THREE-DIMENSIONAL (3D) GIS-BASED TOPOGRAPHICALLY MORPHOLOGICAL ANALYSIS AND DYNAMICAL VISUALIZATION OF ASSATEAGUE ISLAND NATIONAL SEASHORE

Ming Xie[a] and Guoqing Zhou[b]

[a]Laboratory for Remote Sensing and Environmental Analysis (LARSEA), Department of Political Science & Geography, Old Dominion University, USA - mingxief@yahoo.com
[b]Old Dominion University, Kaufman Hall, Rm. 214, Norfolk, VA 23529, USA - gzhou@odu.edu

ISPRS Commission VII , WG VII/4

KEY WORDS: Three-dimensional, DEM/DTM, LIDAR, GIS, Coast, Sea, Visualization

ABSTRACT:

The dynamic and complex nature of shorelines and beach topographic morphology present numerous challenges to geospatial analysis. Displaying and visualizing changes in these environments requires integration of knowledge on spatial data characterization as well as scientific understanding of the underlying coastal processes. This paper presents a method to visualize and analyze topography and topographic changes on Assantage Island Nation Seashore (AINS), which is located along a 37-mile stretch of Assateague Island National Seashore in Eastern Shore, VA. The DEMS data sets from the NASA ATM LIDAR data acquired from 1996 through 2000 for various time intervals, e.g., year-to-year, season-to-season, date-to-date, and a four year (1996-2000), have been created. The spatial patterns and volumetric amounts of erosion and deposition of each part on a cell-by-cell basis were calculated. A 3D dynamic display system using ArcView Avenue for visualizing dynamic coastal landforms has been developed. The system was designed into five functional modules: Dynamic Display, Analysis, Chart analysis, Output, and Help. The Display module includes five types of displays: Shoreline display, Shore Topographic Profile, Shore Erosion Display, Surface TIN Display, and 3D Scene Display. Visualized data include rectified and co-registered multispectral Landsat digital image and NOAA/NASA ATM LIDAR data. The system is demonstrated using multitemporal digital satellite and LIDAR data for displaying changes on the Assateague Island National Seashore, Virginia. The analyzed results demonstrated that a further understanding to the study and comparison of the complex morphological changes that occur naturally or human-induced on barrier islands is required.

1. INTRODUCTION

Traditional surveying of beaches, using widely-spaced transects and profiles, or interpreting aerial photography for morphologic change analysis of barrier islands, is time-consuming and labor-intensive (White et al. 2003). In recent years, airborne LIDAR has been widely employed in coastal mapping for sediment transport computation, creation of nautical charts (Irish and Lillycrop 1999), monitoring beach nourishment and evolution (Irish and white, 1998), coastline erosion and coastal structures change detection, near-shore and upland topography analysis (Williams and Dodd 1997), natural morphologic changes and response to man-made alterations (Guenther 1995), and emergency response to hurricanes, and ship groundings (Parson *et al.,* 1997). Woolard et al. (2002) investigated the effect of using LIDAR data acquired in 1996 and 1997 to derive DEMs with different spatial resolutions to represent the topography of sand dunes, accurately depicting dune changes over this period with 5 by 5 meter DEMs. Meredith et al. (1999) evaluated hurricane-induced beach erosion between 1997 and 1998 along the entire North Carolina coastline (approximately 500 km) using DEMs derived from LIDAR data at a resolution of about 5 by 5 m. More recently, White et al. (2003) utilized LIDAR DEM to analyze morphologic change along the North Carolina coastline. A number of other researchers also have used LIDAR data for similar applications, such as Hofton et al. (2000) for valley analysis, Krabill et al. (2000) for Greenland ice sheet analysis, and Krabill and Wright (2000) for coastal data analysis.

This paper presents our investigation into morphological changes of Assateague Island using DEMs derived from NOAA LIDAR data sets. The DEMs were resampled to a 1.5 by 1.5 m resolution for analysis of spatial patterns of deposition and erosion, deriving volumetric net change, and means of net volume change per unit area (m^3/m^2) during periods of 1996–1997, 1997–1998, and 1998–2000. The study areas were categorized as developed, undeveloped, and nourished beaches on a yearly basis for the period of 1996 to 2000.

2. STUDY AREA

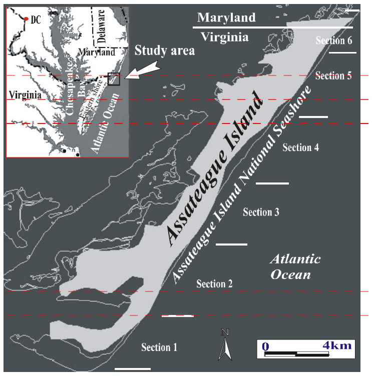

Fig. 1. Study area of Assateague Island on the Eastern Shore, Virginia.

Deleted: of

Deleted: widely

Deleted: al

Deleted: al processes

Deleted: and

Deleted: applied

Deleted: by the types of

Deleted: the

Deleted: on the

Deleted: ation of

Deleted: .

