The South Carolina Geological Survey Surface Elevation Table (SET) Network: 1998-2022

South Carolina Geological Survey Open-File Report (OFR)

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June 2022

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Cover photo: *SET and RSET measurement at Williman Island, Beaufort County in 2020.*

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IV. INTRODUCTION

Since 1998, the South Carolina Geological Survey (SCGS) has installed, measured, maintained, and expanded a state-wide network of Surface Elevation Table (SET) and Rod-SET (RSET) stations in South Carolina's intertidal salt marshes. The SET and RSET instrumentation are designed to measure changes in wetland surface elevation relative to the instrument's mounting location (Cahoon et al., 2002; Lynch et al., 2015). The SCGS utilizes the SET's mounting locations to evaluate the impacts of regional tectonics on the intertidal system by measuring for possible subsidence or uplift. To do this, SCGS collects surface elevation change data relative to the instrument's mount and the mount's elevation (geodetic) data relative to the earth. The SCGS was the first entity in South Carolina to systematically record the vertical elevations of SET and RSET stations with high-resolution geodetic surveying. Geodetic data were collected on the network in 1998, 2005, and 2011 by the South Carolina Geodetic Survey. Subsequent geodetic surveys were done by SCGS in 2018 and 2021.

Over the years, the program's geographic scope and original purpose have expanded. The ongoing goals of the SCGS SET project are to:

1. Use SET and RSET methodology to measure and quantify surface elevation changes in salt marshes that represent a variety of geomorphic, ecological, and tidal settings throughout coastal South Carolina;
2. Collect geodetic elevation data to quantify long-term potential subsidence or uplift, and;
3. Provide a long-term dataset to assess whether South Carolina's salt marshes are maintaining their vertical elevation with regards to relative sea-level rise (RSLR), which combines eustatic sea-level rise (SLR) and local vertical land motion (subsidence or uplift).

V. ACKNOWLEDGEMENTS

The authors acknowledge and thank those who have assisted with station installation, data collection, and maintenance throughout this project: C.W. (Bill) Clendenin, Jr., Charlie Zemp, Michael McKenzie, Joe Koch, Renaldo Jones, Brian Mixon, Morgan Scott, Aaron Kitt, Kyle Benton, Josh Williams, Frank Caruccio, Tom Herford, Gered Lennon, Jaquell Robinson, Brooke Czwartacki, Robby Morrow, Matt King, Matt Henderson, Tanner Arrington, Erin Koch, Evan Cook, Andy Wykel, Zach Zelaya, Jordan Suttles, Michael Georgopulos, Jeff Smoak, Robert McKeown, Richard Woods, Christopher Graffio, and James Gentry.

Additional thanks to Guy (Harley) Means with the Florida Geological Survey (FGS) for assistance locating information about the original FGS stations, as well as to Ronald Hoenstine and James Ladner, formerly with FGS, for introducing the SET to the SCGS and for their mentoring during the early days of the project. We are grateful to Phil Maier, and the ACE Basin National Estuarine Research Reserve (NERR), for partnering with the SCGS to support the update from the original SET design to the RSET in the ACE Basin in 2011. Collaboration with the ACE Basin NERR has been instrumental in developing the SCGS SET network over the years. The authors are also thankful for the collaboration of Erik Smith, Tracy Buck, and Baker Stevens with the North Inlet-Winyah Bay NERR and for the opportunity to include data collection from two of their RSETs into the larger network since 2014. Many thanks for the assistance and advice of the South Carolina Geodetic Survey, especially Richard Woods, Jeff Smoak, and Matt Wellslager, throughout this project. We also thank Robby Morrow, Brooke Czwartacki, Scott Howard, Megan James, Melissa Griffin, and Tanner Arrington for their insightful comments and reviews of different versions of this document.

VI. HISTORY

Original SCGS SET Network (1998 – 2011)

SET Origin and Use in the United States

The SET is a portable leveling instrument based on the Sedi-Eros Table, a device initially developed in the Netherlands in the 1980's as a mechanism for measuring changes in surface elevation of tidal flats (Schoot and de Jong, 1982). The principles and methodology behind the apparatus were adopted and modified by researchers in the United States in the 1990's, where SETs were used in Louisiana to quantify changes in elevation on the marsh platform (Boumans and Day, 1993). The SET instrument (and the more recent iteration, the RSET) attaches to permanent marks installed at specific locations (hereafter referred to as 'stations') in a marsh or wetland being studied.

Origins of SET Research in South Carolina

In 1997, under the direction of Donald Cahoon of the United States Geological Survey, Biological Services (USGS), the Florida Geological Survey (FGS) installed four SET stations (two paired sites) in the ACE Basin National Estuarine Research Reserve (NERR) in Colleton County, South Carolina (Figure 1). These installations were part of a regional initiative that included other stations in Georgia and Florida. The FGS collected marsh platform surface elevation data at these sites from April 1997-June 2001, and the South Carolina Geodetic Survey collected geodetic data in 1998 to establish high-resolution horizontal and vertical positioning. The FGS stations were measured two to three times annually, and feldspar marker horizon plots were established to quantify surface accretion (Boumans and Day, 1993). The FGS also collected two cores (4.87 and 3.9 m total depth at sites FGS1 and FGS2, respectively) to provide material for grain-size analysis and Pb-210 age-dating to estimate longer-term accumulation rates. Data were not collected after 2002. The SCGS attempted to reoccupy the stations in 2011 and discovered that the SET insert pipes had been lost, and the stations were declared nonfunctional.

Establishment and Locations of Original SCGS Stations

The initial SCGS SET network was comprised of ten stations built in the ACE Basin during the winter of 1997-1998 (Figure 1). An eleventh SET station (Station 11) was added in 2001 and is considered part of the initial network. The locations were chosen based on geographic distribution, accessibility, distance to creek edge,

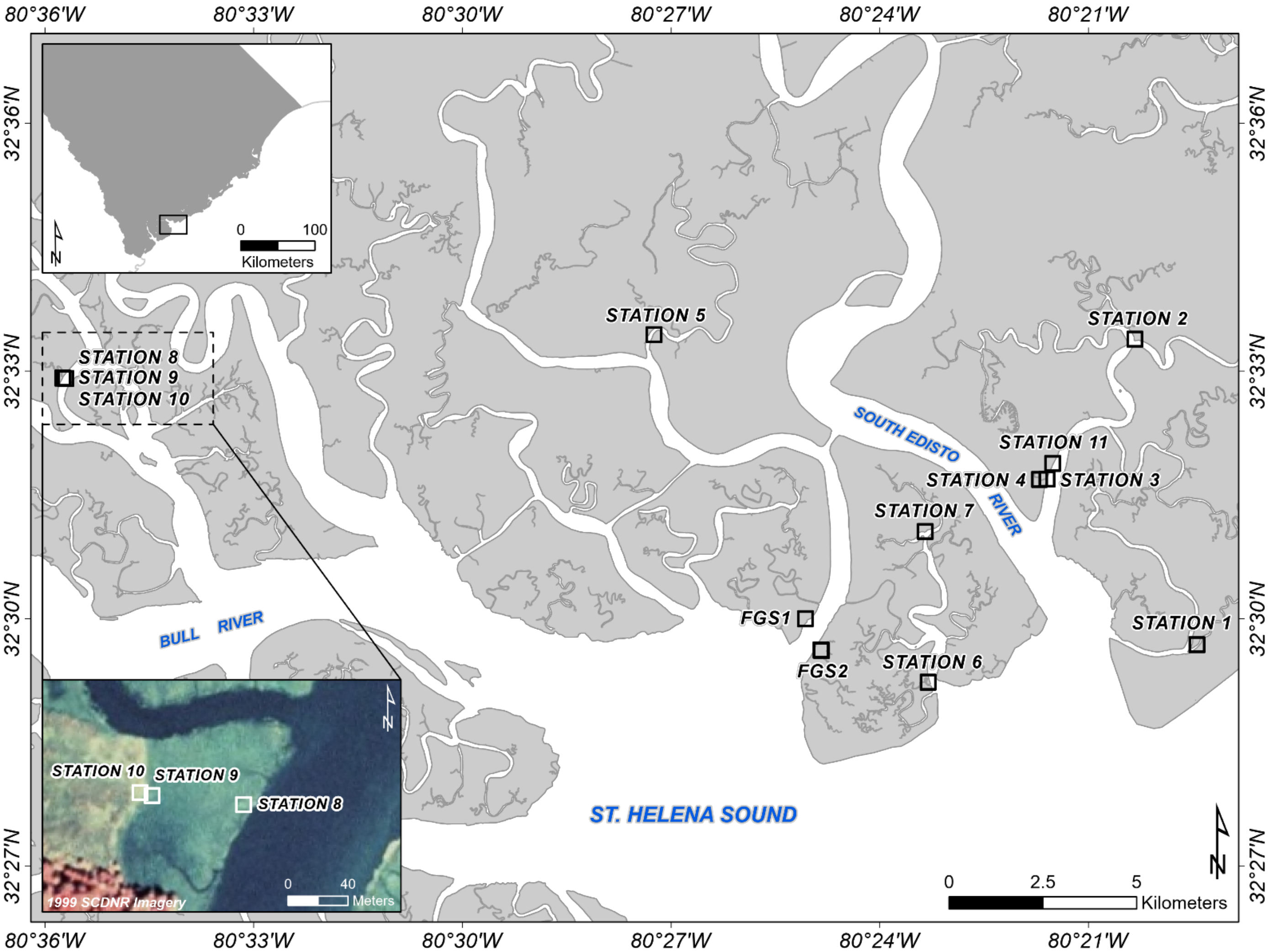

Figure 1. Locations and names of original FGS and SCGS SET stations in the ACE Basin NERR (measured 1998-2009, except for Station 10, which is still measured as of 2022). Inset map imagery is from 1999.

and in one specific area (Williman Island - Stations 8, 9, and 10), ability to compare cross-platform sediment transport. The geographic distribution of the original 11 stations focused on the core of the ACE Basin project (SCDNR, 2009). Accessibility during various points in the tide cycle was also a factor in station placement - having the water depth for boat access while the station was not flooded was critical because these stations are only accessible by water (Appendix A). The placement of the original stations was constrained by the reach of the vibracore equipment (a gas-powered vibrator that remained in the boat in the adjacent creek) used for their installation. Most of the original installations were located along creek levees, within 5 m of the creek bank.

As of 2022, five of the initial installations have been lost to bank erosion or materials failure. As seen in Figure 2 and Table 1, one initial station survives and is still used for data collection (Station 10). At eight of these sites, a newer version of the SET instrumentation, the RSET, was installed in 2009 (Cahoon et al., 2002). Where possible, the newer RSET installations were placed adjacent to the older SET installations in the same measurement plots (Figure 2). Four initial SET installations are still in place but are no longer used for collecting SET data - however, Global Navigation Satellite System (GNSS – GPS + GLONASS) data were collected on these stations using Real-Time Kinematic (RTK) Trimble R8 system in 2021.

SET station construction followed protocols outlined in Boumans and Day (1993). A 7.62-cm (3-inch) diameter, 1 mm wall thickness aluminum irrigation pipe was vibrated to refusal at each site. This depth varied based on the shallow stratigraphy but was typically 3-4 m. This aluminum support pipe was cut off near the sediment surface and a machined aluminum pipe (insert pipe) was cemented into it to serve as the SET mount (Figure 3). Walking piers were constructed on either side of the measuring area. SET construction methodology and materials are detailed in Appendices B, C, and D and are also outlined in Lynch et al., 2015 (the construction style used by SCGS for the original network is referred to as a pipe SET mark).

SET Naming Convention

At the beginning of the project, the SET station naming convention was based on the installation order (Station 1 was installed first, etc.) This naming convention was used for the eleven original ACE Basin SET stations (Figure 1; Table 1).

Modern (RSET) SCGS SET Network (2011 – Present)

Establishment and Locations of Rod-SETs (RSETs)

The original aluminum pipe used in SET station construction to support the insert pipe had an anticipated lifespan of approximately ten years. By 2008, several had failed due to corrosion. In the early 2000's, interest had grown for longer-term data collection, more corrosion-resistant materials, and a more compact, lighter weight, less expensive instrument. As a result, SET researchers developed and widely adopted the RSET instrument and stainless-steel mounting system in the early to mid-2000s (Cahoon et al., 2002; Lynch et al., 2015).

