the adapter were needed in order to determine the height of the antenna (Figure 1).

- Measurement 1 is the height from the top of the benchmark (with PVC cap removed) to the underside base of the metal plate and was measured using calipers.
- Measurement 2 is from the underside base of the metal plate to the bottom of the Manfrotto ball notch and measured using a meter tape measure.
- Measurement 3 is from the bottom of the Manfrotto ball notch to the underside base of the mounting plate and measured using a meter tape measure.
- Measurement 4 is the width of the mounting plate and measured using calipers.
- Measurement 5 is the length of the survey rod.

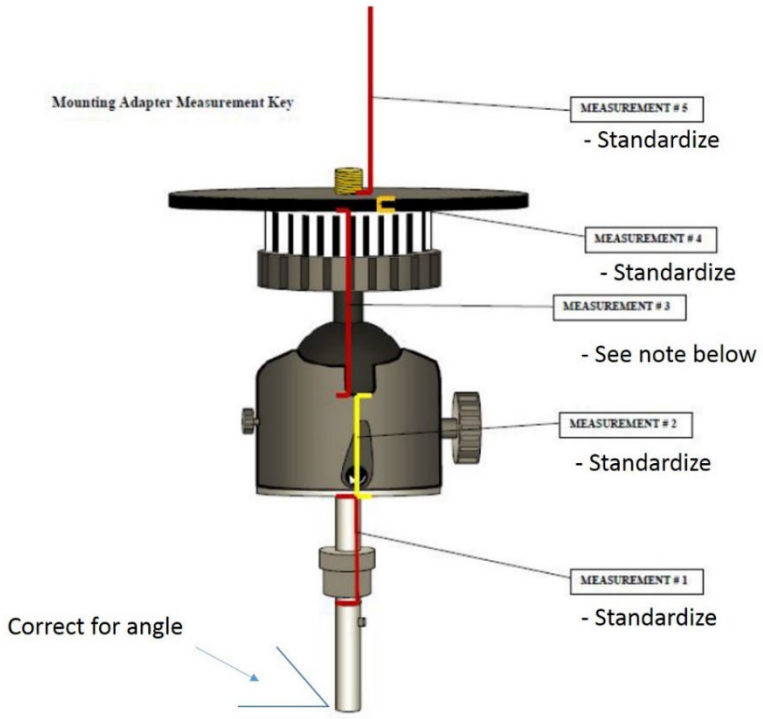
Measuring the tilt/correcting for angle: We used a digital tiltmeter to determine the greatest tilt angle of the RSET benchmark. We held the digital tiltmeter against the side of the adapter above the threaded cap and below the stainless steel plate, and recorded the tilt angle at multiple locations along the circumference of the adapter. We recorded the highest tilt.

Determining the height of the antenna: Repeated measurements of all five parts of the adapter were made in the lab using the 3 USGS adapters. Table 1 demonstrates that the greatest measurement variability came from measurement 3 (=/- 1 mm). We deduced that this was because Measurement 3 will be affected by the angle of the ball in the socket. For this reason, it is important to always make Measurement 3 at the point with the greatest tilt.

Table 1. Mean, standard deviation (STDEV), and standard error (SE) from lab measurements (cm) of adapter equipment used in 2015 and 2016, 1-5.

	1	2	3	4	5
Mean	8.90	7.27	10.04533	0.72	95.80
STDEV	0.036275	0.036522	0.122332	0.008238	0
SE	0.014809	0.01491	0.049942	0.003363	0

Figure 1. Schematic of USGS adapter used in 2015/2016.



Additionally, all five parts were measured in the field each time a survey was conducted. This information was evaluated to determine the variability of these measurements (Table 2). Based on logic, Measurements 2, 4, and 5 should always be the same, but Measurement 1 could vary if the length of the notch varied, and measurement 3 could vary based on the tilt of the Manfrotto ball in the socket. The variability in Measurements 2 and 5 were likely measurement (observational) error of using the meter tape measure to determine measurements in the field.

