Abstract

SHROYER, WILLIAM JAMES. Resolution Assessment and Spatial Characterization of Airborne LIDAR Data: Assateague Island National Seashore. (Under the direction of Dr. Hugh A. Devine.)

The purpose of this research was to determine the effect of spatial data resolution change on the representation of barrier island topographic surfaces. A study area of approximately three kilometers of the northern section of the Maryland portion of Assateague Island National Seashore (ASIS) was chosen.

Utilizing the Level 4 LIDAR data, provided by the United States Geological Survey in GeoTiff format, the data was converted into raster elevation Grids at four resolutions (0.5 m, 1 m, 2 m, and 10 m). Using the 1999 and 2001 LIDAR surveys the grids were processed as Digital Elevation Models (DEM’s) at the varying resolutions and compared.

An interpretation of volumetric change was established to determine the effect of resolution on representing change in topography. Subtraction of the elevation grids for 1999 and 2001 was used to estimate the volumetric change. Slope and hillshade surfaces were also used as a means to determine the variations in spatial distribution that occur when changing resolution.

Although the amount of change in volume varied between resolutions the spatial distribution of change in each surface was consistent between resolutions. Using an analysis of variance (ANOVA) of mean elevation change, revealed no significant difference with resolution.

There was also very little slope change observed when comparing each resolution. Subtracting the slope surfaces and reclassifying the values into slope increase, slope
decrease and no change provided insight into the spatial distribution of slope change. Throughout the varying resolutions the position in which these slope classifications were represented was consistent.

The visual comparison of hillshade surfaces and topographic profiles represented the generalization that takes place when resampling to coarser resolutions. As the cell size increased with each resolution, the profile of the topography represented less relief. This was also illustrated in the hillshade surfaces of each resolution as the topographic features became more apparent from the 0.5 m to the 10 m sizes.

Constantly interrupted by coastal processes, the barrier island system exists in a continued flux of change. This constant change presents coastal scientists with a difficult challenge in measuring and monitoring the barrier island topography. Dependant upon application, the use of precision LIDAR surveys allows for an assessment of the continuing process of barrier island evolution.
RESOLUTION ASSESSMENT AND SPATIAL CHARACTERIZATION OF AIRBORNE LIDAR DATA: ASSATEAGUE ISLAND NATIONAL SEASHORE

by

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NATURAL RESOURCES, SPATIAL INFORMATION SYSTEMS TECHNICAL OPTION

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INTRODUCTION

1.1 Natural Processes of Coastal Barrier Islands

The barrier islands of the Atlantic coast are subject to constant physical change through natural processes. These processes affect the topography of the barrier islands in terms of form and structure. Through time, fluctuations in wind and water shape and reshape the topographic landscape. Barrier island topography indicates the influence of storm surge, overwash and sand accretion (Leatherman, 1988).

Topography is the representation of surface features on a landform. The features that are included in the topography of the coastal environment are the beach, dunes, overwash zones, etc. representing the relief of the landscape. Weather conditions continually alter the topography through a sequence of erosion and renewal. Related to the coastal environment these processes include other systems, such as wind and wave action, which creates the coastal process.

The coastal process is a routine of systems influenced by several factors (Rogers and Nash, 2003). Storm surge inundation, sand supply, and aeolian transport of sand move large amounts of sediment modifying the topography (Goldsmith V, 1978). Aeolian transport refers to the movement of sand by wind. As wave energy deposits sand on the beach the grains are transported by wind to the dune areas. Loose airborne sediment collects against larger structures, such as dunes. As the airborne sediment is transported sand-trapping grasses stabilize the sediment increasing the size of the dune (Rogers and Nash, 2003).

Diurnal tide activity as well as the large seas of storm events, such as hurricanes and nor’easters, disrupt the sand and vegetation, and continue the alteration of the
Areas of low lying island topography (usually 1.5 m above mean sea level or less), are more susceptible to wave run-up than barrier islands with larger topographic features such as dunes (Sallenger, 2000). As wave height and water level increase, contact with the dune system weakens the stability. This can create dune breaches and overwash the protective structures. The barrier island shape, in terms of topography, plays a crucial role in providing protection for coastal development from severe storms (Rogers and Nash, 2003).

Human impact can also be a factor in the modification of the barrier island topography. Whether intentional or accidental the landscape can be artificially transformed. In the case of the North Carolina Outer Banks the introduction of a large dune ridge by the Civilian Conservation Corps in the 1930s made an attempt to stabilize the islands (State of the Coast Report, 2000). This stabilization made development appear safe on the islands. Traditionally an overwash dominated environment, the introduction of these dunes transformed the system to contain more aeolian transport of sand.

Such modifications to the barrier islands prevent the coastal process from establishing equilibrium. Equilibrium is the condition in which the coastal process maintains a stable or balanced system. Although barrier islands are in a constant state of change, these natural fluctuations maintain equilibrium. Stabilization, impervious surfaces, and development prohibit natural topographic fluctuation and equilibrium is temporarily lost. As chronic erosion breaks down existing dunes, overwash from periodic storms push large amounts of sand past the protective dunes and damage...
developed areas (Rogers and Nash, 2003). Sand and water breaching the dune can create disastrous results to property and personal well-being.

Restoration initiatives have been undertaken in several instances to replenish eroding beaches and stabilize developed shorelines. Restoration of the coastal area attempts to bring the shoreline back to a natural equilibrium therefore decreasing the amount of erosion to the beach and the dune (Rogers and Nash, 2003). By supplying sand artificially the beach is widened allowing the wave energy to reshape the beachface, thus reducing the impacting wave energy on the dune system. The additional restoration of dune stabilizing grasses promotes dune growth and reduces aeolian loss. Seasonal fluctuations however, will continue the coastal process of attrition and accretion.

The rapid change in barrier island topography presents coastal scientists with a difficult challenge. Observation and research provides a greater understanding of the coastal process and how the barrier island topography maintains equilibrium. The dynamic changes that occur within the coastal environment create difficulties in measuring the existing topography and monitoring the natural system. Many methods of surveying have been undertaken to provide a better understanding of these systems.

1.2 Survey Methods

Coastline features and the natural processes acting upon them occur over a variety of scales (Bird, 2000), therefore, collection and measurement of precise topographic data are also a matter of scale. Whether to focus on the micro (meter to tens of meters), meso (tens of meters to hundreds of meters) or macro (hundreds of meters to
thousands of meters) scales is dependent upon the nature of the study (Andrews et al. 2002).

As a means to measure the macro topography, ground surveying can only make assumptions about the meso and micro topography. Traditionally, ground surveys of widely spaced transects represented the only means of obtaining topographic measurements over portions of the shoreline (Woolard and Colby, 2002). Due to the spacing in transect data collection methods, however, detail in the variability of the coastal topography may not be represented (Andrews et al. 2002). Ground surveying requires that measurements at certain points be taken manually. Since the entire landscape is not measured, estimates are made to fill in the remaining positions between the points. Thus, additional surveying techniques are required to measure the meso and micro topography.

Remotely sensed imagery, from aerial photography or satellite, can provide detailed topographic information at the macro to meso scale. Traditionally used as a means to detect shoreline change, remotely sensed imagery is subjected to coarser resolutions in which detail in the vertical assessment may be lost. Mazak (1995) used a Geographic Information System (GIS) to obtain shoreline rates-of-change of Assateague Island National Seashore by comparing historic shoreline data that had been collected using aerial photographic interpretation (Mazak, 1995). As a means to map the horizontal position of the shoreline, aerial imagery can be used to determine the coincident line where the wave action meets the beach. This is traditionally determined as the wet-dry line. Coarse resolution of the imagery however can degrade the determination of this boundary. Aerial photography used to collect vertical and
horizontal data in coastal morphology can become laborious and create inaccuracies (White and Wang, 2003).

Although aerial photographic mapping can measure the entire terrain, the images only reflect the topography at one instance in time. In a dynamic environment, aerial photography would have to be flown and mapped continuously. To acquire data at a micro scale, survey and aerial photographic methods require a large commitment of time and manpower. This task becomes even more daunting when attempting to frequently collect accurate time series data for the purpose of detecting change in the coastal process. Quantifying volumetric change over a large area using the traditional aerial photography methods would be virtually impossible. Further refinement in surfaced-based remote sensing, however, holds promise for reasonably accurate measurements of horizontal and vertical data at meso to micro scales.

