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Utilizing DEMs derived from LIDAR data to analyze morphologic change in the North Carolina coastline

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Abstract

By using digital elevation model (DEM) data derived from light detection and ranging (LIDAR) data, an approximately 70-km stretch of the southern North Carolina coastline was studied. The coastline consists of five barrier islands located between Masonboro Island at the southern extent and Topsail Island at the northern extent. The high-resolution DEM data allowed for a comprehensive visual/quantitative investigation into the spatial patterns of morphologic change that occurred to the barrier islands' oceanfront beaches between 1997 and 2000. This study also demonstrated the usefulness of using laser altimetry to examine barrier islands' response to level of tropical activity, and showed that the coastal process of overwash was recognized as an integral component of barrier island landward migration. Means of net volumetric change per unit area (m^3/m^2) for study areas of different beach management practices, characterized as developed, undeveloped, and nourished beaches on a yearly basis for the period between 1997 and 2000 were derived. *t*-Test of the means has been conducted, and results showed that beaches differed statistically if different management practices were applied to them, and the differences were minimized or disappeared if sequential hurricanes or storms affected the beaches.

Keywords: DEMs; LIDAR data; Morphologic change

1. Introduction

The interaction of humankind with the natural coastal system has led to a great deal of concern for the geomorphic change and effective management of the coastal zonal area (Carter, 1989; Gares & Nordstrom, 1991; Nordstrom, 1994). Approximately 53% of the current US population resides largely within what is considered the coastal margin (Coastal, 2000). The waters that surround and meet the coastal margin also provide very important areas that serve as breeding grounds for numerous marine species that offer a large percentage of the world's food supply. The current influx of people to and development in coastal areas emphasize the need to provide a better understanding of their impacts on the environment and of changes that might be occurring. Some of the greatest impacts and changes seen involve the immediate coastal environment.

The immediate coastal environment may be defined as the narrow zone of interaction between land and ocean, which can consist of barrier islands. The islands are located on most coastlines where four factors are met: a rising sea level, a large sand supply, a coastal plain of gentle slope, and a sufficient amount of wave energy required to move the sand. The islands are typically elongated narrow strips of sand, and intersected by inlets on either end that permit the flow of salt and fresh water into and out of the estuary located behind the islands (Pilkey et al., 1998). Barrier islands are dynamic because a complex intertwining system of processes such as the wave action of water and aeolian processes acts upon them to shape and mold their form through time. Also, weather systems such as hurricanes, northeasters, and frontal boundaries have been acknowledged as significant events that can affect the form of barrier islands (Dolan & Davis, 1992; Inman & Dolan, 1989). North Carolina's coastline, like other developed barrier island areas, is experiencing a battle with an increase in the development and natural processes that affect the morphology of the barrier islands. Particular portions of the North Carolina coastline have exhibited a loss of shoreline with rates of 5 to 12 m per year (Pilkey et al., 1998). Barrier islands are the main morphological units that this study considers.

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When studying morphologic changes on barrier islands, in the past, researchers have been faced with the laborious task of surveying beaches in limited areal extents using widely spaced transects and profiles, or interpreting aerial photography. These time consuming historic efforts designed to capture coastal topographic data can now be gathered within hours by an airborne light detection and ranging (LIDAR) data-gathering mission. LIDAR is a technology that uses a transmitted laser beam to depict the terrain of the earth (e.g., Brinkman, 2000; Hofton et al., 2000; Huising & Gomes Pereira, 1998; Krabill, Abdalati et al., 2000; Krabill, Thomas, Martin, Swift, & Frederick, 1995; Krabill, Wright et al., 2000; Wright, Swift, & Manizade, 1997). Through a combined use of a laser transmitter with high repeating pulse frequency (RPF) and a high speed scanning system, very dense measurements of x, y, and z on the terrain surface by the laser beam are produced. Thus, the creation of an elevation dataset with very fine spatial (x and y) resolution of up to 1.5 m, and fine vertical (z) resolution of 0.15 m or better become possible. The global positioning system (GPS) and inertial navigation systems onboard the aircraft also allow accurate registration of the LIDAR data to ground surface.