Table 2. Mean, standard deviation (STDEV), and standard error (SE) from field measurements (cm) of adapter equipment used in 2015 and 2016, 1-5.

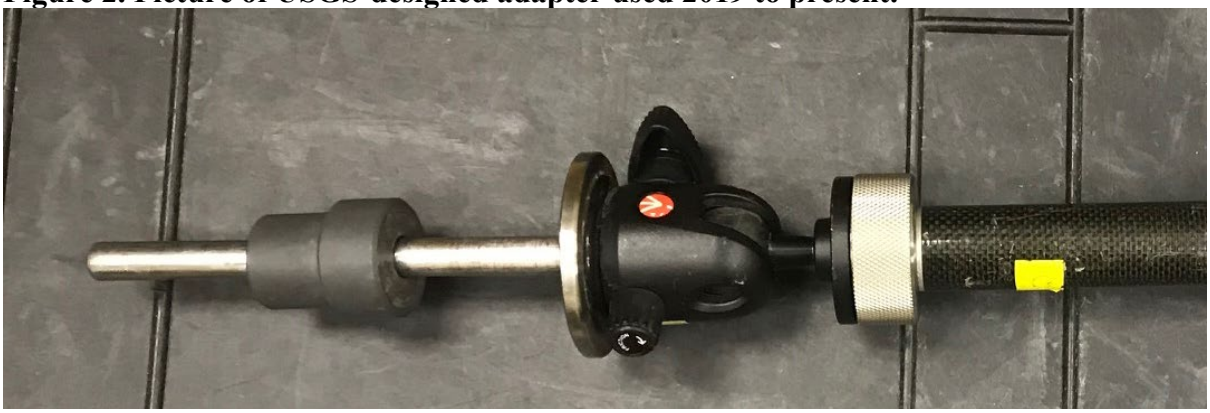
	1	2	3	4	5	Height of Quick Release
Mean	8.958387	7.147151	9.913441	0.71	95.45618	5
STDEV	0.119212	0.137136	0.133779	0.001474	0.180879	
SE	0.012362	0.01422	0.013872	0.000153	0.019173	

Decision: We decided to standardize Measurements 2, 4, and 5 based on lab measurements and to use field measurements for Measurements 1 and 3 in the equation to calculate the antenna height. The original field measurements (Raw Calculations) and the calculated antenna heights using the standardized measurements (Standardized Calc) are available in the field sheet, FinalAntennaHeight_NR.xlsx

Surveys, 2019

In 2019, we began a survey of the remaining RSET sites in the USFWS South Atlantic Coastal Wetland Elevation Monitoring Network. Additionally, we resurveyed the Pocosin Lakes NWR site due to errors that occurred during the initial survey. Prior to the 2019 survey, new adapters were manufactured by Nolan's machine shop because the old adapters were slipping. This required that new adapter measurements be made. This document outlines the process used for determining the height of the antenna above the benchmark which changed slightly from the methods used in 2015-2016. This measurement is needed in order to derive benchmark elevations from field surveys.

Figure 2. Picture of USGS-designed adapter used 2019 to present.



Parts of the adapter. We calculated the height of the GNSS antenna when attached to the USGS Fixed-Dimension Adapter (Figure 1) using methods from the national geodetic survey (NOAA, Undated Report). Due to differences between the old and new adapters, Measurements 2, 3, and 4 need to be recalculated.

- Measurement 1 is the height of the top of the benchmark (with PVC cap removed) to the to the underside base of the metal plate. This measurement was standardized to the lab measurement from 2015/2016, 8.9 cm, since it did not change. This also was done

because in the field we measured to the bottom of the cap. In order to correct the measurement to the height of the benchmark, we used a standard value for Measurement 1 and we found that there was a 35 mm difference (+/- 0.5 mm) between the bottom of the cap and the top of the benchmark. Due to the consistencies in these measurements, we felt comfortable standardizing measurement 1.