Deleted: He

Deleted: depicts

Deleted: the topographic

Deleted: of dunes

Deleted: Other

Deleted: various

Our study area (Assateague Island) is located within the Assateague Island National Seashore in Virginia (Fig. 1) between 37.883747° S to 38.020204° S latitude, and 75.389548° W to 75.220216° W longitude. The 37-mile-long Seashore lies along the central Delaware Peninsula, stretching along the Atlantic coast and subject to severe gales and waves. Assateague Island is exceptionally dynamic, experiencing average erosion rates as high as 10 feet per year in some areas (http://soundwaves.usge.gov/2002/11/research.html). Important features of Assateague are its fragile coastal elements, characterized by sand dunes, maritime forests, inlets, lagoons, back-barrier marshes and vegetation. The island is one in a chain of barrier islands along the U.S. Atlantic seaboard that are built as wave action piles up sand from the ocean floor (Allen et al. 2000), so its study is useful for us to more fully understand the dynamics of coastline change in the mid-Atlantic. Like other barrier islands, Assateague is constantly changing shape and geographical position (Dolan et al. 1997, 1992).

3. DATA ACQUISITION

We downloaded LIDAR data from the NOAA Coastal Services Center (http://www.csc.noaa.goc/crs/tcm/index.htm) for our study. The data sets acquired on October 11, 1996, September 16-18, 1997, February and December 1998, as well as September and November 2000 cover the entire study data, while the date set acquired on Oct. 11, 1996, Sept. 16-18, 1997 only covered the south end of Assateague Island, and the data acquired on April 3, 1998 only covered the eastern shoreline. Because of coastal conditions and environment as well as the LIDAR data volume, the study area has been divided into six sections.

The downloaded LIDAR data was resampled into grid DEMs using ArcView inverse distance weighting (IDW) methods with a planimetric (cell) resolution of 1.5 by 1.5 m. All the DEMs were geo-referenced to the WGS84 spheroid and North American Vertical Datum (NAVD) of 1988, respectively.

4. ANALYSIS OF TOPOGRAPHIC AND MORPHOLOGIC CHANGES

4.1 Methods

To most effectively analyze the spatial patterns of topographic and morphological change (erosion, deposition, or no change) along the coastline, we partitioned the shoreline into six sections. In each section, three study sites (also referred to as *Areas Of Interest (AOIs))* were created. Ancillary data, such as the spatial surface profiles of the DEMs, slope and relief data of the DEMs, panchromatic images, and USGS color infrared (CIR) digital orthophoto quads (DOQs), are used to assist in the identification and creation of each AOI. Heavily vegetated areas, man-made structures such as houses and piers, and wave activity were excluded because these factors would impact the reliability of the change analysis (White et al. 2003). Finally, three representative AOIs in each section were selected for topographical and morphological change analysis using the successive DEM data pairs in the periods of 1996–2000. The selected AOIs represent a particular segment of coastline, where the dune line and dry beach are obviously distinguished, and where the processes of erosion and deposition may be easily studied spatially. Each AOI was chosen so as to cover almost exactly the same location and portion of coastline for each yearly analysis. Because the data was not perfectly consistent, dune transects and profiles were created to assist in comparing the accuracy of the DEMs between each yearly survey.

The basic method for topographic change identification using DEMs is differencing the Z coordinates of the second year to the first year values on each grid cell for each DEM pair. The volume change at each cell location can then be computed. A positive, negative, or zero volumetric value (m^3) at a cell represents the amount of deposition, erosion, or no change. The morphological change of topography over the entire study area can be obtained through summing the positive and negative volumetric values (m^3) in each cell. The volumes of deposition for each Section can be calculated by summing the all positive volumetric values of cells. Similarly, the volumes of erosion for each Section can be calculated by summing the all negative values of the cells. The net change is calculated by differing the total deposition to the total erosion. Considering that each Section does not cover exactly the same size of beach area in each yearly LIDAR data, the net volumetric change per meter square (m^3/m^2) is adopted for comparing the volumetric changes at various time intervals. Using the proposed methods above, the topographic change between selected years, and the total volumetric change of the beach and sand dunes of the 6 sections are observed.

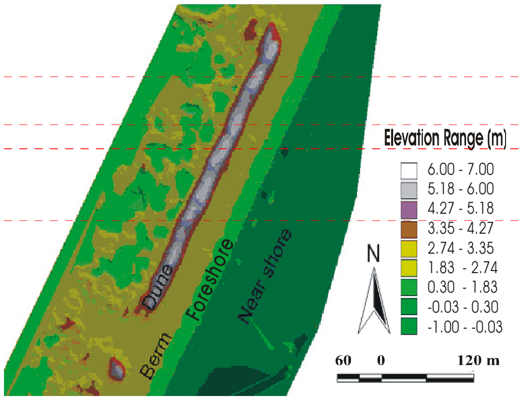

Figure 2. Section 6 segment of coastline consisting of the primary portion of the dune line and dry beach.

4.2 Spatial Pattern of Topographical Change

The topographic differences of the study area between 1996 and ~~2000 are visualized via Triangulated Irregular Network (TIN) data structure. We found that the widths of the dune,~~ berm, foreshore, and near shore for each section vary. For example, the width of dune in Section 5 is wider than one in Section 6. The berm in Section 4 narrows from north to south and finally disappearing in Section 3, as the dune transitions directly into the foreshore, forming a ridge. The ridge of Section 2 is narrower than that of the other Sections, and its height is lower ne of the other Section. The topographic ~~elevation in the southern Assateague Island (Section 1) has~~ changed greatly between 1996 and 2000. This change is irregular over the entire study area.