Using the 1996 and 1997 LIDAR data, Woolard (1999) investigated the effect of using the data to derive DEMs with different spatial resolutions on the representation of the topography of sand dunes. His study area was on a small portion of the dune line, a couple of kilometers long and several hundred meters wide, near Coquina Beach on the northern Outer Banks of North Carolina. Woolard pointed out that to accurately depict the topography of the dunes, the DEM's spatial resolution should be less than 5 by 5 m. Meredith, Eslinger, and Aurin (1999) evaluated hurricane-induced beach erosion between 1997 and 1998 along the entire North Carolina coastline (approximately over 500 km long). They used DEMs derived from LIDAR data at a resolution of about 5 by 5 m. A volumetric change analysis of deposition or erosion was performed for the dry beach areas to compute the volume of sediment gained or lost caused by the hurricane. Their results showed a great potential to use the DEMs derived from LIDAR data to study certain morphological aspects such as deposition and erosion along a coastline at a large areal extent. However, their study only covered one time period, 1997–1998, and the DEMs of a 5- by 5-m spatial resolution used might be too coarse to accurately represent the topography of the beaches and dunes and to fully understand morphological changes of coastal lines. This paper reports the recent progress on using the DEMs derived from the LIDAR data to study the morphological changes of five barrier islands along North Carolina coastal lines. In particular, we use DEMs at 1.5- by 1.5-m spatial resolution to analyze spatial patterns of depositional and erosional processes, and volumetric net change of the islands during periods of 1997–1998, 1998–1999, and 1999–2000. Also, means of net volume change per unit area (m^3/m^2) of study areas categorized by different beach management practices, developed, undeveloped, and nourished beaches on a yearly basis between 1997 and 2000 are derived. t-Test is used to verify whether the means are statistically different.

2. Analytical approach

2.1. Study area

North Carolina's coastline is a unique coastal system, which is evident from the protruding barrier islands of the Outer Banks and the cusp shaped forms that are so prominent within the shoreline (Fig. 1). The coastline can be divided into two distinct provinces, northern and southern. The barrier island systems within these two provinces vary greatly in relation to the underlying geologic framework (Riggs, 1998). Within this study, five barrier islands covering an approximately 70-km stretch of coastline in the southern province are examined. The islands are oriented in about 45° off the north direction, with Topsail Island at the northern extent and Masonboro Island at the southern extent (Fig. 1). Most parts of Topsail Island, Figure Eight Island, and Wrightsville Beach have experienced rather dense development and beach nourishment programs over the last few years. Lea and Coke Island and Masonboro Island have been left in an almost natural state with overwash dominating. Due to the closure of Old Topsail Inlet that occurred between 1997 and 1998, original Lea Island and Coke Island are considered as one island, Lea and Coke Island.

2.2. Dataset

Between 1997 and 2000, there were four annual LIDAR data acquisitions over the study area. The 1997 dataset was acquired on September 21. The second data acquisition mission was flown on September 5, 1998 just a few days after the passage of Hurricane Bonnie. Bonnie made landfall in the Wilmington (North Carolina) vicinity on August 26, 1998 as a minimal category three storm. During the fall of 1999, the North Carolina coastline was directly affected by two hurricanes, Dennis and Floyd. Hurricane Dennis, resembling a northeaster, stalled just off the Outer Banks and battered the coast for about 5 days before making landfall near Cape Lookout on September 4, 1999. Floyd made landfall in the Wilmington area as a category two storm on September 16, 1999. The third LIDAR data-gathering mission was flown on September 18, 1999 just following the passage of the two hurricanes. The last LIDAR data were acquired on August 2 and 3 of 2000. No hurricanes directly impacted the North Carolina coast since the 1999 data acquisition.

Using the collected LIDAR data, we created the DEMs of 1997, 1998, 1999, and 2000 for the study area, respectively. The DEMs represent the topography of the study area