- Measurement 2 is from the bottomside of the metal plate to the bottom of the Manfrotto ball notch and has been standardized from lab measurements.
- Measurement 3 is from the bottom of the Manfrotto ball notch to the underside base of the mounting plate and measured using calipers.
- Measurement 4 is the width of the mounting plates (the black mounting plate plus the wider metal mounting plate) and has been standardized from lab measurements made with calipers.
- Measurement 5 is the length of the survey rod and has been standardized from lab measurements.

Table 3. Mean, standard deviation (STDEV), and standard error (SE) from standardized lab measurements (cm) of adapter equipment used from 2019.

	1	2	3	4	5	Height of Quick Release	Height of Antenna
Mean	8.90	4.35	4.8	2.95	95.78	5	122
STDEV	0.036275	0.026227		0.009045	0.045227		
Stde error	0.014809	0.007571		0.002611	0.013056		

Standardizing adapter heights moving forward: After discussing these adapter measurements with Jim Lynch (NPS), we decided to standardize all antenna heights moving forward to **1.22 m** as long as the current equipment continues to be used. Based on his experience and the results from this work, we did not find a significant difference between antenna heights that accounted for tilt and antenna heights that simply added all parts of the adapter together. Comparison of all the antenna height data from 2015/2016 and 2019 show that the standard deviation of all the measurements was +/- 1 mm. Considering that it is hard to obtain sub centimeter accuracy during a GNSS survey for orthometric height, we decided a standardized measurement would provide an adequate answer for the antenna height required when calculating the elevation of the benchmark. The one caveat to this measurement would be if two poles are screwed together to raise the antenna height. In that case, 0.96 m would need to be added to the antenna height for each pole added. Ultimately, the GNSS survey of the benchmark is conducted to tie the surface elevation derived from the RSET readings to a known elevation. The accuracy of the benchmark elevation will not affect the rate of elevation change measured with the RSETs, which provides mm accuracy.

Table 4. Standardized antenna heights (m) to be used to calculate the elevation of the benchmark.

Poles used in the field	Standard Antenna Height used in OPUS-S (m)
1 pole	1.22
2 poles	2.18
3 poles	3.14

Appendix C. Antenna height calculations, 2015-2019. All Antenna heights calculated from 2019 data need a -3.5 cm correction in order to account for the fact antenna height was measured to the bottom of the gray cap.