Through a partnership with the ACE Basin NERR, seven of the original SCGS SET stations were updated to the RSET design between 2009 and 2011 following installation protocols from Cahoon et al. (2002). For the stations that were converted, RSET assemblies were positioned as close to the original aluminum SET pipes as practical (within approximately a decimeter, Figure 3). Immediately following RSET construction, surface elevation and geodetic data were collected from both the original SET instrument and the RSET to allow for the

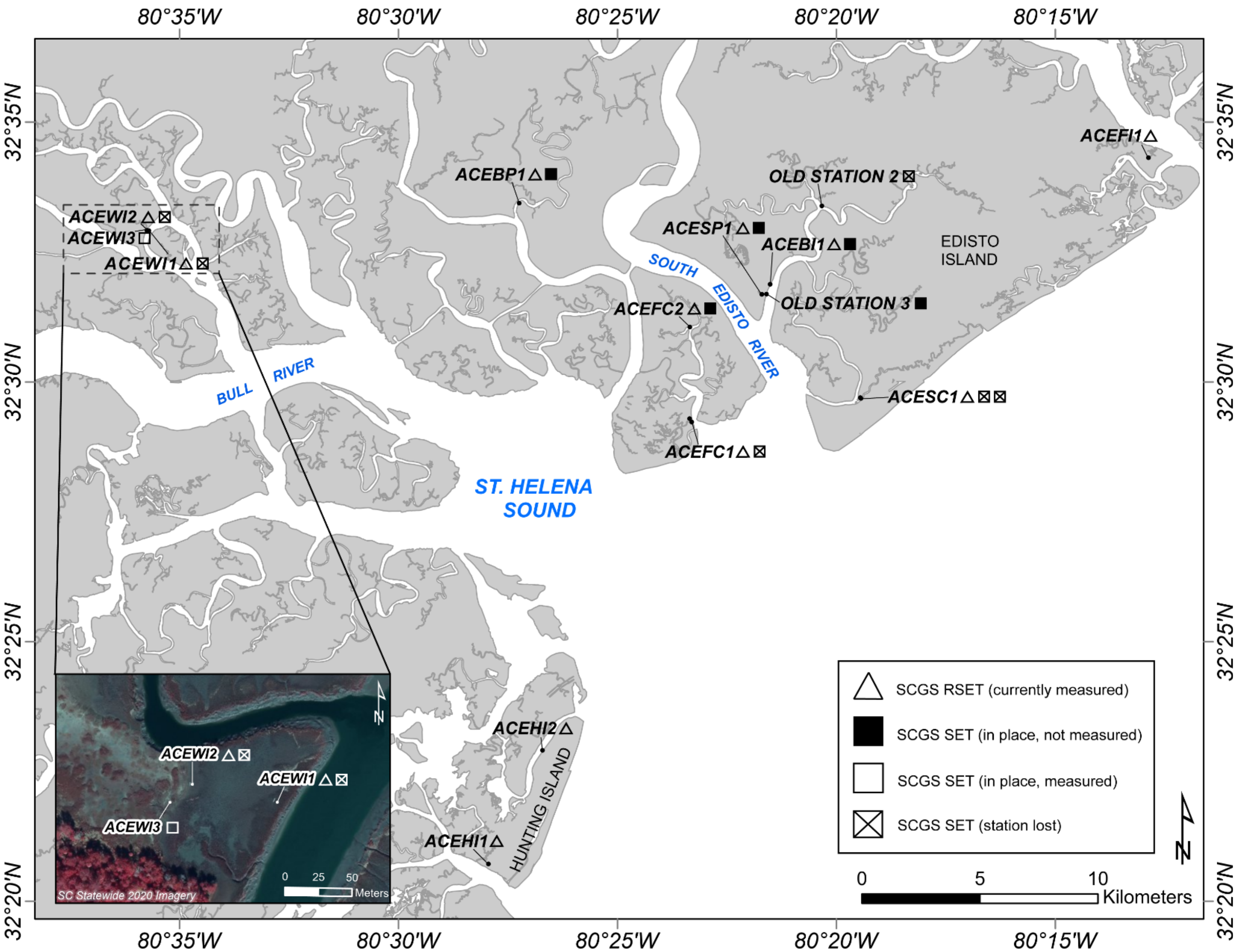

Figure 2. Present-day distribution, status, and location of all SCGS SET and RSET stations in the ACE Basin NERR. Symbology includes SET stations that have been lost to corrosion or shoreline change, and those that are still in place but are not measured. Inset map imagery is from 2020.

data to be converted between the two instruments. This dual collection allowed a hand-off from the original SET to the RSET. Details of this process are discussed in Cahoon et al. (2001).

NOTE: RSET pins do not measure the precise locations of the original SET pins because the RSETs are not located in the center of the original SET mount, have a shorter arm length, and have a linear pin arrangement versus the older square grid arrangement (Boumans and Day, 1993; Cahoon et al., 2002). However, both SET and RSET instruments collect the same number of data points (36) within the boundaries of the original measuring area. Cahoon et al. (2001) established that SET and RSET data collected at the same sites had similar variances; therefore, the SCGS concluded that the data collected by both instruments are comparable.

The RSET data are carried forward as an extension of the original SET data for stations that were converted from the original design.

With the development of the RSET, the requirements for installing new stations changed. The equipment used to install RSET stations is more portable than the original SET. New stations could be installed farther from creek edges, in more desirable locations that were not limited by boat-based accessibility. This flexibility allowed SCGS to expand the network geographically beyond the ACE Basin NERR. Between 2011 and 2021, 14 additional RSET stations were installed (Figure 4). The network is still broadly referenced as the SCGS SET network, although it now includes both SET and RSET. RSET installation is detailed in Appendices B and D.

RSET Naming Convention

When the RSET design came into use, and the SCGS SET network expanded beyond the ACE Basin in 2011, the station naming convention was updated. For this new convention, the coast was sub-divided into five compartments: Long Bay (LB), Cape Romain (CR), Charleston (CHS), ACE Basin (ACE), and Port Royal (PR) (Figure 4).

Figure 3. RSET installation adjacent to original SET. Note: gray anvil is on top of the RSET mark rods.

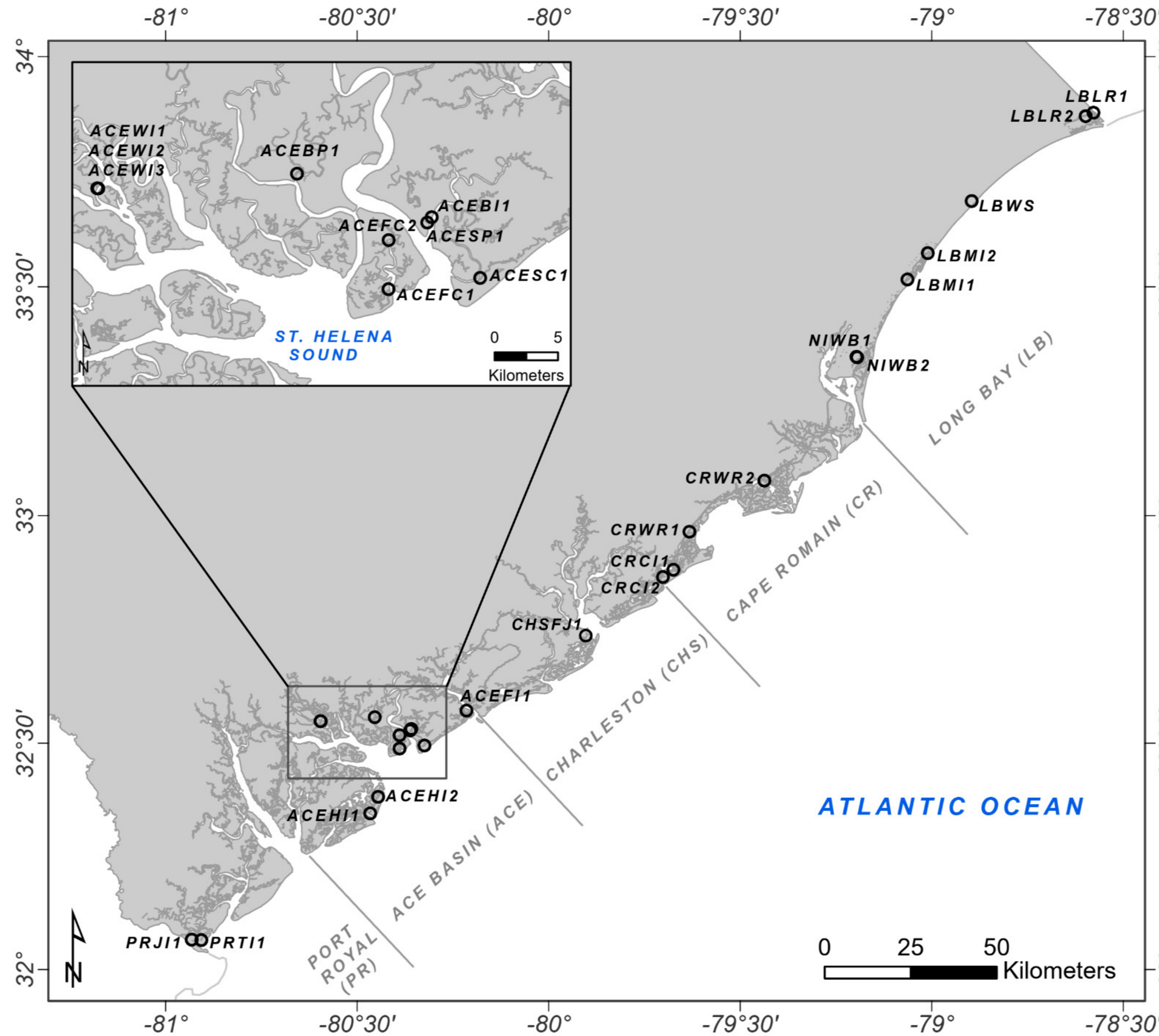

Figure 4. Stations within the SCGS SET and RSET network that are currently measured quarterly for elevation data, as of 2022.

Table 1. SCGS SET and RSET stations and associated years measured, listed by location. PRJI1, PRTI1, and CHSFJ1 (Figure 4) are RSETs that have been installed but have not been measured as of early 2022.

Location	Associated Stations	Station Type	Years Measured
ACE Basin - Scott Creek	Station 1	SET	1999 - 2003
	Station 1(b)	SET	2005 - 2006
	ACESC1	RSET	2010 - Present
ACE Basin - Bailey Creek at St. Pierre Creek	Station 2	SET	1999 - 2006
ACE Basin - St. Pierre Creek (Outer)	Station 3	SET	1999 - 2010
ACE Basin - St. Pierre Creek (Inner)	Station 4	SET	1999 - 2009
	ACESP1	RSET	2009 - Present
ACE Basin - Bennetts Point	Station 5	SET	1999 - 2009
	ACEBP1	RSET	2009 - Present
ACE Basin - Fish Creek (Mouth)	Station 6	SET	1999 - 2001
	ACEFC1	RSET	2009 - Present
ACE Basin - Fish Creek (Upper)	Station 7	SET	1999 - 2009
	ACEFC2	RSET	2009 - Present
ACE Basin - Williman Island (Low)	Station 8	SET	1999 - 2009
	ACEWI1	RSET	2009 - Present
ACE Basin - Williman Island (Middle)	Station 9	SET	1999 - 2011
	ACEWI2	RSET	2017 - Present
ACE Basin - Williman Island (High)	Station 10, ACEWI3	SET	1999 - Present
ACE Basin - Bailey Island	Station 11	SET	2001 - 2009
	ACEBI1	RSET	2009 - Present
ACE Basin - Fig Island	ACEFI1	RSET	2009 - Present
ACE Basin - Hunting Island (South)	ACEHI2	RSET	2010 - Present
ACE Basin - Hunting Island (North)	ACEHI1	RSET	2010 - Present
Cape Romain - Capers Island (South)	CRCI1	RSET	2010 - Present
Cape Romain - Capers Island (North)	CRCI2	RSET	2010 - Present
Cape Romain - Venning Creek	CRWR1	RSET	2013 - Present
Cape Romain - Clubhouse Creek	CRWR2	RSET	2013 - Present
North Inlet/Winyah Bay NERR (Upper)	NIWB1	RSET	2014 - Present
North Inlet/Winyah Bay NERR (Lower)	NIWB2	RSET	2014 - Present
Long Bay - Murrells Inlet (South)	LBMI1	RSET	2013 - Present
Long Bay - Murrells Inlet (North)	LBMI2	RSET	2013 - Present
Long Bay - Withers Swash	LBWS1	RSET	2013 - Present
Long Bay - Little River (South)	LBLR1	RSET	2013 - Present
Long Bay - Little River (North)	LBLR2	RSET	2013 - Present

The station names are a combination of the abbreviation or acronym of the compartment (ACE Basin- ‘ACE’), the abbreviation of a geographic reference such as a nearby creek, island, inlet, etc. (St. Pierre Creek - ‘SP’), and a number to signify the generation of the station at that location (first - ‘1’; if the station is lost to shoreline erosion, it is replaced and becomes ‘2’). ACE-SP1, for example, is the first RSET built at the SCGS site on St. Pierre Creek in the ACE Basin compartment. RSET stations are listed by location in Table 1.

Required Field Equipment for Data Collection

Portable equipment required to collect SET and geodetic data consists of the kits labeled in Appendix E and a cross board (2x10x12’, or an appropriate length for the station being measured) for accessing the stations.

SET and RSET Data Collection

The field methodology used for recording SET and RSET surface elevation measurements are detailed in Appendix F.

Geodetic Data Collection

In 1998, the South Carolina Geodetic Survey produced a high-resolution elevation survey on the original SET network (the original ACE Basin NERR SET stations except for Station 8) using the Height Modernization (HeightMod) standard’s base station and rover technique for a 2-cm local ellipsoid accuracy standard (Zilkoski et al., 1997). The rover antenna was attached to the top of a two-meter pole supported by a bi-pod. The tip of the pole was placed on the geodetic measuring (control) point and then leveled and checked for plumb (Figure 5). The level bubbles on the 2-meter fixed height pole were repeatedly checked for plumb before data collection. Initial observations were collected twice per station on two separate days, during different windows of time, to ensure different atmospheric conditions and satellite geometries as per National Geodetic Survey (NGS) standards (Zilkoski et al., 1997). The duration of the original rover observation was one hour, providing a minimum of 30 minutes of data collection overlap with the base station. Measurement standards included a 15-second epoch and Position Dilution of Precision (PDOP) of 4 or less, and station spacing did not exceed 10 km (6.2 miles) (M. Wellslager, SC Geodetic Survey, personal communication). Trimble Business Center (TBC) software was used to process the data according to procedures outlined in Zilkoski et al. (1997).

