Geomorphological Assessment of the North Myrtle Beach (SC) Continental Shelf for Wind Energy Development

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Eighty percent of the world's energy relies on fossil fuels and is under increasingly strict regulations on greenhouse gas emissions. Development of renewable energy is a vital solution for reduction of carbon emissions and energy security. This study is focused on a geomorphological assessment of the inner continental shelf along the eastern seaboard of the United States (US) offshore of North Myrtle Beach (South Carolina). Offshore wind resources in the US Atlantic are abundant, stronger, and more consistent than land-based wind resources. This area has been identified by the US Bureau of Ocean and Energy Management as a major potential resource for wind energy. Included here is a thorough analysis of seabed bottom type and slope geometry, seafloor roughness and geomorphology as well as potential sites of cultural resources that could have an impact on sitting installations for wind energy. This work shows promise for future wind energy development in the study area.

El ochenta por ciento de la energía global se basa en los combustibles fósiles y es sujeto a regulaciones cada vez más extritas sobre las emisiones de gases de efecto invernadero. El desarrollo de la energía sostenible es una solución viable para la reducción de carbón y la seguridad de energía. Este estudio se enfoca en un análisis geomorfológico de la plataforma continental interior a lo largo de la costa de los Estadios Unidos por North Myrtle Beach en Carolina del Sur. Los recursos eólicos marinos en el atlántico estadounidense son abundantes, fuertes, y más consistentes que los recursos eólicos en la tierra. Esta área ha sido *identificada por la oficina de manejo de océanos y energía de los Estados Unidos como posible fuente importante de energía eólica. Incluido aquí es un análisis de tipo de fondo del lecho marino y geometría de la pendiente, rugosidad del fondo marino y la geomorfología tanto como posibles sitios de recursos culturales que podrían tener un impacto en la instalación de mecanismos de la energía eólica. Este trabajo muestra una forma de abarcar en futuros trabajos de desarrollo de energía eólica en el área de estudio*

KEYWORDS: Multi-beam, Side-scan sonar, Chirp, Bathymetric survey

PALABRAS CLAVES: Multi-rayo, sonar de barrido lateral, Chirp, levantamiento batimétrico