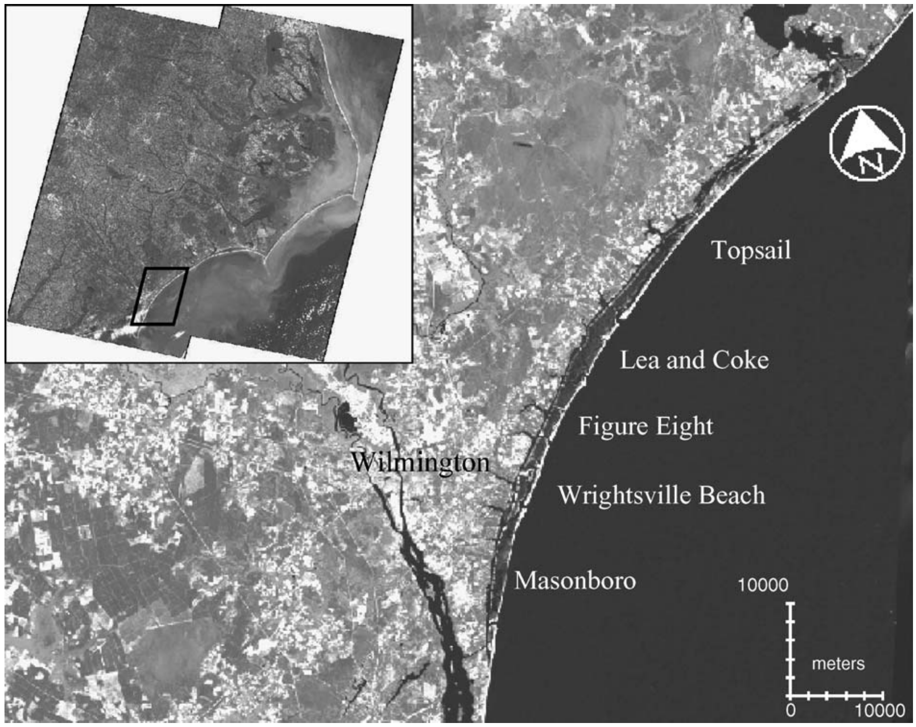

Fig. 1. Study area consists of five barrier islands in the southern portion of the North Carolina coastline. The islands are near Wilmington, North Carolina. TM imagery is used as the background.

at the time of data acquisition. The DEMs have a (cell) resolution of 1.5 by 1.5 m and a vertical resolution of 0.15 m. Also, in the creation of DEMs, if there are multiple vertical (*z*) values in a cell, all values were averaged to create one *z* value for that cell (http://www.csc.noaa.gov/crs/tcm/index.html), and if there are no data points in a cell, an inverse distance weighting (IDW) method is used to interpolate a *z* value for that cell from nearby cells that contain *z* values. Finally, all the DEMs were geo-referenced to the same coordinates using the World Geodetic System (WGS) 84 model as spheroid and North American Vertical Datum (NAVD) 88 as vertical datum. NAVD 88 depicts mean sea level as zero. The projection is Universal Transverse Mercator (UTM).

2.3. Analysis

To facilitate the spatial analysis of topography and topographic change (erosion, deposition, or no change) along the coastline for each island between time intervals 1997–1998, 1998–1999, and 1999–2000, study sites or areas of interest (AOIs) on each island are created. Each AOI designates a particular segment of coastline and consists of the primary portion of the dune line and dry beach where the processes of erosion and deposition can be easily studied spatially. The AOIs also allow for exclusion of heavily vegetated areas, structures such as houses and piers, variability in shoreline position, and wave activity that may add significant error into the analysis. Lastly, each AOI covers approximately the same location and portion of coastline for each yearly analysis. The spatial transects and surface profiles of the DEMs, slope and relief data of the DEMs, panchromatic and video data acquired concurrently with LIDAR acquisition, USGS's color infrared (CIR) digital orthophoto quads (DOQs), and ground observations are used to help identify and create each AOI. In particular, the transects and profiles assist in comparing the accuracy of the DEMs between each yearly survey. The slope and relief data, panchromatic and video data, CIR DOQs, and ground observations helped delineate areas where the morphology of a barrier island is not well depicted on the DEMs alone. There are totally 99, 97, and 97 AOIs used in the volumetric analyses of the periods of 1997–1998, 1998–1999, and 1999–2000, respectively (Table 1).

Using the DEM data pairs between years 1997–1998, 1998–1999, and 1999–2000, a method to analyze the

Table 1
Number of area of interest (AOI) constructed to designate particular portions of five barrier islands in each time pair

Islands	1997–1998	1998–1999	1999–2000
Topsail Island	46	46	46
Lea and Coke Island	15	13	13
Figure Eight Island	12	12	12
Wrightsville Beach	10	10	10
Masonboro Island	16	16	16
Total	99	97	97

Due to the variation of ground coverage of the LIDAR data, DEMs for two AOIs of Lea and Coke Island are not available in 1999 or 2000 dataset.

Table 2
Number of AOIs characterized as developed, nourished, and undeveloped categories of five barrier islands in each time pair

Management practices	1997–1998	1998–1999	1999–2000
Developed	34	42	16
Undeveloped	25	16	26
Nourished	27	21	47
Total	86	79	89

AOIs near an inlet or a jetty are excluded.

topographic change due to deposition and erosion from previous year to current year, and total volumetric change of the beach and sand dunes within each AOI of the five barrier islands is designed. There are two major steps, differencing the vertical value of year 2 to year 1 on a cell-by-cell basis for each time pair, and computing the volume change at each cell location. A positive, negative, or zero volumetric value (m^3) at a cell is the amount of deposition, erosion, or no change occurring at that location. With the analysis of the deposition, erosion, or no change of all cells within each AOI, the spatial patterns of deposition and erosion of sand within the AOI are studied between each time interval. By adding all the positive volumetric values and all the negative values of the cells, respectively, the total volumes of deposition and erosion for each AOI, and then for each island can be derived. Also, a net change or difference of total deposition and total erosion is calculated. Because each AOI does not cover exactly the same size of beach area, the net volumetric change is normalized or divided by the AOI's area. Therefore, using the normalized value (m^3/m^2) allows one to compare the volumetric changes that occur in the AOIs on a more or less equal basis.