Analyzing the DEM data pair between 1996 and 2000, we found the shoreline topographic change varies largely from south ~~(Section 1)~~ to north ~~(Section 6) of the study area (see Fig.~~

Deleted: In particular,
Deleted: the
Deleted: 75.389548° W to 75.220216° W
Deleted: 37.883747° S to ... [1]
Deleted: Delaware
Deleted: and stretches
Deleted: year 2
Deleted: of the Delaware ... [2]
Deleted: is
Deleted: year 1
Deleted: averagely
Deleted: ,
Deleted: deeply
Deleted: In addition, Ass ... [3]
Deleted: Section
Deleted: from the last yea ... [4]
Deleted: S
Deleted: South
Deleted: the fact of
Deleted: of LIDAR
Deleted: six Sections of
Deleted: entire
Deleted: are
Deleted: are
Deleted: finally exactly
Deleted: Sections
Deleted: Section
Deleted: or called
Deleted: *areas*
Deleted: *o*
Deleted: *interest*
Deleted: S
Deleted: er
Deleted: ,
Deleted: disappears
Deleted: , resulting in
Deleted: transitioning
Deleted: in Section 3
Deleted: one
Deleted: than o
Deleted: Section
Deleted: Additionally, t
Deleted: s
Deleted: South
Deleted: North

3). A 1.5-km-long shoreline in the southern end of Assateague Island in Section 1 experienced significant deposition from 1996 through 2000 over an area that is 190 meters wide and 1.5 km long from near shore to foreshore. Meanwhile, erosion 200m width in the dune and berm area also occurred (see Fig. 3a), and more significant erosion of 100m width and 980m length in the berm and foreshore area of the northern end of Section 1 is evident (see Fig. 3a). A 1700m length of shoreline facing the Atlantic Ocean in Section 2 has experienced severe erosion of up to 40m extent in the foreshore and dune portions of the beach in the period of 4 years (from 1996-2000). A 400m length on the west side (berm areas) near the middle of Section 2 has experienced deposition over a width of up to 100m (see Fig. 3b), and from Section 3 to Section 6 the erosion appears to have slowed from 1996 to 2000. Only a small area experienced severe erosion, such as Profile 1 in Section 3 (see Fig. 3c). In Section 4, the most rapid deposition occurred in a 1200m long by 85m wide area of the foreshore (see Fig. 3d). In Section 5, erosion occurred in the near shore, foreshore, and dune areas facing the Atlantic, and deposition occurred in the berm and dune areas not facing Atlantic (see Fig. 3e). In contrast, the foreshore in Section 6 experienced deposition, while the berm and dune area experienced erosion. Additionally, a 40m wide by 415m long foreshore area experienced significant deposition (see Fig. 3f).

In order to analyze in detail the topographic changes in the study area during the four years, four seasonal (September-November) data sets were created to investigate topographic change at a seasonal interval from 1996 through 2000. Through observation of DEM seasonal changes, we also note that the coastal area was generally eroded in summer and fall, and most deposition occurred in winter. In the early spring and late fall, the coastal topographic change undulates; we think this may be caused by varying weather. We selected three profiles in each Section to demonstrate the topographic changes within the study area, and Figures 4 present the elevation curves of each profile in different years.

From Fig. 3a and Fig. 4c, we found that a length of about 1500 m in the south end of Section 1 has seen significant deposition of up to 1.37m in height over a 190m width from the near shore to the foreshore, and significant erosion up to a maximum 0.8m in the 200m-wide dune and berm area. This resulted in the formation of a flat, elevated area of 0.6-0.9m in the south end as observed in 2000. Most of the 4267m long by 100m wide berm area along the eastern shoreline of Section 1 experienced severe erosion in the berm area like that shown in profile 2 of Section 1 in the period of 1996-2000. In only two years, from 1998 to 2000, a 67m wide berm was eroded 2.4m, resulting in the coastline shifting 67m inland (see Fig. 3a and Fig. 4b). Additionally, a 700m long foreshore in Section 1 sustained deposition like that seen in profile 1 of Section 1 (see Fig. 4a), and an approximate 67m wide foreshore near shore gained 1m in height, resulting in shoreline movement outward by 67m, and an equally wide dune area that experienced erosion, resulting in the formation of a berm area.

A 1700 m shoreline in Section 2 has experienced severe erosion of 3.35m in depth for a 40 m width from foreshore to berm (see Fig. 4f). However, the berm and dune areas with a 400 m length by 100m width at the middle of Section 2 saw deposition of more than 0.3m height (see Fig. 3b). Most of foreshore and dune areas have experienced more than 2 m erosion, resulting in the coastline shifting inland approximately 18-24 m (see Fig. 4d and 4e).

Observing Sections 3 through 6, the erosion velocity obviously was less than that of Sections 1 through 2 in the study period of 1996 through 2000, but a small area in the profile of Section 3 experienced faster erosion at speed of approximate 4m per year (see Fig. 3c). Since the foreshore slope was eroded, the near shore was extended to the foreshore by 36m (see Fig. 4g). In Section 4, the most deposition occurred in a 1220m length by 85m width foreshore area (see Fig. 3d), resulting in a wrack line movement out by 27-30m (see Fig. 5b, and 5c). On the other hand, as observed from Profile 2 of Section 4, Profile 1 of Section 4, and Profile 3 of Section 5, the top of dunes increased in height some 0.7 to 1.5m (see Fig. 5b, 5a, and 5f). In Section 5 and Section 6, the areas near the shore, the foreshore, and the dune were all generally eroded, which caused the dune areas and the shoreline to retreat 6-15m (see Fig. 5d, 5e, 5g, 5h, and 5i), and the near shore extended to foreshore by 30-45m (see Fig. 5e, and 5f). Observing Section 6, the tops of the dune decreased by 0.8m in the south of Profile 3, by 1.5m in the middle of Profile 2, and by 1.8m in the north of Profile 1 (see Fig. 5g, 5h, and 5i).

