USING A LONG-TERM SURFACE ELEVATION TABLE (SET) NETWORK TO INVESTIGATE LANDSCAPE-SCALE UPLIFT AND SUBSIDENCE THROUGH HEIGHTMOD, RTK, AND GNSS

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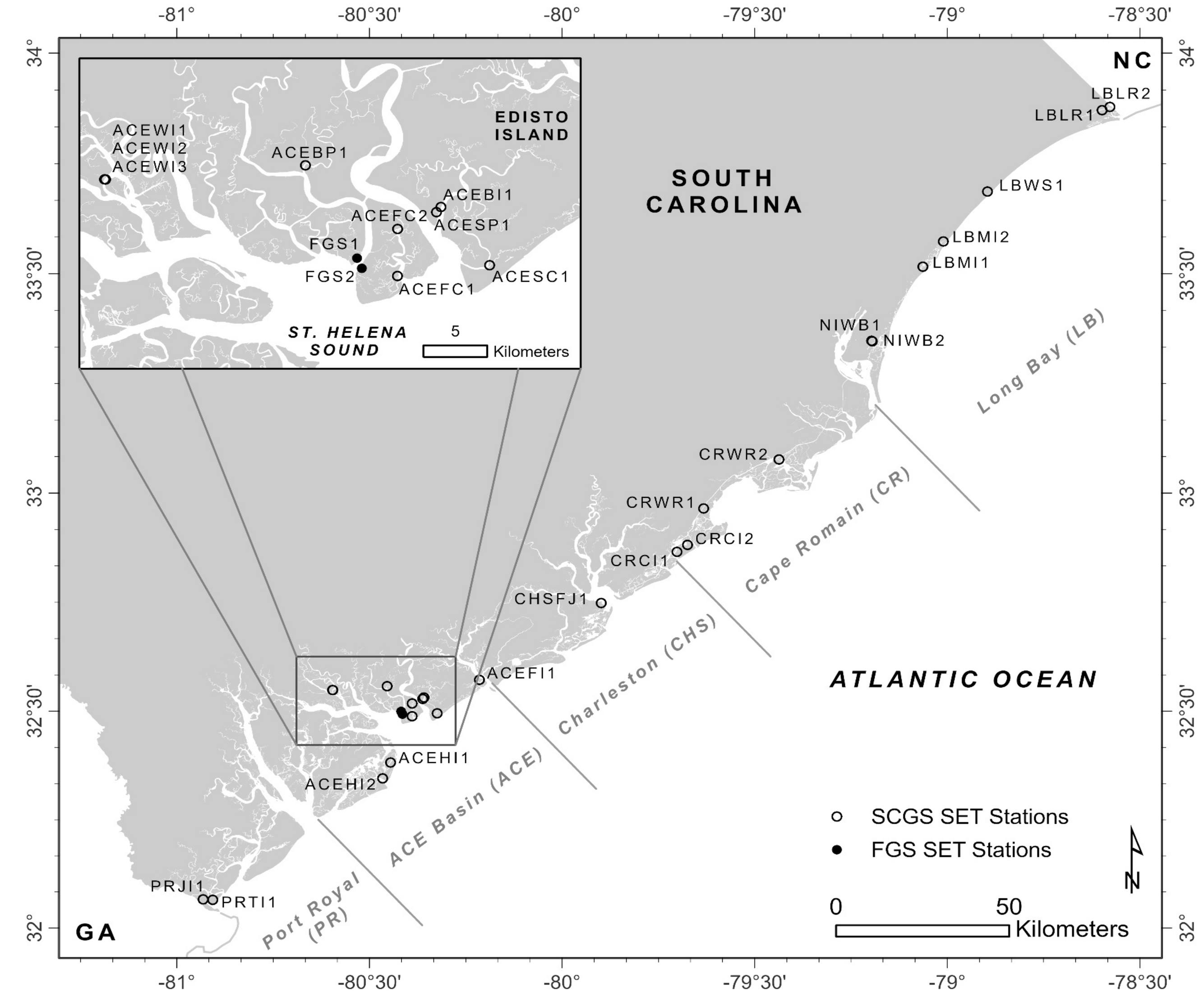
ABSTRACT AND PROJECT OVERVIEW

The South Carolina Geological Survey (SCGS) has installed and monitored a coast-wide array of Surface Elevation Tables (SETs) in South Carolina's salt marshes since 1998 **(Figure 1)**. In addition to using the technique to measure and quantify millimeter-scale surface elevation changes to the marsh platform, and to assess whether marshes are maintaining their vertical elevation with regards to relative sea-level rise (RSLR), another long-term goal of the project has been to collect geodetic elevation data to quantify subsidence or uplift.