It should be noted that the manner in which a barrier island is managed is believed to affect its topography significantly. The management practices include whether a nourishment program is allowed or not, whether the beach is directly affected by a jetty, seawall, and/or groin, and whether there is a dune line present or not. Thus, to study the impact of varying management practices, the AOI is then differentiated based upon whether it is developed, nourished, or undeveloped (Table 2). An AOI affected by a jetty or inlet is not included in the table. A *t*-test is executed to test if means of the net volume change per unit area of the AOIs characterized by developed, nourished, and undeveloped management practices statistically differ for periods 1997–1998, 1998–1999, and 1999–2000.

3. Result and discussion

3.1. Spatial pattern of morphologic change

Analyzing the DEMs derived from the LIDAR data for the study area between 1997–1998, 1998–1999, and 1999–2000, the following is found. Between 1997 and 1998, erosion along the lower beach face caused mainly by Hurricane Bonnie was noticed on the majority of the islands with the following exceptions. A significant gain or addition of beach between 1997 and 1998 was noticed near the pier on Wrightsville Beach in response to the beach nourishment project performed along the majority of the island's extent (Fig. 2). The northern portion of Wrightsville Beach, not included within the nourishment project, however, experienced noticeable loss of sediment along the shoreline. Two predominantly undeveloped islands Masonboro and Lea and Coke had significant depositional sites in association with overwash fans (Fig. 3), a direct result of allowing the coast to respond in an almost natural manner. The overwash fans are an apparent morphologic feature present along the majority of Masonboro and Lea and Coke

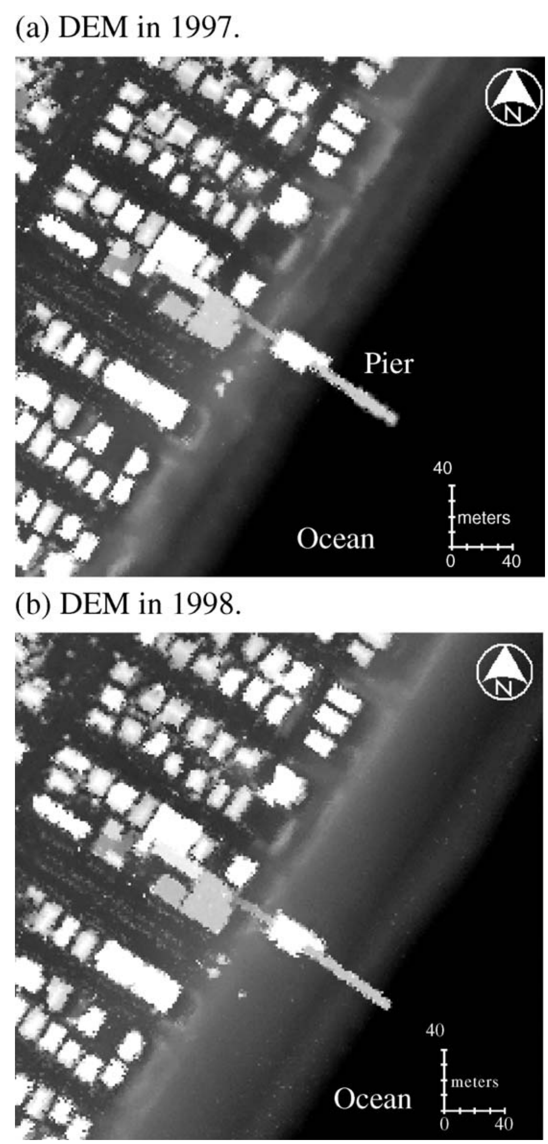

Fig. 2. Beach nourishment performed on Wrightsville Beach between 1997 and 1998 extends the beach seaward. Houses and real estate properties behind sand dunes look roughly like white rectangles oriented by a row and column pattern.

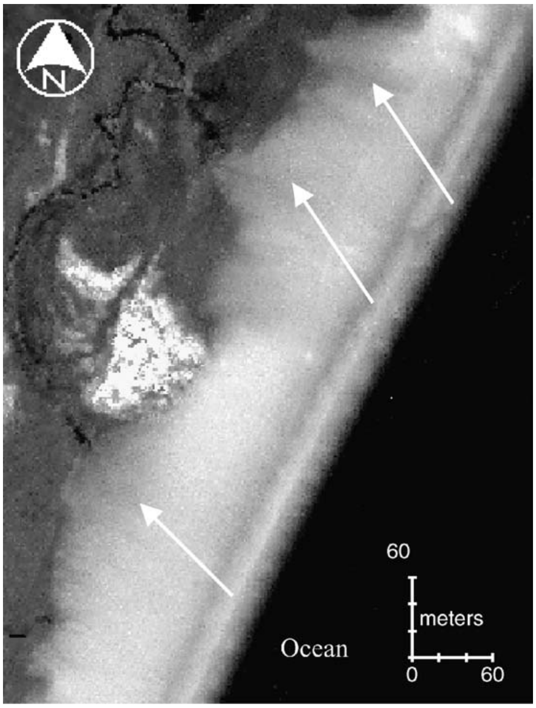

Fig. 3. Overwash fans present on Masonboro Island in 1998 are pointed to by arrows.