Based on the DEM analysis above, we can make some overall observations: (1) Most of the dune elevations have decreased, and the dune areas have moved towards the west (retreated). This observation may be able to explain why the entire island becomes narrower and narrower from 1996 to 2000. We illustrated these changes using 18 profiles in Figure 6 through 7. (2) The near shore areas decreased about 0.3-1m in height, and migrated west into the foreshore from 1996 to 2000. (3) The berm connected with foreshore experienced serious erosion, resulting in the shoreline migration inland. Moreover, the slopes of foreshores in all six sections have grown steeper. (4) Dune changes differ in topographic profile and morphology over the course of the study. For example, the dunes from Section 1 to Section 3 decreased in volume, accreted in Section 4, and retreated west in both Section 5 and Section 6. Additionally, their rate of change was not the same. For example, the dunes from Section 1 through Section 3 rapidly decreased between 1997 and 1998 (see Fig 4c, 4d, 4e, and 4g), while the dunes from Section 5 to Section 6 rapidly retreated between 1998 and 2000 (see Fig 5d, 5e, 5f, 5g, 5h, and 5i). In contrast, the dunes in Section 4 rapidly built up between 1996 and 1997 (see Fig 5a, 5b, and 5c). An approximate 2.6km long shoreline has retreated inland from 2 - 40m through different coastal conditions and environments; an example is the foreshore in Section 2, which retreated about 40m from 1996 to 2000.

4.3 Volumetric Morphologic Changes

To quantify the 4-year topographic change of the study area, volumetric analysis (deposition, erosion, and net change) of each section was conducted. Table 1 summarizes the deposition, erosion, and net change results of the six sections for the period of 1996 through 2000.

As seen from Table 1, Section 1 had the largest amount of both deposition (14,647.9 m^3), as well as erosion (17,261.3 m^3). Section 6 showed the least amount of deposition (2,835.9 m^3). Section 4 experienced a positive net volumetric gain (1,998.6 m^3). Section 4's gain, near 1,998.6 m^3, might largely be contributed to beach nourishment during the study period. The entire study area exhibited a net volumetric loss of 26,693.5 m^3 from 1996-2000 at an average loss rate of 0.011 m^3/m^2. The total erosion was 67,389.7 m^3; Section 1 contributes 17,261.3 m^3 to this loss at an average loss rate of 0.602 m^3/m^2. The net loss of Section 1 is 2,613.4 m^3 at loss rate of 0.005 m^3/m^2. Over

Deleted: Assateagus …. The deposition…covers … an… of the…….A …has occurred…). From …,…seems …occurred severe …, but…in Section 6,…Alongshore ... [5]

Deleted: Section…slowed relative to…duration …occurred s…the …moved …profile profile …profile …from …was ed…profile …profile …pro ... [6]

Deleted: yield ….phenomenon …listed…their migrated …towards …6 Sections…steepened…deposited time…T…been eroded…to upon …, …such as… in Se ... [7]

Deleted: compared …With s…are deposited…, …diffe ... [8]

Deleted: 200m …has …election in …occurred …in …has been…moved …towards occurred …has deposited…that the moved …island …67m …f ... [9]

Deleted: S…6…S ... [10]

Deleted: of about 1700m long… a…by …has …deposited …moved towards ... [11]

Deleted: Sectoin …the es…e…is …, …in which …might the …of 17,261.3 m^3 ... [12]

the entire study area, the estimated average erosion rate is approximately 0.485 m³/m², and the average rate of deposition is 0.005 m³/m².

Volumetric change for the year of 1996–1997 showed that entire study area experienced more deposition than erosion. For example, Section 3 had the largest amount of deposition (10,929.1 m^3) while Section 6 had the largest amount of erosion (5,446.6 m^3) and exhibited the greatest net loss of 1,117.1 m^3. In contrast, volumetric changes for the year of 1997–1998 showed that entire study area experienced more erosion than deposition. For example, Section 1 had the largest amount of erosion (14,794.2 m^3), and at the same time had largest amount of deposition (16,846.3 m^3). Section 2 exhibited the largest net loss of 9,169.1 m^3, and Section 4 demonstrated the largest amount of sand exchange (between deposition and erosion) with a loss of 6,073.9 m^3 and deposition of 4,498.5 m^3. For the period of 1998–2000, volumetric analysis showed that entire study area experienced more erosion than deposition. For example, Section 1 had the largest amount of erosion (16,274.6 m^3) and at the same time had largest amount of deposition (10,729.3 m^3). The erosion and deposition in Section 1 are almost twice that of other sections, and Section 2 exhibited the largest amount of net loss (3,962.2 m^3).