Doar and Luciano, 2023

Figure 1. Distribution of the SCGS SET array, as of 2024. Two stations installed and measured by the Florida Geological Survey (FGS) from 1997-2001 are displayed as black circles.

Stations are constructed by creating a benchmark to National Geodetic Survey (NGS) standards (*Doar and Luciano, 2022*). The original SET benchmark was aluminum pipe; the newer Rod SET (RSET) benchmark uses stainless-steel rods. For both, the pipe and rods are driven to refusal (*Cahoon et al., 2002; Lynch et al., 2015* – **Figure 2**).

Geodetic data collected on the oldest SET installations in the array from 1998 **(inset, Figure 1; Figures 4A and 4B)** and 2021 were used to determine a rate of vertical change over time.

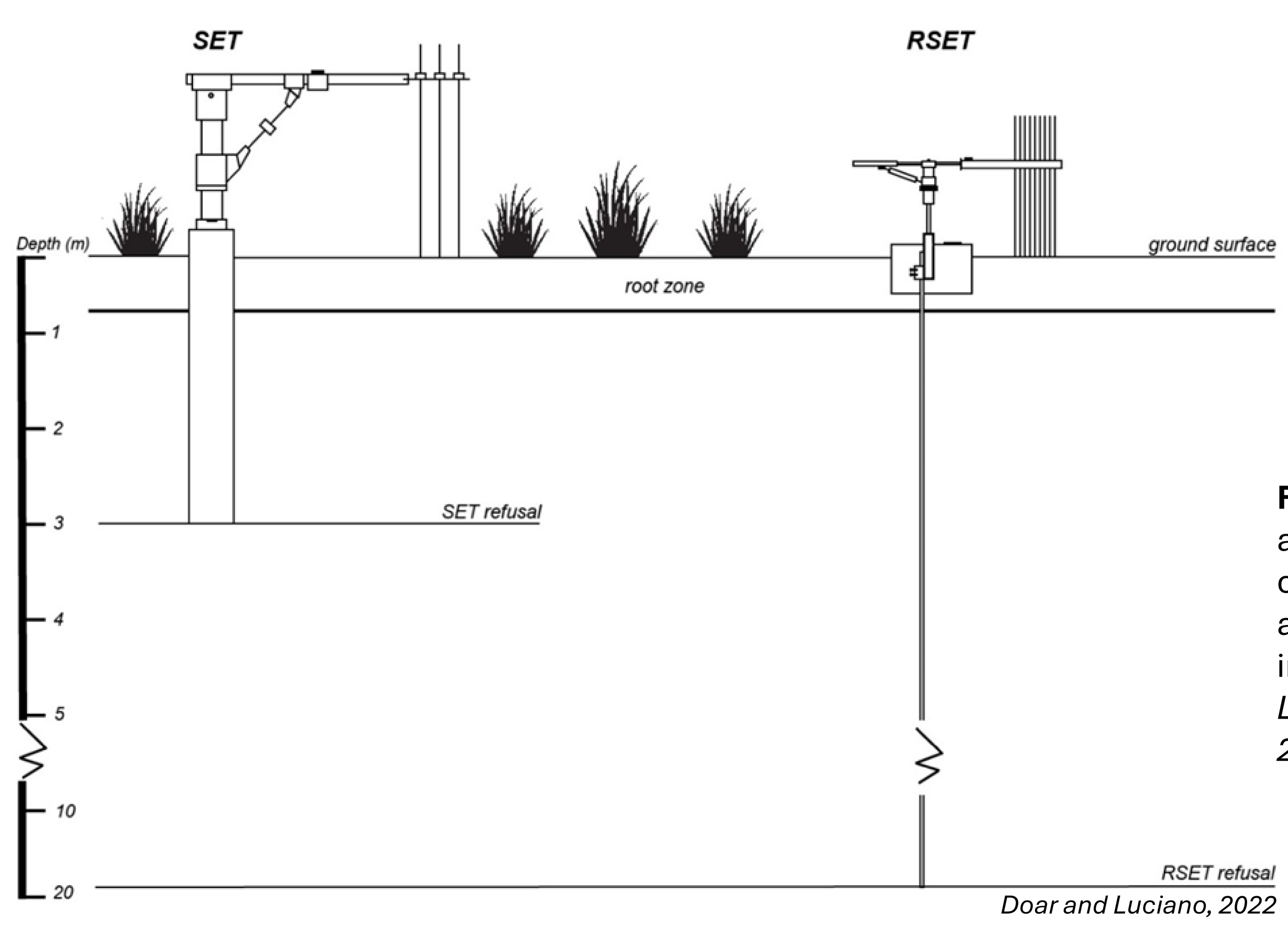


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Figure 2. Above and belowground comparison of SET and RSET installations (after *Lynch et al., 2015*).

METHODS

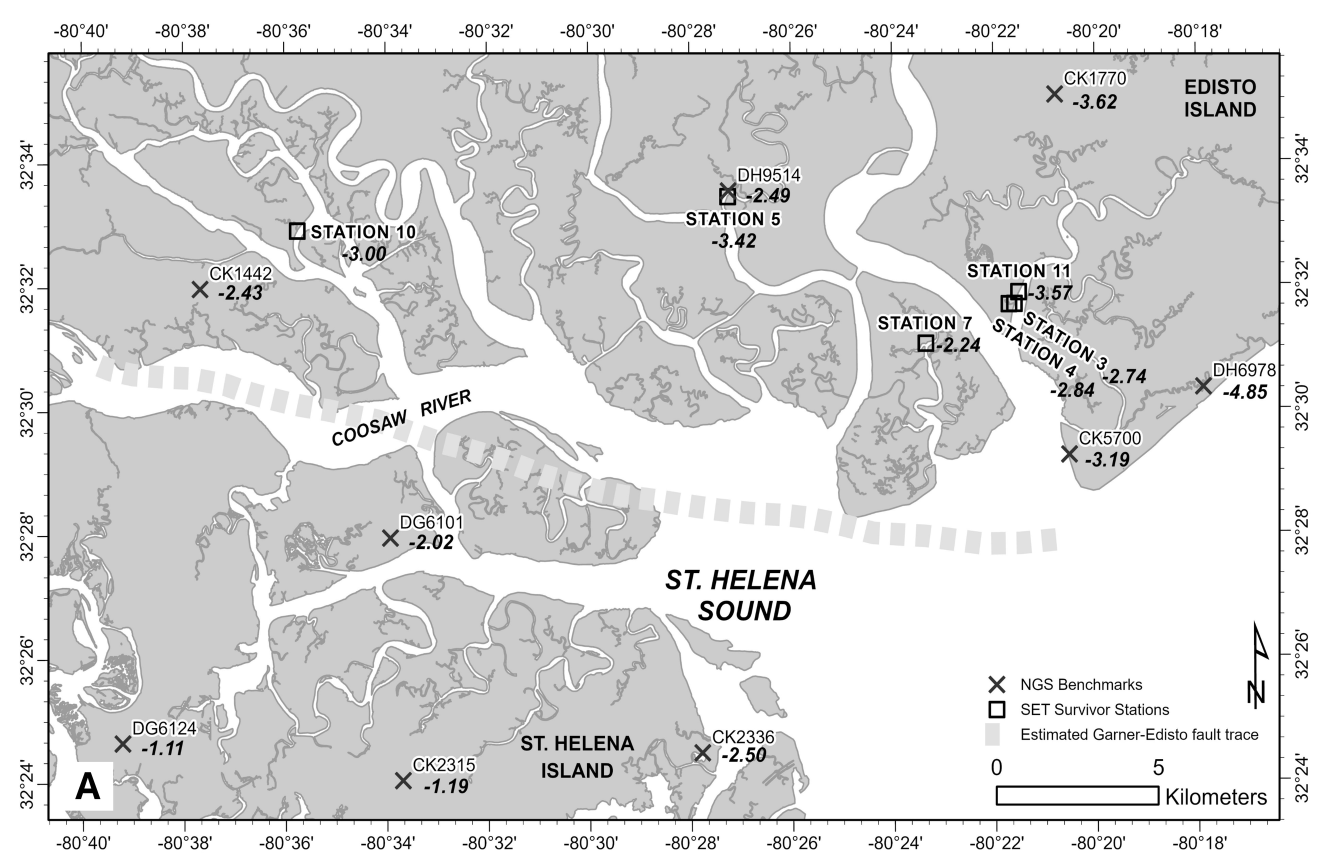
The South Carolina Geodetic Survey worked with SCGS to produce a high-resolution elevation survey of the original stations in the array in 1998, using the Height Modernization (HeightMod) standard's base station and rover technique. Since 2011, geodetic control has been obtained by SCGS through global navigation satellite system (GNSS) surveying using a Trimble R8 system connected to South Carolina's Virtual Reference Station (VRS) Network **(Figure 3)**. This method has been repeated in 2018, 2021, and 2024. Geodetic data were also collected at nine upland benchmarks using SCGS GNSS protocol in early 2022 to provide additional geodetic control for the area of focus.

Doar and Luciano, 2022

Figure 3. Geodetic data collection on SET sites evolved from base and rover (Heightmod) surveys in 1998 (A) to RTK-GNSS survey methods currently used (B). For the original SET design, a temporary benchmark cap is needed for the 3-inch aluminum pipe (C).

RESULTS

- Comparing 1998 and 2021 ellipsoidal values for the six original SET installations revealed total changes in ellipsoidal height of 51.53 to 76.86 mm, corresponding to -2.24 ± 0.09 to -3.42 ± 0.09 mm/year **(Figures 4A and 4B)**.
- The 2022 benchmark geodetic datasets were compared to previous ellipsoidal values recorded by the NGS. Overall negative vertical change was measured at these benchmarks, with total changes in ellipsoidal height of 19.75 to 85 mm, corresponding to -1.11 ± 0.11 to -4.85 ± 0.12 mm/year **(Figures 4A and 4B)**.



B

SCGS Station Name	NGS Station Name	NGS PID	Timespan	Total Change Ellipsoid Height (mm)	Rate of Change (mm/yr)
Station 3	WELL PIPE F	AI7202	12/1998 - 8/2021	61.68	-2.74 ± 0.10
Station 4	WELL PIPE E	AI7201	12/1998 - 6/2021	64.20	-2.84 ± 0.08
Station 5	WELL PIPE L	AI7196	12/1998 - 6/2021	76.86	-3.42 ± 0.09
Station 7	WELL PIPE B	AI7198	12/1998 - 9/2021	51.43	-2.24 ± 0.09
Station 10	WELL PIPE I	AI7205	12/1998 - 8/2021	68.22	-3.00 ± 0.09
Station 11	WELL PIPE M	DH9531	11/2001 - 6/2021	70.45	-3.57 ± 0.10
CK5700	2115	CK5700	6/2004 - 4/2022	56.87	-3.19 ± 0.11
DH6978	SCW1	DH6978	11/2004 - 5/2022	85.00	-4.85 ± 0.12
CK1770	Y 109	CK1770	5/2006 - 4/2022	57.65	-3.62 ± 0.13
DH9514	NERRS ACE BASIN	DH9514	5/2006 - 4/2022	39.80	-2.49 ± 0.12
CK1442	B 108	CK1442	8/2000 - 4/2022	43.17	-2.43 ± 0.11
DG6101	CASSENA	DG6101	6/2004 - 4/2022	36.00	-2.02 ± 0.11
CK2315	7 165	CK2315	8/2000 - 4/2022	25.68	-1.19 ± 0.09
DG6124	SIP	DG6124	6/2004 - 4/2022	19.75	-1.11 ± 0.11
CK2336	866 8146 TIDAL 5	CK2336	12/1999 - 4/2022	63.50	-2.50 ± 0.09

Figure 4A (Figure 3 from *Doar and Luciano, 2023*) and Figure 4B (Table 2 from *Doar and Luciano, 2023*). SET and benchmark sites used for 2021/2022 GNSS surveys (4A); Table of SET stations, benchmarks, and GNSS results (4B).

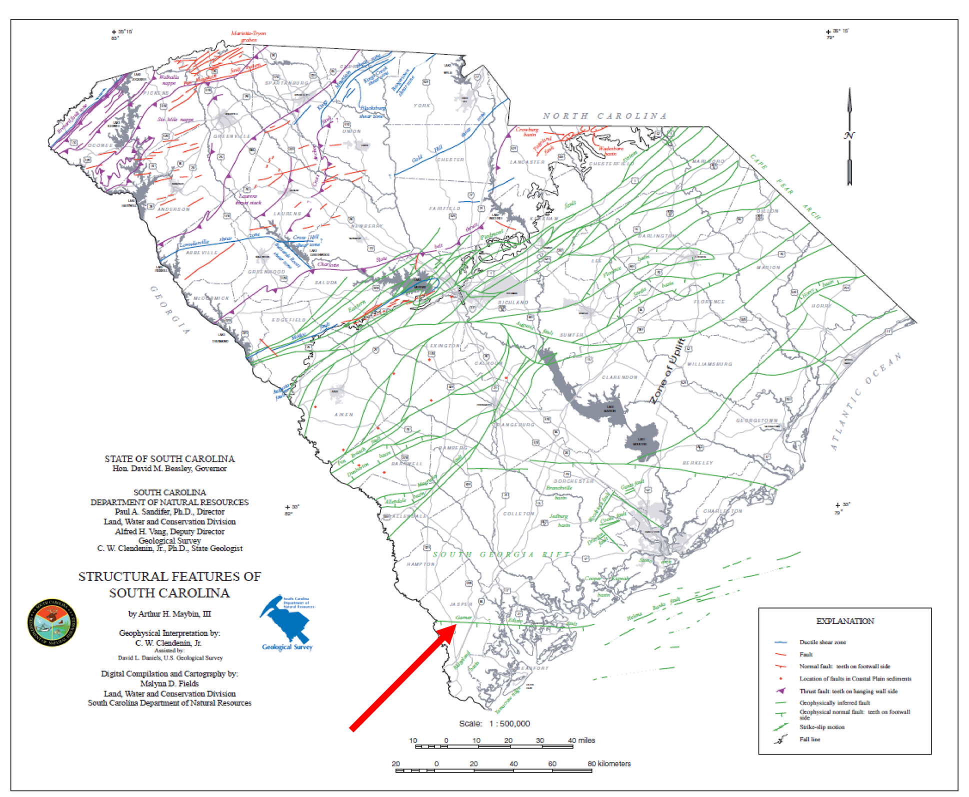
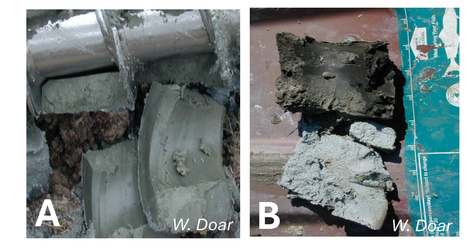


Figure 5. Structural Features map of South Carolina (*Maybin and Clendenin, 1998*). Red arrow is pointing to the Garner-Edisto Fault, oriented east-west across the southernmost corner of the state.

RESULTS (CON'T)

- There is spatial variability in the vertical change data, with higher rates in the northern part of the area of focus, north of St. Helena Sound **(Figure 4A)**.
- A structural features map compiled by Maybin and Clendenin, 1998 shows that the Garner-Edisto fault runs east-west through St. Helena Sound **(Figure 5)**.
- Lithologic descriptions collected from auger drilling by SCGS and USGS **(Figure 6)** show that the Oligocene section is largely missing south and west of St. Helena Sound **(Figure 7)**, and in a subset of the same bore holes, the Miocene section is also missing. In cores 7-304, 7-318, and 7-319, the Eocene is within the first 20 feet below sea level **(Figure 7)**. In all other bore holes, the Eocene (where reached) is deeper.