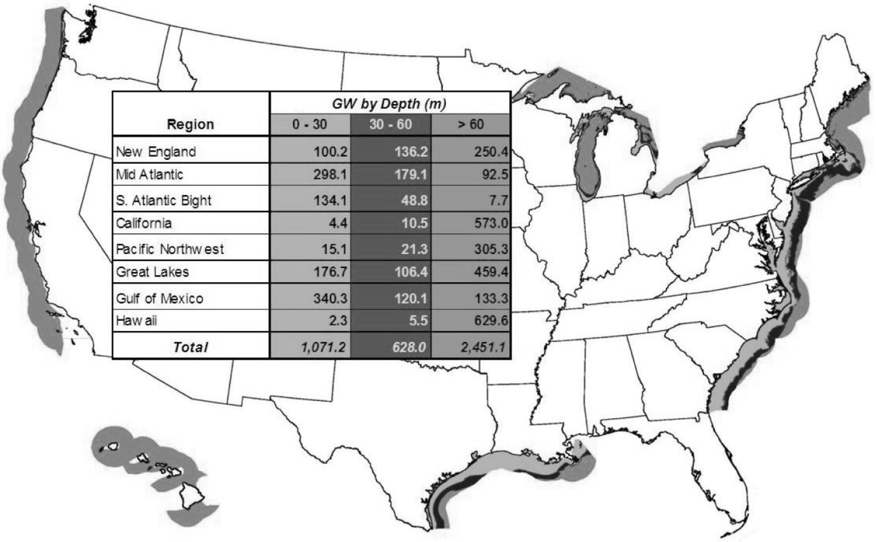
INTRODUCTION

Discussions addressing climate change have long been focused on atmospheric concentrations of greenhouse gasses, in particular, carbon dioxide. With the global human population rising, the discussions have recently begun to include the term energy security. Energy security, as defined by the International Energy Agency, is “the uninterrupted availability of energy sources at an affordable price” and affects many dimensions of our society. With the demand for fossil fuel energy ever increasing and the supply ever decreasing, energy security is a topic of national security. The United States (US) military has made a paradigm shift to be less dependent on fossil fuels and to go further and do more with the same amount of non-renewable energy. To achieve this end, subsidizing with renewable energy is the most simple and effective solution. Between 2001 and 2015, the armed forces doubled their renewable power generation. While the motivation for the US military is national security, it is a direct indication of the future of energy supply to meet the needs of the civilian population. A large sector of ongoing research in the renewables arena is offshore wind energy (Barrie et al., 2013). According to the US Department of Energy National Renewable Energy Laboratory (DOE NFEL), the gross offshore resource capacity for the US is 10,800 GW (Musial et. al., 2016). A major economic challenge of offshore wind energy is the depth of the water column. For this reason, the continental shelf along the Eastern Seaboard of the US has the highest technical offshore resource potential since it has a relatively flat sea-bottom for approximately 75 miles from the coastline (DOE NFEL, 2016) (Figure 1).

The first offshore wind project was installed off the coast of Denmark in 1991. Since that time, commercial-scale offshore wind facilities have been operating in shallow waters around the world, mostly in Europe. With the US Department of the Interior’s “Smart from the Start” initiative, wind power projects will soon be built offshore of the US (Dvorak et al., 2009).

Newer turbine and foundation technologies are being developed so that wind power projects can be built in deeper waters further offshore (https://www.boem.gov/Offshore-Wind-Energy/). The Bureau of Ocean Energy Management (BOEM) has identified potential Wind Energy Areas (WEAs) on the continental shelf of South Carolina characterized by good wind resource potential and minimal environmental and societal use conflicts based on existing regional data sets.

The submerged continental margin of the southeastern US records a geologic history of continental collision during the Paleozoic time (500–300 MYA),



Region	GW by Depth (m)		
	0 - 30	30 - 60	> 60
New England	100.2	136.2	250.4
Mid Atlantic	298.1	179.1	92.5
S. Atlantic Bight	134.1	48.8	7.7
California	4.4	10.5	573.0
Pacific Northwest	15.1	21.3	305.3
Great Lakes	176.7	106.4	459.4
Gulf of Mexico	340.3	120.1	133.3
Hawaii	2.3	5.5	629.6
Total	*1,071.2*	*628.0*	*2,451.1*

Figure 1. US offshore wind resource by region and depth (from the Bureau of Ocean Energy Management).

and subsequent continental rifting and break-up with associated magmatism during the early Mesozoic time (230–180 MYA). Subsequent development as a passive continental margin has resulted in accumulation of a thick sedimentary cover deposited through numerous cycles of sea level change on the margin (Dillon et al., 1979). The most recent phase of deposition (Pleistocene; <1.8 MYA) took place during repeated, large-scale (120 m) sea-level changes which resulted in extensive exposure and inundation of the shelf (Pinet and Popenoe, 1985). A multi-sensor geophysical survey has been performed to provide a more thorough determination of the shallow geologic framework, bottom habitat and cultural resources potential to further refine future wind farm siting (Ojeda et al., 2004). The study focuses on the inner continental shelf from approximately 18 to approximately 26 km (approximately 11 to approximately 16 miles) offshore of North Myrtle Beach, SC. Three adjacent areas named blocks N1, N2, and N3 have been surveyed with a suite of geophysical methods (Figure 2).

OBJECTIVES

The spatial distribution and extent of hard-bottom habitats, reef habitats, essential fish habitat, and archeological artifacts are significant pieces of information for wind energy development. The University of South Carolina (USC) and Coastal Carolina University (CCU) have conducted geophysical surveys including high-frequency Chirp sub-bottom profiling and seafloor mapping (side-scan, multibeam and magnetic surveys) to assess the spatial extent of sensitive hard-bottom habitats and the sediment