Deleted: T
Deleted: increasing
Deleted: rate
Deleted: amount of
Deleted: over the entire study area
Deleted: es
Deleted: case
Deleted: of
Deleted:
Deleted: and
Deleted: of
Deleted: ,
Deleted: S

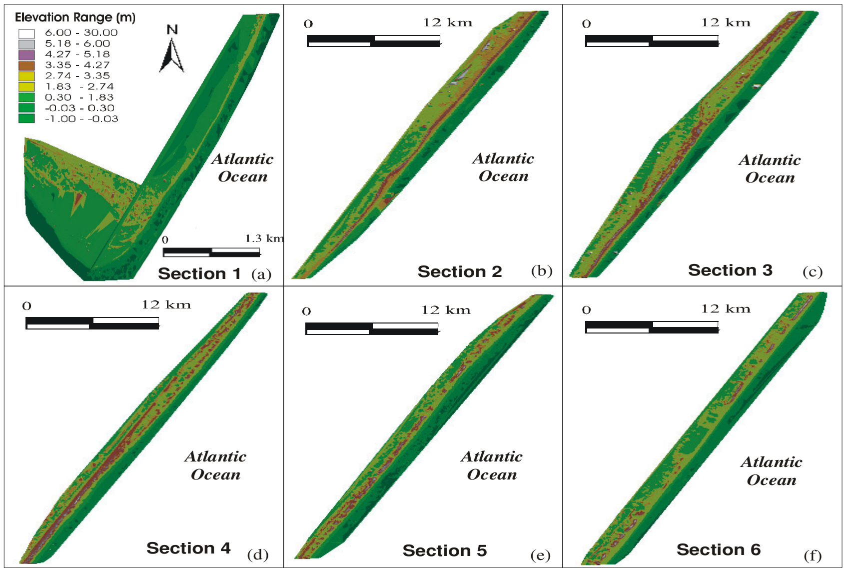

Figure 3. The dune line and dry beach of six sections in 1996

Deleted: Sections

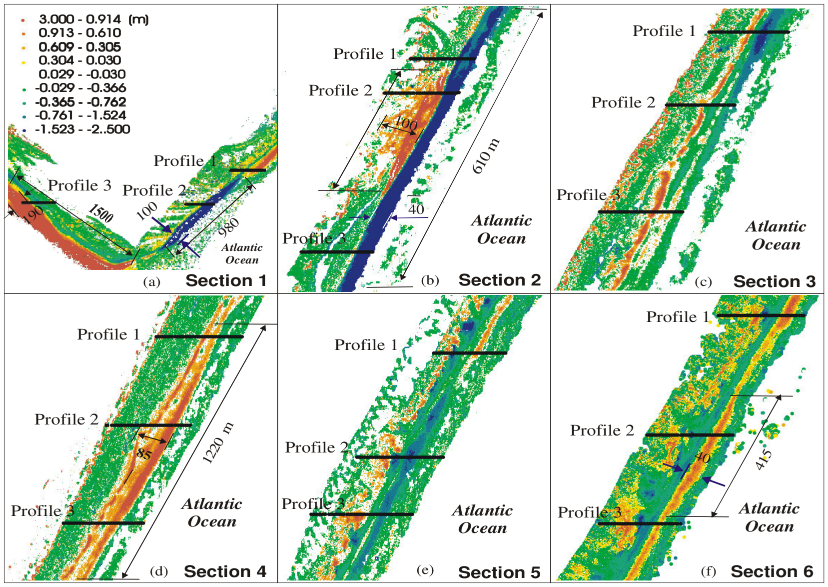

Figure 4. The quantitative representation of topographic changes in six sections from 1996 to 2000; the blue colors denotes erosion, the orange colors denotes deposition, and the white denotes no change (between –0.03 and 0.03 m.). The black lines indicate the location of a profile, which is useful for study of rapid change.

Deleted: Sections
Deleted: ,
Deleted: ;
Deleted: (
Deleted: d
Deleted: steep

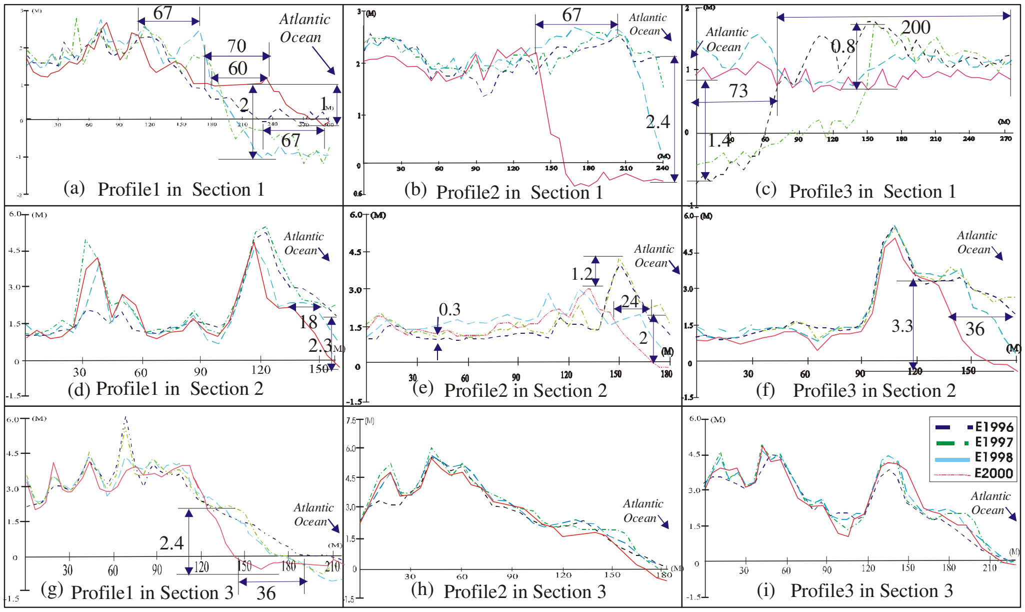

Figure 5. The profile analysis of topographic changes for Section 1-3 from October 1996 to November 2000

Table 1. Summary of volumetric change per unit area (m³/m²) for all Sections from 1996-2000.