Benchmark ID	Survey Date	AM1	AM2	AM3	AM4	AM5	Tilt (deg)	A = 1+2	A' = A[cos (Tilt)]	B = 3+4+5	Antenna Height (cm) = A'+B+5	Antenna height correction (cm)
PLD010A	6/4/2015	8.88	7.27	9.8	0.72	95.8	0.3	16.15	16.15	106.32	127.47	
PLD010B	6/4/2015	8.94	7.27	9.7	0.72	95.8	0.4	16.21	16.21	106.22	127.43	
PLD010C	6/4/2015	9.01	7.27	9.7	0.72	95.8	0.5	16.28	16.28	106.22	127.50	
PLD010A	6/5/2015	8.88	7.27	9.8	0.72	95.8	0.5	16.15	16.15	106.32	127.47	
PLD010B	6/5/2015	8.92	7.27	9.8	0.72	95.8	0.4	16.19	16.19	106.32	127.51	
PLD010C	6/5/2015	8.89	7.27	9.8	0.72	95.8	0.3	16.16	16.16	106.32	127.48	
CDR027A	6/8/2015	8.89	7.27	9.8	0.72	95.8	1.2	16.16	16.16	106.32	127.48	
CDR027B	6/8/2015	8.89	7.27	9.8	0.72	95.8	0.5	16.16	16.16	106.32	127.48	
CDR027C	6/8/2015	8.91	7.27	9.8	0.72	95.8	1.25	16.18	16.18	106.32	127.50	
CDR027A	6/9/2015	8.89	7.27	9.8	0.72	95.8	1.25	16.16	16.16	106.32	127.48	
CDR027B	6/9/2015	8.89	7.27	9.8	0.72	95.8	0.5	16.16	16.16	106.32	127.48	
CDR027C	6/9/2015	8.91	7.27	9.8	0.72	95.8	1.25	16.18	16.18	106.32	127.50	
SWQ000A	6/11/2015	8.94	7.27	9.8	0.72	95.8	0.75	16.21	16.21	106.32	127.53	
SWQ000B	6/11/2015	8.89	7.27	9.8	0.72	95.8	0.5	16.16	16.16	106.32	127.48	
SWQ000C	6/11/2015	8.89	7.27	9.8	0.72	95.8	0.35	16.16	16.16	106.32	127.48	
SWQ000A	6/12/2015	8.9	7.27	9.8	0.72	95.8	0.6	16.17	16.17	106.32	127.49	
SWQ000B	6/12/2015	8.91	7.27	9.8	0.72	95.8	0.5	16.18	16.18	106.32	127.50	
SWQ000C	6/12/2015	8.9	7.27	9.8	0.72	95.8	0.5	16.17	16.17	106.32	127.49	
POC016A	6/23/2015	8.88	7.27	9.8	0.72	95.8	2.5	16.15	16.13	106.32	127.45	
POC016B	6/23/2015	8.92	7.27	9.8	0.72	95.8	0.35	16.19	16.19	106.32	127.51	
POC016B	6/24/2015	8.98	7.27	9.8	0.72	95.8	0.5	16.25	16.25	106.32	127.57	
POC016C	6/24/2015	8.96	7.27	9.8	0.72	95.8	1.6	16.23	16.22	106.32	127.54	
POC016A	6/25/2015	8.89	7.27	9.8	0.72	95.8	2.7	16.16	16.14	106.32	127.46	
POC016C	6/25/2015	8.91	7.27	9.8	0.72	95.8	1.7	16.18	16.17	106.32	127.49	
PKY008A	7/23/2015	8.94	7.27	9.8	0.72	95.8	0.5	16.21	16.21	106.32	127.53	

