Three-dimensional Morphological Change Analysis of Assateague Island National Seashore via GIS and Remotely Sensed Series Datasets

Guoqing Zhou[1], and Ming Xie[2]

[1]Lab for Earth Observation and Geospatial Data Processing
Old Dominion University, Kaufman Hall, Rm. 214, Norfolk, VA 23529
Tel: (757) 683-3619, Fax: (757) 683-5565, Email: gzhou@odu.edu

[2]Laboratory for Remote Sensing and Environment, Department of Poli. Sci. & Geography
Old Dominion University, Norfolk, VA 23529

ABSTRACT

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 light detection and ranging (LIDAR) data acquired from 1996 through 2000 for various time intervals, e.g., year-to-year (1996-1997, 1997-1998, 1998-2000), season-to-season (September, January), date-to-date (e.g., September 15 to 16), and a four year (1996-2000), have been created, These DEMs allowed for a comprehensive visual/quantitative investigation into the spatial patterns of morphologic change that occurred to the Assateague island's oceanfront beaches between 1996 and 2000. The spatial patterns and volumetric amounts of erosion and deposition of each part on a cell-by-cell basis were calculated. As presented by this study, it is evident that the Assateague Island National Seashore 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.

1. INTRODUCTION

With the continuing trend of increasing population and economic activities in coastal zones, the decision-makers for coastal management require providing a better understanding on the immediate coastal environment of barrier islands, which has been defined as the narrow zone of interaction between land and ocean (Coastal, 2000; Carter, 1989; Gares et al., 1991; Nordstrom, 1994). The islands are generally located along coastlines, where rising sea level, large sand supply, coastal plain of gentle slope, and sufficient amount of wave energy for moving the sand happen (White et al., 2003; Pilkey et al., 1998). Assateague Island is a barrier island built by sand that persistent waves have raised from the ocean's gently sloping floor (Dolan et al., 1992; Inman et al., 1989). Assateague Island is experiencing a battle with an increase in the development and natural processes that affect the morphology of the barrier islands and have exhibited a loss of shoreline with rates of 5 to 12 m per year in some particular portion (Pilkey et al., 1998).

Traditional surveying beaches using widely spaced transects and profiles, or interpreting aerial photography for morphologic change analysis of barrier islands was time-consuming and labor-intensive (White et al., 2003). In current years, airborne LIDAR has been widely applied in coastal mapping for sediment transport computation, creation of nautical charts, monitoring beach nourishment and evolution (Irish et al., 1999), coastline erosion and coastal structures change detection, near-shore and upland topography analysis (Williams, *et. al.*, 1997), natural morphologic changes, and response to man-made alterations (Guenther, 1995), emergency response to hurricanes, ship groundings for NOAA and Navy (Parson *et al.*, 1997), and coastal morphological analysis (Krabill et al., 2000; Meredith et al., 1999; White et al., 2003). This paper reports the recent progress on study of the morphological changes with DEMs derived from NOAA LIDAR data sets at 5- by 5-feet resolution to analyze spatial patterns of depositional and erosional processes, and volumetric net change of the islands during periods of 1996–1997, 1997–1998, and 1998–2000. Also, means of net volume change per unit area (feet^3/feet^2) of study areas on a yearly basis between 1996 and 2000 are derived.

2. STUDY AREA

Our study area is on Assateague Island National Seashore of Eastern Shore of Virginia (Fig. 1). The area extends from 75.389548° W to 75.220216° W latitude, and 37.883747° S to 38.020204° S longitude. A 37-mile-long Assateague Island National Seashore lies off the coast to face the fierce Atlantic. The relentless gales and waves of a northeaster pound the coast for days on end, thereby Assateague are not stationary, but dynamic. Its shoreline is continually changing with daily tidal movements (Assateague Island, 2002). Assateague is one in a chain of barrier islands along the Atlantic seaboard that are built as wave action piles up sand from the ocean floor (Tom et al., 2000) so its study is useful for us to deeply understand the coastline change along the Atlantic. Assateague is one of many barrier islands that rim the eastern coast of the United States. Like other barrier islands, Assateague is constantly changing shape and geographical position. At one time, it lays far seaward of where it is today. Sea level rise and storms will cause Assateague Island to erode until it becomes narrow enough for storms to push sand over onto the bay side (Dolan et al., 1997).