Period	Sections	Net-Change		Deposition		Erosion	
		Sum (m³)	PUA (m³/m²)	Sum (m³)	PUA (m³/m²)	Sum (m³)	PUA (m³/m²)
1996-2000	Section 1	-2613.39	-0.005	+14647.92	+0.639	-17261.32	-0.602
	Section 2	-9501.69	-0.038	+4961.35	+0.607	-14463.03	-0.983
	Section 3	-2244.34	-0.005	+7140.12	+0.471	-9384.46	-0.394
	Section 4	+1998.63	+0.005	+7714.21	+0.420	-5715.59	-0.271
	Section 5	-4817.29	-0.014	+3396.59	+0.322	-8213.88	-0.383
	Section 6	-9515.45	-0.023	+2835.99	+0.321	-12351.44	-0.422
	Total	-26693.54	-0.011	+40696.18	+0.485	-67389.72	-0.485

5. CONCLUSION

This paper has presented a method to analyze topographic changes using DEM data sets acquired by the NASA ATM LIDAR over various time intervals, e.g., year-to-year (1996-1997, 1997-1998, 1998-2000), season-to-season (September, January), and a multi-year (1996-2000). Six sections in our study area are divided according to their historical changes, and coastal conditions. Three profiles of each section were extracted from the DEMs, and the spatial patterns and volumetric amounts of erosion and deposition of each section on a cell-by-cell basis were calculated. The means of volumetric net change per unit area (m^3/m^2) of each section were derived. With the analysis of the deposition, erosion, or no change of the study area, the spatial patterns of deposition and erosion can be traced in both detailed and broad extent over varying time periods and frequencies. The analyzed results demonstrated that the coastline change of Assateague Island is very complex and dynamic, and that further understanding and analysis of the topographic changes that occur through natural or human action is required. Active coastal management, shoreline protection, and beach nourishment programs are believed to affect Assateague Island topography significantly.

These results also demonstrated that LIDAR sensors provide an extraordinary capability for capturing data upon which high-accuracy, high-density coastal DEMs can be created and used for quantitative analysis of coastal topographic morphology. Topographic morphology analysis can provide precise and reliable information for the effective planning and management of the coastal area.

ACKNOWLEDGEMENTS

This project was supported by NASA research grant NAG-13-01009 "Virginia Access." The assistance of Changqing Song was indispensable to the research. Carl Zimmerman, Chief of Division of Resource Management at Assateague Island National Seashore, provided essential support for topographic change data interpretation, such as deposition, erosion, and net change. Andrew Meredith of the Coastal Service Center at NOAA provided us help in LIDAR data delivery and interpretation.

Deleted: the

Deleted: with high-accuracy and high-density, which is used for exactly

Deleted: S

Deleted: data in

Deleted: would be able to

Deleted: exact

Deleted: four

Deleted: Sections

Deleted: S

Deleted: .

Deleted: T

Deleted: S

Deleted: Section

Deleted: .

Deleted: A

Deleted: comparison

Deleted: ly

Deleted: -induced

Deleted: in the future. High-quality

Deleted: coastal

Deleted: its

REFERENCES

Allen, Thomas, and George Oertel, 2000. Extending change vector analysis for monitoring coastal ecosystems, Virginia Barrier Islands. *The sixth Rnternational Conference on Remote Sensing for Marine and Coastal Environments,* Charleston, South Carolina. May 1 – 4, pp. 123-128.

Carter, R. W. G., 1989. Coastal environments, an introduction to the physical, ecological, and cultural systems of coastlines. Academic Press, London.

Dolan, R., Bruce Hayden, Jeffrey Heywood, 1997. Atlas of Environmental Dynamics, *Assateague Island National Seashore, October*.

Dolan, R., and R. E. Davis, 1992. An intensity scale for Atlantic Coast Northeast storms. *Journal of Coastal Research*, vol. 8, no. 4, pp. 840– 853.

Gares, P. A., and K. F. Nordstrom, 1991. Coastal dune blowouts-dynamics and management implication, *Proceedings of the Seventh Symposium on Coastal and Ocean Management* Long Beach, CA. July 8 – 12, pp. 2851– 2862.

Guenther, G.C., 1995. Airborne Laser Hydrograph, US Department of Commerce, Washington, DC.

Hofton, M. A., J. B. Blair, J. B. Minister, J. R. Ridgway, N. P. Williams, J. L. Bufton, and D. L. Rabine, 2000. An airborne scanning laser altimetry survey of Long Valley, California. *International Journal of Remote Sensing*, vol. 21, no. 12, pp. 2413–2437.

Irish, J. L, and W. J. Lillycrop, 1999. Scanning laser mapping of he coastal zone: the SHOALS system, *ISPRS Journal of Photogrammetry & Remote Sensing*, vol. 54, no. 2, pp. 123-129.

Irish, J., and T.E. White, Coast Engineering applications of high-resolution LIDAR bathymetry, *Coastal Engineering, vol.* 35, no. 3, pp. 47-71.

Krabill, W., W. Abdalati, E. Frederick, S. Manizade, C. Martin, J. Sonntag, R. Swift, R. Thomas, W. Wright, and J. Yungel 2000. Greenland ice sheet: high-elevation balance and peripheral thinning, *Science*, vol. 289, pp. 428– 430.

Krabill, W., W. Wright, R. Swift, E. Frederick, S. Manizade, J. Yungel, C. Martin, J. Sonntag, M. Duffy, and J. Brock, 2000. Airborne laser mapping of Assateague National Seashore Beach. *Photogrammetric Engineering and Remote Sensing*, 66(1), 65–71.