Islands. In varying locations along Topsail Island, deposition to the dune line was apparent. On Figure Eight Island, there were more places of erosion than deposition.

During 1998–1999 period, significant erosion along the lower beach face, caused mainly by Hurricanes Dennis and Floyd, was noticeable within the majority of the study area. The greatest erosion occurred at two locations on Wrightsville Beach. One was located in the center of the island where the largest amount of beach nourishment was performed between 1997 and 1998, and the other at the northern end of the island near Mason Inlet. It should be noted that even though erosion of the foredune on Topsail Island was easily identifiable in numerous locations, the sediment being eroded appeared to be redistributed in depositional sites in the corresponding back beach.

Due to the lack of major storms during 1999 and 2000, accretion and deposition were observed on most parts of the islands. The shoreline accretion and deposition was an opposite morphologic response than what was noticed at the same spatial locations before; the shoreline was highly erosive in periods 1997–1998 and 1998–1999. On Masonboro and Lea and Coke Islands, the majority of shoreline accretion and deposition occurred on the lower beach face. This was due in part by the lack of overwash occurring in response to a decrease in storm activity, and the majority of morphologic activity being located in the foreshore and lower back beach. Masonboro and Lea and Coke Islands, both not nourished, also show higher accretional patterns than nonnourished (during 1999 and 2000), highly developed Wrightsville Beach. Wrightsville Beach demonstrated actually some losses of shoreline along the middle and southern portions of the island, excluding the most southern end where a jetty is located to help trap sediment and northern portion of the island (in the Shell Island Resort vicinity). Deposition was also recognized on Figure Eight in response to beach and dune nourishment projects that were performed (Fig. 4). Topsail Island showed alternating morphologic patterns of erosion and deposition along the island's shoreline. Depositional sites were also evident in response to dune nourishment practices along Topsail.

3.2. Volumetric morphologic changes of barrier islands of years 1997–1998, 1998–1999, and 1999–2000

To quantify the morphologic changes, volumetric analysis (deposition, erosion, and net change) of each island has been performed using the DEMs derived for the study area. Fig. 5a presents the results in 1997 and 1998 period. Masonboro Island had the largest amount of deposition

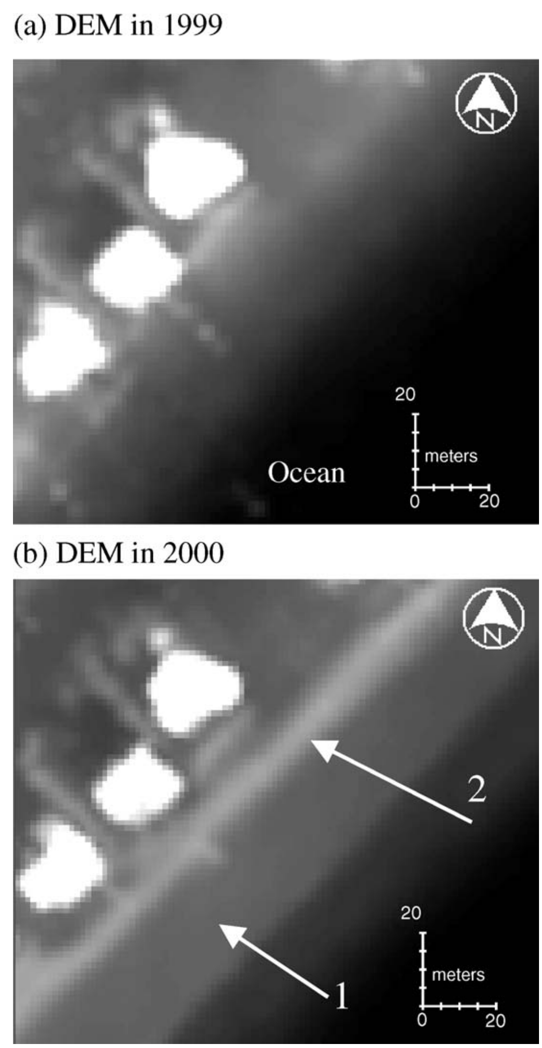

Fig. 4. White arrows show the creation of a back beach through beach nourishment (1) and dune nourishment (2) of Figure Eight Island between 1999 and 2000.