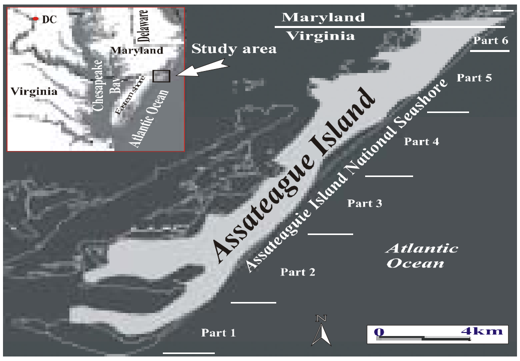


Fig. 1. Study area of Assateague Island on Eastern Shore, VA

3. DATA SETS

We have downloaded the original LIDAR data from NOAA web at http://www.csc.noaa.goc/crs/tcm/ index.htm for our study area. The data set along the shoreline of Assateague Island National Seashore covers from 1996 through 2000, but 1999. Because of the nature of coastal condition and environment in addition to the volume limit of data set during the downloading LIDAR data, six parts of the entire study area are divided (see Fig. 1). Data sets acquired in October 1996, September 1997, February and December 1998, as well as September and November 2000 cover the entire study data, while the date sets acquired in the other periods are not available. The downloaded LIDAR data are resampled into a grid DEMs using ArcView inverse distance weighting (IDW) methods with a planimetric resolution (cell) of 5 by 5 feet and a vertical resolution of 0.001 feet. Finally, all the DEMs were geo-referenced to same coordinates system, in which the World Geodetic System (WGS) 84 and North American Vertical Datum (NAVD) 88 are taken as spheroid and vertical datum, respectively.

4. ANALYSIS OF TOPOGRAPHICALLY MORPHOLOGICAL CHANGES

4.1 Analysis Methods

The analysis method is very similar to one described by White et al. (2003). With the DEM data pairs in various time intervals, the difference of the vertical values between year 1 and year 2 on a cell-by-cell basis for each time pair is computed for the volume change at each cell location. A positive, negative, or zero volumetric value (feet^3) at a cell represents the amount of deposition, erosion, or no change, respectively. 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 part are come out. Also, a net change is defined as the difference between total deposition and total erosion. Because each AOI area does not cover exactly the same size, the net volumetric change, which is divided by the part's area, i.e., feet^3/feet^2, is used for comparing the volumetric changes of each AOI in different time interval.

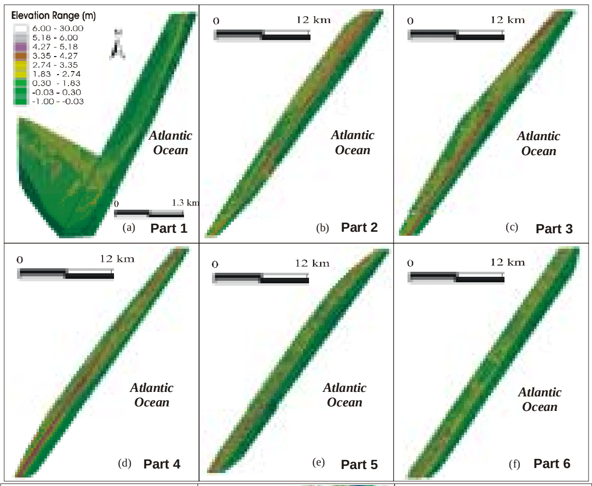
To exactly analyze the spatial patterns of topographically morphological change (erosion, deposition, or no change), three study sites (or called *areas of interest (AOIs)* at each part are created. Each AOI consists of a segment of coastline, where the dune line and dry beach are obviously distinguished and the processes of erosion and deposition can be easily studied spatially (see Fig. 2). Those segments of coastline with heavily vegetated areas, man-made building, such as houses, or piers, and wave activity that may add significant error into the analysis were excluded. Some ancillary data, such as panchromatic aerial images, Landsat-7 ETM image, digital orthophoto quads, map, and USGS DLG data are used to assist the identification and creation of each AOI. Finally, three representative AOIs in each part are selected for volumetric analyses in the periods of 1996–1997, 1997–1998, and 1998–2000, respectively.