Meredith, A.W., 1999. An evaluation of hurricane induced erosion along the North Carolina coast using airborne LIDAR surveys. NOAA Coastal Services Center Technical Report, NOAA/CSC/99031-PUB/001.

NOAA. 2000. The potential consequences of climate variability and change on coastal areas and marine resources. A Report of the National Coastal Assessment Group for the U.S. Global Change Research Pro-gram, October 2000. NOAA Coastal Ocean Program Decision Analysis Series No. 21, Silver Spring, MD: NOAA Coastal Ocean Program, p. 163.

Nordstrom, K. F., 1994. Beaches and dune of human-altered coast, *Progress in Physical Geography*, vol. 18, no. 4, pp. 497–516.

Parson, L.E., W. J. Lillycrop, C. J. Klein, R. C. P. Ives, and S. P. Orlando, 1997. Use of LIDAR Technology for Collecting Shallow Water Bathymetry of Florida Bay*, Journal of Coastal Research,* vol. 13, no. 4, pp. 1173-1180.

Pilkey, O.H., W.J. Neal, S.R. Riggs, C.A. Webb, D.M. Bush, D.F. Pilkey, J. Bullock, and B.A. Cowan, 1998. *The North Carolina shore and its barrier islands, restless ribbons of sand*. Durham, Duke University Press.

White, S.A., and Y. Wang, 2003. Utilizing DEMs derived from LIDAR data to analyze morphologic change in the North Carolina coastline, *Remote Sensing of Environments,* vol. 85, no. 2, pp. 39-47.

Williams, S.J., G.W. Stone, and A.E. Burruss, 1997. A Perspective on the Louisiana Wetland Loss and Coastal Erosion Problem, *Journal of Coastal Research*, vol. 12, no. 3, pp.593-594.

Williams, S. J., K. Dodd, and K. K. Gohn, 1997, Coasts in Crisis-online version, *U.S. Geological Survey Circular* 1075.

Woolard, J.W., and Colby, J.D., 2002, Spatial characterization, resolution, and volumetric change of coastal dunes using airborne LIDAR: Cape Hatteras, North Carolina. *Geomorphology,* Vol. 48, 269-287.

Page 2: [1] Deleted **Jack Granger** **12/26/2003 8:30:00 PM**

37.883747° S to 38.020204° S

Page 2: [2] Deleted **Jack Granger** **12/26/2003 11:33:00 PM**

of the Delaware Peninsula, between Chesapeake Bay and the ocean. The coast faces Atlantic ocean

Page 2: [3] Deleted **Jack Granger** **12/26/2003 11:38:00 PM**

In addition, Assateague is one of many barrier islands that rim the eastern coast of the United States.

Page 2: [4] Deleted **Jack Granger** **12/27/2003 8:17:00 PM**

from the last year to the following year

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:03:00 PM**

Assateagus

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:04:00 PM**

. The deposition

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:05:00 PM**

covers

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:06:00 PM**

an

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:06:00 PM**

of the

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:07:00 PM**

.

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:07:00 PM**

A

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:07:00 PM**

has occurred

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:14:00 PM**

).

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:15:00 PM**

From

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:15:00 PM**

,

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:15:00 PM**

seems

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:15:00 PM**

occurred

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:17:00 PM**

severe

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:18:00 PM**

, but

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:18:00 PM**

in Section 6,

Page 3: [5] Deleted **Jack Granger** **12/27/2003 11:20:00 PM**

Alongshore

Page 3: [6] Deleted **Jack Granger** **12/27/2003 11:55:00 PM**

Section

Page 3: [6] Deleted **Jack Granger** **12/27/2003 11:56:00 PM**

slowed relative to

Page 3: [6] Deleted **Jack Granger** **12/27/2003 11:57:00 PM**

duration

Page 3: [6] Deleted Jack Granger 12/27/2003 11:57:00 PM

occurred

Page 3: [6] Deleted Jack Granger 12/27/2003 11:58:00 PM

s

Page 3: [6] Deleted Jack Granger 12/28/2003 12:02:00 AM

the

Page 3: [6] Deleted Jack Granger 12/28/2003 12:02:00 AM

moved

Page 3: [6] Deleted Jack Granger 12/28/2003 12:02:00 AM

profile

Page 3: [6] Deleted Jack Granger 12/28/2003 12:02:00 AM

profile

Page 3: [6] Deleted Jack Granger 12/28/2003 12:03:00 AM

profile

Page 3: [6] Deleted Jack Granger 12/28/2003 12:03:00 AM

from

Page 3: [6] Deleted Jack Granger 12/28/2003 12:04:00 AM

was

Page 3: [6] Deleted Jack Granger 12/28/2003 12:05:00 AM

ed

Page 3: [6] Deleted Jack Granger 12/28/2003 12:06:00 AM

profile

Page 3: [6] Deleted Jack Granger 12/28/2003 12:06:00 AM

profile

Page 3: [6] Deleted Jack Granger 12/28/2003 12:07:00 AM

profile

Page 3: [7] Deleted Jack Granger 12/28/2003 12:08:00 AM

yield

Page 3: [7] Deleted Jack Granger 12/28/2003 12:08:00 AM

.