Since 2011, geodetic control has been obtained through global navigation satellite system (GNSS) surveying using a Trimble R8 system connected to South Carolina’s Virtual Reference Station (VRS) Network. The Trimble R8 on its own can provide real-time corrections when using the base and rover method; however, the

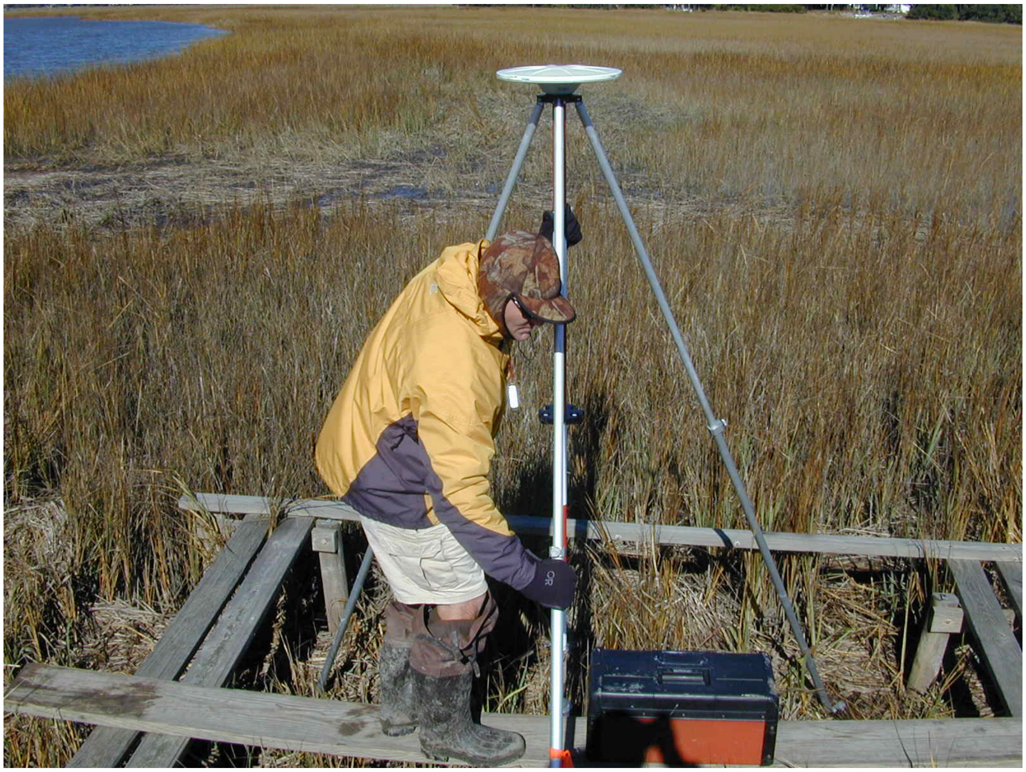

Figure 5. Setting up the rover on a SET station with the base station and rover technique.

VRS is a Real Time Network (RTN) that provides centimeter-scale positional accuracy through real-time corrections relayed to the rover instrument using a wireless connection, eliminating the need for physical base stations (Lapine and Wellslager, 2007; Geoghegan et al., 2009). The rover is a Trimble TSC2 data collector connected to the R8 receiver (antenna) via Bluetooth wireless connectivity. Data are collected for 10 minutes during two separate occupations and the two datasets are averaged to determine a single value for orthometric height at the geodetic reference point. Orthometric height is 'for practical purposes "height above sea level" based on the current NAVD 88 datum tied to a defined elevation at one point rather than to local mean sea level.' (Lynch et al., 2015). Field methodology follows the procedures outlined in Zilkoski et al. (2008) for estimating GNSS-derived orthometric heights.

The RTK+RTN method was first used on the SCGS SET network for a 2011 dataset collected by the SC Geodetic Survey. The method was repeated for network-wide surveys completed by SCGS in 2018 and 2021. Vertical elevation data were obtained using two ten-minute occupations on two different days, during offset windows of time, to ensure different atmospheric conditions and satellite geometries, as per NGS standards (Zilkoski et al., 2008). The South Carolina Geodetic Survey and SCGS used TBC software to import and organize data and relevant metadata in 2011, 2018, and 2021. Additional information on GNSS data collection and processing protocols can be found in Appendix G.

General Data Analysis Methods

SET and RSET

For basic analysis, the 36 data points collected at each station are averaged into one value (nine (9) data points per quadrant over four (4) quadrants). If this averaged measurement value increases over time, the station gains elevation relative to the SET mount; if it decreases, the station loses surface elevation. For more detailed analyses, such as calculating the rate of orthometric elevation change, the averaged pin data are converted to NAVD88-referenced surface elevation using the procedure in Appendix H. The standard error is then calculated and a simple linear regression trendline can be generated. Before analysis, collecting at least five years' worth of data is recommended to overcome short-term variability (i.e., seasonal changes) and obtain trends that represent marsh response to sea level (Lynch et al., 2015).

Geodetic

Geodetic data collected in the field are exported from TBC into .csv files or shapefiles. With repeated measurements over time, the geodetic data are checked for significant changes (i.e., beyond the error of the technology and methods). During SET installation, the aluminum pipe for each station was driven to refusal (typically ~3 m in depth). Any geodetic elevation change, including subsidence, uplift, and compaction between the bottom of the pipe and the next stable substrate, is assumed to occur below the bottom of the pipe (Cahoon et al., 2002). Any geodetic elevation change for the RSETs is assumed to occur below the mark rod, which was driven to refusal (~10-15 m depth) for all stations (Appendix B, Figure 1B). This geodetic change may include subsidence, uplift, or compaction between the bottom of the rod and the next stable substrate (Cahoon et al., 2002).

Deriving Orthometric Surface Elevations from Geodetic Data

The first step in using these data in a meaningful way requires extrapolating the actual orthometric elevation of the marsh platform measuring surface from the orthometric elevation data values collected at the RSET and SET geodetic reference points. The procedure for converting the original GNSS data to orthometric elevations for the marsh surface is detailed in Appendix H.

Although the RTK+RTN geodetic surveying methodology used by the SCGS for the SET network can provide millimeter-level precision, all GNSS survey data are compared on the level of centimeters due to the accuracy limitations of conducting geodetic field campaigns in remote areas (outlined in Geoghegan et al., 2009).

Data Storage

All SCGS SET and RSET field data are collected with pencil in waterproof notebooks and archived in the SCGS office. The data are also transcribed into computer-based spreadsheets to allow for alternate data storage and easier data processing. Data from the FGS SET stations (1997-2002) are housed with the FGS, SCGS, and ACE Basin NERR. All geodetic data are archived at the SCGS office. Geodetic data from the initial ACE Basin SET network are monumented within the NGS Database and accessible via the National Geodetic Survey Data Explorer (geodesy.noaa.gov/NGSDataExplorer).

VII. STATUS OF NETWORK

As of June 2022, the SCGS SET network includes 26 stations that range geographically from Turtle Island Wildlife Management Area, Jasper County, to Little River, Horry County. Two of these stations, NIWB1 and NIWB2, are managed by the North Inlet-Winyah Bay NERR. The most recent station (CHSFJ1) was installed in December 2021 at Fort Johnson, Charleston County. Of the 26 stations currently measured in the network, 25 are RSETs. As of 2022, Station 10 (ACEWI3) is the only initial SET that is still measured. As an experiment, the newly created CHSFJ1 is a combined SET-RSET site, with both instrument mounts installed together in the same support collar (see Appendix D for a detailed field guide based on the installation of CHSFJ1).

VIII. FUTURE WORK

Future expansion of the SCGS SET network will further the existing goals of the project by:

1. Quantifying changes to the elevation of salt marsh platforms representing a variety of geomorphic, ecological, and tidal settings throughout coastal South Carolina;
2. Continuing to collect geodetic elevations to quantify long-term potential subsidence or uplift at locations along the South Carolina intertidal zone, and;
3. Providing a long-term dataset that is available to assess whether South Carolina's salt marshes are maintaining their elevation with regards to relative sea-level rise (RSLR).

Future stations will target gaps in coverage, most notably in the central part of the coast near Charleston, and will seek out opportunities for collaboration with coastal communities, universities, and state and county parks. The SCGS is also considering moving field data entry from waterproof field books to a tablet-based ArcGIS Field Maps or Survey123 application platform. This new methodology could allow for rapid data entry into a database and more accessible collection of field notes related to SET station maintenance.

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APPENDIX A. SITING CONSIDERATIONS FOR ESTABLISHING SET AND RSET STATIONS IN SOUTH CAROLINA

Selecting a site for a SET or RSET station can be as simple as saying 'I want one there' and installing it. BUT: there are myriad items to consider, and each has follow-on issues. The first questions to address are: What are the research goals and where do you need data? What kinds of factors (vegetation type, geographic distribution, salinity, etc.) are you hoping to better understand and compare between sites?

The primary objective of the SCGS SET network is to research long-term surface elevation changes from geodetic and marsh platform elevation data collected in coastal intertidal environments. Based on these goals, SET and RSET stations must:

1- ***Be accessible for data collection during each meteorological season.*** The growth patterns of intertidal plant species and coinciding changes in root mass or vegetation may influence surface elevation differently during each season. Measurements are collected quarterly to account for these patterns.
2- ***Be accessible before the marsh platform surface is inundated by water.*** The soft nature of intertidal sediments and turbidity of intertidal waters limits data collection to when the pin contact with the marsh surface is possible (i.e., when the surface is dry and not flooded).
3- ***Be accessible by land or boat.*** If a site is not accessible by walking in from dry land, boat access is required. The boat must be able to travel safely from the launch site to reasonably near the station on a rising tide. Measurements must be timed correctly to allow for navigation to the site before it is inundated by the rising tide.
4- ***Be situated within a reasonable distance for transportation of installation equipment.*** The equipment required for installation may impose some logistical limitations on where a station is placed.
5- ***Allow access without creating permanent damage to the environment.*** Walking to and from the station should not damage vitally sensitive ecosystems.
6- ***Allow access without endangering personnel.*** Some intertidal marsh sediments have high water content and low surface strength. Walkability is essential – ask yourself if the site is firm enough to allow for potential decades' worth of measurement visits and maintenance work, which will require carrying materials and tools across the marsh surface.
7- ***Take into consideration the permissions needed to install and maintain a station on the selected site.*** Different entities have jurisdiction over different intertidal areas. The US Army Corps of Engineers (USACE) has ultimate jurisdiction, and any structure built in USA intertidal areas must have a permit or waiver. Often the State of South Carolina has the next level of jurisdiction, but occasionally another

Federal agency or a King's Grant supersedes the state jurisdiction. The appropriate permission or waiver must be secured prior to construction.

Other considerations should include:

- ***Vegetation at the site*.** If possible, visit your site during the growing season to help understand how dense the vegetation can get. Dense vegetation can hinder the ability to see the pin-surface contact. Be aware that the presence of *Juncus roemerianus* (black needlerush) in your plot may necessitate eye protection while measuring.
- ***Nearby shoreline change rates and patterns.*** Consider the long-term dynamics of nearby creek banks to the best extent possible. Several SCGS SETs have been lost to shoreline erosion. At some locations (i.e., Scott Creek and Fish Creek in the ACE Basin) stations have been lost more than once. Consulting topographic maps and aerial photography can provide insight into how the site has changed on a multi-decadal scale and if shoreline erosion may be an issue.
- ***Awareness of the viewshed your planned research site will be a part of.*** It is ideal to locate stations away from homes and heavily trafficked areas when possible.

APPENDIX B. METHODOLOGY FOR CONSTRUCTING SET AND RSET STATIONS IN SOUTH CAROLINA

PHASE I – BUILDING WALKING PIERS

1- For most RSET and SET installations, it is a good idea to construct protective walking piers to allow for measurements to be collected without disturbing the research plot. The piers and measuring area itself must be wider than the swing radius of the RSET or SET instrument. Typically, the piers are constructed with treated lumber and galvanized or corrosion-resistant fasteners (Appendix C). The two piers are installed parallel to each other, pointing north-south (see Appendix F, Figure 3).

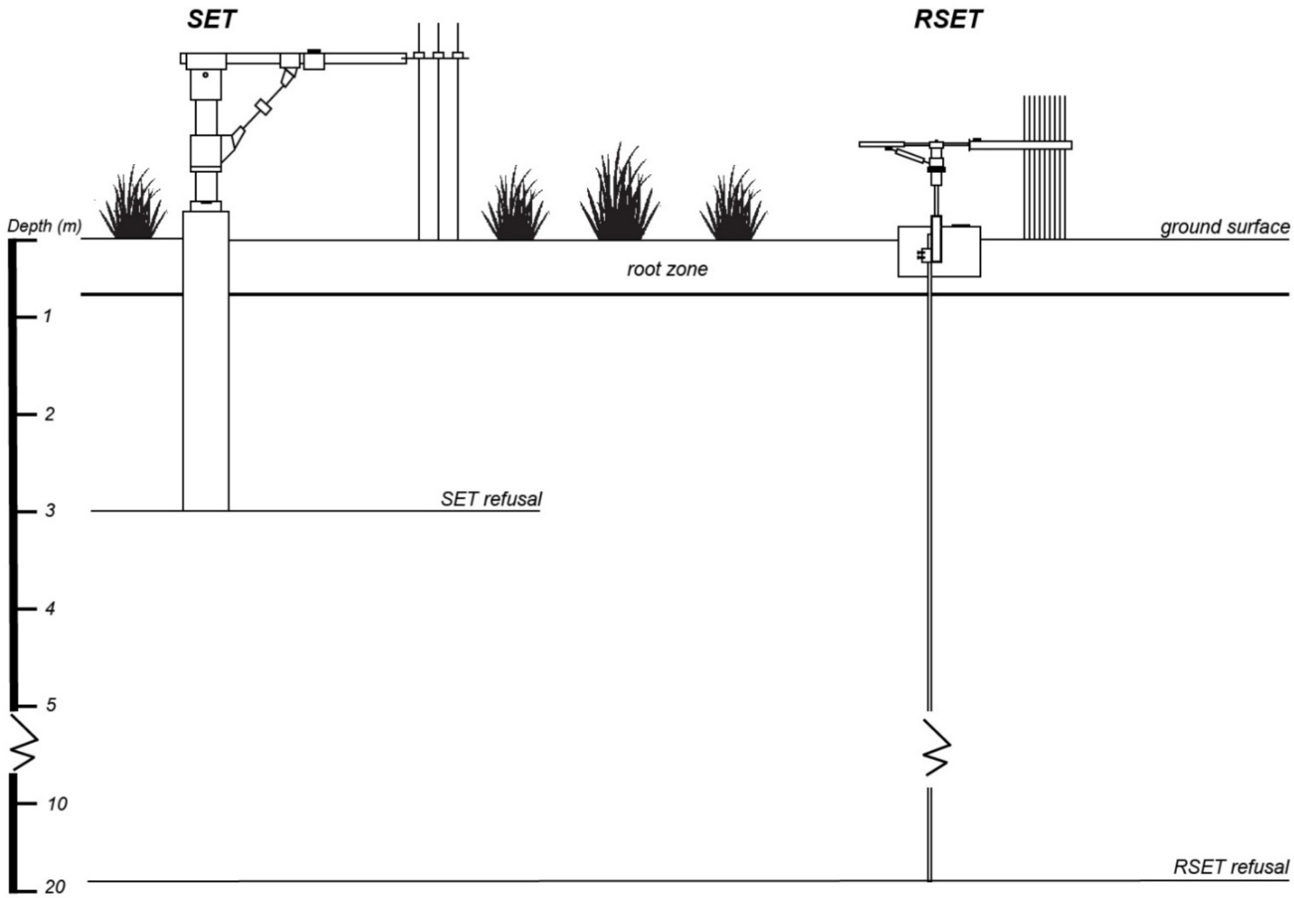
2- The posts used to anchor each corner can be landscaping timbers or 4x4-inch at 6- or 8-foot lengths. Eight posts are required per station - two on each end of the piers. Hammer in the pairs of posts with enough space (typically 15 inches or more) to follow up with an installation of two 2x6-inch, 8-foot pier boards between them (see Appendix D, Figure 3).