Benchmark ID	Survey Date	AM1	AM2	AM3	AM4	AM5	Tilt (deg)	A = 1+2	A' = A[cos (Tilt)]	B = 3+4+5	Antenna Height (cm) = A'+B+5	Antenna height correction (cm)
PKY008B	7/23/2015	8.94	7.27	9.8	0.72	95.8	1.4	16.21	16.21	106.32	127.53	
PKY008C	7/23/2015	8.95	7.27	9.8	0.72	95.8	0.6	16.22	16.22	106.32	127.54	
PKY008A	7/24/2015	8.95	7.27	9.8	0.72	95.8	1.5	16.22	16.21	106.32	127.53	
PKY008B	7/24/2015	8.95	7.27	9.8	0.72	95.8	0.9	16.22	16.22	106.32	127.54	
PKY008C	7/24/2015	8.95	7.27	9.8	0.72	95.8	0.5	16.22	16.22	106.32	127.54	
HSN033A	7/28/2015	8.99	7.27	9.8	0.72	95.8	1.7	16.26	16.25	106.32	127.57	
HSN033B	7/28/2015	8.97	7.27	9.8	0.72	95.8	0.4	16.24	16.24	106.32	127.56	
HSN033C	7/28/2015	8.95	7.27	9.8	0.72	95.8	0.4	16.22	16.22	106.32	127.54	
HSN033A	7/29/2015	8.96	7.27	9.8	0.72	95.8	2.85	16.23	16.21	106.32	127.53	
HSN033B	7/29/2015	8.95	7.27	9.8	0.72	95.8	0.25	16.22	16.22	106.32	127.54	
HSN033C	7/29/2015	8.94	7.27	9.8	0.72	95.8	0.25	16.21	16.21	106.32	127.53	
WSW001A	8/5/2015	8.93	7.27	9.8	0.72	95.8	0.9	16.2	16.20	106.32	127.52	
WSW001B	8/5/2015	8.94	7.27	9.8	0.72	95.8	3.3	16.21	16.18	106.32	127.50	
WSW001C	8/5/2015	8.93	7.27	9.8	0.72	95.8	2.4	16.2	16.19	106.32	127.51	
WSW001A	8/6/2015	8.98	7.27	9.8	0.72	95.8	1.1	16.25	16.25	106.32	127.57	
WSW001B	8/6/2015	8.95	7.27	9.8	0.72	95.8	3.35	16.22	16.19	106.32	127.51	
WSW001C	8/6/2015	8.95	7.27	9.8	0.72	95.8	2.35	16.22	16.21	106.32	127.53	
SAV004A	3/16/2016	8.93	7.27	9.99	0.72	95.8	0.6	16.2	16.20	106.51	127.71	
SAV004B	3/16/2016	8.92	7.27	9.98	0.72	95.8	0.65	16.19	16.19	106.5	127.69	
SAV004C	3/16/2016	9.1	7.27	9.98	0.72	95.8	0.5	16.37	16.37	106.5	127.87	
PKY008A	5/3/2016	9.15	7.27	9.98	0.72	95.8	1.2	16.42	16.42	106.5	127.92	
PKY008B	5/3/2016	8.95	7.27	9.98	0.72	95.8	0.65	16.22	16.22	106.5	127.72	
PKY008C	5/3/2016	8.94	7.27	9.98	0.72	95.8	1.65	16.21	16.20	106.5	127.70	
PKY008A	5/4/2016	9.15	7.27	9.98	0.72	95.8	1.2	16.42	16.42	106.5	127.92	
PKY008B	5/4/2016	8.95	7.27	9.98	0.72	95.8	0.65	16.22	16.22	106.5	127.72	
PKY008C	5/4/2016	8.94	7.27	9.98	0.72	95.8	1.65	16.21	16.20	106.5	127.70	