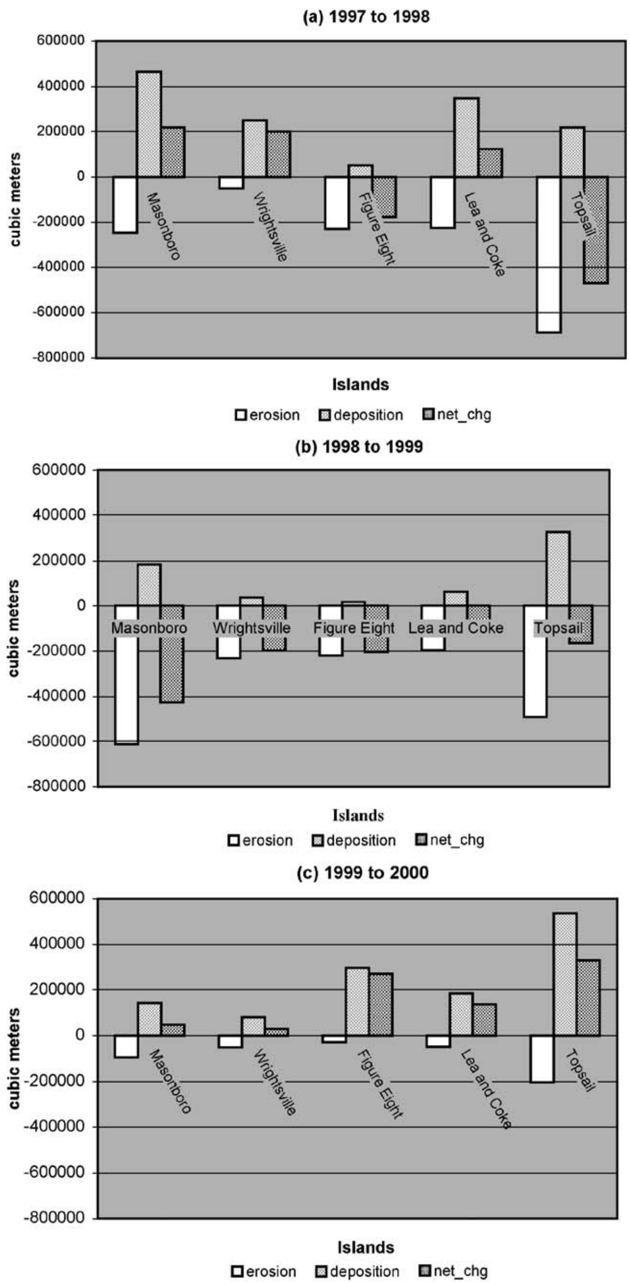

Fig. 5. Volumetric changes (erosion, deposition, and net change) derived from the DEMs of each yearly interval.

(464,876 m^3) but Topsail Island the largest amount of erosion (688,144 m^3). Figure Eight Island showed the least amount of deposition (50,409 m^3), and Wrightsville Beach showed the least amount of erosion (50,515 m^3). Masonboro Island, Wrightsville Beach, and Lea and Coke Island experienced positive net volumetric gains. The over 200,000 m^3 gain on Masonboro Island could be largely attributed to the overwash caused by Hurricane Bonnie, as well as a nourishment program that occurred on a small portion of beach on Masonboro Island as part of a bypass construction project associated with the dredging of Masonboro Inlet and its associated jetties. Wrightsville Beach's gain, near 200,000 m^3, might largely be attributed to the beach nourishment project (see also Fig. 2). Lea and Coke Island's gain was in response to the closure of Old Topsail Inlet and prevalent overwash along the majority of the island's length. The AOI that encompasses the Old Topsail Inlet closure site demonstrated the greatest deposition of all AOIs between 1997 and 1998. Topsail and Figure Eight, both nonnourished developed islands, exhibited net volumetric losses.

Volumetric changes for the yearly interval of 1998–1999 showed that all islands experienced more erosion than deposition or net losses (Fig. 5b). The losses were most likely attributed to the impacts of Hurricanes Dennis and Floyd in 1999. In particular, Masonboro Island had the largest amount of erosion over 600,000 m^3 and exhibited the greatest net loss, over 400,000 m^3. Topsail Island demonstrated the highest amount of sand exchange (between deposition and erosion), most likely attributed to the island's extent (35 km long), disposal of sediment in the swash zone, dune nourishment projects between 1998 and 1999, and erosion caused by two hurricanes. Both the northerly and southerly ends of Topsail received approximately 45,600 m^3 of beach quality material from inlet dredging, which is disposed in the surf zone on an annual basis. Figure Eight Island underwent a dune nourishment program, but showed the lowest overall deposition (Fig. 5b). If the nourishment projects on both Topsail and Figure Eight islands were not performed, results would show these islands as being much more erosive environments. It should be noted that overwash might have possibly occurred in marsh areas along the back portion of Mansonboro Island where deposition in vegetated areas cannot be easily identified by the LIDAR data. Also for Lea and Coke Island, the LIDAR data might not completely cover all areas of overwash fans. Depositional rates for this particular yearly interval may therefore be somewhat less erosive than what this analysis reported.