3- Bolt a 2x6-inch support board spanning the posts at each corner at a reasonable height above the marsh surface (this varies depending on the site, but typically at least 1/3 of a meter or several feet) to support the pier boards. Attach the pier boards to the 2x6-inch support boards with nails or screws.

4- Record details about the installation (depth to refusal, location, general description of the area) in a waterproof field book.

5- Before proceeding to Phase II of the installation, lay two loose planks across the station on the pier boards so that the center of the measuring area can be accessed. See Appendix D, Figure 6 for additional detail.

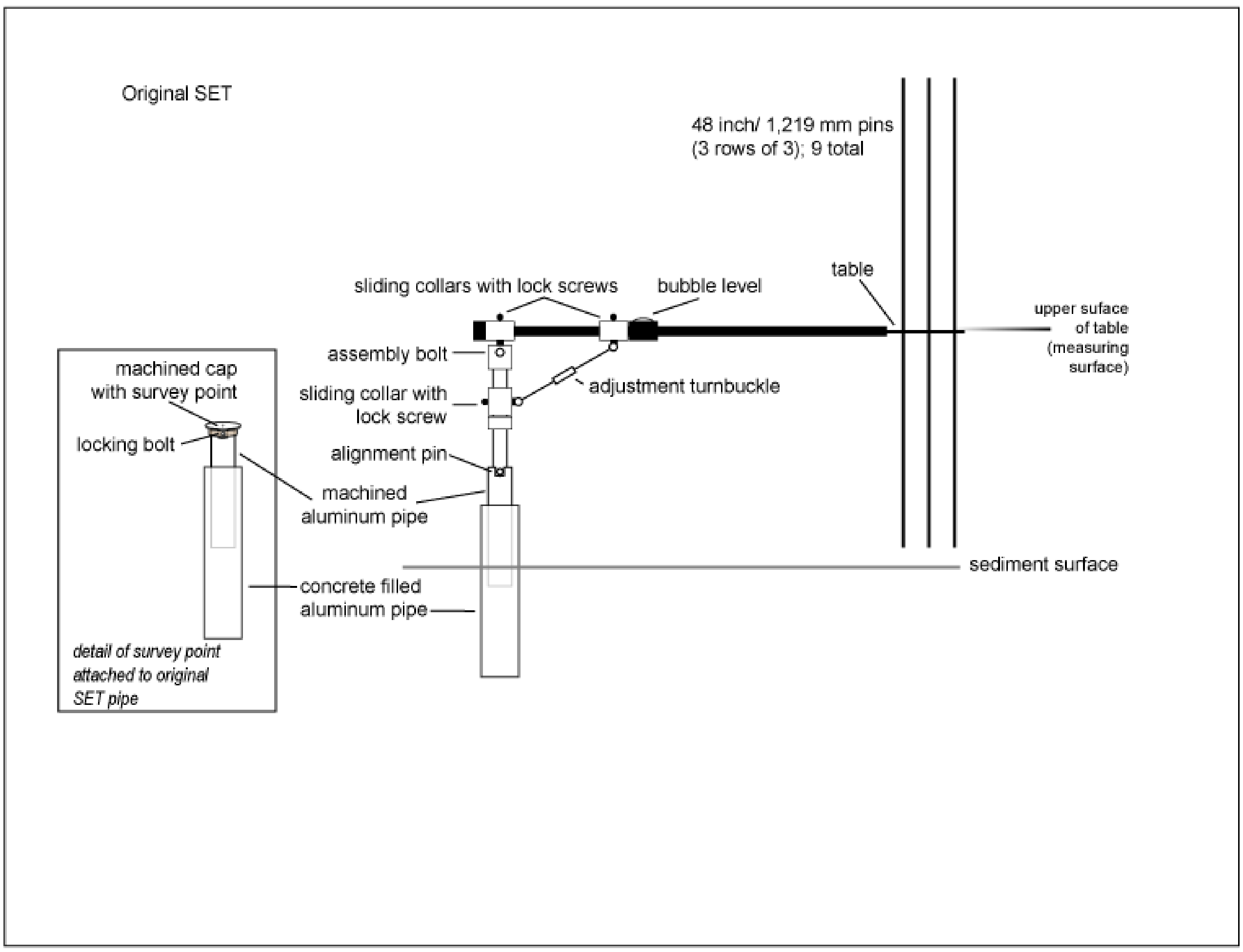
PHASE II – INSTALLATION OF SET OR RSET BENCHMARK
Schematic of typical completed installations



Appendix B, Figure 1. Above and belowground comparison of SET and RSET installations (after Lynch, 2015 and USGS, 2021). Figure not to scale. Details in Appendix B, Figures 2 and 3.

SET

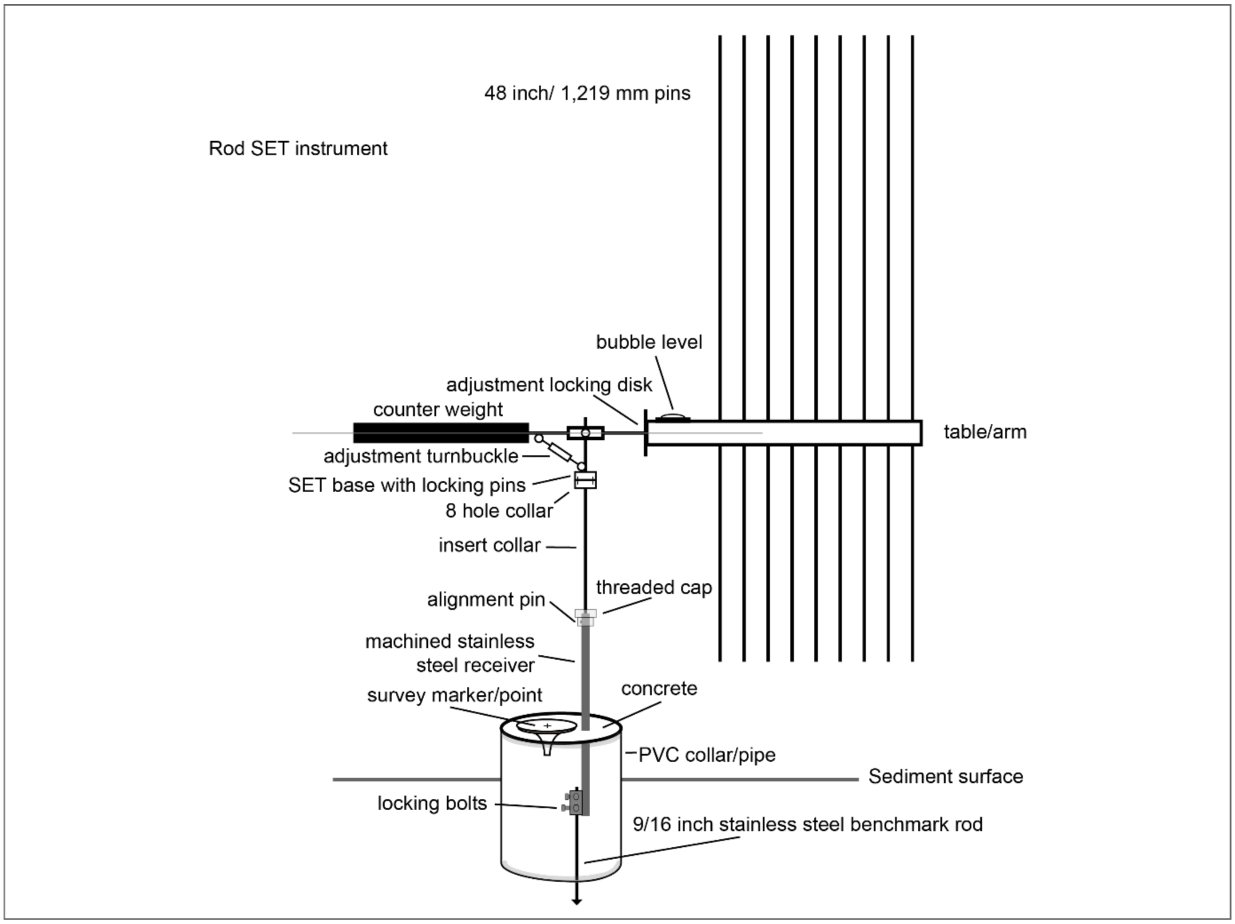
1- For the original SET: Drive a 3-inch diameter aluminum irrigation pipe to refusal using a concrete vibrator with 2 ¾-inch head with a clamp mounted to it to allow for attachment to the pipe (Lanesky et al., 1979).
2- After reaching refusal with the vibracorer assembly, cut away the excess pipe above the ground surface with a hacksaw or other cutoff tool. Test fit the SET insert pipe to check for required concrete depth.
3- Mix an appropriate amount of concrete, to the consistency of cookie dough. Place a handful or two of concrete into the driven pipe. Set the SET insert pipe into the wet concrete. Fill the void between the pipes with concrete. Do not allow the concrete inside the insert pipe to rise high enough to prevent the SET instrument from sitting on its locating pins when placed. The top surface of this pipe should be as level as possible, and the quadrants arranged to allow measurements in N, S, E, and W directions.
4- Allow at least a month for the concrete to set before placing the instrument on the insert pipe.



Appendix B, Figure 2. Details of SET instrumentation.

RSET

1- For the RSET: 9/16-inch- diameter stainless-steel benchmark rods in 4-foot sections are driven into the ground to refusal by one of, or a combination of: tomato stake driver, sledgehammer, and a power hammer with at least 27-lbs of driving force. Use an anvil to protect the top-most stainless-steel rod from damage during installation. Refusal is reached when there is less than 1 foot of motion per minute (Floyd, 1978). The rod will sometimes “bounce” at refusal – if this happens, stop immediately – refusal has been reached. If you do not stop hammering, you risk bending the rods or backing the rods out of the ground.
2- After reaching refusal, cut the exposed rod off less than a foot above the ground surface with bolt cutters, hydraulic jaws, or a side grinder (grinder preferred). Record the footage of rod below marsh surface (this is depth to refusal) and the remaining above-ground length. Bolt the stainless-steel RSET receiver (from Nolan’s Machine Shop, see Appendix C) to the rod.
3- Place a 6-inch or 8-inch diameter PVC collar around the exposed rod. Mix an appropriate amount of concrete, to the consistency of cookie dough. Fill the collar with concrete, enough to cover the receiver bolt heads. Before the concrete sets, use the RSET insert collar assembly to line the holes in the collar up with quadrants A (NW), B (SW), C (NE), and D (SE) by rotating the connected rod and stainless-steel RSET receiver in the wet concrete. Once aligned, put the RSET insert collar assembly back in the RSET field kit (Appendix E).
4- Set the bronze geodetic disk into the wet concrete to one side of the rod (Appendix D, Figure 13).
5- Allow at least a month for the concrete to cure before assembling the instrument on the receiver.



Appendix B, Figure 3. Details of RSET instrumentation.

NOTES AND RECOMMENDATIONS (See Appendix D for additional photographs and detail)

1- For SET: refusal is typically at between 3-9 meters in depth (Appendix B, Figure 1).
2- For RSET: refusal is typically at between 10-15 meters in depth (Appendix B, Figure 1).
3- At least one 4x8-foot ¾-inch sheet of treated plywood, cut lengthwise into 3 equal sections, with rope handles at each end and several 1-inch holes drilled in them to lighten them, serve well as walking boards in the marsh. They cannot be used as gangplanks or cross boards.
4- At some point, a core should be collected near the station to establish an idea of subsurface geology.
5- If possible, attempts should be made to establish sediment accumulation rates for the marsh platform near the measuring area using marker horizons or sediment plates. Marker horizons are artificial soil horizons placed on the marsh surface to measure vertical accretion (i.e., the accumulation of material above the horizon) (Lynch et al., 2015). Apply the marker horizon material on the marsh surface OUTSIDE of the measuring area. At specific time intervals, collect shallow core samples of the marker horizon area to estimate how much sediment has been deposited at the surface. These measurements

can be compared to the net change of elevation for the station measured with the SET or RSET. Sedimentation plates have also been used, with varying amounts of success. See Lynch, 2015 for a thorough discussion of marker horizons and estimating sedimentation at the marsh surface.