4.2 Spatial Pattern of Topographically Morphologic Change

The difference of DEMs between 1996 and 2000 covering 6 parts are visualized via TIN data structure. The basic patterns in AINS, we found, are that the widths of the dune, berm, foreshore, and near shore of each Part in the entire study area are different. The dune's width in Part 5 is bigger than one in Part 6. The berm's width in Part 4 became narrower and narrower from north to the south, finally, disappeared in Part 3. This nature made the dune connect with foreshore to form a dam in Part 3. The dam became narrower and lower in Part 2 (see Fig. 2). The topographic elevation in the south AINS (Part 1) has greatly changed from 1996 to 2000. Moreover, the change is irregular over entire area.

Analyzing the DEM data pair of 1996 and 2000, we found the shoreline topographically morphological change is largely various from South end of AINS (Part 1) to North of AINS (part 6) (see Fig. 5). A 5000 feet-long shoreline in the south end of AINS in Part 1 has a significant deposition with 630 feet wide from near shore to foreshore from 1996 through 2000, and a dune and berm erosion with 680 feet wide (see Fig. 3a). Besides, a significant erosion with 325 feet by 3230 feet has been occurred in the berm and foreshore area of the top of Part 1 facing Atlantic Ocean (see Fig. 3a). The coastline of about 5600 feet long facing Atlantic Ocean in Part 2 has experienced a severe erosion with a 130 feet extent from foreshore and dune during the past 4 years (from 1996-2000), but the west side at the middle of Part 2, the berm area with about 1345 feet by 335 feet had deposition (see Fig. 3b). From Part 3 to Part 6, the erosion obviously slowed from 1996 to 2000. Only small area occurred severe erosion, such as Profile 1 in Part 3 (see Fig. 3c). In Part 4, the most severe deposition occurred in a region of 4000 feet long and 280 feet wide foreshore (see Fig. 3d). In Part 5, the erosion occurred in near shore, foreshore and the dune area facing Atlantic Ocean, and the deposition occurred in the berm and dune area backing Atlantic Ocean (see Fig. 3e). In Part 6, the difference with the Part 5 was that the foreshore experienced the deposition when the berm and dune area experienced erosion. Along shoreline, a 128 feet wide and 1360 feet long foreshore had experienced severe deposition (see Fig. 5f).

In order to detailedly analyze the topographic changes of study area during the four years, four closely seasonal (between September and November) data sets from the time intervals of 1996-2000 were selected to investigate a topographically morphologic change at seasonal interval. With observation of DEMs seasonal changes, we also note that the coastal area was eroded in summer and fall, and are deposited in winter. In the early spring and late fall, the coastal topographic change undulates, we think this may be caused by different weather. We also selected three profiles in each part to demonstrate the topographic changes of study area with four years seasonal data. Figure 4 presented the elevation curves of each profile in different years.



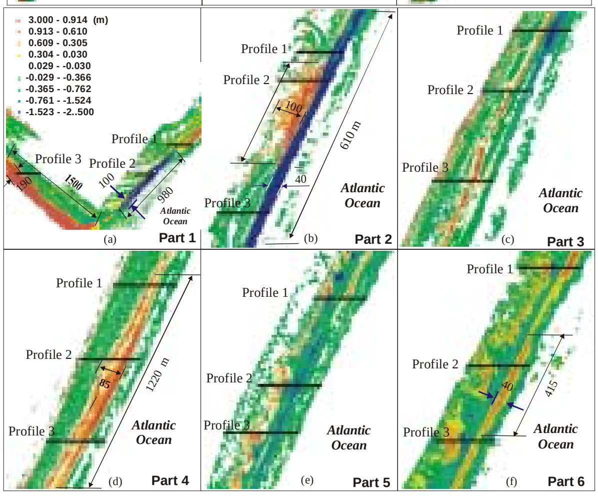
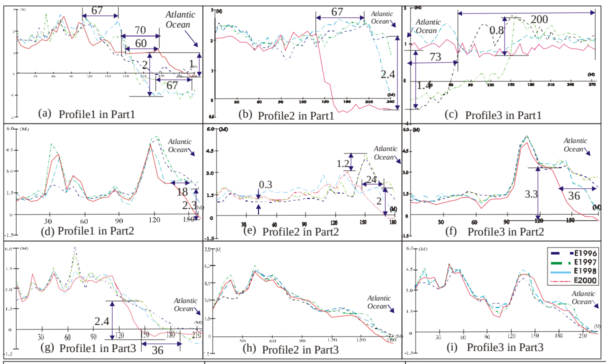


Fig. 2. The dune line and dry beach of six parts in 1999 Fig. 3.



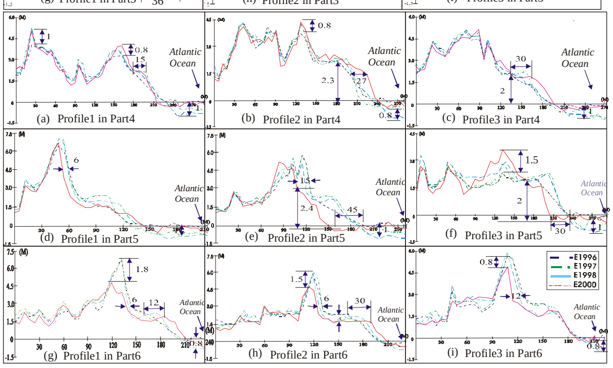


Fig. 4. The profile analysis of topographic Fig. 5.

The quantitative representation of topographic changes of six parts from 1996 to 2000

The profile analysis of topographic changes from 1996 to 2000 for Part 1-3 changes from 1996 to 2000 for Part 4-6

From Fig. 3a and 4c, we found an about 5000 feet-long shoreline in the south end of AINS in Part 1 had significant deposition of 4.5 feet height with a 630 feet wide from near shore to foreshore, and significant erosion of maximum 2.7 feet in the 680 feet wide dune and berm area, resulting in the area of south end formed a flat ground of elevation 2-3 feet in 2000. In addition, an 14000 feet long eastern shoreline in Part 1 has had severe erosion in berm area like Profile 2 in Part 1, and a 320 feet wide berm area has severely eroded during four years. Observing the time interval of two years (from 1998 to 2000), the berm with 220 feet wide has been eroded 8 feet, and the coastline moved towards inland island 220 feet (see Fig 3a and Fig. 4b). Only the foreshore with 2300 feet long in Part1 occurred deposition, as illustrated in the profile 1 of Part 1 in Fig. 4a). About the foreshore and near shore with 220 feet wide had deposited 3.5 feet, and the shoreline moved toward Atlantic 220 feet, and the dune with about 220 feet wide has been eroded to form the berm area. The coastline of about 5600 feet long facing Atlantic Ocean in Part 2 has experienced a severe erosion of 11 feet depth with a 130 feet wide from foreshore to berm (see Fig. 3f). However, the berm and dune areas at middle of Part 2, covering about 1345 feet long has deposited more than 1 feet height and 335 feet width (see Fig. 5b). Most foreshore, dune area has been eroded more than 7 feet (see Fig. 4d and 4e), so the coastline move towards inland about 60-80 feet. Observing Part 3 through Part 6, the erosion obviously become slow from 1996 to 2000, except that a few area occurred severe erosion, such as Profile 1 in Part 3 (see Fig. 3c). The foreshore slope has been eroded, so the near shore extended the foreshore 120 feet in Fig. 4g. In Part 4, the most severe deposition occurred in foreshore area of 4000 feet long by 280 feet wide (see Fig. 5d), so the shoreline has moved toward Atlantic Ocean 90 to 100 feet (see Fig. 7b, 7c, 7f). The top of dune has increased 2.5 feet to 4.9 feet from south to north. As illustrated in Profile 2 of Part 4, Profile 1 of Part 4, and Profile 3 of Part 5 (see Fig. 5b, 5a, and 5f). In Part 5 and Part 6, the near shore, foreshore, and dune facing Atlantic Ocean area have generally been eroded, resulting in the dune and shoreline moved toward inland 20 to 50 feet (see Fig. 5d, 5e, 5g, 5h, 5i), and the near shore extended to foreshore 100 to 150 feet (see Fig. 5c and 5f). The tops of dunes in Part 6 have been eroded seriously from south to north. For example, the tops of dune have decreased 2.5 feet at the south of Profile 3, 5 feet in the middle of Profile 2, and 6 feet in north of Profile 1 (see Fig. 5g, 5h, and 5i).

Moreover, from analyses to all topographic changes, we have observed that these changes have some common features: (1) Elevations of the most dunes have decreased and the dunes moved toward west due to erosion. This nature may explain why the entire island becomes narrower and narrower since 1996 to 2000. We measured the width from DEMs, and list their changes in 6 profiles (see Fig. 4 and 5). (2) The berm areas have expanded in width in Part 1 and 2 along coastline (see Fig. 4c, 4e). The natures may be caused by the elevation of dunes rapidly decreasing, i.e., dune erosion. (3) The near shore areas are generally decreasing about 1 to 3 feet, and spread to foreshore from 1996 to 2000. (4) The berm connected with foreshore has severely been eroded, resulting in the shoreline move toward inland. Moreover, the slopes of the foreshores in all 6 Parts have become steeper and steeper. We think that the phenomena may be caused by both the spreading of the near shores and the decreasing of the dunes. Their changes seem to be different when analyzing different topographies aspect and landscape. For example, the elevations of dunes are rapidly decreased between 1996 and 2000 (see Fig. 3b, 3c, 3f, 3g, and 3h), but almost no changes in other years in 1996 - 2000 (see Fig. 3h, 4a, 4c, 4d, 4h, and 4i). However, the elevations of dunes rapidly decreased between 1996 and 2000 in Part 1, Part 5, and Part 6 (see Fig. 3 and 4). The foreshore area in Part 2 has been eroded seriously. We also have noted that an about 8,500 feet long shoreline has been eroded from several feet to 130 feet upon different coastal conditions and environments, for example, the foreshore backed to berm about 130 feet from 1996 to 2000 in Part 2.

4.3 Volumetric Morphologic Changes

To quantify a 4-year topographically morphologic change, volumetric analysis (deposition, erosion, and net change) of each Part had been performed using the DEMs. Table 1 lists the statistic summary of the deposition, erosion, and net change for 6 parts from 1996-2000. The largest amount of deposition with 26,709,192.4 feet^3 and the largest amount of erosion with 44,582,057.0 feet^3 have happen for Part 1 in the period of 1996-2000. The least amount of deposition with 2,532,129.3 feet^3, at same time, the least amount of erosion with 11,028,070.3 feet^3 occurred in Part 6 from 1996-2000. Part 4 has experienced positive net volumetric gains of 1,784,486.9 feet^3. The over 39,122,993.8 feet^3 volume was negative in entire study area. Part 4's gain, near 1,784,486.9 feet^3, might largely be contributed to the beach nourishment project. The entire study area, but Part 4 nonnourished, is exhibited net volumetric losses. As seen from Table 1, the net volumetric losing of land in study area is 39,122,993.8 feet^3 from 1996-2000 at an average losing rate of 4.293 feet^3/feet^2. The total erosion is 128,789,365.8 feet^3. In the total erosion, Part 1 had contributed to the losing of 17,872,864.6 feet^3 with an average losing rate of 1.594 feet^3/feet^2. In fact, the real losing of Part 1 is 44,582,057.0 feet^3 with a losing rate of 6.096 feet^3/feet^2 from 1996-2000. All Parts, but Part 4, have severely been eroded because of storm, hurricane, and wave. The average erosion rate is estimated at 24.479 feet^3/feet^2. Some measurement has been taken or nourishment has been made to protect the erosion in Parts 4, resulting in the net increasing at 1784486.9 feet^3 at the increasing rate of 0.166 feet^3/feet^2.

From Table 2, Part 3 had the largest amount of deposition, and Part 6 had the largest amount of erosion of 4863036 feet^3 and exhibited the greatest net loss of over 997441 feet^3. Part 5 demonstrated the highest amount of sand exchange (between deposition and erosion), most likely contributed to the island's area, disposal of sediment, dune nourishment projects between 1996 and 2000. The volumetric changes for the yearly interval of 1996–1997 demonstrated that the entire study area had experienced more deposition than erosion or net losses.