Page 3: [7] Deleted Jack Granger 12/28/2003 12:10:00 AM

phenomenon

Page 3: [7] Deleted Jack Granger 12/28/2003 12:11:00 AM

listed

Page 3: [7] Deleted Jack Granger 12/28/2003 12:11:00 AM

their

Page 3: [7] Deleted Jack Granger 12/28/2003 12:12:00 AM

migrated

Page 3: [7] Deleted Jack Granger 12/28/2003 12:13:00 AM

towards

Page 3: [7] Deleted Jack Granger 12/28/2003 10:52:00 AM

6 Sections

Page 3: [7] Deleted Jack Granger 12/28/2003 10:52:00 AM

steepened

Page 3: [7] Deleted Jack Granger 12/28/2003 10:54:00 AM

deposited

Page 3: [7] Deleted Jack Granger 12/28/2003 10:56:00 AM

time

Page 3: [7] Deleted Jack Granger 12/28/2003 10:58:00 AM

T

Page 3: [7] Deleted Jack Granger 12/28/2003 10:59:00 AM

been eroded

Page 3: [7] Deleted Jack Granger 12/28/2003 10:59:00 AM

to

Page 3: [7] Deleted Jack Granger 12/28/2003 11:00:00 AM

upon

Page 3: [7] Deleted Jack Granger 12/28/2003 11:00:00 AM

,

Page 3: [7] Deleted Jack Granger 12/28/2003 11:00:00 AM

such as

Page 3: [7] Deleted Jack Granger 12/28/2003 11:00:00 AM

in Section 2

Page 3: [8] Deleted Jack Granger 12/27/2003 11:21:00 PM

compared

Page 3: [8] Deleted Jack Granger 12/27/2003 11:21:00 PM

With

Page 3: [8] Deleted Jack Granger 12/27/2003 11:27:00 PM

s

Page 3: [8] Deleted Jack Granger 12/27/2003 11:28:00 PM

are deposited

Page 3: [8] Deleted Jack Granger 12/27/2003 11:29:00 PM

,

Page 3: [8] Deleted Jack Granger 12/27/2003 11:29:00 PM

different

Page 3: [8] Deleted Jack Granger 12/27/2003 11:30:00 PM

.

Page 3: [9] Deleted Jack Granger 12/27/2003 11:35:00 PM

200m

Page 3: [9] Deleted Jack Granger 12/27/2003 11:36:00 PM

has

Page 3: [9] Deleted Jack Granger 12/27/2003 11:35:00 PM

election

Page 3: [9] Deleted Jack Granger 12/27/2003 11:40:00 PM

in

Page 3: [9] Deleted Jack Granger 12/27/2003 11:40:00 PM

occurred

Page 3: [9] Deleted Jack Granger 12/27/2003 11:40:00 PM

in

Page 3: [9] Deleted Jack Granger 12/27/2003 11:41:00 PM

has been

Page 3: [9] Deleted Jack Granger 12/27/2003 11:41:00 PM

moved

Page 3: [9] Deleted Jack Granger 12/27/2003 11:42:00 PM

towards

Page 3: [9] Deleted Jack Granger 12/27/2003 11:42:00 PM

occurred

Page 3: [9] Deleted	**Jack Granger**	**12/27/2003 11:43:00 PM**

has deposited

Page 3: [9] Deleted	**Jack Granger**	**12/27/2003 11:47:00 PM**

that the

Page 3: [9] Deleted	**Jack Granger**	**12/27/2003 11:47:00 PM**

moved

Page 3: [9] Deleted	**Jack Granger**	**12/27/2003 11:48:00 PM**

island

Page 3: [9] Deleted	**Jack Granger**	**12/27/2003 11:48:00 PM**

67m

Page 3: [9] Deleted	**Jack Granger**	**12/27/2003 11:49:00 PM**

forming

Page 3: [10] Deleted	**Jack Granger**	**12/28/2003 11:02:00 AM**

S

Page 3: [10] Deleted	**Jack Granger**	**12/28/2003 11:02:00 AM**

6

Page 3: [10] Deleted	**Jack Granger**	**12/28/2003 11:02:00 AM**

S

Page 3: [11] Deleted	**Jack Granger**	**12/27/2003 11:50:00 PM**

of about 1700m long

Page 3: [11] Deleted	**Jack Granger**	**12/27/2003 11:50:00 PM**

a

Page 3: [11] Deleted	**Jack Granger**	**12/27/2003 11:53:00 PM**

by

Page 3: [11] Deleted	**Jack Granger**	**12/27/2003 11:54:00 PM**

has

Page 3: [11] Deleted	**Jack Granger**	**12/27/2003 11:54:00 PM**

deposited

Page 3: [11] Deleted	**Jack Granger**	**12/27/2003 11:55:00 PM**

moved towards

Page 3: [12] Deleted	**Jack Granger**	**12/28/2003 11:03:00 AM**

Sectoin

Page 3: [12] Deleted	**Jack Granger**	**12/28/2003 11:56:00 AM**

the

Page 3: [12] Deleted	**Jack Granger**	**12/28/2003 11:57:00 AM**

es

Page 3: [12] Deleted	**Jack Granger**	**12/28/2003 11:57:00 AM**

e

Page 3: [12] Deleted	**Jack Granger**	**12/28/2003 11:58:00 AM**

is

Page 3: [12] Deleted	**Jack Granger**	**12/28/2003 11:58:00 AM**

,

Page 3: [12] Deleted	**Jack Granger**	**12/28/2003 11:59:00 AM**

in which

Page 3: [12] Deleted	**Jack Granger**	**12/28/2003 11:59:00 AM**

might

Page 3: [12] Deleted	**Jack Granger**	**12/28/2003 11:59:00 AM**

the

Page 3: [12] Deleted **Jack Granger** **12/28/2003 11:59:00 AM**

of 17,261.3 m^3