CREATION OF HIGH RESOLUTION, PRECISE DIGITAL ELEVATION MODELS OF OCEAN CITY AND ASSATEAGUE ISLAND, MD

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ABSTRACT

Researchers of NASA's GSFC are currently developing a scanning airborne photon-counting laser altimeter. This paper summarizes the creation of high resolution, precise DEMs from repeat passes of airborne laser scanning surveys to validate this new system. To study coastal erosion several sections of the Atlantic and Pacific coast have been mapped by NASA's Airborne Topographic Mapper (ATM) conical scanning altimeter. We selected two 5 km long and about 1 km wide stretches of the coast in Maryland to create precise Digital Elevation Models. One site is urban area (southern Ocean City) and the other is characterized by coastal marshes and beaches (northern Assateague Island). To obtain a dense data set, we combine laser altimetry data from 21 swaths acquired in 4 different missions. Laser points over planar surfaces, such as flat roofs and parking lots were analyzed to check the the repeatibility of the measurements. The absolute accuracy of the laser scanning was assessed by comparing surfaces extracted from the laser point cloud with GPS and photogrammetry results. These studies confirm the 0.1-0.2 m vertical and submeter horizontal accuracy of the ATM system. At the heart of the interpolation procedure is a bilinear interpolation that determines the surface elevation at the grid posts from planes fitted through the points located within 2 m by 2 m grid cells. Outlier observations are detected by using a robust estimator. The residual of the plane fitting and the uniformity of the distribution of the observations within the grid cells are used to assess the accuracy of the DEM. These parameters suggest an accuracy of 0.3 m or better for 90.4 % of the DEM points on the urban area, and 48.5 % of the points have an accuracy of 0.1 m or better. Similar accuracy is achieved on the site covered by natural vegetation on Assateague Island.

1 Introduction

NASA GSFC is currently developing a photon-counting laser scanning system, capable of daylight operations from altitudes of 6-12 km ([Degnan01]). The nominal footprint size of the system is 0.5-1 meter. This report summarizes the creation of a DEM from airborne laser scanning data over the Ocean City-Assateague area to validate this new system. The area is well suited for laser altimetry calibration purposes, because of its proximity to NASA Wallops Flight Facility and the repeat laser altimetry coverage during 1996-1999.

2 Study Site and Data Acquisition

To study coastal erosion several sections of the Atlantic and Pacific coast have been mapped by NASA's Airborne Topographic Mapper (ATM) laser system ([Sallenger99] and [Krabill99]). The ATM conical laser scanning system was developed by NASA's Arctic Mapping group from the Goddard Space Flight Center's Wallops Flight Facility to measure surface elevation changes of the Greenland ice sheet as part of NASA's Global Climate Change program ([Krabill95], [Krabill00]).

The main sensor of the ATM-II system is a Spectra Physics TFR (Tightly Folded Resonator) laser transmitter that provides a 7 nsec wide, 250 mJ pulse at frequency-doubled wavelength of 523 nm in the blue-green spectral region. The laser beam of the ATM is reflected toward the surface by a nutating mirror that has adjustable off-nadir settings of 5, 10 and 15 degrees. The scan mirror is spun at 10 or 20 Hz, producing a series of overlapping spirals of data points as the aircraft moves forward. For the missions used in this study the pulse rate was selected to 3,000 or 5,000 Hz. The nominal operating altitude of 600 m lead to an illuminated footprint size of approximately 1.5 m on the ground. The laser altimeter suite, which also includes geodetic GPS receivers and an INS unit is mounted on NASA's P-3 aircraft. A vertical accuracy of better than 10 cm has been achieved by the ATM system on polar ice sheets and coastal beaches (for example [Krabill00], [Krabill99]) and preliminary studies indicated submeter horizontal accuracy ([Schenk99]).

To create precise Digital Elevation Models for the Microlaser altimeter calibration we selected two 5 km long and about 1 km wide stretches of the coast in Maryland (Figure 1). The northern site covers part of Ocean City. Ocean City occupies a a barrier island with high-rise buildings on the east and residential areas on the west side. Along the east coast are a number of sandy beaches while harbors and docks are found on the west coast (Figure 3.d). Our southern test site comprises the coastal marshes and beaches of Assateague National Seashore Beach on northern Assateague Island.

The most important technical parameters of the 21 laser altimeter survey flights used in this study are summarized in Table 1. These surveys were primarily flown as functionality checks prior to conducting polar or beach mapping missions. Interested researchers can obtain the data acquired on April 25 and 30, 1997, through ISPRS WG III/6. Since large scale aerial photography and multispectral data was also collected at the same time, the combined data set is frequently used for accuracy and data fusion studies (for example [Schenk99], [Csatho99], [McIntosh99]).