Table 1. Statistic summary of volumetric change per unit area (Feet³/Feet²) for all parts from 1996-2000

Period	Parts	Net-Change		Deposition		Erosion	
		Sum (Ft³/)	Mean (Ft³/Ft²)	Sum (Ft³/)	Mean (Ft³/Ft²)	Sum (Ft³/)	Mean (Ft³/Ft²)
1996-2000	Part 1	-17872864.6	-1.594	+26709192.4	+4.502	-44582057.0	-6.096
	Part 2	-8483649.7	-1.362	+12839602.9	+4.54	-21323252.5	-5.902
	Part 3	-1753872.9	-0.189	+16866311.7	+3.24	-18620184.6	-3.429
	Part 4	+1784486.9	+0.166	+17254297.3	+3.283	-15469810.3	-3.117
	Part 5	-4301152.2	-0.494	+13464838.7	+3.569	-17765991.0	-4.063
	Part 6	-8495941.2	-0.820	+2532129.3	+1.052	-11028070.3	-1.872
	Total	-39122993.8	-4.293	-89666372.4	+20.186	-128789365.8	-24.479

Table 2. Statistic summary of net volumetric change per unit area (Feet³/Feet²) for all AOIs of each part

Period	Parts	Net-Change		Deposition		Erosion	
		Sum (Ft³)	Mean (Ft³/Ft²)	Sum (Ft³)	Mean (Ft³/Ft²)	Sum (Ft³)	Mean (Ft³/t²)
1996 – 1997	Part 1	-9782759.1	-0.642	+6094014.3	+1.113	-15876773.4	-1.755
	Part 2	+3240790.5	+0.520	+6066121.5	+1.449	-2825330.9	-0.929
	Part 3	+6962721.1	+0.656	+9758081.8	+1.303	-2795360.7	-0.647
	Part 4	+3324392.8	+0.310	+7270391.3	+1.112	-3945998.5	-0.802
	Part 5	-168237.7	-0.019	+4438789.5	+0.989	-4607027.2	-1.008
	Part 6	-997441.4	-0.096	+3865595.3	+0.821	-4863036.7	-0.917
	Total	+2579466.2	+0.729	+37492993.7	+6.787	-34913527.4	-6.058
1997 – 1998	Part 1	-1673936.8	-0.110	+11930185.2	+1.477	-13604121.2	-1.587
	Part 2	-8186726.8	-1.315	+3187506.5	+1.564	-11374233.3	-2.879
	Part 3	-5893782.3	-0.555	+2063582.7	+0.621	-7957365.1	-1.176
	Part 4	-1406565.2	-0.131	+4016520.1	+0.812	-5423085.3	-0.943
	Part 5	-2208749.6	-0.254	+3622888.5	+0.994	-5831638.1	-1.248
	Part 6	-3396278.3	-0.328	+3262737.2	+0.760	-6659015.5	-1.088
	Total	-22766038.4	-2.693	+28083420.2	+6.228	-50849458.5	-8.921
1998 – 2000	Part 1	-6416169.5	-0.422	+8684992.9	+1.912	-15101162.4	-2.334
	Part 2	-3537713.4	-0.568	+3585974.9	+1.527	-7123688.3	-2.095
	Part 3	-2822811.7	-0.289	+5044647.2	+1.316	-7867458.8	-1.605
	Part 4	-133340.6	-0.012	+5967385.9	+1.359	-6100726.5	-1.371
	Part 5	-1924164.9	-0.221	+5403160.7	+1.586	-7327325.6	-1.807
	Part 6	-4102221.3	-0.396	+4239053.6	+1.215	-8341275.0	-1.611
	Total	-18936421.5	-1.908	32925215.2	+8.915	-51861636.6	-10.823