From 1999 to 2000, five islands were not affected directly by any significant tropical storms, and resulted in more deposition than erosion or net increases to all islands (Fig. 5c). The results appeared to show a rehabilitation stage for the barrier islands following a series of stormy periods previously. The net increases of Figure Eight (270,519 m^3) and Topsail (329,725 m^3) should also be partly attributed to nourishment projects occurring during that period.

It should be noted that the volumetric analysis of yearly interval 1997–1998 was also performed by Meredith et al. (1999). They evaluated erosion/deposition along the entire North Carolina coast induced by Hurricane Bonnie (that made landfall on August 26, 1998). For the five islands used in both studies, their results and ours may be similar in terms of erosion and deposition patterns. However, the amount of erosion and deposition from this study is slightly less than those reported by Meredith et al. The difference can most likely be attributed to the finer spatial resolution, and careful delineation of coastline used in this study. The 1.5- by 1.5-m spatial resolution used in our study can better depict the morphology of the beach with more detail than

Table 3
Statistic summary of net volumetric change per unit area (m^3/m^2) for all AOIs of each barrier island

	Islands	Minimum	Maximum	Median	Mean	Standard deviation
1997–1998	Topsail	−0.84	0.14	−0.28	−0.28	0.23
	Lea and Coke	−0.15	0.50	0.06	0.09	0.18
	Figure Eight	−0.77	0.03	−0.36	−0.32	0.24
	Wrightsville	−0.09	1.23	0.15	0.39	0.50
	Masonboro	−0.03	0.62	0.07	0.12	0.16
1998–1999	Topsail	−0.59	0.32	−0.09	−0.09	0.21
	Lea and Coke	−0.43	0.21	−0.25	−0.20	0.19
	Figure Eight	−1.26	−0.08	−0.25	−0.37	0.37
	Wrightsville	−0.88	0.01	−0.23	−0.37	0.34
	Masonboro	−0.58	0.02	−0.27	−0.27	0.14
1999–2000	Topsail	−0.22	0.60	0.17	0.20	0.21
	Lea and Coke	−0.96	0.39	0.23	0.14	0.35
	Figure Eight	−0.20	1.13	0.44	0.46	0.40
	Wrightsville	−0.23	0.33	0.02	0.03	0.18
	Masonboro	−0.32	0.22	0.05	0.04	0.12

that of an approximately 5- by 5-m resolution adopted by Meredith et al. Our delineation of AOIs along coastline could also affect the results; the delineation determined what AOIs/areas were included in the analysis.

3.3. Volumetric net change per unit area

Descriptive summaries of volumetric net changes per unit area (m^3/m^2) or rate for short were given in Table 3. These statistics were calculated from each AOI of five islands, at time intervals of 1997–1998, 1998–1999, and 1999–2000. In period 1997–1998, all the minimum rates were negative, but the maximum rates positive. The largest and smallest ranges of the rates were 1.32 m^3/m^2 occurred at Wrightsville Beach, and 0.65 m^3/m^2 at Lea and Coke and Masonboro islands, respectively. Also, due to the heavily nourished beach of Wrightsville for 1997–1998, it had the largest mean rate (0.39 m^3/m^2). In contrast, Figure Eight Island had the most negative mean rate, −0.32 m^3/m^2 (even though Topsail Island experienced the greatest absolute loss, Fig. 5a). For each island, its mean rate was greater than or equal to its median rate, thus, the distribution of each rate may be slightly positively skewed or symmetric.

During 1998–1999, the minimum, median, and mean rates were negative, one maximum rate negative, and two other maximum rates close to zero (Table 3). These rates showed that most AOIs on each island were erosive (cf. Fig. 5b). By mean rates, developed Figure Eight Island and Wrightsville Beach had a greater loss of sand per unit area than two undeveloped islands Lea and Coke and Masonboro. Topsail Island had the least mean rate. Again based on mean and median rates, the rate distributions of Topsail and Masonboro islands may be symmetric, the rate distribution of Lea and Coke Island slightly positively skewed, and the rate distributions of Figure Eight Island and Wrightsville Beach slightly negatively skewed.

Between 1999 and 2000, the maximum, median, and mean rates were positive (Table 3), which could indicate more deposition than erosion on these islands. Figure Eight Island showed the highest net gain, measured by relative large positive maximum, median, and mean rates, and the gain could be largely attributed to the intense beach nourishment project performed at the island during 1999 and 2000. Topsail's gain, measured by median and mean rates, might be in part due to significant nourishment and construction of dunes, annual inlet dredge disposal, and accretion patterns during a rehabilitation phase.