Benchmark ID	Survey Date	AM1	AM2	AM3	AM4	AM5	Tilt (deg)	A = 1+2	A' = A[cos (Tilt)]	B = 3+4+5	Antenna Height (cm) = A'+B+5	Antenna height correction (cm)
PKY008A	5/5/2016	9.15	7.27	9.98	0.72	95.8	1.2	16.42	16.42	106.5	127.92	
PKY008B	5/5/2016	8.95	7.27	9.98	0.72	95.8	0.65	16.22	16.22	106.5	127.72	
PKY008C	5/5/2016	8.94	7.27	9.98	0.72	95.8	1.65	16.21	16.20	106.5	127.70	
SAV004A	6/28/2016	8.96	7.27	10.1	0.72	95.8	0.5	16.23	16.23	106.62	127.85	
SAV004B	6/28/2016	8.96	7.27	10.05	0.72	95.8	1.1	16.23	16.23	106.57	127.80	
SAV004C	6/28/2016	8.96	7.27	9.98	0.72	95.8	1.25	16.23	16.23	106.5	127.73	
SMK000A	7/6/2016	8.95	7.27	10.05	0.72	95.8	0.9	16.22	16.22	106.57	127.79	
SMK000B	7/6/2016	8.96	7.27	10.02	0.72	95.8	0.4	16.23	16.23	106.54	127.77	
SMK000C	7/6/2016	8.92	7.27	9.98	0.72	95.8	1.95	16.19	16.18	106.5	127.68	
SMK000A	7/7/2016	8.92	7.27	10.16	0.72	95.8	0.9	16.19	16.19	106.68	127.87	
SMK000B	7/7/2016	8.96	7.27	9.89	0.72	95.8	0.4	16.23	16.23	106.41	127.64	
SMK000C	7/7/2016	8.94	7.27	9.98	0.72	95.8	1.95	16.21	16.20	106.5	127.70	
ALL005A	7/20/2016	8.92	7.27	10.03	0.72	95.8	0.9	16.19	16.19	106.55	127.74	
ALL005B	7/20/2017	9.96	7.27	9.69	0.72	95.8	3.3	17.23	17.20	106.21	128.41	
ALL005C	7/20/2016	8.91	7.27	9.89	0.72	95.8	1.05	16.18	16.18	106.41	127.59	
ALL005A	7/21/2016	8.92	7.27	10.08	0.72	95.8	0.9	16.19	16.19	106.6	127.79	
ALL005B	7/21/2016	8.95	7.27	9.72	0.72	95.8	3.3	16.22	16.19	106.24	127.43	
ALL005C	7/21/2016	8.9	7.27	9.84	0.72	95.8	1.05	16.17	16.17	106.36	127.53	
CRT026A	7/26/2016	8.96	7.27	9.94	0.72	95.8	1.6	16.23	16.22	106.46	127.68	
CRT026B	7/26/2016	8.98	7.27	10.07	0.72	95.8	0.6	16.25	16.25	106.59	127.84	
CRT026C	7/26/2016	8.94	7.27	10.16	0.72	191.6	2.45	16.21	16.20	202.48	223.68	
CRT026A	7/28/2016	8.96	7.27	9.99	0.72	95.8	1.6	16.23	16.22	106.51	127.73	
CRT026B	7/28/2016	8.95	7.27	10	0.72	95.8	0.6	16.22	16.22	106.52	127.74	
CRT026C	7/28/2016	8.92	7.27	10.14	0.72	191.6	2.45	16.19	16.18	202.46	223.64	
WAW000A	8/9/2016	8.92	7.27	10.13	0.72	95.8	0.65	16.19	16.19	106.65	127.84	
WAW000B	8/9/2016	8.91	7.27	9.93	0.72	95.8	1.3	16.18	16.18	106.45	127.63	