NOTE: SCGS attempted to use powdered feldspar as a marker horizon early in the project and found that rapid removal from bioturbation and export of the powder quickly rendered this method useless. Researchers at North Inlet-Winyah Bay NERR report similar experiences. No suitable replacement has yet been identified, and surface measurements are not part of the SCGS protocol.

APPENDIX C. DETAILED MATERIALS LIST FOR SET AND RSET CONSTRUCTION

SET Construction

	Description of Item	Dimensions or Specifics	Purpose	# Needed
Phase I	Landscaping Timbers or 4x4's	6 or 8' length	Used to anchor in piers	8
	2x8' Treated Wood Planks	2'x8"x8'	Walking boards	4
	2x10' Treated Wood Planks	2'x6"x10'	Cut into shorter lengths for cross-boards	2
	Galvanized hex-head bolts	5/16" or larger, 4 or 5' long	Attach landscaping timbers to cross-boards	8
	Galvanized hex nuts and washers	Same size as the bolts		8 pairs
	Galvanized nails or coated deck screws			10
Phase II	Aluminum irrigation pipe (Benchmark Pipe)	3" diameter, length depends on anticipated depth to refusal (typically between 15 and 30')	Serves as support for machined, notched aluminum pipe used for SET attachment	1
	Aluminum SET Insert Pipe	24" long, 2" diameter	The SET instrument attaches directly to this machined, notched pipe. The insert pipe is cemented into the top of the 3" benchmark pipe, and has 4 or 8 notches machined into one end.	1
	Concrete	40 lb bag	Used to encase SET pipe into larger-diameter irrigation pipe	2
Tools	Concrete vibrator with 2 3/4' head, clamp mount (gas-powered)		Used to drive aluminum irrigation pipe to refusal	1
	Hacksaw with spare blades		Used to cut off excess irrigation pipe	1
	Battery-powered drill		Used to drill holes in landscaping timbers and cross boards, and to attach walking boards	1
	Drill bits		Used for drilling bolt holes	Various, 2 minimum
	Driver bits		Used for deck screws	Various, 2 minimum
	Battery-powered skill saw		Used to trim landscaping timbers	1
	Wrenches		Used to tighten bolts (both pier construction and vibrator)	2
	Framing hammers			2
	Measuring tape			1
	Bucket	5 gallon	Used for water that is needed to mix concrete	1
	Bubble level			2
	Gloves		Construction; hand-mixing concrete	1 pair per person, plus extra gloves for hand-mixing concrete
	Hearing protection			1 pair per person
	Eye protection			1 pair per person
	NOTE: (') = 'foot' and (") = 'inch'			

RSET Construction

	Description of Item	Dimensions or Specifics	Purpose	# Needed
Phase I	Landscaping Timbers or 4x4's	6 or 8' length	Used to anchor in piers	8
	2x8' Treated Wood Planks	2'x8"x8'	Walking boards	4
	2x10' Treated Wood Planks	2'x6"x10'	Cut into shorter lengths for cross-boards	2
	Galvanized hex-head bolts	5/16" or larger, 4 or 5" long	Attach landscaping timbers to cross-boards	8
	Galvanized hex nuts and washers	Same size as the bolts		Many, extras
	Galvanized nails or coated deck screws	3" 10d or larger		Many, extras
Phase II	Screw-together stainless-steel benchmark rods with threaded connectors	9/16" x 4'	Used to install RSET benchmark, which will attach to instrument adaptor.	Recommended starting number of 20 rods for a total 80' per station. Refusal for SCGS installations has typically been met at between 40 and 60')
	Screw-on stainless steel driving point matched to benchmark rods	9/16" x 3'	Connected to bottom tip of rods for installation	1
	Stainless steel RSET Receiver	2.2-cm x 12-cm. One end is externally-threaded with a 5/8-inch socket machined to accept the insert collar. The opposite end has a 5/8-inch inner diameter stainless steel pipe welded to side. This is drilled and tapped for four (4) stainless steel 3/8-inch hex bolts.	Connects to benchmark rod. Available for purchase from Nolan's Machine Shop, Lafayette, Louisiana – (337) 233-4963	1
	Stainless-steel machined RSET Insert Collar Assembly	9/16" stainless steel rod with alingment pin, screw cap, and a welded-on stainless steel SET rod collar.	The RSET instrument attaches directly to this Insert Collar Assembly, which is stainless steel rod welded to an 8-hole stainless steel collar. The assembly is available for purchase from Nolan's Machine Shop, Lafayette, Louisiana – (337) 233-4963	1
	Rod driver attachment/anvil	9/16", or larger, diameter rod, longer than 3"	Screws into the uppermost stainless-steel rod being driven. Functions to protect rods while power hammer is being used. SCGS is currently using a driving point during RSET installation, which can be bought when rods are purchased. Others use a short piece of stainless-steel rod that has been cut previously.	1
	PVC collar	6" or 8" diameter, minimum length of 2'	Used to encase rod and receiver in concrete with geodetic disk	1
	Bronze geodetic disk	3" diameter	Measuring point for geodetic surveys	1
	Concrete	40 lb bag	Used to encase rod, receiver, and disk	2

RSET Construction (Continued)

Tools	Tomato Stake Driver		Can be used to drive initial rods	1
	Sledgehammer	comfortable weight	Can be used to drive initial rods; also needed for pier installation	2
	Power Hammer	At least 27-lb of force	Used to drive rods to refusal	1
	Post-Hole Digger		Can be used to help with installation of landscaping timbers/4x4's	1
	Shovel		Used to carve out area for installation of PVC collar	1
	Hacksaw with spare blades			1
	Battery-powered drill		Used to drill holes in landscaping timbers and cross boards, and to attach walking boards	1
	Drill bits	larger than hex bolts	Used for drilling bolt holes	Various, 2 minimum
	Driver bits		Used for deck screws	Various, 2 minimum
	Battery-powered side grinder with metal-cutting blade		Used to cut off stainless-steel rods above marsh surface	1
	Battery-powered skill saw		Used to trim landscaping timbers	1
	Wrenches	sized for any hex bolts used	Used to tighten bolts (for pier construction and receiver bolts)	2
	Framing hammers			2
	Measuring tape			1
	Bucket	5 gallon	Used for water that is needed to mix concrete	1
	Bubble level			2
	Gloves		Construction; hand-mixing concrete	1 pair per person, plus extra gloves for hand-mixing concrete
	Hearing protection			1 pair per person
	Eye protection			1 pair per person
	NOTE: (') = 'foot' and (") = 'inch'			

APPENDIX D. INSTALLING A SET AND RSET – IN PICTURES (FIELD GUIDE)

STAGE I: SITE SELECTION AND PIER INSTALLATION

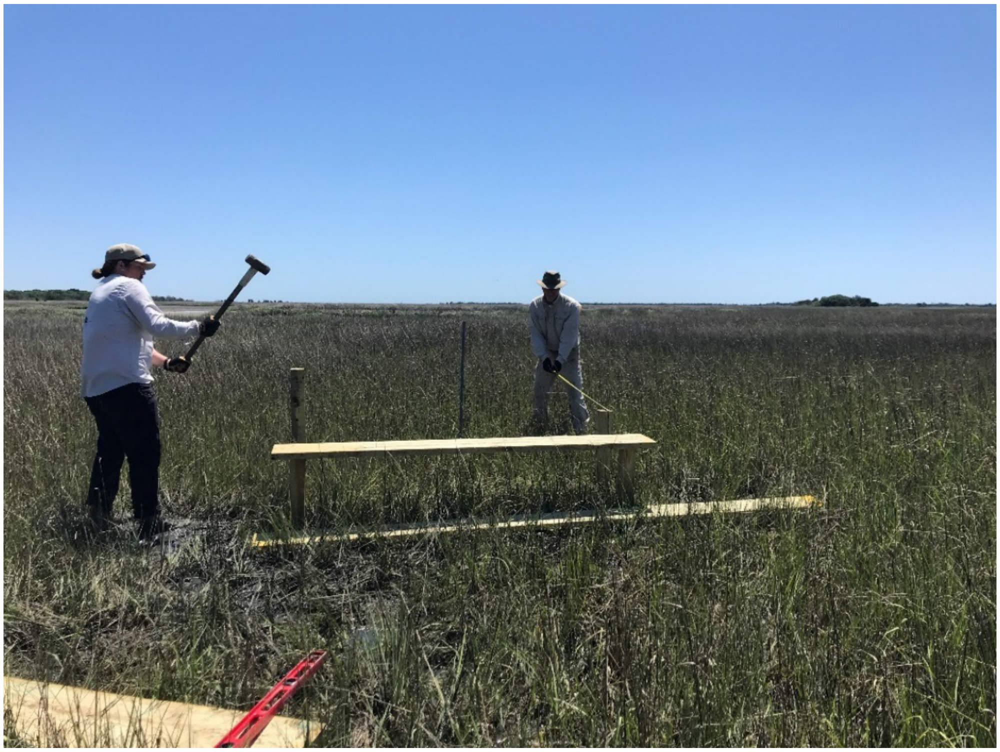
1- Choose a location for installation following siting recommendations in Appendix A *(**equipment:** maps, aerial photographs, local knowledge, with the goal of siting a station in an area where it will persist for several decades).*

2- Gather supplies for installation (a detailed list can be referenced in Appendix C) and crew for installation. Installing a SET or RSET requires a minimum of three people.

3- Determine compass directions at the chosen site (will impact location of quadrants, part of the SET protocol) *(**equipment:** compass).*

Appendix D, Figure 1. Using a Brunton Pocket Transit to establish cardinal directions at the site. This station was established at Fort Johnson, on James Island (near Charleston), SC in April (Phase I) and December (Phase II) 2021.

4- Construct walking piers to protect the marsh surface while measuring. Not all stations necessarily need piers if the ground surface is firm enough to support the weight of the researchers without deflecting the sediment surface in the measuring area. Nearly all stations in South Carolina require piers *(**equipment:** landscaping timbers, 2x4's, 4x8's, sledgehammers, measuring tape, levels, bolts, nuts, washers, wrenches, saw, drill).*



Appendix D, Figure 2. Use a sledgehammer to drive in landscaping timbers or 4x4's to create pilings (two per corner, a total of eight).

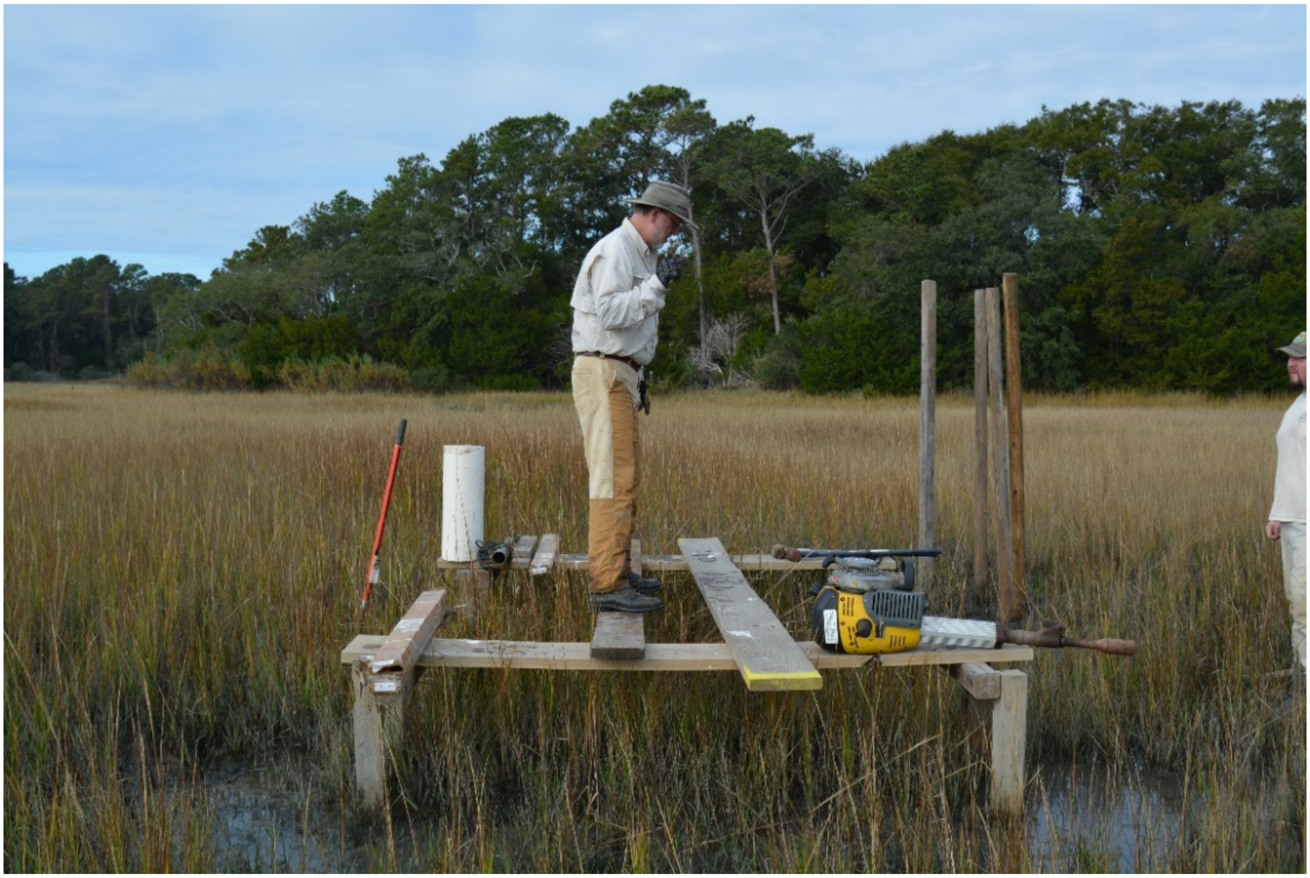
Appendix D, Figure 3. Use a measuring tape to ensure consistent distances between piers. The measuring area should be at least the swing radius of the instrument.