3 Accuracy of laser scanning data

The accuracy of the ATM system has been rigorously evaluated by comparison with surface elevations obtained by ground GPS surveys and photogrammetry ([Csatho98], [Schenk99]). These studies confirmed the 0.1-0.2 m vertical and submeter horizontal accuracy of the ATM system ([Krabill00]).

Prior to the DEM generation we examined the data sets for unremoved bias between the different laser surveys. First planar, horizontal surfaces, such as parking lots and flat roofs were identified on the aerial photographs. Then the parameters of the planar surface patches were estimated from each laser survey. The excellent agreement between the plane parameters suggests that there is no bias between the different surveys. A random elevation error of 8 cm (RMS) is indicated by the residuals of the plane fitting.

4 Generation of Digital Elevation Models

The DEMs cover the southern 5 km of Ocean City and the northern 5 km of the Assateague Island (Figure 1). Each area contains more than 2 million irregularly distributed points with an average point density of 1.5 points/m^2.

At the heart of the interpolation procedure is a bilinear interpolation that determines the surface elevation at the grid posts from planes fitted through all points within the 2 m by 2 m grid cells. Outlier observations are detected by using a robust estimator, the Least Median of Squares (LmedS) technique ([Köster00]). This approach provides a robust model estimate in data sets with up to 50 percent of the data heavily corrupted by outliers and it also performs well for small data sets. The residual of the plane fitting and the uniformity of the distribution of the observations within the grid cells are used to assess the accuracy of the DEM. Nearest neighbor interpolation is used if the number of observations is not sufficient for plane fitting or if their distribution is not isotropic enough.

Each grid post is classified into one of the following categories:

- PLANE IN 10 (label:0)
  Elevation is interpolated by fitting planes through points that are distributed in at least 3 quadrants. All residuals are less than 10 cm.
- PLANE IN 30 (label:1)
  Elevation is computed by plane fitting interpolation. Points are distributed in at least 3 quadrants. All residuals are between 10 and 30 cm.
- PLANE B IN 10 (label:2)
  Elevation is computed by plane fitting interpolation. Points are distributed in at least 3 quadrants. Blunders are detected and removed by using LmedS before plane fitting. All residuals (except blunders) are less than 10 cm.
- PLANE B IN 30 (label:3)
  Elevation is computed by plane fitting interpolation. Points are distributed in at least 3 quadrants. Blunders are detected and removed by using LmedS before plane fitting. All residuals (except blunders) are between 10 and 30 cm.
- PLANE TH (label:4)
  Elevation is computed by plane fitting. Points are distributed in at least 3 quadrants. There is at least onw observation with a residual larger then 30 cm.
- NN IN (label:5)
  Elevation is computed by using nearest neighbor interpolation. There are not enough observations for plane fitting (less than 6 points) or the distribution of points is not sufficient (points in one or two quadrants only). The distance between the grid post and its nearest neighboring point is smaller than 1/3 cell size (0.6 m).
- NN DIST (label:6)
  Elevation is computed by using nearest neighbor interpolation. There are not enough observations for plane fitting (less than 6 points) or the distribution of points is not sufficient (points in one or two quadrants only). The distance between the grid post and its nearest neighbor is larger than 1/3 cell size.
- NA (label:7)
  No elevation is computed. There are no points within the DEM cell.
- NN OUTRANGE (label:8)
  Elevation is computed by using nearest neighbor interpolation. Although the number of points and their distributions sufficient, the z value estimated by fitting a plane is larger than the predefined elevation range of [-50m, 50m]. These points are usually on object boundaries.

Figure 2.a-b depicts the Ocean City DEM as color-coded imagery and an aerial photograph of the southern part of the DEM is shown in Figure 3.d.

5 Evaluation of the DEMs

From the residuals of the plane fitting and the distribution of the laser points within the grid cells we infer an accuracy of 0.3 m or better for 90.4 % of the DEM points on the urban area, and 48.5 % of the points have an accuracy of 0.1 m or better. Similar accuracy is achieved on the site covered by natural vegetation on Assateague Island. Points in categories 4-8 have larger errors. For the sake of completeness these points are included in the original DEM (Figure 2.b), but a DEM including only the precise grid points is also created (Figure 2.a). This filtered DEM, which does not include the DEM points classified in categories 4-8, is used for most of the subsequent analysis, for example to compile the profiles in Figure 3.a-c.