Benchmark ID	Survey Date	AM1	AM2	AM3	AM4	AM5	Tilt (deg)	A = 1+2	A' = A[cos (Tilt)]	B = 3+4+5	Antenna Height (cm) = A'+B+5	Antenna height correction (cm)
WAW000C	8/9/2016	8.97	7.27	9.91	0.72	191.6	0.5	16.24	16.24	202.23	223.47	
WAW000A	8/10/2016	8.93	7.27	9.9	0.72	95.8	0.65	16.2	16.20	106.42	127.62	
WAW000B	8/10/2016	8.99	7.27	10.26	0.72	95.8	1.3	16.26	16.26	106.78	128.04	
WAW000C	8/10/2016	8.95	7.27	9.99	0.72	191.6	0.5	16.22	16.22	202.31	223.53	
WLF035A	8/17/2016	8.94	7.27	9.95	0.72	95.8	2.8	16.21	16.19	106.47	127.66	
WLF035B	8/17/2016	9.2	7.27	10.12	0.72	95.8	0.55	16.47	16.47	106.64	128.11	
WLF035C	8/17/2016	8.92	7.27	10.06	0.72	95.8	0.2	16.19	16.19	106.58	127.77	
BLB011A	8/18/2016	8.97	7.27	10.09	0.72	95.8	0.4	16.24	16.24	106.61	127.85	
BLB011B	8/18/2016	8.92	7.27	10.2	0.72	95.8	2.7	16.19	16.17	106.72	127.89	
BLB011C	8/18/2016	8.96	7.27	10.04	0.72	95.8	1.4	16.23	16.23	106.56	127.79	
BLB011A	8/19/2016	8.95	7.27	10.06	0.72	95.8	0.4	16.22	16.22	106.58	127.80	
BLB011B	8/19/2016	8.96	7.27	10.16	0.72	95.8	2.7	16.23	16.21	106.68	127.89	
BLB011C	8/19/2016	8.97	7.27	9.97	0.72	95.8	1.4	16.24	16.24	106.49	127.73	
WLF035A	8/25/2016	8.92	7.27	10.05	0.72	95.8	2.8	16.19	16.17	106.57	127.74	
WLF035B	8/25/2016	8.98	7.27	10.08	0.72	95.8	0.55	16.25	16.25	106.6	127.85	
WLF035C	8/25/2016	8.91	7.27	10.12	0.72	95.8	0.2	16.18	16.18	106.64	127.82	
ABS017C	3/12/2019	13.01	3.73	5.86	2.24	95.78	3.1	16.74	16.72	103.88	125.60	-3.5
ABS017B	3/12/2019	13.11	3.73	5.71	2.24	95.78	1.6	16.84	16.83	103.73	125.56	-3.5
ABS017A	3/12/2019	13.06	3.73	5.55	2.24	95.78	0.8	16.79	16.79	103.57	125.36	-3.5
ABS017C	3/13/2019	13.01	3.73	5.86	2.24	95.78	2.45	16.74	16.72	103.88	125.60	-3.5
ABS017B	3/13/2019	13.11	3.73	5.71	2.24	95.78	1.6	16.84	16.83	103.73	125.56	-3.5
ABS017A	3/13/2019	13.07	3.73	5.85	2.24	95.78	1.4	16.8	16.79	103.87	125.66	-3.5
ALL030A	3/6/2019	13.05	3.73	4.73	2.95	95.78	4.65	16.78	16.72	103.46	125.18	-3.5
ALL030A	3/7/2019	13	3.73	4.92	2.95	95.78	4.65	16.73	16.67	103.65	125.32	-3.5
ALL030B	4/4/2019	13.1	3.73	5.68	2.24	95.78	3.2	16.83	16.80	103.7	125.50	-3.5
ALL030B	3/6/2019	12.98	3.73	4.87	2.95	95.78	2.2	16.71	16.70	103.6	125.30	-3.5

Benchmark ID	Survey Date	AM1	AM2	AM3	AM4	AM5	Tilt (deg)	A = 1+2	A' = A[cos (Tilt)]	B = 3+4+5	Antenna Height (cm) = A'+B+5	Antenna height correction (cm)
ALL030B	3/7/2019	12.99	3.73	4.85	2.95	95.78	2.2	16.72	16.71	103.58	125.29	-3.5
ALL030A	4/4/2019	13.03	3.73	5.8	2.24	95.78	5.1	16.76	16.69	103.82	125.51	-3.5
ALL030C	3/6/2019	13.1	3.73	4.71	2.95	95.78	3.4	16.83	16.80	103.44	125.24	-3.5
ALL030C	3/7/2019	13.08	3.73	4.7	2.95	95.78	3.4	16.81	16.78	103.43	125.21	-3.5
ALL030C	4/4/2019	13.02	3.73	5.7	2.24	95.78	3.25	16.75	16.72	103.72	125.44	-3.5
MCI026C	4/16/2019	13.12	3.73	4.81	2.95	95.78	1.55	16.85	16.84	103.54	125.38	-3.5
MCI026C	4/17/2019	13.12	3.73	4.81	2.95	95.78	1.55	16.85	16.84	103.54	125.38	-3.5
MCI026B	4/16/2019	12.98	3.73	4.84	2.95	95.78	0.55	16.71	16.71	103.57	125.28	-3.5
MCI026B	4/17/2019	12.98	3.73	4.84	2.95	95.78	0.55	16.71	16.71	103.57	125.28	-3.5
MCI026A	4/16/2019	13.09	3.73	4.8	2.95	95.78	0.7	16.82	16.82	103.53	125.35	-3.5
MCI026A	4/17/2019	13.09	3.73	4.8	2.95	95.78	0.7	16.82	16.82	103.53	125.35	-3.5
POC016A	2/25/2019	13.1	3.73	4.76	2.95	95.78	2.5	16.83	16.81	103.49	125.30	-3.5
POC016A	2/26/2019	13.13	3.73	4.79	2.95	95.78	2.7	16.86	16.84	103.52	125.36	-3.5
POC016B	2/25/2019	13	3.73	4.94	2.95	95.78	0.4	16.73	16.73	103.67	125.40	-3.5
POC016B	2/26/2019	13	3.73	4.95	2.95	95.78	0.4	16.73	16.73	103.68	125.41	-3.5
POC016C	2/25/2019	13.06	3.73	4.77	2.95	95.78	1.6	16.79	16.78	103.5	125.28	-3.5
POC016C	2/26/2019	13.06	3.73	4.77	2.95	95.78	1.6	16.79	16.78	103.5	125.28	-3.5
RRV013B	3/18/2019	13.04	3.73	5.6	2.24	95.78	1.7	16.77	16.76	103.62	125.38	-3.5
RRV013B	3/19/2019	13.06	3.73	5.63	2.24	95.78	1.55	16.79	16.78	103.65	125.43	-3.5
RRV013A	3/18/2019	13	3.73	5.81	2.24	95.78	3.3	16.73	16.70	103.83	125.53	-3.5
RRV013A	3/19/2019	13	3.73	5.81	2.24	95.78	3.3	16.73	16.70	103.83	125.53	-3.5
RRV013C	3/18/2019	13.12	3.73	5.6	2.24	95.78	3.15	16.85	16.82	103.62	125.44	-3.5
RRV013C	3/19/2019	13.11	3.73	5.6	2.24	95.78	3.45	16.84	16.81	103.62	125.43	-3.5