Appendix D, Figure 4. Use bolts (and washers and nuts) to attach support boards to pilings. Use a bubble level to level-in surfaces where possible.

Appendix D, Figure 5. Attach pier boards (2x8's) to the tops of the support boards using screws.

STAGE II: INSTALLING SET OR RSET BENCHMARK

1- Lay two loose boards (2x8's or 2x10's are ideal) across the already constructed pier assembly. Locate the approximate center point of the plot – this is where the benchmark will be installed.



Appendix D, Figure 6. Position two boards across the measuring plot to facilitate locating the middle of the plot and installing the benchmark.

2- Install benchmark using 9/16" steel rods in 4' sections. A tomato stake driver (T-post driver) can be used to drive the first few rods down, until progress stalls. USE HEARING PROTECTION.

Appendix D, Figure 7. Using a tomato stake driver to drive down first rods.

3- When progress with the tomato stake driver stalls, use a power hammer to drive rods down until refusal is reached. USE HEARING PROTECTION. Record the total length of the rod used for depth to refusal.

Appendix D, Figure 8. A power hammer is used along with a rod driver attachment (anvil) that screws into the top of the rod being driven (to protect the integrity of the rod, allowing for multiple 4’ sections to be screwed together).

4- Install PVC collar offset around the rod to allow space for additional instrumentation (in the case of this installation, SET and RSET benchmarks were installed next to each other) and a geodetic control point disk, if one is used *(**equipment:** shovel, PVC collar)*

Appendix D, Figure 9. The PVC collar is installed in the center of the measuring plot, enclosing both the rod and the SET insert pipe.

5- For the RSET, the steel rod is cut off below the top of the PVC collar. Use the RSET receiver (see Figure 11) to determine where to cut the rod. The top of the steel rod and the hex bolts on the SET receiver should both be situated below the top of the PVC collar – the bolts will be encased in concrete *(**equipment:** grinder)*

Appendix D, Figure 10. The steel rod is cut below the top of the PVC collar. The insert pipe must remain above the height of the collar.

Appendix D, Figure 11. RSET receiver is affixed to steel rod benchmark, and a check is performed to ensure that geodetic disk will fit into PVC collar.

6- Mix cement (until it is roughly the consistency of cookie dough) in the plastic mixing bin. Fill the PVC collar and encase constituent SET components in cement.

Appendix D, Figure 12. Cement is mixed by hand with water (typically from an adjacent creek, or fresh water brought to the site). The cement is then applied until it is flush with the top of the PVC collar.

Appendix D, Figure 13. In the final stage of installation, before the concrete cures, the bronze geodetic control point disk is set into the upper surface of the concrete.

APPENDIX E. SET, RSET, AND GNSS FIELD KITS

SET Field Kit

Description of Item	Dimensions or Specifics	# Needed
SET Version 3 Instrument	Haupt Machine	1
Fiberglass rods	48-inch long (1,219.2-mm), 3/16-inch diameter (4.76-mm)	9
Metal ruler	Metric - 1.0 meter graduated in mm	1
ID badge clip		dozen
Stainless steel hexbolt	1/2-inch diameter	2
Waterproof field book	sewn binding	1
Pencil	no. 2 or 3	4
WD 40	spray can	1
Pelican case	#1750 long rifle case	1
Geodetic control point cap	2.5-inch diameter aluminum geodetic benchmark cap, lightly machined to fit over SET insert pipe, with added 3/8-inch stainless steel bolt to locate it on the insert pipe notches.	1

RSET Field Kit

Description of Item	Dimensions or Specifics	# Needed
RSET Instrument	Nolan's Machine	1
Stainless Steel Insert Rod Assembly	Nolan's Machine	1
Fiberglass rods	48-inch long (1,219.2-mm), 3/16-inch diameter (4.76-mm)	9
Metal Ruler	Metric - 1.0 meter graduated in mm	1
ID badge clip		dozen
Waterproof field book	sewn binding	1
Pencil	no. 2 or 3	4
WD 40	spray can	1
Pelican case	#1750 long rifle case	1

Description of Item	Dimensions or Specifics	# Needed
Data controller	Trimble TSC2	1
Receiver (antenna)	Trimble R8	1
Cellular data router	State contract Cellular Phone Router- Verizon 'MiFi'	1
Carbonite rod	2-meter length with spirit level	1
Bi-pod	Connects to rod to provide stability	1
Data collector mount	Attaches data collector to tripod	1
Velcro router pouch	Attaches cellular router to tripod	1
Batteries	For Trimble receiver	2
Battery chargers	For Trimble receiver and data controller	2
Spare stylus	For data controller	1
Pelican case	Model 5800	1
Power invertor	12V to 110V - to provide a charge to batteries while in transit, if needed	1
Hand towel		1
Geodetic control point cap	2.5-inch diameter aluminum geodetic benchmark cap, lightly machined to fit over SET insert pipe, with added 3/8-inch stainless steel bolt to locate it on the insert pipe notches.	1

APPENDIX F: SET AND RSET SURFACE ELEVATION DATA COLLECTION PROTOCOLS

Surface elevation data for all SCGS SET and RSET stations are collected using the following protocol and best practices:

1- Measure stations on a rising tide so the marsh surface is relatively dry and free of standing water.
2- The safety of the boat and personnel is first and foremost when choosing a time to measure a station. Do not risk grounding the boat and stranding personnel.
3- All stations should ideally be measured by the same person to reduce variability (Lynch et al., 2015). The SET and RSET can be carried and measured by one researcher but having two people in the field is preferable – for safety reasons (especially when accessing stations by boat) and to assist in carrying the instrumentation and cross board to the site.
4- Due to the elevation differences between stations, the order in which they flood will be variable. Establishing a preferred order for measuring the stations may involve some trial and error. Timing measurements for a tide cycle with an early afternoon high tide is often ideal. Measuring during neap rather than spring tides is also recommended due to slower tidal elevation changes and lower high tides that are less likely to flood the entire marsh platform.
5- Do not step in or lay equipment within the measuring area. The wooden piers are elevated above the marsh surface to provide a platform that can protect the marsh surface from being disturbed.
6- Use a loose wooden board as a cross board when accessing or measuring the site. This board spans the gap between the piers and allows for walking between the piers without touching the marsh surface. The diagonal distance between the piers will determine the length of the board. Some older stations require up to a 12-foot-long board; SCGS also uses shorter boards (10 or 8 feet). The board can either be carried into the field for measurements or permanently tied to the station's piers - this is a judgment call and depends on where the station is located and associated issues (i.e., is there a chance that the board could be lost in high spring tides? Does the convenience of having a permanent board at a particular site outweigh any negatives?)
7- Insert the nine pins into the instrument before measuring. The instrument can be carried with the pins in it. Secure pins with metal ID badge clips or other fasteners (Appendix F, Figure 1).
8- For the SET: The SET instrument will fit directly into the notches in the top of the insert pipe at the station (Appendix F, Figure 2).
9- For the RSET: The RSET fits on top of the RSET insert collar assembly, which is a separate piece of hardware (Appendix F, Figure 2).
10- For the RSET: Locate the benchmark and unscrew the protective cap from the receiver (attached to stainless-steel benchmark rods during construction and part of the permanent installation – see

Appendix D). Attach the stainless-steel RSET insert collar assembly (carried in the case with RSET instrument) to the receiver. The collar on the insert collar assembly has four (4) sets of holes (eight (8) holes total). The RSET instrument will lock into these holes during measurement. Only use the holes oriented to the four quadrants at that station. The pairs of holes will be situated 90 degrees from each other. Measuring all quadrants will involve flipping the instrument between the pairs of holes (Appendix F, Figure 2).

11- Fit the instrument onto the insert pipe (SET) or the insert collar assembly (RSET) based on the quadrant to be measured first. Four quadrants are measured, and they are designated by direction. The RSET quadrants are identified by letters (A, B, C, D), each of which represents a specific direction: A (NW), B (SW), C (NE), D (SE). For the SET, quadrant directions are N, S, E, and W (Appendix F, Figure 3).

12- Be certain the instrument is fully inserted onto the insert pipe (SET) or the insert collar assembly (RSET) (Appendix F, Figures 4 and 5).

13- Level instrument with bubble level.

14- Lower pins to marsh platform so that they just touch the surface. Set ID badge clip to hold the pin at that height. If there is plant debris, wrack, etc., that covers the entire area, leave it in place and lower pins onto the debris. This protocol was determined unofficially by convention with the world-wide SET researchers. If the debris is scattered, move it as necessary. The marsh surface is the top of the mud, sand, or wrack, not the water surface (Appendix F, Figures 4 and 5).

15- Measure with a metric ruler (in millimeters) the length of the pin ABOVE the flat surface (table) of the SET or RSET instrument (Appendix F, Figures 6 and 7).

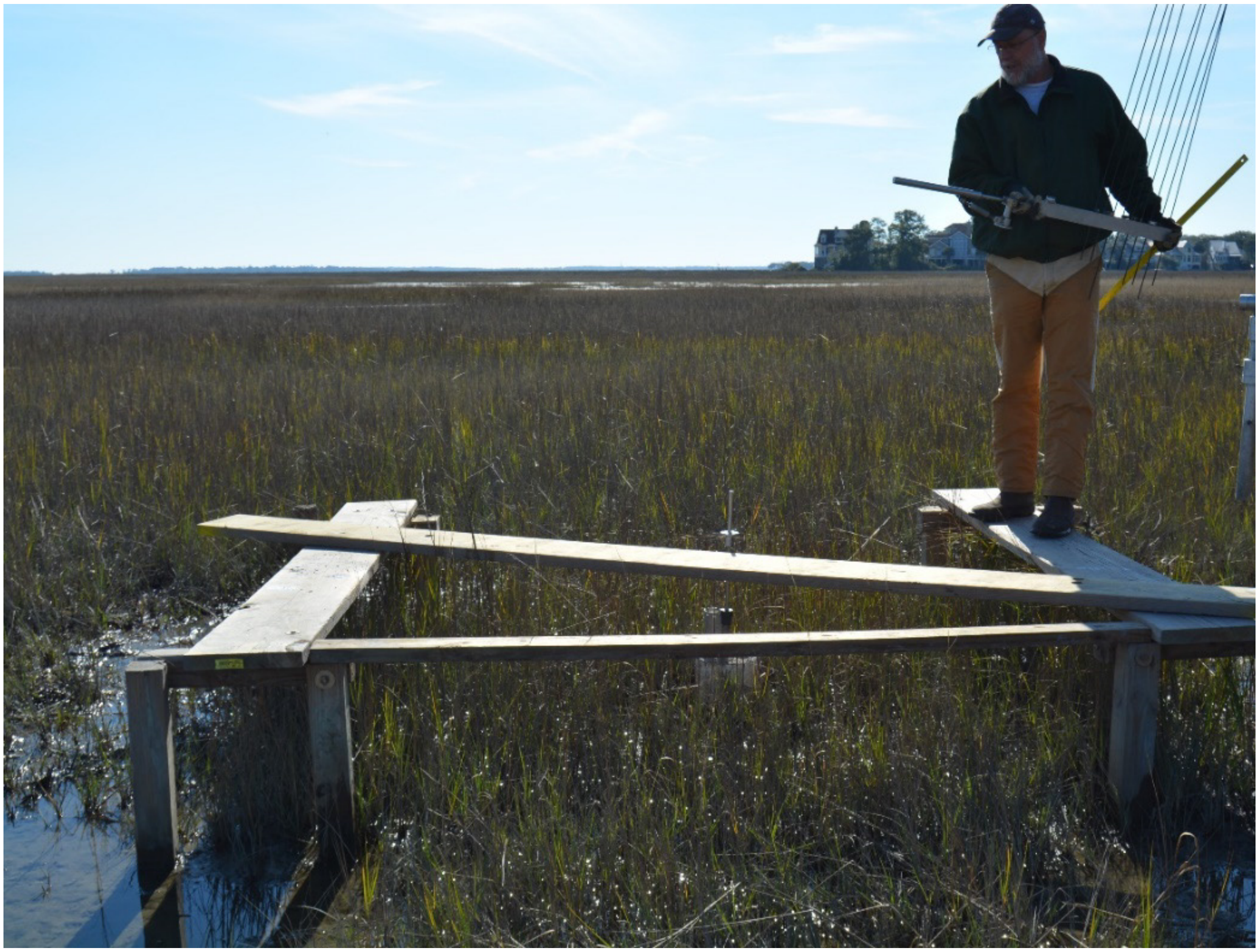
16- Record the measurement for each pin in that quadrant into a waterproof field book with a pencil. Repeat for the other three quadrants (Appendix F, Figure 8).

17- Make a note of storm wrack, erosion, damage, repairs needed, etc.

18- Lift and clip pins, remove the instrument from the insert pipe (SET) or insert collar assembly (RSET). For RSET, unscrew the insert collar assembly and remove, replace the cap on the receiver, and load equipment back into the case.