Airborne Topographic Mapping (ATM) currently provides the most accurate means in which to map land surfaces (Brock and Sallenger, 2001). The primary instrumentation of the ATM is the laser scanning technology known as Light Detection and Ranging (LIDAR). Deployed from low-level aircraft LIDAR has revolutionized the collection of accurate elevation data to sub-meter resolutions. With vertical accuracies close to fourteen centimeters within a 1 m x 1 m footprint, ATM (i.e. LIDAR) provides true topographic data at the micro scale. This resolution is based on bald earth or “bare earth” digital elevation data collected from LIDAR surveys. Bare earth data are free from interference from vegetation, buildings, or other man-made structures. Developments in this technology will aid researchers and resource managers in
determining spatial patterns and further the study of surficial coastal topographic
structure (Sallenger and Brock, 2001).

1.3 Coastal Change Investigation

Cooperation between NASA, USGS, and NOAA is allowing coastal scientists to
study the geologic framework and assess topographic change at a very high level of
accuracy. The cooperative began the Airborne LIDAR Assessment of Coastal Erosion
(ALACE) project and conducted several mapping missions along both coasts of the
United States (Meredith et al. 1999). With the ultimate objective of improving predictive
capabilities for coastal change hazards, ALACE seeks to quantify the interaction of
routine coastal processes with extreme weather events such as hurricanes and El Niño
events. Using the Airborne Topographic Mapper (ATM), LIDAR survey measurements
have been collected over three quarters of the U.S. coastline, on both the East and West
coasts (Brock et al. 2001).

El Niño events have a significant impact on long-term rates of change in coastal
topography (Sallenger et al. 2002). During the El Niño years of 1997 and 1998, NASA,
NOAA, and USGS began planning a survey assessment of El Niño impacts and coastal
erosion on the West coast (Sallenger et al. 1999). The initial objective was to quantify
volumetric coastal change. This determination was focused on understanding of the
magnitude and spatial patterns of beach and coastal cliff change.

The collection of these accurate time series spatial coverage’s during the ALACE
project has furthered research in many areas of coastal science. Additional investigations
into categorizing storm impacts by magnitude have been undertaken by the USGS Center
for Coastal Geology in which four new *Impact Levels* are proposed. Within the proposed scale of each impact level, the regime of wave action enacting upon the coast poses a methodology for defining patterns and magnitude of volumetric change (Sallenger, 1999).

The ALACE surveys have also enabled significant progress in accurate determination of shoreline position. Within 0.5 m the shoreline position can be extracted using the horizontal and vertical measurements collected by the LIDAR. A determination of the slope of the foreshore region can then be made (Stockdon et al. 2002). The initiation of the ALACE project has furthered coastal research as well as advanced mapping technologies through the use of the Aerial Topographic Mapping instrumentation.

### 1.4 Aerial Topographic Mapping and LIDAR

Initially developed by NASA to survey global climate change on the Greenland ice sheet, the Airborne Topographic Mapper (ATM) provides a spatially dense collection of data greater than one elevation measurement per square meter at 10 cm vertical accuracy (Krabill et al. 2002). The ATM instrument is a combination of LIDAR laser scanning, inertial navigation, and global positioning systems. Using an aircraft mounted scanning laser pulses of powerful radiation bursts in ultraviolet to near infrared wavelengths are reflected to the earth’s surface using a rotating scanning mirror (Figure 1). Generating an elliptical scan pattern, the scanning mirror produces a swath width approximately 50% of the aircraft’s altitude at a 10° off-nadir angle (Krabill et. al, 2002).
LIDAR refers to any laser emitting remote sensing application that detects, ranges, or identifies objects based on the calculated reflection of light from an object. A variety of laser-based sensors have been developed for terrestrial, marine, and atmospheric environmental sensing. These sensors have even been used to stimulate and measure fluorescence from crude oils, coral, plants and oceanic phytoplankton (Hodge, 1988; Brock 2001).

Laser-scanning measurements are an active remote sensing technique that requires an energy source to illuminate objects (Brock et al. 2001). Since active remote sensing provides the light source, measurements can be taken at night. Cloud cover or hazy conditions however can affect this method of remote sensing.

At an altitude of approximately 700 m, the laser transmitter can produce elevation measurements from 2,000 to greater than 20,000 points per second (Brock and Sallenger, 2001). ATM, in conjunction with the LIDAR, uses an onboard Global Positioning System (GPS) and Inertial Navigation System (INS) to triangulate the position of the
aircraft and the elevation measurements. The INS or Inertial Measurement Unit (IMU) provides a three-dimensional orientation of the aircraft. The in-flight attitude of the aircraft, in terms of pitch, yaw and roll, are recorded in an onboard computer and correlated with the LIDAR time interval measurements and the GPS receiver (Krabill et al. 2002). The geodetic grade GPS receiver determines the aircraft position in terms of latitude, longitude and altitude, or x, y, and z coordinates. The use of kinematic GPS allows the collection of a dual frequency carrier-phase position signal to be recorded simultaneously with a base station and the mobile antenna in the aircraft providing greater accuracy in spot elevation location (Huising and Pereira, 1998). The GPS base station is located on a ground control point no greater than 30 kilometers away from the project area. By comparing the base station data to that of a GPS reference station on a known point or benchmark, any errors introduced in the signal can be rectified. Through the concurrent collection of aircraft antenna and base station GPS data the aircraft trajectory can be determined within 5 centimeters (Brock et al. 2001).

1.5 LIDAR Accuracy

The objective of collecting LIDAR data is to consistently and accurately measure the target over each pass. Improper calibration of the GPS and the INS will greatly deteriorate accuracy (Huising and Pereira, 1998). Hence, calibration of the LIDAR is necessary before and after each mission flown.

Two types of calibration are employed for the LIDAR. The first method of calibration is done when the topographic mapping system is still on the ground. The laser beam is reflected, via a mirror, to a flat target board. The distance between the mirror
and the target is measured with both a steel tape measure and electronic range finder while the strength of the laser beam is modulated. This is done pre-mission and post-mission in order to produce a correction table for post-flight processing (Meredith et al. 1998). The second calibration is to determine the mounting of the LIDAR instrumentation platform relative to the inertial navigation system (INS). Since the INS records the aircraft attitude, the orientation of the laser scan relative to the INS must be determined. The current protocol requires an agreement of at least 0.1 degrees (Krabill et al. 2002). At an altitude of 700 m an angle of 15 degrees pitch or roll with a mounting error greater than 0.1 degrees would introduce a vertical error of 32 cm and a horizontal error of 131 cm (Brock et al. 2001). Using a known reference, such as a parking lot, the pre-mission position can be determined by flying over the surface and coordinating the measurements between the aircraft GPS antenna, the INS and the position of the scanning mirror (Meredith et al. 1998).

Upon the completion of a mission, the post-processing of the raw elevation file requires four additional steps. First, calibration data collected pre-mission is compared to that of the post-mission calibration data. Then, the INS measurements are used to correct for pitch, roll and heading during the flight. Thirdly, the geo-referenced elevation measurements of the aircraft GPS antenna are differentially corrected using the data collected by a GPS base station (Brock and Sallenger, 2001). Finally, the mounting biases of the equipment in the aircraft are determined.

In order to determine the accuracy of the LIDAR multiple ground surveys, of varying methods, are collected and timed to coincide with LIDAR surveys (Meredith et al. 1998). Elevation measurements are compared over two data sets by selecting points
from one data set and locating all other points within a fixed radius of the first point (Meredith et al. 1999). By comparing the LIDAR elevation measurements to additional ground surveys a vertical accuracy is established at approximately 15 cm RMS with a horizontal accuracy of 1 m (Sallenger, 2001).

### 1.6 Processing Raw Data

Further processing is required after the collection of LIDAR data. The calibration of pre- and post-mission records are considered Level 1 processing and require three additional levels of processing (Brock and Sallenger, 2001). The additional levels of processing are done through a series of routines in the LaserMap software package developed by the USGS Center for Coastal and Marine Studies. Since LIDAR relies on overlapping swaths for full coverage of the study area the data points are first separated relative to the flight path. Typically for beach mapping this occurs on a north-south to south-north heading (Nayegandhi, 2001).

The ordering of the ground positions (latitude and longitude) and a coordinate transformation are then done in the Level 2 processing step. Level 3 processing provides a large gridded elevation map of full vertical and horizontal accuracy and is tiled using a 1 km grid index (Nayegandhi, 2001). The Level 4 process tiles the grids to cover an area approximately 10 km by 10 km and converts the grid to an image map in GeoTiff format.

With the conversion of the Level 4 data set, the raster grids can then be used in many GIS systems such as ERDAS Imagine and ESRI ArcInfo. Analysis may be done at this level in geomorphic change, shoreline definition, and the mapping of wildlife and
plant communities (Brock et al. 2002). For further description of raw data processing see Appendix G-Processing Raw Data.