Appendix D. Definition of headings and includes in tables for individual station solutions.

Table D1. Definition of headings included in the table, **Quality of the solutions for the GNSS** survey conducted at the stations for the site.

Field Name	Field Definition
ID	Type of Survey Solution: OPUS-S 1, OPUS- S 2: OPUS solution for daily sessions Session 1, Session 2: OPUS Projects solution for daily sessions Network 1: Average of OPUS Projects session
RSET	Abbreviation for site (in parentheses in station header)
Solution	Date of data used to obtain solution
Obs (%)	Percent of observations used (good solutions have > 90%)
Fixed (%):	Percent of ambiguities are fixed (good solutions have > 50%)
SE	Standard Error of the vertical Solution (good solutions are close to 1)
RMS	Root mean squared error of vertical solution (Good solutions are < 3 cm)

Table D2. Explanation of Solution types (IDs) included in the table, **Average Position Solutions.**

ID	Type of Survey Solution
OPUS-S 1, OPUS- S 2	Opus solution for daily sessions
aOPUS-S	Average of OPUS-S solutions
Network 1	OP Network solution
Range	Difference between average OPUS-S (aOPUS-S) and OP Network (Network 1) solutions

Appendix E. List of Acronyms

List of Acronyms	Definition
cm	centimeter
CORS	Continuously Operating Reference Stations
CWEM	Coastal Wetland Elevation Monitoring
DOP	Dillution of Precision
FL	Florida
GA	Georgia
GNSS	Global Navigation Satellite System
I&M	Inventory and Monitoring
m	meter
mm	millimeter
NAVD88	North American Vertical Datum of 1988
NC	North Carolina
NGS	National Geodetic Survey
NPS	National Park Service
NOAA	National Oceanic and Atmospheric Administration
NSRS	National Spatial Reference System
NWR	National Wildlife Refuge
OP	OPUS Projects
OPUS-S	Online Positioning User Service-Static
PAGES	Program for Adjustment of GPS Ephemerides
RMS	root mean squared
RSETs	rod surface elevation tables
SALCC	South Atlantic Landscape Conservation Cooperative
SC	South Carolina
SE	standard error
TEC	Total Electron Content
US	United States

List of Acronyms	Definition
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey