Investigating Temporal Groundwater Interactions between a Barrier Island and High Marsh Environment

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Introduction

Electrical Resistivity Tomography (ERT) is a common low-impact geophysical investigatory tool capable of imaging electrical structures in earth materials that may vary due to hydrological processes and geologic features. By utilizing a linear array of electrodes, electrical current is passed between pairs of electrodes where resulting voltage drops can be measured and attributed to resistive properties within the soil, generating a two-dimensional resistivity tomogram. Although widespread in its use, little work has focused on applying this technology within high marsh environments to image pore waters in the vadose zone through time.

Figure 1. Typical instrument package for electrical resistivity surveys including SuperSting R8 head unit, switchbox, imaging processing laptops and remote power.

Study Site

Waties Island, South Carolina is characteristic of many barrier islands located along the southeastern United States coast in that it supports an extensive back barrier saltmarsh system, bound by Hog Inlet to the south and Little River Inlet to the north (Figure 1).

Electrical resistivity measurement transects extended from the landward side of Waties Island into the high marsh (Figure 1 inset). Groundwater wells and the vibracore site were located within the middle of the short transect, where the highest resolution resistivity image could be obtained.

Figure 2. Satellite imagery of Waties Island, SC, inset shows short transect line (blue) and long transect line (red) and vibracore and groundwater well locations.

Methods

Electrical resistivity measurements were collected once a month between March 2021 and February 2022 for the shorter (17 m) transect and between April 2021 and February 2022 for the longer (112 m transect). Resistivity data was processed using AGI EarthImager 2D software where a finite element inversion model generated resistivity tomograms. Three groundwater wells were installed at .75 m, 1.2 m, and 2 m depths and sampled during resistivity surveys to provide insight into porewater temperature and salinity gradients throughout precipitation events and seasonal changes. A vibracore provided sediment samples from the upper 3.1 m of the marsh platform. Soil samples were taken at 10 cm intervals from the top of the core for organic content (loss on ignition) analyses. Soil horizons were characterized based on sediment type and grain size in addition to shell fossils and organic matter.

Figure 3. Vibracore retrieval from high marsh site.

Figure 4. Groundwater wells after installation (right), short transect electrode and cable array (left).

Results

Soil resisitivites ranged from 3.5 – 0.92 Ω-m along both transects. Regions of high resistivity occurred in the short transect at depths of around .80 m. This layer was not resolvable with the electrode spacing of the long transect, however high resistivity regions in long transect inversions were observed around 6.5 m deep. In both transects, high resistivity regions increased in intensity with decreasing distance to the Waties Island headland portion of the transect. Groundwater well salinity and temperature had decreased variability with increased depth. The shallowest well recorded salinities between 16.7 ppt during December and 12.9 ppt in October with maximum and minimum temperatures of 6.3 °C and 24.9 °C, respectively. Deeper well salinity and temperature remained between the maximums and minimums set forth by the shallowest well throughout the study. Maximum recorded rainfall between data collections was 7.17 in during late summer. A 3.6 m vibracore barrel yielded 3.1 m of sediment with 7% compaction. The upper 45 cm of core is largely fine-grained sandy mud with root mat intermixed. Sediment located between 46 and 128 cm deep contained mostly fine sand with roughly 1 cm wide interjections of muddy sand at depths of 122 cm and 126 cm. Muddy sand persisted from 127 cm to 177 cm depth wherafter extensive fossilized shell fragments including multiple pieces of *Crassostrea virginica* were present to 280 cm depth. Fine muddy sediment comprised the remainder of the core section. Percent of soil sample weight lost on ignition ranged from 0.28% to 10.4% with horizons comprised of mud and muddy sands having the most mass lost on ignition.

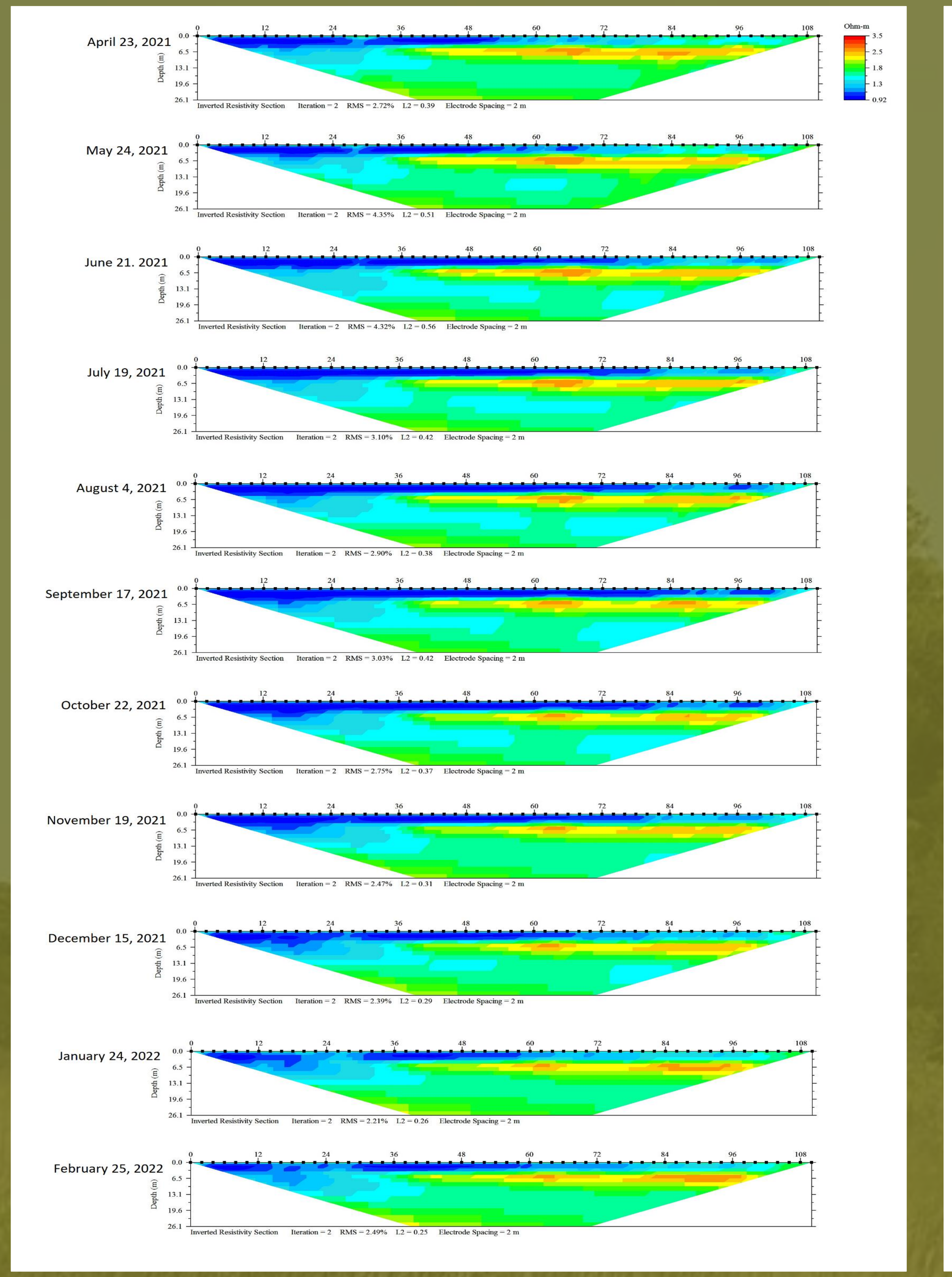

Figure 5. Resistivity tomograms from the long transect collected between April 2021 and February 2022.

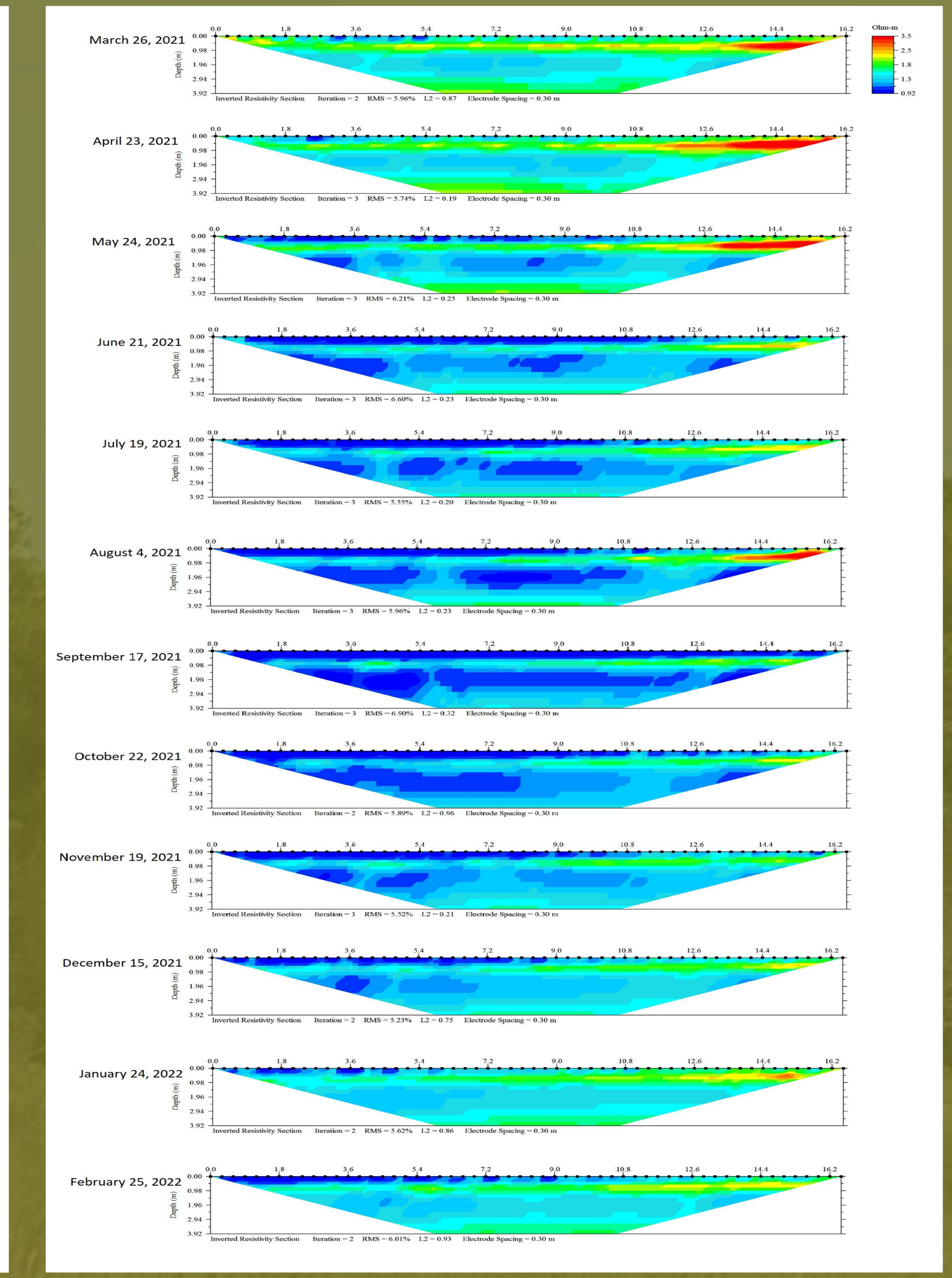

Figure 6. Resistivity tomograms from the short transect collected between March 2021 and February 2022.

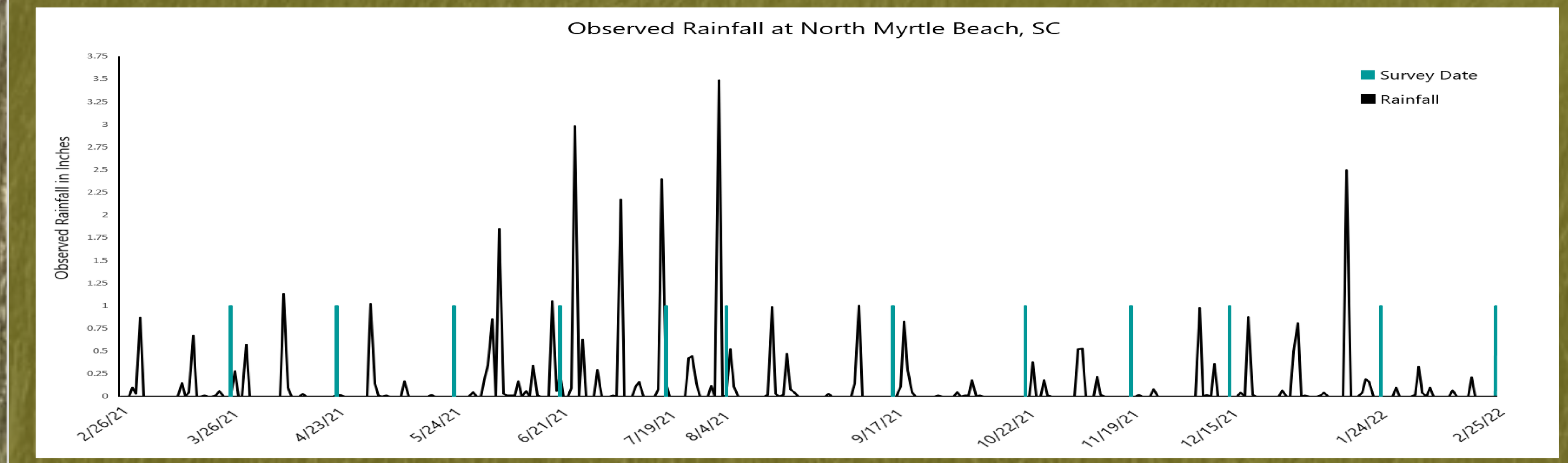

Figure 7. Accumulated rainfall at North Myrtle Beach NOAA weather station, blue lines indicate dates of data collection.

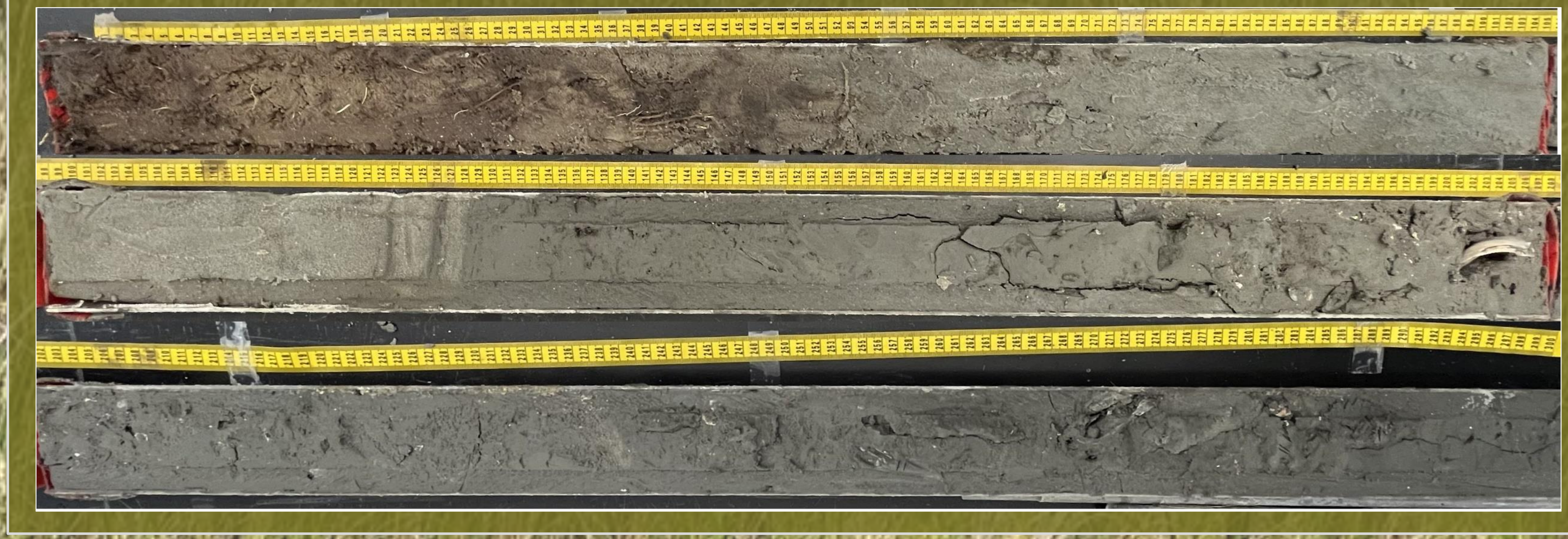

Figure 8. High marsh sediments collected from vibracoring efforts, including upper marsh platform muds, fine sands, clays, and fossil rich sediments.

Discussion

Soil resistivity can be driven by a number variables including, sediment type, grain size, porosity, and pore water characteristics. Groundwater wells maintained sufficient water levels for sampling throughout the study, and were not able to be pumped dry by means of peristaltic pump even after an extended period of pumping. These observations indicate extensive pore water saturation throughout high marsh sediments. Given the influence that dissolved sodium chloride ions have on electrical resistivity, it can be interpreted that higher resistivity values indicate fresher or brackish pore water while lower resistivity values indicate more saline pore water. Groundwater inputs into the high marsh are typically derived from headlands or barrier islands providing fresh or brackish water from shallow aquifers, and saline inputs from tidal pumping, however precipitation events in addition to evapotranspiration by area flora can also affect groundwater composition.

Resistivity data obtained from the long transect remained remarkably consistent throughout the study period. Despite Waties Island experiencing nearly 1.5 m diurnal tides, no signals of tidal pumping were detected throughout resistivity measurements taken over a variety of tidal conditions. A constant resistivity interface was observed 72 m landward of the Waties Island headlands on the long transect. The resistivity signal which creates this lateral boundary appears to not be affected by immediate lithology and may be indicative a freshwater and saltwater mixing zone. The shorter transect provided more variable results with apparent seasonal changes in resistivity in a shallow band originating from the Waties Island headlands. Here, resistivity measurements taken over winter months were notably higher than those taken in the summer, with the exception of the August 2021 survey, which preceded a large precipitation event.

Throughout several survey dates, the presence of standing water on the marsh platform after precipitation events was noted. Informal investigation of puddles and ponding on the high marsh proved this to be fresher water, likely runoff from the headlands rather than tidally driven flooding. The presence of surface water attests to the impermeability of the high marsh sediment package. As observed in the vibracore, the upper soil horizon is muddy consisting of fine sands and clays with extensive root mats mixed in. A layer of fine sands was located directly underneath this uppermost region of mud and was resolvable in high resolution by the short transect. This layer is additionally bound by another mud layer at its bottom, roughly 127 cm deep. Two groundwater wells were located within this sandy layer and experienced slightly higher variability in salinity than the deepest well which was located in a more mud rich layer. Given the characteristics of this soil horizon it can be interpreted that this sandy layer between roughly 45 and 127 cm deep maintains high enough porosity and permeability that its pore water contents are detectable by means of electrical resistivity.

Conclusions

The high marsh hydrology of southeastern barrier islands is exceptionally dynamic given the vast array of inputs and processes that contribute to its characteristics. Results achieved from this study prove electrical resistivity tomography techniques to be capable of imaging these hydrologic interfaces. Further investigation is needed to determine whether lithology and sediment properties or porewater composition contribute more to resistivity signals observed here. Understanding the hydrologic processes in this region is of great importance when considering implications of hydrology on developed barrier islands where shallow drinking water wells, decreased maritime forest and upland swamp environments, and sea level rise may provide additional stress on freshwater resources.

Figure 9. Sediment analyses of vibracore material. Further investigation into grain size analysis is required for porosity calculations for each sediment layer.

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