1.7 Benefiting from New Technologies

The mission statement of the National Park Service Organic Act of 1916 "...to promote and regulate the use of the...national parks...which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations," clearly defines the task for the National Park Service (The National Park Service Organic Act (USC l)). The task becomes daunting with encroaching urbanization and increasing visitation and yet the National Park Service strives to reach those goals while undertaking additional conservation responsibilities. Leading the world in park preservation, the National Park Service protects America’s open space and the cultural and recreational resources within it (NPS, 2001).

The National Park Service Inventory and Monitoring Program assists with this mission through research initiatives. These initiatives inventory natural resources to provide a base description of relevant ecosystem environments, such as the distribution of plants and animals, water quality, landscape morphology and climate change (NPS, 2002). Monitoring adds a temporal dimension to this inventory and is designated to identify changes that might necessitate a management action at the detection of change (NPS, 2002).

Through cooperatives such as the ALACE data collection initiative, and advancements in Geographic Information Systems (GIS) and remote sensing
technologies, inventory and monitoring is made feasible. Inventory collection has become more automated and easier to disseminate to researchers and the public. Databases now provide comprehensive storage and retrieval of time series data. The use of such technology has furthered the National Park Service’s objective of understanding ecological processes. An example of the National Park Service’s ability to benefit from this improvement in inventory and monitoring capabilities is the Assateague Island National Seashore (ASIS) assessment.

Established as a national seashore in 1965, after a damaging storm event in 1962, Assateague Island runs parallel to the Atlantic coast and straddles the border of Maryland and Virginia (Figure 2). Assateague Island is noted for the two herds of horses inhabiting the island. Introduced to the island in 1669 the horses were allowed to graze freely on the dune grass to avoid the taxation of fencing and livestock (De Stoppelaire et al, 2001). In an attempt to understand the impact of the grazing horses on the dune grass and the subsequent growth of the dunes, the National Park Service and the United States Geological Survey used the LIDAR elevation data collected by the ATM to determine the change in the topography over an eight-year period (1993-2001). By establishing six pairs of study plots, in which half of each plot was fenced to restrict horse grazing, observations were made to track topographic change and describe the dune development process on ASIS. The 1 m resolution LIDAR data was used in this research to determine the change-over-time of the study plots. Upon the completion of the study the LIDAR elevation data revealed a distinct difference in the topography of the fenced study plot pairs. The results from this study allow computer models to simulate the effects of various horse management strategies (De Stoppelaire et al. 2001).
1.8 The Purpose of This Project

The resolution of LIDAR elevation data may have an impact on assessing change in barrier island topographic surfaces. As resolution diminishes the cell size increases simplifying or smoothing the surface being represented. The increase of cell resolution decreases the cell size and may create more variability within the surface. The decreasing of cell size also increases both disk space and processing time. Several studies recommend different cell sizes for analysis. Woolard and Colby (2002) used the 1996 and 1997 LIDAR data to derive Digital Elevation Models (DEMs) of a portion of the northern Outer Banks of North Carolina. Using the data to compare the volumetric change between the two years at resolutions of 1, 2, 10, 15 and 20 m they suggest that a spatial resolution less than 5 m should be used to depict the dune topography. Meredith
et al, (1999) used the 1997 and 1998 LIDAR data of the coast of North Carolina to determine hurricane induced beach erosion. They used DEMs at 5 m resolution for the entire coastline. Using DEMs derived from LIDAR data between 1997 and 2000 White and Wang (2003) suggest that DEMs of 5 m resolution are too coarse to accurately represent coastal topography. In their study they chose a DEM spatial resolution of 1.5 m to analyze coastal morphology of the North Carolina coastline.

The current collection of LIDAR surveys since 1996 has created a wealth of time-series information available for analysis at the Level 4 map grid. However, there seems to be some confusion as to the potential effect of resolution on topographic representation. Further alteration of the original 1 meter Grid to an increased or decreased resolution may drastically influence the representation of the topography. In this research, several resolutions are tested for topographic analysis.

The objectives of this project are to determine this potential effect of resolution on the topographic surface on northern Assateague Island National Seashore (Figure 2). An interpretation of volumetric change will be established at 0.5 m, 1 m, 2 m, and 10 m resolutions in order to determine the effect resolution has on representing the change in topography. Slope and hillshade surfaces will also be used as a means to determine the variations in topography that occur when changing resolution.

In order to determine resolution impact the following tasks were implemented:

1. Derive elevation grids representing a sample area of Assateague Island National Seashore varied by resolution and sample date.

2. Determine the total volumetric change from two dates using elevation grids of different resolutions.
3. Map the spatial distribution of the above volumetric change.

4. Calculate the total area in several slope classes using different spatial resolutions.

5. Visually evaluate this same resolution effect on distribution maps of slope classes.

The cell resolutions defined for each analysis Grid in this project are chosen to make the best attempt to sample a significant extent of resolutions that could be used in coastal analysis.
Methodology

2.1 Overview of Methodology

Provided by the United States Geological Survey (USGS) Center for Coastal Geology in St. Petersburg Florida, the Assateague Island National Seashore LIDAR data are Level 4 GeoTiffs captured in 1999 and 2001 LIDAR surveys. Initial conversion of the GeoTiff images to Grids yields a default cell size of 1 m resolution. Since there is approximately one elevation measurement per m² taken in the original survey, this measurement is considered the default resolution to which other resolutions will be compared. Figure 3 provides a diagram of the methodologies used in this research.

The first step requires the conversion of the images to Grids. Once this is complete an area of interest is clipped and further refinement can be made to the grid values. The second step allows for the processing of the Grids to alternate resolutions for later analysis. Once the Grid resolutions are defined additional surfaces such as a slope and hillshade are created for each resolution. The third step uses the Grids for input and analysis of volumetric change and spatial distribution comparison. Additional classification of slope surfaces and topographic profiles are also created. The fourth step incorporates the results of the analyses in the creation of maps. The maps are necessary for visual comparison of change and displays the results of the spatial distribution created during analysis.

The primary software package used for analysis is ArcGIS Desktop. The software suite includes ArcCatalog, ArcToolbox and ArcMap and additional extensions. The extensions Spatial Analyst and 3D Analyst provide the tools in which study surfaces
can be produced and analyzed. Spatial Analyst contains the Raster Calculator and Raster Query necessary for mathematically processing Grids and allows for the querying and selecting specified values. The 3D Analyst module contains the topographic profile tool for analyzing transect cross-sections of the topographic surfaces. In addition to ArcGIS, Microsoft Excel is also used for attribute calculations and graphing the results.
Methodology

- GeoTiff to Grid
- Querying Values and Clipping Grids

Resolution and Surface Preparation

- Convert Grids to 0.5, 2, and 10 meter resolutions
- Creation of Slope and Hillshade Surfaces

Input and Analysis

- Volume Calculation and Spatial Distribution
- Slope Classification and Topographic Profiles

Presenting the Results

- Mapping Volumetric Change and Spatial Distribution of Separate Resolutions

Figure 3. Diagram of methods
Initially the GeoTiff images of both years require conversion to a raster Grid. This conversion allows the Grids to be used in ArcMap. Prior to the creation of a specific area of interest for analysis, the data must be reduced in size and clipped to a generalized area of interest created by the user. In the initial creation of the Level 4 data a vertical offset of the elevation values is applied to the GeoTiff image. Since the elevation values contain negative elevation measurements, such as –500 cm (below sea level), all elevation values are summed by the –500 cm value measurement to create an unsigned (all positive values) integer grid accepted by the GeoTiff format. This offset must later be eliminated from the Grid in order to represent the true elevation values. The Grid can then be clipped to a more refined study area. Finally, the base raster can be queried to remove erroneous data values. Suggested in the attached USGS help file with the GeoTiff images the no-data values are given a numerical code of 3051. These cells take up the extra space in the 10 km tile around the LIDAR survey. Removing these values reduces the data size of the image from approximately 190 mb to 35 mb. Erroneous data values, such as those greater than 20 m, are also removed as suggested in the USGS helpfile. The study area can then be defined to the proper projection, and will be maintained throughout additional raster conversions. Each of these steps must be carried out twice, once for each year of the GeoTiff images.

Once the study areas have been reduced and the appropriate elevation values are represented, resampling of the raster cell sizes can take place. The Nearest Neighbor Statistics method from theSpatial Analyst extension was chosen to resample the base 1 m raster to the additional resolutions. To create alternate elevation rasters at different resolutions, the mean values of the cells within a 3 x 3 cell analysis window were
calculated. By comparing the 3 x 3 neighboring cells the mean aggregation is assigned to the new cell of a given cell size or resolution (Figure 4). The Nearest Neighbor Statistics also allows for the conversion of a finer resolution. This method converts each raster while maintaining the boundary extents of the area of interest. The resolutions were converted from the 1 m to 0.5 m, 2 m, and 10 m Grids for comparison.