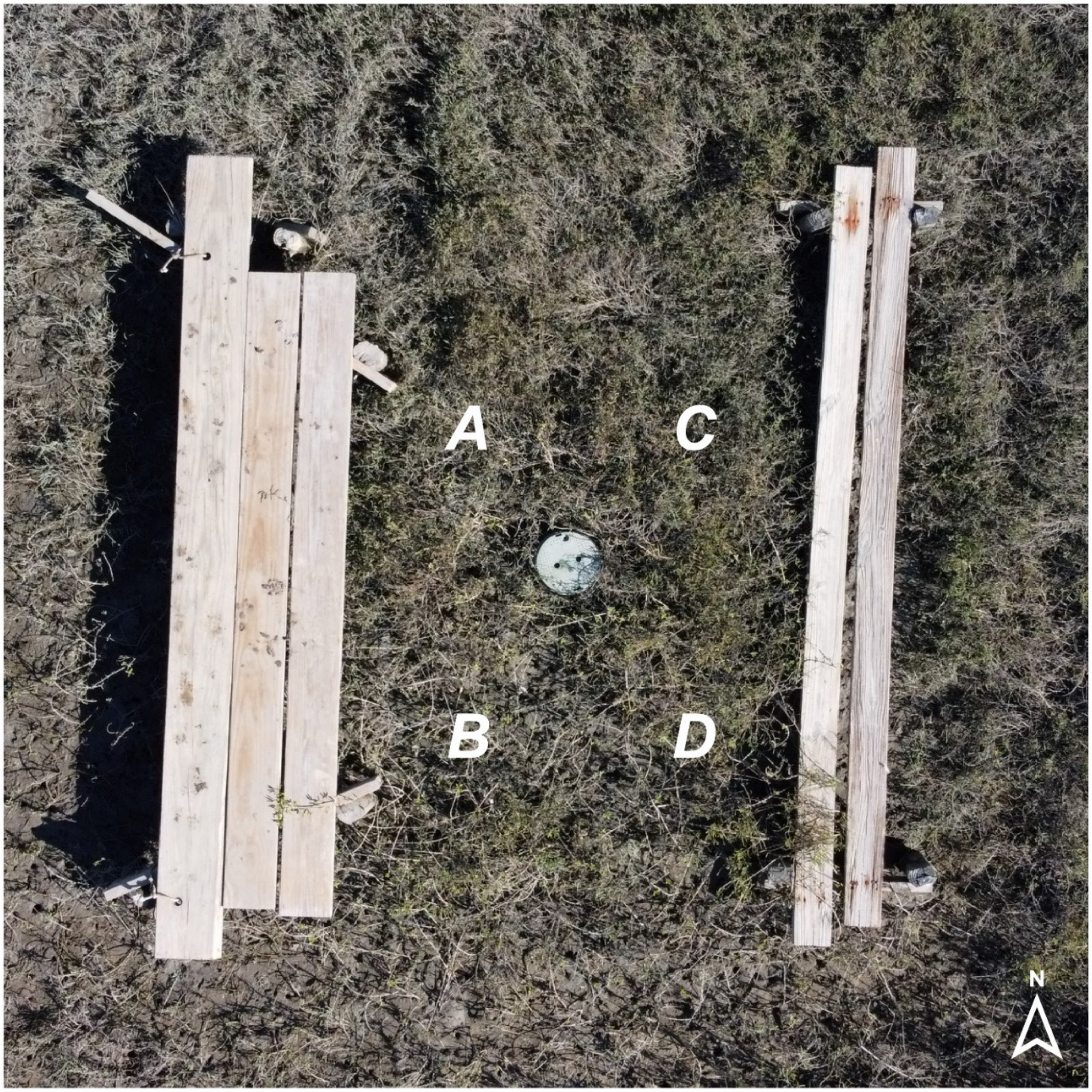
19- Move to the next station.

20- When that day's work is completed, spray equipment (instrument, pins, ruler, etc.) with a light coat of WD 40 before replacing it into the case.

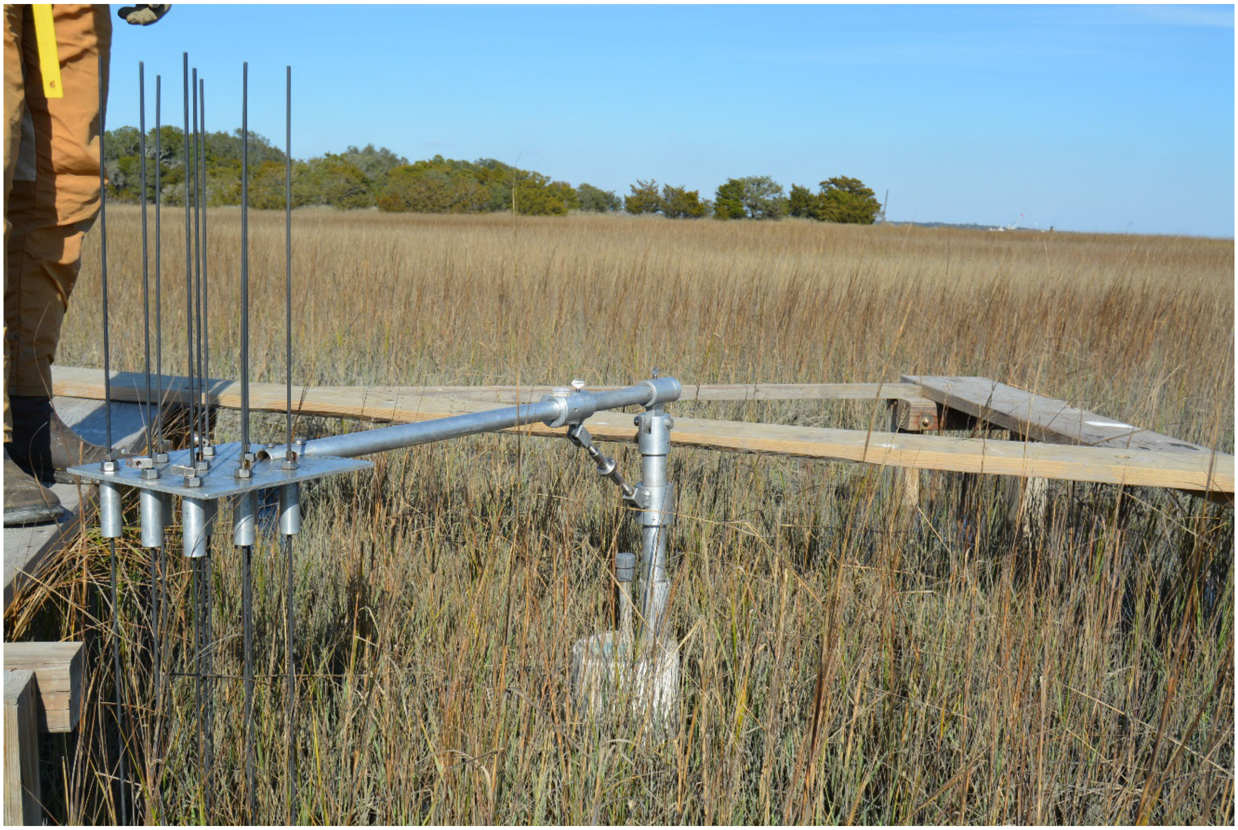


Appendix F, Figure 1. Carrying the RSET instrument to the station with pins inserted. A cross board has been placed across the piers.

Appendix F, Figure 2. Pictures of the SET insert pipe, the RSET insert collar assembly attached to receiver, and the bronze geodetic control point disk. The left-hand picture shows the locator pin notches in the SET insert pipe (wider pipe on the left). The right-hand picture is an overhead view of the holes in the RSET insert collar assembly. Two pairs of holes are used to measure the four quadrants at each site; they may vary by site. The pairs are oriented at 90-degree angles to one another.

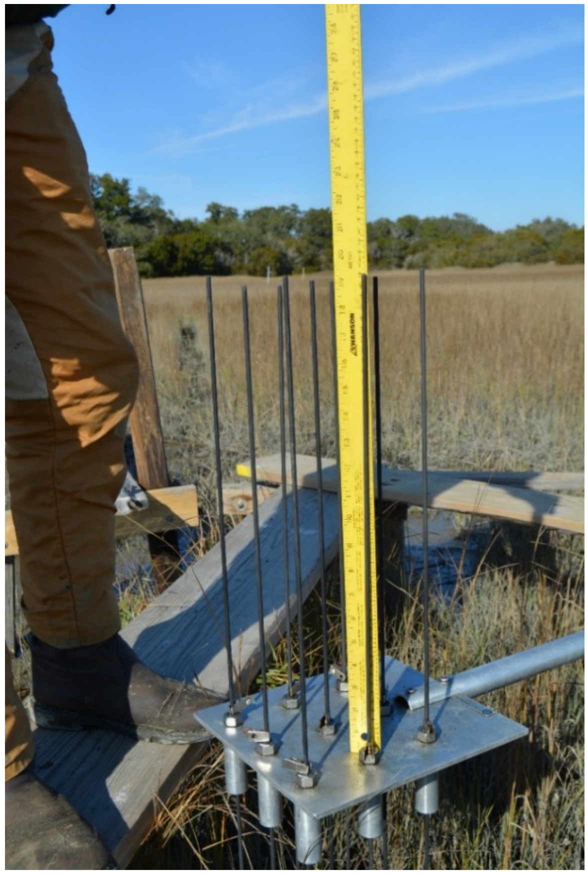


Appendix F, Figure 3. RSET quadrants A, B, C, and D at ACEHI2. Quadrant locations are set as related to cardinal direction (for RSET, A is northwest, C is northeast, B is southwest, D is southeast; for SET, N, S, E, and W are used). This RSET station at ACEHI2 has been modified over time with new pier settings (left) and a plastic vault protecting the receiver (center) to allow for continued access as accretion has built up the marsh platform over time. Photograph courtesy of Emma Paz.



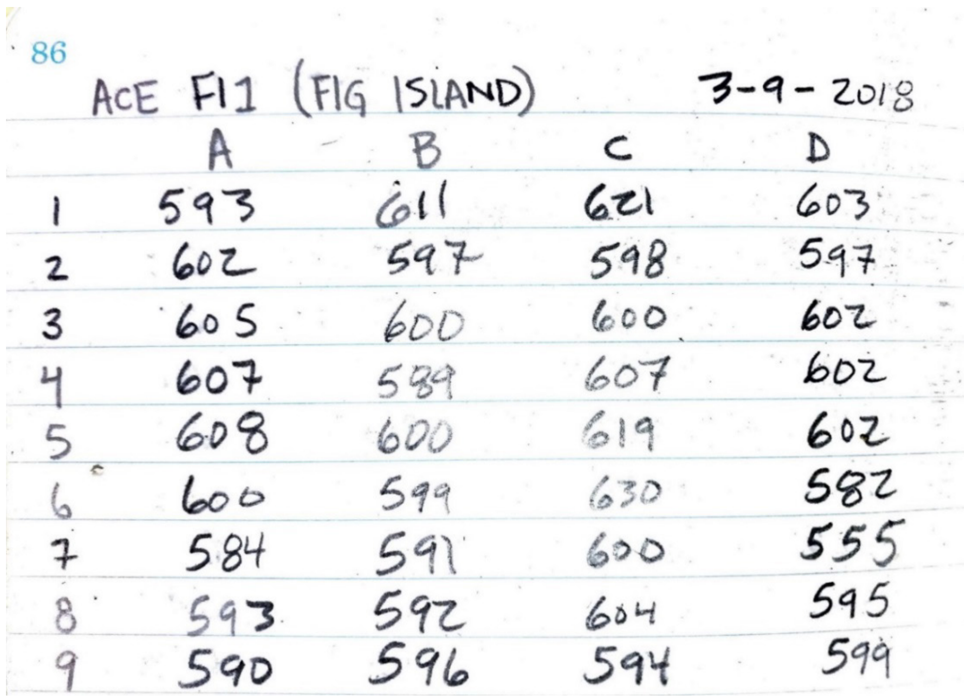
Appendix F, Figure 4. SET instrument, installed for data collection and seated directly onto insert pipe.

Appendix F, Figure 5. RSET installed with RSET pins being lowered to the marsh platform surface.



Appendix F, Figure 6. Measuring the length of pin remaining above the flat surface of the SET instrument with a metric ruler. For the SET, measurements are collected starting with the innermost left pin (1). Measure left to right until reaching the outside right-hand pin (9). The instrument may be stamped with these numbers.

Appendix F, Figure 7. Measuring the length of pin remaining above the table of the RSET instrument. For the RSET, measurements are collected starting at the innermost pin (1) to outermost (9). The instrument may be stamped with these numbers.



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ACE FI1 (FIG ISLAND) 3-9-2018

	A	B	C	D
1	593	611	621	603
2	602	597	598	597
3	605	600	600	602
4	607	589	607	602
5	608	600	619	602
6	600	599	630	582
7	584	591	600	555
8	593	592	604	595
9	590	596	594	599

Appendix F, Figure 8. Field data entry example for RSET ACEFI1, written in a waterproof notebook in pencil. Data are recorded in rows and columns specifying quadrant (A, B, C, D or N, S, E, W) and pin number (1-9).

APPENDIX G: METHODOLOGY FOR COLLECTING GEODETIC DATA IN THE FIELD

It is recommended that a geodetic survey be completed several months post-installation of new SET and RSET stations. Geodetic data will establish a vertical elevation dataset and allow for orthometric elevations to be calculated from the SET and RSET pin data (Appendix H). For the SCGS SET project, global navigation satellite system (GNSS) data are collected at every SET or RSET station once every 3-5 years.

SCGS uses a Trimble RTK R8 system, consisting of a receiver (antenna) and a handheld TSC2 data controller, for GNSS-based (GPS + GLONASS) surveys of the SET array. The instrumentation connects to South Carolina's Virtual Reference Station (VRS) network, a Real Time Network (RTN) that provides centimeter-scale positional accuracy through real-time corrections relayed to the rover instrument in the field using a wireless connection (Lapine and Wellslager, 2007). This feature is essential for remote SET or RSET sites that cannot be leveled to an NGS benchmark.