From Table 2, Part 1 had the largest amount of erosion, at the same time had largest amount of deposition (11930185 feet^3). Part 2 exhibited the largest amount of net loses with 8186726.8 feet^3, and Part 4 demonstrated the highest amount of sand exchange (between deposition and erosion) with losing 5423085.3 feet^3 and depositing 4016520.1 feet^3. The volumetric changes for the yearly interval of 1997–1998 showed that entire study area had experienced more erosion than deposition or net losses (Table. 2). By observing a two-year interval of 1998-2000 in Table 2, Part 1 had the largest amount of erosion (15101162.4 feet^3), at the same time had largest amount of deposition (8684992.9 feet^3). Part 2 exhibited the largest amount of net loses with 133340.6 feet^3. Thus, the volumetric changes of the two-year interval of 1998–2000 showed that entire study area had experienced more erosion than deposition or net losses. As observed from Table 2, the volumetric amount of loses was increasing year by year (from 1996-2000) from 34913527.4 feet^3 to 51861636.6 feet^3, and the volumetric amount of deposition was varying from time to time since 1996. The net loses from 1996 to 1998 was dramatically increasing from 2,579,466.2 feet^3 to 22766038.4 feet^3, but decreasing from 22766038.4 feet^3 to 18936421.5 feet^3. This fact demonstrated that a dune nourishment program was probably deployed in 1999, resulting in the depositional rates for this yearly interval was somewhat less erosive than one for other yearly interval. Part 5 showed that more deposition than erosion or net increases from 1998 to 2000. The results appeared to show a series of stormy periods had happened in the barrier islands.

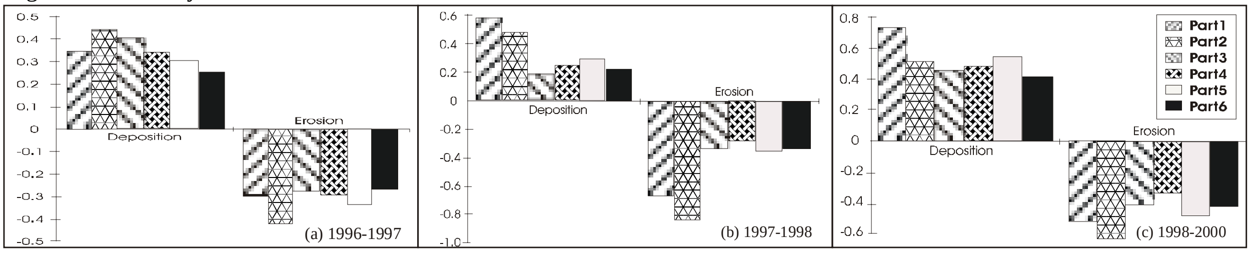


Fig. 6. The average volumetric change per unit area in 1996-1997, 1997-1998, and 1998-2000

4.4 Volumetric Net Change Per Unit Area

Table 2 also gave summaries of volumetric net changes per unit area. These statistics were calculated from each Part at time intervals of 1996–1997, 1997–1998, and 1998–2000. In the period of 1996–1997, the rates in Part 1, 5 and 6 were negative, but positive Part 2, 3, and 4. The largest and smallest ranges of the rates were 0.656 Ft^3/Ft^2 occurred at Part 3, and -0.642 Ft^3/Ft^2 at Part 1, respectively. The largest mean erosion rate is 1.008 Ft^3/Ft^2 occurred in Part 5, and the largest mean deposition rate is 1.449 Ft^3/Ft^2 occurred in Part 2. During 1997 through 1998, the largest erosion rate is 2.87 Ft^3/Ft^2 occurred in Part 2 and largest deposition rate is 1.564 Ft^3/Ft^2 also occurred in Part 2. All net change rates in 6 Parts are negative ranging from 0.131 to 1.315 Ft^3/Ft^2. Similarly, the erosion and deposition rates in the time interval of 1998-2000 is like the cases of the time interval of 1997-1998. These rates showed that almost all coast area were erosive. Part 2 and Part 3 had a greater loss of sand per unit area than other coastal area, e.g., Part 4 and 5, which had the least mean rates. We conjecture that so low mean rates might be in part due to significant nourishment and construction of dunes, and annual inlet dredge disposal (Fig. 6).