Figure 4. Mean Cell Aggregation
After the completion of raster conversion, additional surfaces can be created at each resolution. For each 0.5 m, 1 m, 2 m and 10 m raster a slope grid and hillshade grid was created with Spatial Analyst. The slope grid, measured in degree slope, represents the steepness of the plane passing through the tangent cell as defined by the surrounding cell values. In terms of analysis, slope is an indicator of the variability of the terrain (Zhang et. al, 1999). Hillshade is a hypothetical illumination of the surface providing dimension and representation of the relief of a surface. Representing the angle of the sun an azimuth of 315 degrees is used with an angle above the horizon at 45 degrees to enhance the surface for visualization.

For the purpose of comparing change over time at different resolutions, the 2001 grid was subtracted from the 1999 elevation grid. Yielding positive and negative values the grid tables were exported to a Microsoft Excel spread sheet, separated and summed. Subtracting the resulting values allowed for a determination of the net change between each year at each resolution.

The slope surfaces of year 2001 were also subtracted from 1999 at the different resolutions. The resulting grids provided a visual representation of where change has taken place. The grids can then be compared to determine the distribution of change at each resolution.

The hillshades were visually compared and modeled. Using a profile graph, the varying resolutions demonstrate the change in the relief of the surface. The profile graphs are created using the elevation grids for each resolution. Comparing the profile transect with that of the hillshade Grids shows the smoothing that takes place with increasingly coarse resolutions.
2.2  Procedure for Preparing the LIDAR GeoTiff Image for Analysis

The first step in processing the LIDAR survey is to convert each GeoTiff image to a grid. The image files chosen were the r6_t1_991001, for 1999, and the r6_t1_010905, for 2001, both representing the area of north Assateague Island and portions of Ocean City, Maryland. Each image represents a 10 km x 10 km area including the barrier island (Figure 5).

![Assateague Island National Seashore, MD VA Level 4 Tile Map Index](image)

Figure 5. Level 4 Map Tile Index (USGS)

Using ArcToolbox the images were converted to Grids using the Image to Grid conversion module. The Nearest Neighbor resampling method was chosen within the ArcToolbox module. This Nearest Neighbor resampling method maintains the value of each cell taken from the GeoTiff and provides a one to one conversion of the values from the image to the grid. Once the image is converted to a grid certain values must be removed. Since only a portion of the 10 km x 10 km index grid contains LIDAR data, the remaining extents of the frame contain a no-data value of 30501 (Figure 6).
The Raster Query module in Spatial Analyst was used to remove the no-data values (Figure 7). The first step in the process was to create a shapefile that generally describes the Area of Interest (AOI) for the study. The next step was to eliminate the no-data values. Using Raster Query the no-data values were removed and the study area was clipped with the AOI shapefile. This allows for the reduction in data, provides a more specific study area for analysis, and reduces processing time in additional procedures.
The next step required the use of Raster Calculator in Spatial Analyst. In order to maintain a positive (unsigned) integer grid during the production of the GeoTiff all data values were offset by a value of 500. Since the data are in centimeters this equates to a 500 cm offset. Using Map Algebra the area of interest grid was converted back to the original elevations measurements by subtracting the values by −500 cm. The values for the grid now range from -500 cm to 14543 cm. However, since 14543 cm is not a valid elevation in the natural Atlantic coastal environment it was obvious that some erroneous data values must be removed. Inspection of the attribute table shows that the grids contain few cells representing these values. The USGS help file provided with the GeoTiff images suggest that any value greater than 20 m (2000 cm) is invalid and can be removed. Again using Raster Query, the data are reduced using a query that selects the
values less than or equal to 2000 cm. Extracting values with this method replaces the cells with no-data.

Once the grids were refined and clipped the projection was defined as NAD1983 UTM Zone18N in ArcCatalog. Using these procedures for each year the 1999 and 2001 grids were prepared at the 1 m resolution and ready for resampling and analysis.

2.3 Resolution Conversion Methods

Several analysis methods were compared in order to convert the raster to different resolutions. The chosen method would convert to all resolution sizes specified and combine the data values appropriately across the surface.

The first method applied was the Inverse Distance Weighting (IDW) method. The IDW method averages the values according to influence or weight of points, in a fixed search radius, around a target point to generate an output value for each cell. Using this method required that the raster cells be converted to point features, each representing a cell value. The elevation point cloud was large and the processing time was extremely long, taking in some cases hours to complete. This time constraint was not feasible for creating six additional grids. The IDW method was abandoned.

Since the point features were already created for the IDW method a TIN surface or Triangulated Irregular Network was next created. The processing time was long, but once the TIN was created additional grids could be converted from this base surface. The TIN uses the node values at each triangulated intersection to determine the cell values of the raster. During the process of creating the network, however, the point values along the coastline were connected. Since the coast is an irregular shape, slightly concave, the
points furthest from the shoreline were connected back along the shoreline. This created additional surface area that was not consistent with the original grid and would be carried as additional values throughout subsequent surfaces. Since applying a mask of a refined area was not an option, the TIN method was abandoned.

The third conversion method applied was the Spatial Analyst function of “Features to Raster”. This method uses the interpolation function and applies a selected elevation value within a 3 x 3 cell sample window to each new cell of different resolution. The point features were again used to create a raster at the specified resolution. This method, however, would not create a continuous raster at the 0.5 m resolution. The point values were centered on cells of 0.5 m with 0.5 m gaps between each cell. The “Features to Raster” method was also abandoned.

The method finally chosen was the Neighborhood Statistics module in Spatial Analyst. This method allowed for the input of the 1 m resolution raster instead of using the point features. Neighborhood Statistics has the option to use the mean statistic type to aggregate the values over a rectangular neighborhood of a controlled height and width. Using a 3 x 3 cell sample window the data values were averaged within the window and assigned to the cell resolution set prior to conversion. This method also allowed for conversion to the finer resolution of 0.5 m and maintained consistency in converting to all other resolution sizes.

2.4 Volumetric Analysis

Once the resampling of each resolution for each year was complete the volumetric change analyses were performed (See Figures 21-24 in Appendix A). For each
resolution, grids from 1999 were subtracted from the 2001 grids in the Raster Calculator. The difference output grid represented the areas of negative change (erosion) and areas of positive change (deposition) (See Figures 25-28 in Appendix B). The attribute table of the difference grid was exported to an Excel spreadsheet allowing for subsequent calculations. The elevation change values and the tally of cells associated with each value were separated into columns by positive, negative and zero (or no change values). Since the elevation values are represented in centimeters and the area of the cells in meters, the elevation values were divided by 100 to convert each value to meters.

The attribute table created with each grid yields a cell count for each value represented. Each elevation change value was then multiplied by its associated cell count. The sum of each positive and negative column was found and multiplied by the cell area of each resolution to find the volumetric change in cubic meters. For example, the sum of the positive vertical change values over the entire surface for the 10 m resolution was 1631.46 m. This number multiplied by the area of each 10 m cell (100 m²) yields a volume of 163146 m³ of positive change. To find the net change over the surface the total volumetric change of the negative values column was subtracted from the total of the positive values column.

To demonstrate the distribution of the percent of change over the surface the sum of the number of cells in each grid was used. The total number of cells of each positive, negative and zero classification were divided by the total number of cells in the grid and multiplied by 100 to determine the percent of the surface that changed between the two years.
2.5 Slope Comparison

Slope surface grids were prepared for each resolution of the two years in degrees of slope (See Figures 29-32 in Appendix C). In order to represent the slope properly the elevation grids were converted to meters. This allowed for the slope to be calculated in the same measurement units. The slope function calculates the maximum rate of change in elevation between the cell and its eight neighbors, finding the slope of the plane.

Since slope is a representation of the topographic complexity, change in resolution can estimate the relief of the terrain. As resolution increases, the length of the x-y plane through a vector averages more of the surface. In order to determine how slope classification is dependant upon resolution the attribute table of each slope grid for each year was exported to an Excel spreadsheet. The degree values and associated cell count were separated into four classifications: 0 degrees, greater than 0 to 45 degrees of slope, greater than 45 to 75 degrees, and greater than 75 degrees of slope. The sum of the cell count for each classification was found and divided by the total number of cells in the grid, then multiplied by 100 to determine the percent of the surface represented by each classification. The percent of each classification by resolution was subtracted between 1999 and 2001 to determine the percent difference between the classifications of each year.