Miocene Silty, stiff, subangular, fine quartz sand with few phosphate grains and pebbles, mottled color, moderate yellow (5Y 7/6) and medium olive gray (5Y 4/2). (Bore Hole 7-120)

Oligocene Medium olive brown (5Y4/4), well-sorted, silty, quartz-foram shell, fine sand with abundant glauconite and phosphate. (Core EDISTO_1)

Eocene Stiff, dry- to sticky, calcareous mud, shell sand – calcareous nannofossil sand. Greenish-white (5GY 9/1) to yellowish-white (5Y 9/1). (Bore Hole 7-120)

Figure 6. Example photos from SCGS auger cuttings, showing Miocene (A) and Miocene over Eocene (B); to the right, unit descriptions from the logs.

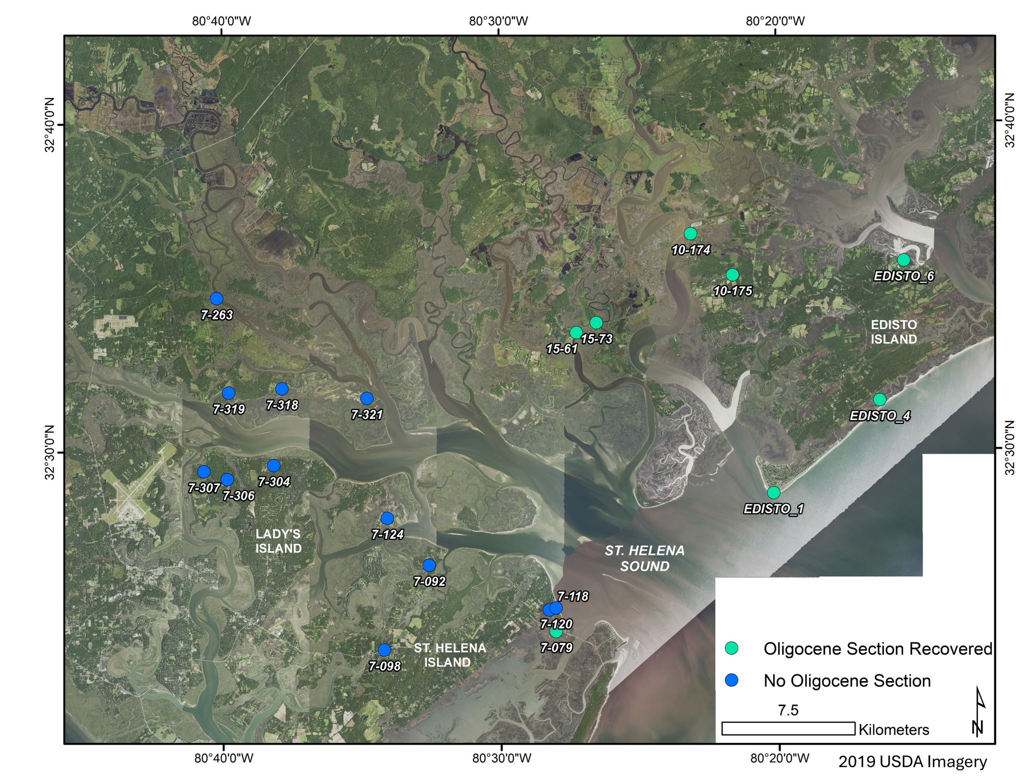


Figure 7. Locations of SCGS and USGS bore holes - coded for the existence of the Oligocene section. Whether or not the Oligocene section exists has implications for the history of fault motion.

CONCLUSIONS AND FUTURE WORK

- This methodology, which is based on calculating differences in ellipsoidal values collected over time, requires multi-decadal datasets to ascertain millimeter-scale rates of subsidence or uplift.
- This study provides evidence that localized GNSS surveys can be useful for understanding the influence of structural features on the landscape. Remote sensing analyses using satellite-derived data (i.e., InSAR) may be effective for understanding subsidence and uplift across broader scales (*Ohenhen et al., 2023*).
- Collecting periodic (5-year intervals) GNSS data on the SCGS SET network will provide information across a latitudinal gradient spanning the South Carolina coast.

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ACKNOWLEDGEMENTS: The authors thank all who have assisted with station installation and data collection over the life of the project. We also thank the South Carolina Geodetic Survey for their expertise and support, from the original 1998 Heightmod survey to recent advice on best practices for RTK-GNSS. We would especially like to thank Matt Wellslager, Bob McKeown, Richard Woods, Lew Lapine, and Jeff Smoak.