5. CONCLUSION

This paper has presented a method to analyze topography and topographic changes on Assantage Island Nation Seashore within Virginia coastline. The DEMS data sets from the NASA ATM LIDAR data acquired from 1996 through 2000 for various time intervals, e.g., year-to-year (1996-1997, 1997-1998, 1998-2000), season-to-season (September, January), date-to-date (e.g., September 15 to16), and a four year (1996-2000), have been created. The DEMs data pairs have been used for the analysis of topographic change between each time interval. 6 Parts in our study area are divided according to their historical changes, and coastal conditions. 3 profiles of each part were extracted from the DEMs. The spatial patterns and volumetric amounts of erosion and deposition of each part on a cell-by-cell basis were calculated. The means of volumetric net change per unit area (feet^3/feet^2) of the AOIs in each category were derived. The analyzed results demonstrated that the Assateague Island National Seashore coastline is a very complex and dynamic system. A further understanding to the study and comparison of the complex morphological changes that occur naturally or human-induced on barrier islands is required. High-quality management, coastal protection, and nourishement are believed to affect its topography significantly. The investigation results also deomstrated that LIDAR sensors provide an extraordinary capability for capturing the high-accuracy and high-density coastal DEM, which is used for exactly quantitative analysis of coastal topographic morphology. Topographic morphology analysis would be able to provide exact and reliable information for the effective planning and management of the immediate coastal area.

ACKNOWLEDGEMENTS

This project was supported by NASA research grant NAG-13-01009, Virginia Access. Carl Zimmerman, Chief of Division of resource management at Assateague Island National Seashore and Andrew Meredith of the Coastal Service Center at NOAA are acknowledged.

REFERENCES

Allen, T.R. and G.F. Oertel, 2000. Application of Change Vector Analysis to Ecosystem Monitoring, Virginia Barrier Islands, U.S.A. *Proceedings of the Sixth International Conference on Remote Sensing for Marine and Coastal Environments*, 2: pp. 234-242.

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

Coastal (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 (p. 163). Silver Spring, MD.

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

Dolan, R., and Davis, R. E. (1992). An intensity scale for Atlantic Coast Northeast storms. *Journal of Coastal Research*, 8(4), 840– 853.

Gares, P. A., et al., (1991). Coastal dune blowouts-dynamics and management implication. Proceedings of the Seventh Symposium on Coastal and Ocean Management, pp. 2851– 2862. Held at Long Beach, CA. July 8 – 12, 1991. Published by American Society of Civil Engineers.

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

Hofton, M. A., et al., (2000). An airborne scanning laser altimetry survey of Long Valley, California. *International Journal of Remote Sensing*, 21(12), 2413–2437.

Huising, E.J., et al., (1998). Errors and accuracy estimates of laser data acquired by various laser scanning systems for topographic applications. *ISPRS Journal of Photog. and Remote Sensing*, 53, 245–261.

Inman, D. L., & Dolan, R. (1989). The outer banks of North Carolina: budget of sediment and inlet dynamics along a migrating barrier island system. *Journal of Coastal Research*, 5, 193–237.

Irish, J. L,; W. J. Lillycrop, 1999. Scanning laser mapping of he coastal zone: the SHOALS system, *ISPRS Journal of Photogrammetry & Remote Sensing*, 54(1999), 123-129.

Krabill, W., Wright, et al., (2000). Airborne laser mapping of Assateague National Seashore Beach. *Photogrammetric Engineering and Remote Sensing*, 66(1), 65–71.

Meredith, A. W., et al. (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.

Nordstrom, K. F. (1994). Beaches and dune of human-altered coast. *Progress in Physical Geography*, 18(4), 497– 516.

Parson, L.E., W. J. Lillycrop, et al., 1997. Use of LiDAR Technology for Collecting Shallow Water Bathymetry of Florida Bay, *Journal of Coastal Research*, Vol. 13, No. 4, 1173-1180,

Pilkey, O. H., (1998). *The North Carolina shore and its barrier islands, restless ribbons of sand*. Durham: Duke Univ. Press.

Wright, C. W., Swift, R. N., & Manizade, S. (1997). High resolution air-borne topographic mapping LIDAR description and preliminary results. NASA Report. Wallops Island, VA: NASA (4 pp.).

White, S.A., Y. Wang, 2003. Utilizing DEMs derived from LIDAR data to analyze morphologic change in the North Carolina coastline, *Remote Sensing of Environments*, vol. 85, pp. 39-47.