Further comparing the slopes of the grids between the years of 1999 and 2001 at different resolutions requires the difference to be calculated between grids. Subtracting the slope grids of 2001 and 1999 for each resolution reveals the spatial distribution of slope change. By reclassifying the output difference grids, the distribution of slope change is designated within three separate classes. The negative values produced in the
output represent the decrease or flattening of slope from 1999-2001, the positive values represent the increase in slope, and the zero values represent no change between the two years.

The difference grids were reclassified in Spatial Analyst using a distribution of 3 classes (See Figures 33-36 in Appendix D). All the negative values up to -1 were classified 1 and the positive values greater than 1 were classified 2. The amount of 0 classifications varied between each grid. Since the range in slope changes between each resolution, 0 was assigned to the difference ranges between -1.0 and 1.0 degrees. For example, the 10 m slope reclassification grid was classified with a 0 for values between –0.9 and 0.1 degree of slope change, 1 for negative values between –2.1 and –5.4 and a 2 for positive values between 1.25 and 5.7. The resulting slope difference maps allowed the distribution of slope change to be observed.

2.6 Hillshade and Topographic Profile

Using the Spatial Analyst hillshade module, hillshade surfaces were created at each resolution for 2001 (See Figures 37-40 in Appendix E). The hillshade requires a light angle to be set for the raster and calculates the illumination value of each cell relative to neighboring cells. The default illumination values used were an azimuth of 315 and an altitude of 45 degrees.

Drawing a line of profile that references the elevation grid creates the topographic profile. The line of profile drawn, using the 3D Analyst module, creates a profile graph that represents the transect topography of that area. Comparison of the topographic
profile graphs for each resolution reveals the smoothing that occurs between each resolution as the cell size is increased.

**Results**

**3.1 Results of Volumetric Analysis**

The results of the volumetric change analysis proved the study area to be erosional between the years 1999 and 2001 throughout all the resolutions (Table 1). At the 0.5 m resolution, the total negative change or erosion for the study area was -5,877,878 m³ and the total positive change was 223,606 m³, equaling a net change of -5,654,272 m³. At the 1 m resolution, the total erosion was -4,926,486 m³ with a depositional amount of 232,431 m³, equaling a net change of -4,694,055 m³. The 1 m resolution showed a greater depositional amount than that of the 0.5 m resolution and greater erosion than that of the 2 m.

When aggregating further to the 2 m resolution the erosion amount was -1,837,848 m³ and the deposition was 188,361 m³, with a net change of -1,649,488 m³. This was approximately a 3 million m³ difference between that of the 1 m resolution for both the erosion and net change. The 10 m resolution represented -771,463 m³ of erosion and 163,146 m³ of deposition with a net change of -608,317 m³.

| Table 1 |
|-------------------|-----|-----|-----|-----|
| **Volumetric Change (m³)** | **.5m** | **1m** | **2m** | **10m** |
| Erosion | -5,877,878 | -4,926,486 | -1,837,848 | -771,463 |
| Deposition | 223,606 | 232,431 | 188,361 | 16,146 |
| Net Change | -5,654,272 | -4,694,055 | -1,649,488 | -608,317 |
The difference in net volumetric change between the 0.5 m resolution and the 1 m resolution was 960,217 m³. This difference increased to 3,044,567 m³ between the 1 and 2 m resolutions. The difference in net volumetric change between the 2 and 10 m resolutions was 1,041,171 m³. Although there is a difference in generalization between the 2 and 10 m grids, the net change is greater between the 1 and 2 m grids.

Since all the resolutions reflect a larger amount of negative values than positive, more erosion than deposition likely occurred between the two years (Figure 8). The net change, however, between the 1 m and 2 m resolutions represents a drastic difference in the predicted amount of change. This could possibly be due to the quadrupling of the cell area from 1 m² to 4 m². This difference was greater than that between 0.5 and 1 m resolutions.

Even though the difference in generalization is greatest between the 2 m and 10 m resolutions the amount of change is not as great. The difference between the net change of the 2 m and 10 m and the 1 m to 2 m could be due to the decrease in the amount of cells representing the surface at the coarser resolution.
To test the equality of the mean in elevation change an analysis of variance (ANOVA) was used. Using JMP statistical software by SAS the mean elevation change for each resolution was compared. The output mean for each resolution showed little difference between the mean change in elevation at each resolution (Table 4). Since the F Ratio value is less than the F Probability value the hypothesis that all means are equal is accepted.

Table 2

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Mean</th>
<th>Std Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>2.7</td>
<td>0.885</td>
</tr>
<tr>
<td>1</td>
<td>2.74</td>
<td>1.77</td>
</tr>
<tr>
<td>2</td>
<td>2.35</td>
<td>3.52</td>
</tr>
<tr>
<td>10</td>
<td>1.372</td>
<td>17.17</td>
</tr>
</tbody>
</table>

F Ratio  F Prob.
0.0053  0.9995
3.2 Frequency Distribution

Using the frequency distribution histogram from the difference grids the distribution of elevation change is charted over the entire surface. For each surface the elevation change (in centimeters) is compared to the frequency of each value. Since an elevation value is represented in each cell of the surface, the frequency is the number of cells that changed from 1999-2001. The distribution of cell change for each resolution reflects the range of values in which change has taken place across the surface. Comparison of these graphs reveals how the change in resolution distributes the values across the surface at each resolution.

At the 0.5 m resolution the minimum change is an erosional value of \(-875\) cm or 8.75 meters. The maximum change, that of the largest amount of deposition, is 1670 cm or 16.70 m. Since the maximum change is such a large number that occurs at a low frequency across the surface, that amount of change may be an anomaly. The mean elevation change is 96 cm and the standard deviation is 431 cm for the 0.5 m difference surface (Figure 9).

Figure 9. 0.5 m Change Distribution
At the 1 m resolution the minimum is again –875 cm of change with a maximum change value of 1648 cm. The mean of the change is 46 cm and the standard deviation is 345 cm (Figure 10).

![Figure 10. 1 m Change Distribution](image)

At the 2 m resolution the minimum value is –350 cm and the maximum is 589 cm (Figure 11). The mean of the 2 m is 26 cm and the standard deviation is 153 cm.

![Figure 11. 2 m Change Distribution](image)
The 10 m resolution distribution is from –124 cm at the minimum to 181 cm at the maximum (Figure 12). This yields a mean of 37 cm and a standard deviation of 81 cm.

![Figure 12. 10 m Change Distribution](image)

### 3.3 Percent of Surface Change

Using the spreadsheet prepared for the volumetric calculations the percent of surface change was found. The study area was erosional in all resolutions between years. However, the actual percentage of the surface that experienced change, either positive or negative, was consistent across resolutions (Table 3).

<table>
<thead>
<tr>
<th>Percent Surface Change</th>
<th>.5 meter</th>
<th>1 meter</th>
<th>2 meter</th>
<th>10 meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Change</td>
<td>43.97%</td>
<td>44.37%</td>
<td>43.90%</td>
<td>43.40%</td>
</tr>
<tr>
<td>Negative Change</td>
<td>53.48%</td>
<td>53.90%</td>
<td>52.08%</td>
<td>52.70%</td>
</tr>
<tr>
<td>No Change</td>
<td>2.54%</td>
<td>1.17%</td>
<td>3.99%</td>
<td>3.80%</td>
</tr>
</tbody>
</table>

Note: The total may not reflect 100% due to rounding

At the 1 m resolution the percent of surface change between the two years showed that 44.37% of the surface increased in elevation while 53.48% decreased (eroded). This leaves only 1.17% of the surface unchanged. Working at the 0.5 m resolution the
positive change was 43.97% of the grid surface and 53.48% negative with 2.54% unchanged. There appears to be little effect due to resolution.

The positive and negative change for the 2 m grid was 43.90% and 52.08% respectively with 3.99% of the surface representing no change. This was similar to that of the 10 m grid with 43.40% positive change, 52.70% negative change and 3.80% no change. Since the absolute number of cells representing the grid surface has decreased upon resampling to a larger resolution, fewer cells are used to represent the surface. The distribution of the unchanged values has also increased when changing from the 1 m to all other resolution (Figure 13).

Figure 13. Percent Surface Change
3.4 Results of Slope Comparison

The comparison of slope through varying resolutions is significant since differences in cell size can affect estimates of the surface relief. The result of comparing slope classifications between resolutions of each year illustrates the distribution of the slope classifications at different resolutions. The percentages of the slope surface classifications were fairly consistent between both years at each resolution (Table 4).

Table 4
Percent Slope Surface Classification

<table>
<thead>
<tr>
<th>Year 1999</th>
<th>.5 meter</th>
<th>1 meter</th>
<th>2 meter</th>
<th>10 meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 degree slope</td>
<td>81.22%</td>
<td>67.66%</td>
<td>69.13%</td>
<td>44.80%</td>
</tr>
<tr>
<td>&gt;0 to 45 degree</td>
<td>14.02%</td>
<td>31.73%</td>
<td>30.86%</td>
<td>55.20%</td>
</tr>
<tr>
<td>&gt;45 to 75</td>
<td>4.75%</td>
<td>0.60%</td>
<td>0.01%</td>
<td>0.00%</td>
</tr>
<tr>
<td>&gt;75</td>
<td>0.01%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year 2001</th>
<th>.5 meter</th>
<th>1 meter</th>
<th>2 meter</th>
<th>10 meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 degree slope</td>
<td>84.22%</td>
<td>71.03%</td>
<td>70.12%</td>
<td>43.42%</td>
</tr>
<tr>
<td>&gt;0 to 45 degree</td>
<td>11.48%</td>
<td>28.28%</td>
<td>29.87%</td>
<td>56.58%</td>
</tr>
<tr>
<td>&gt;45 to 75</td>
<td>4.28%</td>
<td>0.68%</td>
<td>0.01%</td>
<td>0.00%</td>
</tr>
<tr>
<td>&gt;75</td>
<td>0.01%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

Note: The total may not reflect 100% due to rounding
0% = no cells in classification

It is interesting to note that although there is an increase in the 0 degree slope surface for the 0.5 m, 1 m and 2 m resolutions from 1999-2001, there is a decrease in the greater than 0 to 45 degree surface between 1999 and 2001 for the same resolutions (Table 3). This suggests that there was a leveling of the surface between the two years.

The 10 m resolution is an exception, however. The opposite is demonstrated in that there is a decrease of the 0 degree surface between 1999 and 2001 and an increase in the greater than 0 to 45 degree surface between the two years. This suggests that through the aggregation of the surface more cells fall into theses classes as resolution increases.
and therefore the relief of the terrain is represented differently. As the surface is smoothed, by increasing the cell size, the relief is distributed within the 10 m cell. This distribution combines the topographic variability of many cells into one slope classification. Integration of the cells representing the terrain over a 100 m² area yields one continuous slope. For example, if the slope of a 9 x 9 cell area of the 2 m grid is represented by a range of values between 14 and 0 degrees, the 10 m slope of that same area represented by 1 cell is 5 degrees.

Since the largest percentage of surface at any given resolution is within the 0 degree classification subtracting the slope grids yields a large portion of area unchanged. Reclassifying the grids at 0, 1, and 2 reveals the distribution of the areas that have either become steeper in slope or flattened from 1999-2001. The distribution comparison between each resolution is fairly consistent at least in terms of general location as can be seen in the slope distribution maps (Figures 14). A pattern in distribution of slope change is apparent at each resolution however is represented over a larger area as the resolution increases.

Figure 14. 1 and 2m Slope Distribution
3.5 Results of Hillshade and Topographic Profile

Creating hillshade grids reflects the effect of increasing resolution (Figure 15). It can be determined visually that the increase of resolution from the 0.5 m to the 10 m causes a smoothing of the surface. As a matter of scale the 0.5 m grid reflects the micro topography where the 10 m reflects more of the macro and meso topography. This is apparent in each grid as the cell size increases. The profile graph takes this one step further by visually representing a cross section of the relief of the terrain (Figure 16). As the cell size is increased the amount of variability in the surface is smoothed over the entire surface.

Figure 15. 1 and 10 m Hillshade

Figure 16. 1 and 10m Topographic Profiles
Discussion

4.1 Converting the Lidar Image to a Grid

The procedure for converting the Level 4 GeoTiff image to an analysis raster contains many steps and is cumbersome. Careful attention must be paid to the measurement units represented by the values. The USGS help file (See Appendix F) provided with the GeoTiff is essential to understanding the contents of the image and the resulting data from the post-processing methods.

4.2 Converting Grids to Different Resolutions

After much deliberation, the Neighborhood Statistics module was used to convert the grids to the varying resolutions. Using the mean aggregation method provided consistency in interpolating values for larger or smaller cell sizes. Woolard and Colby (2002) suggest that using the mean aggregation of the data for volumetric change would produce equal values through the range of resolutions. This research did not find that to be true in elevation change however, in terms of the variability in the mean elevation change the means were found to be equal. The equality of the means in comparing elevation change could be due to the mean aggregation method used to resample each grid.

4.3 Discussion of Volumetric Change Analysis

The subtraction of the grids in the raster calculator is fairly straightforward for a GIS user. The calculation of the volumetric change, however, requires particular
attention to the data being used. In order for the output attribute table to represent the elevation values, the values must be grouped by the number of cells associated with each value. This is why each value must be multiplied by the cell count to represent the entire surface. Careful attention should also be paid to the measurement units of the cells. Since the resolution of the grids were in meters the area of each cell is in meters. This was important in the calculation of volume since the elevation measurements were in centimeters. All elevation measurements were converted to meters in the spreadsheet to consistently calculate the volume of each cell before determining the volumetric change.

Using the existing spreadsheet the percentage of the surface that changed was easily calculated. Since the purpose of this project is to compare surface response at different resolutions, comparing the percent surface change was very revealing. Although there was a noticeable volume change between the 1 m and 2 m grids the percentage of surface that changed at each resolution did not change spatially. When comparing the volumetric change of the 1 and 2 m grids for example, the positive volume was 232431 cm for the 1 m and 188361 cm for the 2 m grids. The percentage of the positive change in the surfaces however was 44.37% for the 1 m and 43.90% for the 2 m.

4.4 Frequency Distribution

The use of the frequency distribution histograms provides a representation of change across each surface as well as a comparison of change at each resolution. The distribution of elevation value change is represented between the two years of equal resolution. This reveals the range in which change has taken place between the years being compared.
When comparing the effect of resolution, the reduction of values at each resolution is consistent with the process of aggregation across the surface. The difference between the minimum and maximum values is due to the combining of values across the surface when changing resolutions. This effect is apparent when comparing the means of the 2 m and 10 m grids. As the resolutions increased the mean elevation change consistently decreased from the 0.5 m to the 1 and 2 m grids. The frequency distribution was more normal in these resolutions. However, at the 10 m resolution the mean elevation change increased. This difference reflects how the resolution can effect the measurements as they are distributed across the surface when aggregating to a larger resolution. The frequency distribution of the 10 m was more uniform.

4.5 Slope Comparison

Representing the slope of a grid surface in a GIS can be done in either degrees of slope or percent of slope. Degree slope was chosen in order to create an easier classification metric to compare the surfaces. Since slope is a measurement of the vertical distance (rise) over the horizontal distance (run) it was necessary to convert the values to meters prior to creating the slope surface. This was done to maintain consistency in the measurements since the cell sizes were measured in meters.

Comparing the slope distribution in terms of the percent of the area that has changed between the two years reveals the variability in the terrain over time. As the topography fluctuates an increase in slope could be related to additional erosion. In an area of decreasing slope, deposition may be the factor. Such detection in slope change may indicate areas being impacted by coastal processes or aid in the identification of
topographic features such as dune breaches. The slope distribution between the two years however, showed little change. This would suggest that the overall topography remained stable between the two years and was not impacted by any major weather events.

4.6 Visual Representation of Resolution

The ability to visually represent data is a key component in GIS. With the use of the hillshade surfaces and the profile tool in the 3D Analyst extension of ArcGIS, transects of the surface can be taken any where across the surface. The hillshade maps reveal the continued smoothing of the surfaces at the increasing resolutions. Visually comparing the surfaces, the reduction of the relief can be identified throughout the series of resolutions (See Appendix E Hillshade Maps). The profile graph represents the amount of variability across the relief of the surface and is reduced as the resolution is increased. This is important in the identification of surface features at different scales (micro to macro) as they may be averaged out dependent upon resolution.

Conclusions and Recommendations

Due to the dynamic nature of the coastal environment, measurement of change at the centimeter level may be too fine if done over the entire surface. Unless a dramatic movement of sand occurs, perhaps due to a severe storm event, the diurnal shift in the surface can account for most of the volumetric change. Since the fluctuation in the topography is constant, change is continuous. Measurement of this change is dependent upon the scale at which analysis will take place.
To fully understand the relationship between changing resolutions and volumetric change further research would be necessary. The use of LIDAR technology can provide the means to continuously measure the coastal topography in which additional time frames can be compared. Using this method of topographic data collection additional study sites can be chosen and measured systematically to provide greater control when comparing the relationship of spatial resolution and volumetric change of the coastal topography.

The use of different resolutions for analysis is largely dependant upon application. In terms of topographic feature mapping, a larger cell resolution (2 – 10 m) is recommended for elevation, slope, and hillshade surfaces. For example, dune identification or mapping of the physical topographic features on the 2 m grid better defines the boundary and extent of the features. These boundaries will not be as apparent with finer resolutions. This is a case in which aggregation of the neighboring cells would be beneficial in order to identify topographic features in their entirety. Otherwise features may be missed or identified incorrectly.

In terms of scale, the micro topography (meters to tens of meters) is still represented at resolutions larger than 1 m. This provides analysts with the ability to map topographic features accurately, minimizing the assumptions made from traditional survey methods. The larger resolution surfaces, such as the 10 m hillshade, also provide the ability to map at the meso (tens of meters to hundreds of meters) and macro scales (hundreds of meters to thousands of meters). From this perspective generalized boundaries and patterns can be mapped over larger portions of the land surface. This
minimizes data size and reduces an otherwise laborious task. Furthermore, the mapping can be done remotely as data are collected and stored, reducing site visits.

The use of this remote sensing method allows for this type of feature analysis to be possible. However, the relationship of spatial resolution to topographic features should be researched further. A ground truth method should be established in order to measure the topography as it exists. Modeling of LIDAR data at several resolutions could be compared to the ground measurements as a means to determine the best representation of the actual surface.

At the fine resolution of 0.5 m the grid reflects an extensive amount of relief represented by more cells than any of the other resolutions (Figure 17). The 1 m resolution also reflects an extensive amount of relief. Although the 1 m cell size should contain the most accurate of elevation measurements for change detection, since it is the product of the original post processing output, visual interpretation of surface features is still distorted due to the fine representation of the cell size (Figure 18).

At the 2 m cell size, however, features become more apparent and can be differentiated (Figure 19). This is also true at the 10 m resolution, however as it has been illustrated, the actual representation of features can be subject to the aggregation of the cells as they are expanded over the surface (Figure 20).

The 2 m resolution best represents all features without sacrificing the topographic relief. Provided that the features to be identified are larger in surface scale than 2 m, the larger cell resolution will enable an interpreter to easily identify significant features. As seen in the 2 and 10 m topographic feature maps (Figures 19 and 20) the features within the topography are better defined. Since trends in the coastal environment tend to exist at
a larger scale, the use of a coarser resolution would be sufficient for comparison. The 10 m grid for example, would take up less storage space and require less processing time than that of a finer resolution.

Figure 17. Topographic Features 0.5m
Figure 18. Topographic Features 1m

Figure 19. Topographic Features 2m
Since the 1 m resolution is the original product of the LIDAR survey, where one elevation measurement was given for every square meter and the accuracy of the measurements are within ten centimeters, this resolution is best suited for volumetric comparison. Change detection in terms of net increase or decrease of volume would be most accurate at the 1 m resolution. The 1 m resolution however, would be problematic in the identification of the feature perimeters as the terrain at this resolution becomes too erratic.

The identification of coastal features would also be problematic at the 0.5 m resolution. The terrain is more irregular at this resolution as each 0.5 m cell represents an elevation value. Volumetric analysis would also not be recommended at the 0.5 m resolution. The values calculated for a finer resolution grid are only as precise as the
original input values. When converting to a finer resolution more cells are used to represent the surface. Although no new data is created, the original values must be interpolated and distributed among the cells. This creates a larger grid requiring more storage space and longer processing times.

Although the collection of laser surveys makes an attempt to measure the bare earth topography, the extent to which anomalies in the data affect the measurements should be compared. The existence of vegetation during the data collection may account for such anomalies and create erroneous measurements. As this method of data collection advances, a better understanding of these anomalies will allow for more control in modeling the true topographic surface.

The use of alternative resampling methods should also be explored. With regard to altering resolution a further understanding of the effects of data aggregation is necessary. Although not used in this research, TIN’s may provide a useful tool in surface modeling. Used as a control surface, additional surfaces at varying resolutions can be produced from the TIN.

As spatial techniques further develop to remotely represent the landscape closer to actual reality, particular attention should be paid to the use of the data. Measurement analysis versus mapping analysis can vary greatly especially in terms of developing methodologies. The use of fine resolution data for accurate measurements across the surface may suffice, whereas general trends over a surface can be lost.
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Appendix A-Elevation Grids
0.5 Meter Elevation
North End of Assateague Island National Seashore

Figure 21. LIDAR Derived Elevation Grids

Legend

- High Elevation
- Low Elevation

1:24,000
1 Meter Elevation
North End of Assateague Island National Seashore

1999

2001

Figure 22. LIDAR Derived Elevation Grids

Legend

\begin{itemize}
  \item \textbf{High Elevation} \hspace{1cm}
  \item \textbf{Low Elevation}
\end{itemize}

1:24,000
2 Meter Elevation
North End of Assateague Island National Seashore

Figure 23. LIDAR Derived Elevation Grids

Legend

<table>
<thead>
<tr>
<th>Color</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>High Elevation</td>
</tr>
<tr>
<td>Blue</td>
<td>Low Elevation</td>
</tr>
</tbody>
</table>

1:24,000
Figure 24. LIDAR Derived Elevation Grids

Legend

High Elevation

Low Elevation

1:24,000

10 Meter Elevation
North End of Assateague Island National Seashore
Appendix B-Difference Grids
0.5 Meter Difference Grid
North End of Assateague Island National Seashore

Figure 25. Difference Grid with NPS 1999 Shoreline
1 Meter Difference Grid
North End of Assateague Island National Seashore

Figure 26. Difference Grid with NPS 1999 Shoreline
Figure 27. Difference Grid with NPS 1999 Shoreline
10 Meter Difference Grid
North End of Assateague Island National Seashore

Figure 28. Difference Grid with NPS 1999 Shoreline
Appendix C-Slope Maps
0.5 Meter Slope
North End of Assateague Island National Seashore

Figure 29. Slope Surface

Legend
High Degree Slope
Low Degree Slope
1 Meter Slope
North End of Assateague Island National Seashore

Figure 30. Slope Surface
2 Meter Slope
North End of Assateague Island National Seashore

Figure 31. Slope Surface

Legend
- High Degree Slope
- Low Degree Slope

1:24,000
10 Meter Slope
North End of Assateague Island National Seashore

Figure 32. Slope Surface

Legend
- High Degree Slope
- Low Degree Slope

1:24,000
Appendix D-Slope Difference Maps
Figure 33. Slope Distribution

0.5 m Slope Change Distribution
North End of Assateague Island National Seashore
1 Meter Slope Change Distribution
North End of Assateague Island National Seashore

Figure 34. Slope Distribution
2 Meter Slope Change Distribution
North End of Assateague Island National Seashore

Figure 35. Slope Distribution

Slope Change Reclass
- No Change
- Slope Decrease
- Slope Increase

1:5,000
10 Meter Slope Change Distribution
North End of Assateague Island National Seashore

Figure 36. Slope Distribution
Appendix E-Hillshade Maps
0.5 Meter Hillshade
North End of Assateague Island National Seashore

Figure 37. Hillshade Surface
1 Meter Hillshade
North End of Assateague Island National Seashore

Figure 38. Hillshade Surface
2 Meter Hillshade
North End of Assateague Island National Seashore

Figure 39. Hillshade Surface
10 Meter Hillshade
North End of Assateague Island National Seashore

Figure 40. Hillshade Surface
This CD-ROM contains airborne-derived lidar elevation data ready for input into a wide range of image processing or geographic information systems (GIS). The data presented was processed using LaserMap Software developed by the United States Geological Survey, Center for Coastal and Marine Studies.

The raw data was obtained from NASA Wallops Flight Facility, collected by the Airborne Topographic Mapper (ATM) developed there. For more information on the ATM, please visit the website http://aol.wff.nasa.gov/aoltm.html

The data are referenced to the NAD-83 horizontal datum using the GRS-80 Ellipsoid, and NAVD88 vertical sea-level datum using the National Geodetic Survey's GEOID99 model. The observations from multiple swaths captured during several hours on a single day are merged together.

The data contained on this CD are the result of the Level 4 conversion to create large map tiles (of size 10km by 10km) at centimeter level accuracy with 1-meter resolution for visual interpretation and regional quantitative analysis. Each image is offset by 500, in order to accommodate the need for an unsigned-16 bit image. This data is written out in a standard geotiff format (with associated metadata information) so that it can be easily ingested in GIS packages for further analysis.