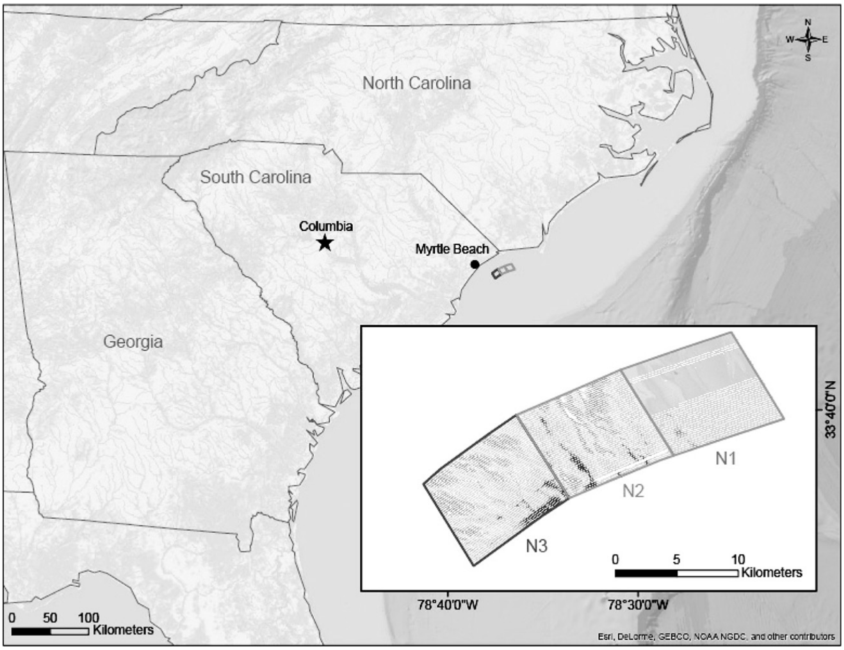


Figure 2. The South Carolina Atlantic offshore wind energy development project study area including three blocks: N1, N2, and N3.

lens in the study area for wind energy infrastructure development. Recent studies indicate that multibeam backscatter and seismic Chirp have significant predictive capability for sediment characteristics and that classifications based on acoustic data have ecological validity (McGonigle and Collier, 2014).

The geophysical data collection focused on the identification of suitable hard ground lithology as well as potential hazards that must be considered in any future wind farm development plans. The potential hazards are diverse and include active zones of sediment transport, faults and fractures, steep slopes approaching 10 degrees, mainly associated with sand ridges and swale topography, paleochannels, together with areas where potential silt and/or clay are exposed on the seafloor (Harris et al., 2005). The presence of such interbedded clays, silts, and sands on the seafloor and within paleochannel complexes may prove hazardous to certain types of development activities and planned structures (Barnhardt et al., 2009).

METHODOLOGY AND DATA

The collaborative effort has generated multibeam and sidescan sonar coverage, as well as Chirp sub-bottom and magnetometer data on a 180-meter line spacing. The 10-km wide swath parallels a similar high-resolution geophysical survey from the shoreline to 8 km offshore, from the North Carolina Border to Winyah Bay, completed as part of the joint USGS-SC

Sea Grant South Carolina Coastal Erosion Study (e.g. Barnhardt (ed.), 2009). Across the region, a thin veneer of sediments overlies indurated Tertiary deposits. The Tertiary geologic section is locally scoured and influenced by small channels and probable karstification and enduring fluid exchange across the sea floor which has been previously identified in the region (Harris et al., 2005; 2013). The sea floor exhibits large-scale (100s of meters) low relief shore-perpendicular bedforms similar to those found within the shoreface and innermost shelf through the South Carolina Coastal Erosion Study (Harris et al., 2013).

Central to the WEA study is the realization that the Outer Continental Shelf (OCS) has the potential to yield a wealth of archaeological information about the early inhabitants of North America and the historic seafaring traditions of exploration, trade, and warfare. During data collection and analyses for this study, we identified three historic shipwrecks as well as paleo-landforms with the potential to contain evidence of human habitation during the last glacial maximum. Consequently, the research team refined data acquisition, processing and analyses to better understand and identify cultural archeological and geological areas of interest.

The proposed investigation was defined by a sequence of tasks to accomplish the objectives and technical needs of the project: 1) acquire the geophysical and oceanographic data, 2) collate a compilation of archaeological and historical records of potential cultural resources in the study area, 3) process and eliminate any obvious abnormalities from the various data sets, 4) observe initial data products and begin interpretation, 5) collect detailed site-specific data from fine-scale geophysical and direct seabed observations for cultural resources assessments and in- situ habitat data, 6) assess potential cable route corridor detailed site survey, and 7) integrate all data and create three-dimensional sub-bottom geologic models.

Multibeam and side-scan echo sounders emit sound waves in the shape of a fan from directly beneath a ship. These marine geophysical acquisition systems measure and record the time it takes for the acoustic signal to travel from the transmitter (transducer) to the seafloor (or object) and back to the receiver. In this way, multibeam sonars produce a "swath" of soundings (i.e., depths) for broad coverage of a survey area (Stuart, 2011). The coverage area on the seafloor depends on the depth of the water, and is typically two to four times the water depth. We identified main seafloor bottom types across the survey area including exposed mud/clay, sand ridges and/or sand waves, and sand with gravel. Magnetic data were also collected in conjunction with the sidescan sonar data to reveal magnetic anomalies to identify zones of potential hazards or cultural resources.

Half-meter resolution multibeam bathymetry data show various geomorphic features in our study area. Our multibeam bathymetry processing workflow has experienced numerous obstacles since the acquisition phase. The most time-consuming processing step stems from the sound-velocity values associated with the raw data. Much of multibeam data were acquired with sound-velocity profiles of approximately 1450–1480 m/s, which is on the low end of the velocity spectrum for pure, distilled water, and far too low

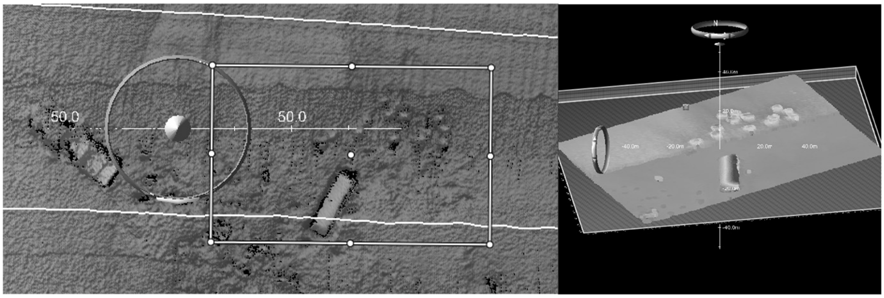


Figure 3. 2D and 3D view of an artificial reef made of shipping containers and imaged in block N1.

for that of sea water which is near to approximately 1530 m/s on average. Due to this low sound velocity, much of our data exhibited a "frowning" phenomenon, much like that seen in post-migrated seismic reflection data with inaccurate velocities. We developed an efficient workflow to process out these velocity artifacts that involved: 1) select a single track-line of raw bathymetry data, 2) open QPS-Qimera's "swath editor" tool, 3) look for the aforementioned "frowns", 4) if frowning, change the sound velocity to a more accurate water column sound velocity factoring water temperature and salinity, 5) check the line within the swath editor tool to see if it has been properly flattened to closer represent the true nature of the seafloor, and 6) repeat process as necessary. Through manipulating the raw default velocities of the data to a more "accurate" fixed sound-velocity, we were able to flatten these artificial "frowning" multibeam swaths and begin to model a more realistic visualization and interpretation of seafloor features, aiding in the archeological, engineering and geoscientific goals of our study. Several areas of interest were identified after this first major step in multibeam bathymetry processing including: artificial reefs, seafloor channels of significant width and length, and areas of anomalous geomorphic constraints. Several artificial reefs made of shipping containers, shipwrecks and other artifacts were imaged within the survey area, the most notable of which lies in the N1_P01 region (Figure 3).

The most notable artifact in our data is an artificial reef made of two shipping containers. It stretches horizontally approximately 180 m, with the longer of the two containers reaching 40 m and the shorter one, 30 m in length. Throughout the dataset lies multiple sand channels of various lengths and widths. Within N1_P02 lies a channel complex with the widest low relief channel stretching approximately 700 m wide at its widest point. All channels and sediment patterns shown throughout the bathymetry follow a pattern of perpendicularity to the coastline, giving the appearance of terrestrial sedimentation including rivers, deltas, estuaries. An example of this is in N1_P02, where a significantly complex set of channels can be noticed (Figures 4A and 4B).

There are several buried channels within this region. The Chirp sub-bottom data corroborates the surficial expressions of these channels (see Figures 4A and 4B), suggesting that there has been a relatively

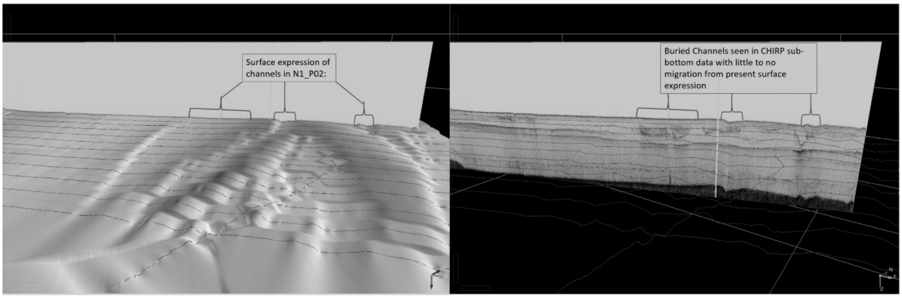


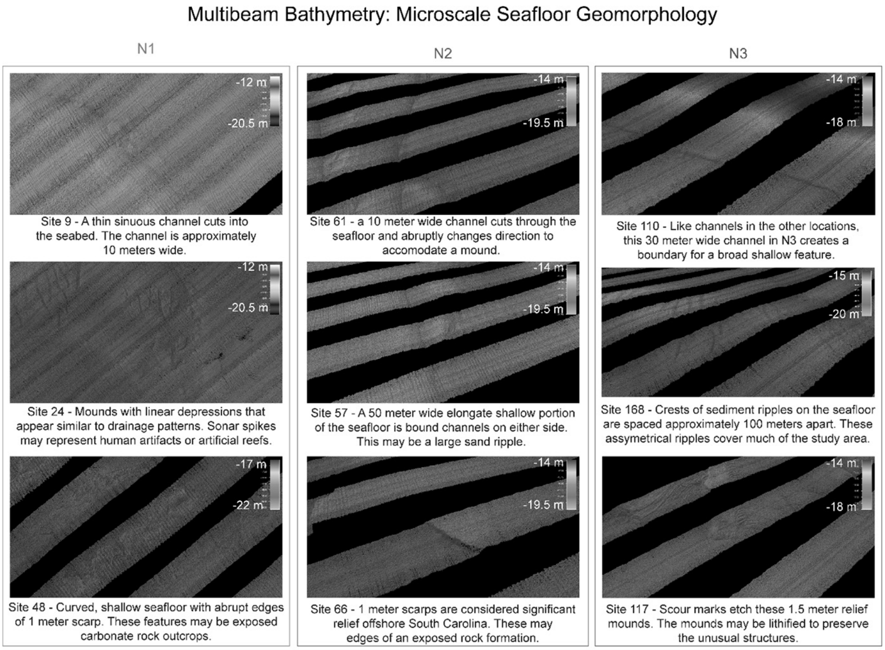
Figure 4. A. Chirp cross-section through bathymetric expression of channels in eastern N1. B. Revealed Chirp profile showing the small amount of migration from buried channel location to present surface expression of channels.

insignificant amount of seafloor drift in our study area over a relatively brief geologic timescale. In addition, within N1_P01 there are areas of anomalous geomorphology that can be seen. When viewing this same area in our backscatter dataset, we see consistently high intensity reflections, suggesting a rocky outcrop that could prove to be an essential sea life habitat.

Another processing challenge was the pairing of our multibeam data with accurate tide data from the North Myrtle Beach area. Our dataset did not come with a co-referenced set of tide data. To supplement, we used the NOAA tide station MROS1 at Springmaid Pier, SC. The Springmaid Pier lies in the middle of Long Bay in Myrtle Beach, SC, which is slightly west of our study area, and on the coast. The entire dataset is tied to tide data from Springmaid Pier from the summer and early fall months of 2015. Accurate tide data and correct Sound Velocity Profiles (SVPs) give confidence in accurate water depths and subsequently an accurate interpretation of the seafloor bathymetry.

For the final step of processing the multibeam bathymetry data, QPS-Qimera's "Spline Filter" was run throughout the dataset. The spline filter works much like a manual processor; it iterates through the dataset and removes outliers (any sonar pings that lie outside of a specified root mean square error (RMS) value between the surface created and the ping shown within Qimera). It does this in two passes, initially covering the data and removing any pings that are obvious, large outliers, and the second pass filters out any additional noise. Qimera allows to choose this specified RMSE value threshold mentioned above through several filter options that range in their level of aggressiveness from "very weak" to "very strong", which are respectively conservative and liberal with their filtering. Given our data had an abundance of outlying pings, we chose to run a "strong spline" filter throughout the entirety of our dataset. This effectively smoothed out the seafloor bathymetry to better reflect accurate topography.

In November 2016, the team conducted a series of refining surveys on the three blocks of our study area. Several zones (outlined as black boxes Figure 5) were chosen for further surveying based on the diversity of geomorphic features,



Site 9 - A thin sinuous channel cuts into the seabed. The channel is approximately 10 meters wide.

Site 61 - a 10 meter wide channel cuts through the seafloor and abruptly changes direction to accomodate a mound.

Site 110 - Like channels in the other locations, this 30 meter wide channel in N3 creates a boundary for a broad shallow feature.

Site 24 - Mounds with linear depressions that appear similar to drainage patterns. Sonar spikes may represent human artifacts or artificial reefs.

Site 57 - A 50 meter wide elongate shallow portion of the seafloor is bound channels on either side. This may be a large sand ripple.

Site 168 - Crests of sediment ripples on the seafloor are spaced approximately 100 meters apart. These assymetrical ripples cover much of the study area.

Site 48 - Curved, shallow seafloor with abrupt edges of 1 meter scarp. These features may be exposed carbonate rock outcrops.

Site 66 - 1 meter scarps are considered significant relief offshore South Carolina. These may edges of an exposed rock formation.

Site 117 - Scour marks etch these 1.5 meter relief mounds. The mounds may be lithified to preserve the unusual structures.

All images were produced in QPS Qimera at 3X Vertical Exaggeration.
All images are also at the same scale, with multibeam swaths = 120 meters.

Figure 5. Multibeam bathymetry seafloor geomorphology showing areas on interest that became the focus for the refining survey.

abundance of multibeam and sidescan sonar anomalies, and magnetic anomalies that indicated potential geologic or paleo-historic significance. Sampling zones were distributed throughout the three blocks to insure a spatial distribution of observations. In the refining cruise effort, data acquisition included: (1) one shallow sub-bottom Chirp profile, (2) camera recordings perpendicular to the shoreline, and (3) near 100% multibeam coverage in block N1. However, the source for tidal data had to be changed since Hurricane Matthew swept through the South Carolina coast in October 2016 and destroyed Springmaid Pier, which was the nearest available source of accurate tide data. For consistency purposes, to match the tide on the refining cruise data as closely as possible to the initial dataset to insure accurate water column depths, we used numerically modeled tide data from NOAA based on previous data from Springmaid Pier. After applying the modeled tide data-files, the refining cruise bathymetric data were corrected from approximately 1-meter difference on the Z- axis to 0-0.4 meters.

RESULTS AND DISCUSSION

A geophysical survey comprised of multibeam, Chirp, side scan sonar and magnetometer track-lines was used to define sea floor habitat, study area geomorphology, shallow geotechnical conditions,

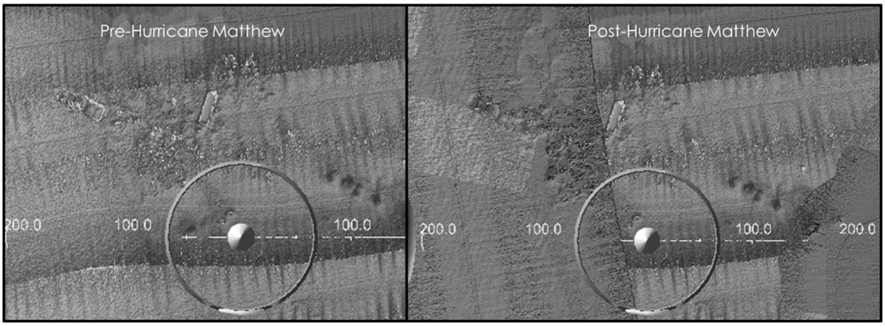


Figure 6. Pre and Post-Hurricane Matthew (2016) artificial reef images.

and potential for important cultural resources to be avoided in the construction of potential future wind energy farms. The surveys were focused on recently delineated Wind Energy Areas (WEAs) in Long Bay, offshore South Carolina. Results to date have identified local areas of hard grounds that might be defined as potential areas of essential fish habitat and shipwrecks of potential archeological interest and importance.

The refining operations have helped the team narrow the focus on these areas of interest and the results of these operations are proving significant from a geological perspective. Perhaps the most significant observation derived from the refining cruise was the lack of movement of seafloor landforms and landmarks post-hurricane. From an engineering perspective, especially one such as wind farm development, it is important to note how a specific area is affected by large storms such as Hurricane Matthew. Figure 6 displays side-by-side the artificial reef within the study area before and after Hurricane Matthew. As shown, there was little to no movement of the reef features themselves, and only some sediment build-up along the edges of the longer shipping container can be observed. Channels within the dataset appear to lack significant spatial migration over a geologic timescale, and the seafloor saw a lack of significant disruption following a major hurricane, Hurricane Matthew.

Post-processed bathymetry shows a radial distribution of coast-perpendicular features that transition between two coastal processes: 1) there is the sediment distribution caused by the longshore currents and wave energy, and 2) there are areas related to the coastal inlets that disrupt the primary sedimentation patterns and impose patterns of terrestrial sedimentation such as those from rivers, deltas and estuaries. A future study would help to further refine this assessment. Closely monitored acquisition parameters such as the sonar head geometries, more accurate collection of water column SVPs, gathering full bathymetry coverage, and making sure that the study is carried out on days when the sea is as calm as possible will provide a high-quality dataset. With these caveats in mind, we believe that offshore South Carolina has significant promise for future wind energy development, an area that our state has been leading in its energy practices [57 percent of SC's electricity was generated through nuclear power in 2013 (eia.gov, 2017)].

CONCLUSIONS

Though our dataset still presents several artifacts from issues related to the marine geophysical acquisition, it has been meticulously processed to allow geological interpretation. We have identified local areas of hard grounds that might be defined as areas of essential fish habitat as well as shipwrecks of potential archeological interest and importance. The recent refining operations have helped the team narrow the focus on these areas of interest and the results of these operations are proving notable from a geological perspective. Channels within the dataset appear to lack significant spatial migration over a geologic timescale, and the seafloor did not exhibit major disruption following a Category 1 to 2 hurricane. Our results indicate that assessment data acquisition parameters - including sonar head geometries, water column SVPs, full bathymetry coverage, and calm seas - would need to be closely monitored to provide a high-quality dataset to work with. Future studies will refine these results. In conclusion, with careful avoidance of the paleochannels and marine habitats, we believe the wind energy area surveyed for this research is the ideal location for an offshore wind energy farm. We also believe that the methodology used for this research, specifically the multi-discipline and multi-geophysical methods, is an efficient and effective method for identifying ideal offshore wind energy areas. The integration of the bathymetric, backscatter, and Chirp data provided a volumetric model of bottom types, near surface geology and structure, stratigraphic sequencing data, and fish habitat. The temporal component, including a hurricane event, added confidence in the relatively quiescent nature of the sediments within the WEA's studied.

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