A range extender can used to improve the wireless connection in locations where service is an issue.

The methodology below details the current data collection and processing protocol, and recommendations to consider before beginning a data collection campaign. Since the satellite constellation geometry repeats itself every 12 hours, the process described below must be repeated for each station to provide two 10-minute occupations collected either 18 hours apart or beyond 30 hours apart (to provide for variation in satellite geometry; Zilkoski et al., 1997).

1- Determine the frequency that geodetic surveying will be needed (for the SCGS array, geodetic data are collected every 3-5 years). This may vary depending on specific research objectives.
2- Plan a field campaign that will maximize data collection at the most optimal times of year and day for GNSS surveying. The summer months (June-September) should be avoided if possible, as should the 30 minutes before and after sunrise or sunset (M. Wellslager, personal communication). Data should ideally be collected early or late in the day - before 11:00AM and/or after 3:00PM - to optimize satellite geometry (favorable Vertical Dilution of Precision, or VDOP; Geoghegan et al., 2009). Ideally, data collection should be completed within the timespan of several weeks to months.
3- Contact the SC Geodetic Survey prior to surveying to ensure that the planned survey methodology meets current best practices. Optimal GNSS data collection protocols are subject to change as the instrumentation technology and access to additional satellite constellations improves. If leveling is to be used (only when SET or RSET sites are within a mile of an established NGS benchmark), a different protocol from the one described here will need to be developed.
4- Using the methodology outlined in this protocol in South Carolina will also require a subscription to the VRS (available through the SC Geodetic Survey).

5- The SCGS uses a Trimble R8 receiver with a TSC2 data controller for GNSS surveying (see Appendix E for a detailed equipment list). The R8 is attached to the end of a 2-meter carbonite rod. The rod is attached to a bi-pod in the field to provide stability during occupations. A handheld wireless MiFi unit and the TSC2 are attached to the rod out of convenience when measuring (Appendix G, Figure 1). Although it is not critical to directly attach either the controller or wireless MiFi unit to the pole, the receiver (antenna) must be mounted to it to allow for a view of the sky and to provide a fixed distance (2 m) between the antenna and the control point.

6- The TSC2 and R8 (receiver) batteries should be fully charged before each field day.

7- **Before going into the field:** a project should be set up in Survey Controller, the data collection software installed on the TSC2 handheld controller. The job will need to have an assigned coordinate system and units.

8- **On the day of the survey:** before occupying any SET or RSET station, a measurement (at least a 3-minute occupation, ideally a 10-minute occupation) should be collected at an established NGS benchmark (check in). This benchmark should be as close as possible to the stations being measured during that day and it should have both established horizontal and vertical control, as per NGS. For example, when surveying stations in the ACE Basin NERR, SCGS will use the NERRS ACE Basin site – D9514 to check in at the beginning of that day's survey and check out at the end of the survey. Collecting data from an established NGS benchmark allows for an accounting of drift due to instrumentation, time of day, and/or atmospheric conditions.

9- In the field, navigate to the desired SET or RSET station.

10- Before collecting a measurement, turn the equipment on. Insert the battery into the antenna and press the circular green power button; attach it to the top of the pole. Turn on the TSC2 handheld using the green button on the bottom left of the keypad. Turn on the mobile wireless device (phone, MiFi, or another Bluetooth-enabled portable WiFi unit).

11- Locate the geodetic control point for the site. For SET stations, the geodetic control point is the center point of a machined cap (Appendix G, Figure 2). This cap, specifically designed for the SCGS, is placed on top of the SET insert pipe (Appendix G, Figures 2 and 3). For SCGS RSETs installed before 2015, the geodetic control point is the center point of the receiver (Appendix G, Figure 4; Appendix H). After 2015, all RSETs were installed with a bronze geodetic benchmark disk set into the concrete supporting the collar around the benchmark rod (Appendix D, Figure 13).

12- For SET stations: gently tap the machined control point cap with a rubber mallet until the bolt is seated in the locator pin notches in the insert pipe. For older RSET installations (without a bronze disk): unscrew the protective plastic cap on the receiver.

13- Set the tip of the 2-meter rod into the receiver or onto the center point of the bronze geodetic benchmark disk (RSET) or the center point of the machined cap (SET).

14- Extend bi-pod legs if using a bi-pod connected to a 2-meter rod. The ends of the bi-pod legs can either be set into the marsh platform surface (avoid placing the ends in quadrants that are measured) or extended to rest on top of a flat surface. To prevent the rod tip from sinking into the marsh, a glove will work for this flat surface, as will a plastic lid or container.
15- Level the instrumentation using bubble level on rod.
16- Connect the TSC2 to the wireless device being used (bottom of the main menu of the startup screen).
17- Start Trimble Survey Controller. The name of your job should be displayed across the top of the screen.
18- The number of satellites will display on the right-hand side of the screen – this number should be greater than 10.
19- Select the 'Survey' icon. Connect to the VRS. Select 'Measure Points.'
20- Connect to the R8. Verify that connection to the R8 is established.
21- Type in the point name. Be sure that the antenna height is correct (2 m), and that the measurement point is correct (measured to the bottom of the antenna mount).
22- Tap on 'measure' to collect data. The time of the occupation can be specified. SCGS uses 10-minute occupations. An occupation time of at least 3 minutes is recommended when using the VRS (Lapine and Wellslager, 2007). Go to 'Options' at the bottom of the screen to set the occupation time.
23- Repeat steps 11-23 for all sites visited in the survey. The point names will need to be modified with each occupation.
24- When the survey is complete, tap 'Esc' in the lower left-hand corner. Then tap 'Exit.'
25- The screen will display 'Shut Down Survey Controller?' Hit 'Yes.'
26- The screen will display 'Power Down Receiver?' Hit 'Yes.'
27- On the main screen, disconnect the wireless device.
28- Shut down the controller using the green button.
29- **In the office:** Trimble Business Center (TBC) software can be used to download and manage the data, apply different geoids, and export data into formats that include .csv and shapefiles. Data can also be downloaded by connecting the data collector to a computer using a USB cable. Files should be exported as fixed-format files (.csv) from the data collector.
30- The vertical elevation values for each station should be within 2.5 cm of each other. If the variability between the two values exceeds 2.5 cm, additional data should be collected until the desired precision is reached.

Appendix G, Figure 1. Trimble R8 receiver, TSC2 data collector, wireless MiFi, and bi-pod setup collecting data on a SET station in the field.

Appendix G, Figure 2. Center point cap used as geodetic control point (center of the triangle) when surveying original SCGS stations.

Appendix G, Figure 3. Side view of the SET insert pipe and center point cap.

Appendix G, Figure 4. RSET receiver, showing interior cavity where the tip of 2-m carbonite rod is placed (geometry detailed in Appendix H).

APPENDIX H. METHODOLOGY FOR CALCULATING ORTHOMETRIC ELEVATION USING HIGH-RESOLUTION GEODETIC DATA

Data Collection Frequency

A high-resolution geodetic survey should be done as soon as possible following SET or RSET installation to establish horizontal and vertical positioning. The possibility that the station could rise or fall with subsurface changes, tectonics or subsidence, or damage must be considered when interpreting data. If possible, the geodetic survey data should be collected as advised by the SC Geodetic Survey to allow for consistent communication of data and standards following Lynch et al. (2015) and Cahoon et al. (2019). Although frequency will vary based on research objectives, a follow-up survey should be collected within five (5) years of the initial survey, and any subsequent surveys should occur no more than five (5) years apart.

Geodetic Elevation of SET Instrument and Sediment Surface

Fixed Variables

There are five fixed values for each SET or RSET instrument at each station (Appendix H, Figure 1). The **first** is the vertical distance from the geodetic control point to the bottom of the locator pin notches (a) (Appendix D). This distance was measured at each station using a level and tape measure. The **second** is the vertical distance from the bottom of the locator pin notches to a fixed point on the instrument (b). This was measured directly on the instrument. The **third** is the vertical distance from this fixed point to the top surface of the table (c) - which is leveled to create the reference plane on which the ruler is placed to measure the SET pins. This was measured directly on the instrument. Adding (a) + (b) + (c) gives the **fourth** fixed value for each station (d). The **fifth** is the length of the pins used (e). The pin length is the same for both the SET and RSET.

For the SET, the geodetic control point is the center of a 3-inch aluminum benchmark cap (Appendix G, Figures 2 and 3). The vertical distance from the control point to the bottom of the locator pin notch is the <u>same</u> for every station.

For the first generation RSET stations (constructed before 2013), the geodetic control point is located inside the opening of the bolted-on receiver (Appendix G, Figure 4). To reach this point, the conical tip of the survey instrument's 2-m rod is set into the receiver. (**Note:** Once this is done, the point on the tip is lower than any surface a researcher can place a ruler on). We mark on the cone where the receiver contacts its sides and calculate the distance between the bottom of the notch and the depth to the tip. The vertical distance from the tip of the 2-m rod to the bottom of the locator pin notch is the <u>same</u> for every station.

For the second generation RSET stations (all stations constructed after 2013), the geodetic control point is a bronze geodetic benchmark disk set into the concrete adjacent to the receiver (Appendix D, Figure 13). The vertical distance from the control point to the bottom of the locator pin notch in the receiver is different at each station.

Changing Variables

Two variables are based on data collected in the field. The first is the length of the SET pins above the table (f) (Appendix F). The second is the geodetic elevation of the control point (g) (Appendix G).

Converting Geodetic Elevation to Sediment Surface Orthometric Elevation

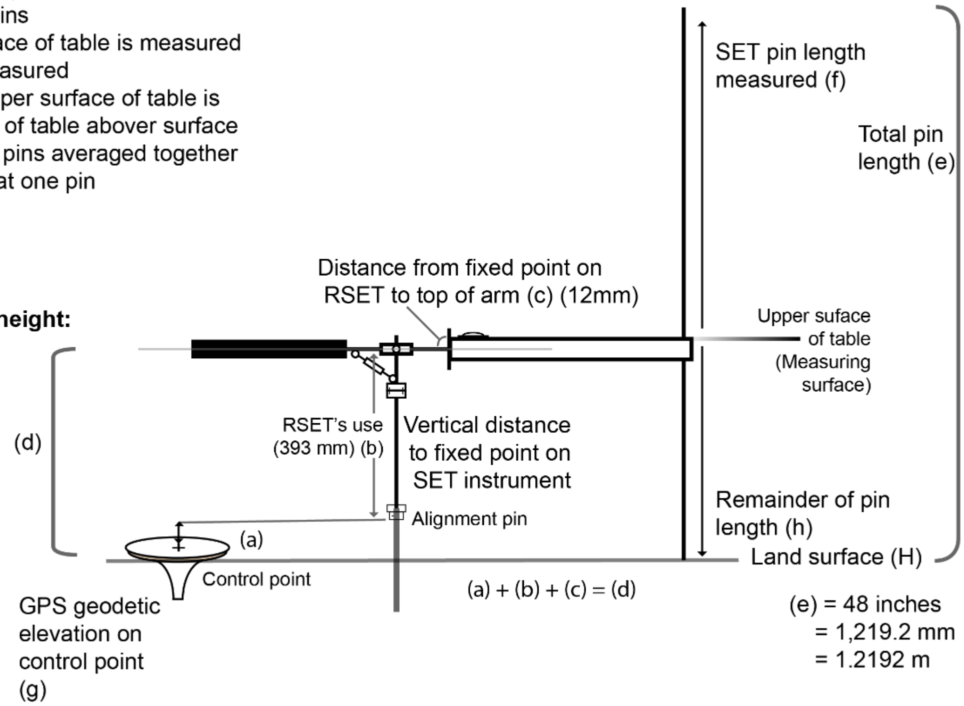
In the field, the pins are lowered from the leveled table to the sediment surface, and the remaining length of the pin above the table is (f) (Appendix F). The (f) is subtracted from the total pin length (e) to calculate (h), which is the height of the table above the surface. To calculate the geodetic elevation of the sediment surface at each pin (H), the geodetic elevation (g) is added to the SET or RSET geometry (d), and then the height of the table (h) is subtracted.

NOTE: Since the data are collected at every pin (9 pins) in each quadrant (4) for a total of 36 data points per station, and since the SCGS project is interested in changes averaged across each station, the 36 data points (f) are averaged to produce one number (f_{avg}). Therefore, the equation for the average across each station is $g+d-h_{avg}=H_{avg}$; where $e-f_{avg}=h_{avg}$.

Geodetic calculation for RSETs: (SET calculations similar)
(a + b + c) = d
(g) + (d) - (h) = H; where:

(a) Distance from geodetic control point to bottom of alignment pin notch is constant at each station
(a) Distance from bottom of alingment pin notch to fixed point on is constant at each instrument
(c) Distance from fixed point to upper surface of table is constant for each instrument
(d) Distance from control point to top of table is constant at each station
(e) Total pin length is fixed for all pins
(f) Length of pin above upper surface of table is measured
(g) Elevation of control point is measured
(h) Remaining pin length below upper surface of table is calculated (e-f) = (h) for height of table abover surface for a single pin; or (f - g) for all pins averaged together
(H) Calculated orthometric height at one pin
(f_{avg}) 36 (f)'s averaged togther
(h_{avg}) 36 (h)'s averaged together
(H_{avg}) Average elevation of station

Therefore average Orthometric height:
(g) + (d) - (h_{avg}) = (H_{avg})



*The data collected from all 9 pins in all 4 quadrants, 36 data points (f)'s, is averaged together to produce a single number for (f_{avg}).

Appendix H, Figure 1. The geometry of geodetic data collection measurements for RSETs.