DISCLAIMER: THE DATA AND ASSOCIATED DATA FILES ON THIS CD-ROM ARE PROVIDED "AS IS," WITHOUT WARRANTY TO THEIR PERFORMANCE, MERCHANTABILITY, OR FITNESS FOR ANY PARTICULAR PURPOSE. THE ENTIRE RISK ASSOCIATED WITH THE RESULTS AND PERFORMANCES OF THE DATA IS ASSUMED BY THE USER.

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Appendix G- Processing Raw Data
**Processing Raw Data**

Upon the collection of LIDAR data further processing is required. The calibration of pre- and post-mission records and the applied coordinate system are considered Level 1 processing and require three additional processing steps. The dense collection of points is not immediately useable in modeling the topography. During the process of capturing spot locations of one or more flight passes, the orientation of the data is relative to the pass. Since LIDAR relies on overlapping swaths for full coverage of the study area the data points are collected relative to the flight, typically for beach mapping on a north-south to south-north heading (Figure 41). The ordering of the ground positions and a coordinate transformation are done in the Level 2 processing step. Level 3 processing provides a large gridded elevation map of full vertical and horizontal accuracy and is tiled using a 1-kilometer grid index (Nayegandhi, 2001). The Level 4 process tiles the grids to cover an area approximately 10 km by 10 km and converts the grid to an image map.
The Level 2 process in LaserMap sorts and distills the data sets to a more useable form without losing essential measurement information (Nayegandhi, 2001). Due to the density of the points collected by the LIDAR and the method of collection, the data must be sorted on a spatial scale and ordered in terms of ground position (Brock et al. 2002) (Figure 42). A “quicksort” algorithm in the Level 2 process of LaserMap combines the flight passes and ranks the order of consecutive point locations by the latitude and longitude in which the points were collected (Figure 43).
Also in the Level 2 process is the geo-referencing of the spot elevations converting the data to the North American Datum 1983 and North American Vertical Datum 1988 (NAD83/NAVD88) coordinate reference for horizontal and vertical datum respectively (Nayegandhi, 2001). The Level 2 pseudo-raster maintains the true horizontal and vertical accuracy of the elevation measurements (Brock et al. 2002).
The purpose of the Level 3 process is to efficiently grid the Level 2 data set to cover the geographic area without introducing loss in accuracy. The points within the Level 3 grid are extracted using the Delaunay Triangulation interpolation method (Nayegandhi, 2001) (Figure 44). Delaunay Triangulation divides the planar region into equilateral triangles connecting the sample points to its two nearest neighbors (Elko et al. 2002). Polygons are arranged around a point of influence and generate a sample point based on the value of neighboring points (DeMers, 1999). The polygons of the Delaunay Triangulation method interpolate the sample points of the vertices of the Voronoi diagram (defined as X, Y, Z) and produce a cell size of 1 m (Nayegandhi, 2001).
Level 3 processing also provides an option to increase the interpolated cell resolution to 2 m, 5 m and 10 m (Nayegandhi, 2001). In order to cover the entire region, 1 km square grid tiles are used to define the geographic extent within the actual survey area (Figure 45).
Although Level 3 processing retains the millimeter vertical accuracy of the original data, the data are still not in the appropriate format for visualization (Brock and Sallenger, 2001). The Level 4 process supports the 1 km Level 3 grid tiles that cover any irregular survey area and converts the grids to a viewable image format in 10 km x 10 km tiles. The corner points of one or more 10 km square map regions manually selected by an analyst are entered into LaserMap (Nayegandhi, 2001). The Level 4 module is able to read either whole or partial grid tiles from the Level 3 index and produce grids of the relative region (Brock et al. 2002). Typically the 10 km x 10 km tiles are wider than the LIDAR surveys. As a result, the Level 4 map tiles contain data outside the region of the actual study area. The additional data restricts file size and must be scaled from the millimeter vertical precision to centimeter vertical precision (Brock et al. 2002). This does not introduce any additional loss of precision since the LIDAR accuracy is approximately 10 centimeters (Nayegandhi, 2001).
A further process of Level 4 map tiles converts the data to the GeoTiff format. An extension of the TIFF format, the GeoTiff tag structure supports geodetically corrected data for geo-referencing in GIS software packages (Figure 46). The conversion to the GeoTiff format changes the Level 4 signed 16-bit integer and outputs the data with an offset as an unsigned 16-bit integer raster. The pre-defined offset is necessary to eliminate any negative values, which are not supported in an unsigned integer raster (Nayegandhi, 2001). For example an elevation value of -500 centimeters would be offset by adding 500 to the entire data set creating an unsigned zero value as the lowest value in the data.

![Figure 46. Level 4 10 km² GeoTiff Map Tile](source: Nayegandhi, 2001)

With the conversion of the Level 4 data set to the GeoTiff format the raster grids can be used in many GIS systems such as ERDAS Imagine and ESRI ArcInfo. The final map tiles are geo-referenced to a common geodetic coordinate, such as NAD83/NAVD88, used by many disciplines including that of coastal scientists, and maintain the vertical accuracy of the original LIDAR survey.
Appendix F - Results Matrix
## Results Matrix

### Spatial Change

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Erosion</th>
<th>Deposition</th>
<th>Net Change</th>
<th>Positive</th>
<th>Negative</th>
<th>No Change</th>
<th>Figures</th>
<th>Figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>.5m</td>
<td>-587787</td>
<td>223606</td>
<td>-5654272</td>
<td>43.97%</td>
<td>53.48%</td>
<td>2.54%</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>1m</td>
<td>-4926486</td>
<td>232431</td>
<td>-4694055</td>
<td>44.37%</td>
<td>53.90%</td>
<td>1.17%</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td>2m</td>
<td>-1837848</td>
<td>188361</td>
<td>-1649488</td>
<td>43.90%</td>
<td>52.08%</td>
<td>3.99%</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>10m</td>
<td>-771463</td>
<td>163146</td>
<td>-608317</td>
<td>43.40%</td>
<td>52.70%</td>
<td>3.80%</td>
<td>16</td>
<td>20</td>
</tr>
</tbody>
</table>

### Volumetric Change (m³)

<table>
<thead>
<tr>
<th>Resolution</th>
<th>.5m</th>
<th>1m</th>
<th>2m</th>
<th>10m</th>
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<tbody>
<tr>
<td>Erosion</td>
<td>-587787</td>
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<td>-771463</td>
</tr>
<tr>
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<td>232431</td>
<td>188361</td>
<td>163146</td>
</tr>
<tr>
<td>Net Change</td>
<td>-5654272</td>
<td>-4694055</td>
<td>-1649488</td>
<td>-608317</td>
</tr>
</tbody>
</table>

### Volumetric Change

![Volumetric Change Diagram](image)

### Percent of Cells that Changed in Elevation

![Percent of Cells Diagram](image)

### Slope Resolution Comparison

#### Year 1999

<table>
<thead>
<tr>
<th></th>
<th>.5 meter</th>
<th>1 meter</th>
<th>2 meter</th>
<th>10 meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 degree slope</td>
<td>81.22%</td>
<td>67.66%</td>
<td>69.13%</td>
<td>44.80%</td>
</tr>
<tr>
<td>&gt;0 to 45 degree</td>
<td>14.02%</td>
<td>31.73%</td>
<td>30.86%</td>
<td>55.20%</td>
</tr>
<tr>
<td>&gt;45 to 75</td>
<td>4.75%</td>
<td>0.60%</td>
<td>0.01%</td>
<td>0.00%</td>
</tr>
<tr>
<td>&gt;75</td>
<td>0.01%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

#### Year 2001

<table>
<thead>
<tr>
<th></th>
<th>.5 meter</th>
<th>1 meter</th>
<th>2 meter</th>
<th>10 meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 degree slope</td>
<td>84.22%</td>
<td>71.03%</td>
<td>70.12%</td>
<td>43.42%</td>
</tr>
<tr>
<td>&gt;0 to 45 degree</td>
<td>11.48%</td>
<td>28.28%</td>
<td>29.87%</td>
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<tr>
<td>&gt;45 to 75</td>
<td>4.28%</td>
<td>0.68%</td>
<td>0.01%</td>
<td>0.00%</td>
</tr>
<tr>
<td>&gt;75</td>
<td>0.01%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

0% = no cells in classification

### Slope Maps

- .5m: 22
- 1m: 23
- 2m: 24
- 10m: 25

### Slope Distribution Maps

- .5m: 26
- 1m: 27
- 2m: 28
- 10m: 29

### Hillshade Maps

- .5m: 30
- 1m: 31
- 2m: 32
- 10m: 33