3.4. Statistic significance of net change rates among different beach management practices

Of all the AOIs of five islands, one can categorize them into AOIs of developed, nourished, and undeveloped beaches (Table 2). t-Tests on their means (Table 4) are run to test if there are significant differences between the developed and nourished beaches, developed and undeveloped beaches, and undeveloped and nourished beaches for periods 1997–1998, 1998–1999, and 1999–2000. In 1997–1998, p-values less than 5% were found (Table 5); beaches characterized as developed, undeveloped, and nourished statistically differed. During 1998–1999, p-values were greater than 28.2%; beaches regardless of what the management practices they went through were statistically the same. This was most likely a response from two hurricanes that directly impacted the study area during this

Table 4
Means of net volumetric change per unit area (m^3/m^2) of AOIs characterized by three management practices

Management practices	1997–1998	1998–1999	1999–2000
Developed	−0.2949	−0.1947	−0.0463
Undeveloped	0.1315	−0.2201	0.1237
Nourished	−0.0071	−0.1063	0.3172

The number of AOI in each management practice category is given in Table 2.

Table 5
p-Values (%) of *t*-test between developed and undeveloped categories, between developed and nourished categories, and between undeveloped and nourished categories

Management practice comparison	1997–1998	1998–1999	1999–2000
Developed vs. undeveloped	0.0	63.8	0.2
Developed vs. nourished	4.9	28.9	0.0
Undeveloped vs. nourished	4.2	28.2	0.1

period; effects caused by sequential hurricanes overwrote any human-induced beach management practices. Finally, in 1999–2000, *p*-values were near to zero; beaches differed statistically if different beach management practices have been applied. These results show potentially that the delineation of coastal segments, characterized by management practices, can be used for comparing and contrasting different morphological responses of beaches.

4. Concluding remarks

A method to visualize and analyze topography and topographic changes on five barrier islands at a portion of the North Carolina coastline was presented. Four sets of digital elevation model (DEM) data created from the light detection and ranging (LIDAR) data acquired in 1997, 1998, 1999, and 2000 were used to represent the topography of the islands at the time of data acquisition. The DEMs were geo-referenced and paired as 1997–1998, 1998–1999, and 1999–2000 to facilitate the analysis of topographic change between each time interval. Near 100 study sites or areas of interest (AOIs) were extracted from the DEMs of five islands. The spatial patterns and volumetric amounts of erosion and deposition of each AOI on a cell-by-cell basis were obtained. Since there were hurricanes that made landfall near the study area in 1998 and 1999, their impacts on the islands' morphology were also studied.

Between 1997–1998 and 1998–1999, erosion along the lower beach face caused mainly by hurricanes was observed on the majority of the five islands. From 1999 to 2000, the islands were not affected directly by any significant storms of tropical nature as in the previous two periods. Volumetric changes of sand for the 1999–2000 period resulted in more deposition than erosion or net increases to all islands, which appears to show a rehabilitation stage for the barrier islands following a series of stormy periods previously. The analysis also showed that the process of overwash has been seen as an important component that is integral in the landward migration of these transgressive barrier islands. At islands or portions of islands where overwash was permitted the areas were not as erosive as the nonnourished developed beaches.

By categorizing the AOIs of five islands into developed, nourished, and undeveloped beaches, the means of volumetric net change per unit area (m^3/m^2) of the AOIs in each category were derived. *t*-Test of the means paired among developed, nourished, and undeveloped groups showed that (1) beaches differed statistically if different management practices were applied to them, and (2) the differences were minimized or disappeared if consecutive hurricanes or storms affected the beaches between data acquisitions. The *t*-test analysis also demonstrated the usefulness of utilizing AOIs to delineate how segments of coastline were managed. A further division of nourishment practices into beach nourishment and dune nourishment is needed in the future to help distinguish the practices by the amount of sediment supplemented to the beach. Thus, the delineation of beaches into developed areas, undeveloped areas, beach nourishment, and dune nourishment will facilitate more in-depth inquiries into the study and comparison of the complex morphological changes that occur naturally or human-induced on barrier islands.

As presented by this study, it is evident that the North Carolina coastline is a very complex and dynamic system that is in desperate need of being better understood. The continual increase in development along the immediate coastal area and applying different management practices on barrier islands will greatly affect the coastline's responses and possibly the outcome of the future coastline. DEMs derived from LIDAR sensors provide an extraordinary capability for capturing the coastline's ever-changing morphology in a quick, cost-effective manner, and hold enormous possibilities to enhance the knowledge of the coastal zone. With additional studies like this, insight into the processes that shape and mold the forms of the dynamic coastal zone can be gained and more intelligent decisions will be made about the effective planning and management of the immediate coastal area.

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