Surface elevation profiles along extended, planar surface patches, such as roads indicate a random error of 0.03-0.04 m RMS for the DEM (Figure 3.a-b). Error propagation also confirms this accuracy:

$$\sigma_{\text{DEM}} = \frac{\sigma_L}{\sqrt{n}} = \frac{0.08\,\text{m}}{\sqrt{6}} = 0.033\,\text{m} \qquad (1)$$

where σ_L is the vertical error of the individual laser points and n is the number of laser points per grid cell.

The elevation profiles extracted from the DEM reveal many interesting details. Notice for example the small (0.2 m deep) depressions at several road crossings (numbered locations in Figure 3.a and 3.d). Roofs and outline of large buildings are depicted very accurately (Figure 3.c and 3.d). Building that are too small compared to the grid size are often distorted or neighboring buildings are merged.

The ATM data set has been acquired in the course of several years. Therefore errors can occur in the DEM on areas with significant surface elevation changes. Elevation changes effecting the DEM include surface erosion on the beach exceeding 0.5 m/year in several places, and new or demolished buildings. For example see the large tents set up for a fair on the southern tip of the island in April 1997 (Figure 3.d), which were not there during the subsequent flights. Comparison of the original and the filtered DEMs shows that large fitting errors occurs in this area (Figure 2.a-b).

6 Conclusion and future work

To validate NASA's microlaser altimeter we have compiled two DEMs covering a total of 7 km^2 on Ocean City and Assateague island. The interpolation is based on plane fitting in local neighborhood. Outlier observations are eliminated by a robust estimator evaluating the same local area. The accuracy of the elevations at the grid posts is derived by the goodness of the planar fit and the distribution of the laser data around the grid post. The resulted DEM is very suitable for calibrating the new laser system, since the estimated vertical accuracy is 0.3 m or better for 90.4 % of the DEM points on the urban area, and 48.5 % of the points have an accuracy of 0.1 m or better. This study is also very useful for research aiming at the automation of DEM generation from laser points in urban areas. The proposed procedure has several advantages. For example no domain knowledge is needed, and no manual thinning or editing is performed. Very accurate DEMs (absolute accuracy of 0.05 m or better) have several applications, for example precise mapping of drainage systems, neotectonic features, or road networks.

The main use of this DEM for the microlaser altimeter validation is to assess the accuracy of the the surface elevation. The combined laser and photogrammetry data set would also allow us to analyze the time-of-flight distribution of the photons measured by the microlaser altimeter. For example the microlaser altimeter footprints can be backprojected to the aerial images to determine the type of objects illuminated and their detailed structure ([Schenk01]). This will also allow to view the laser points stereoscopically for more detailed analysis.

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Figure 1. Location od DEMs: Ocean City S (dashed box) and Assateague Island N (solid box)

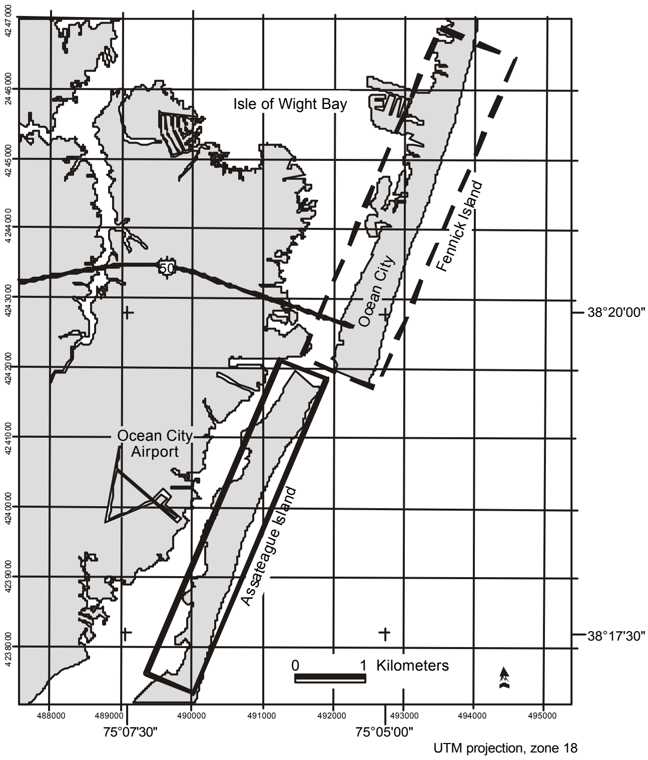

Figure 2.a Southern part of Ocean City S DEM. Grid cells with large error or uncertainty are masked (categories 4-8, black)

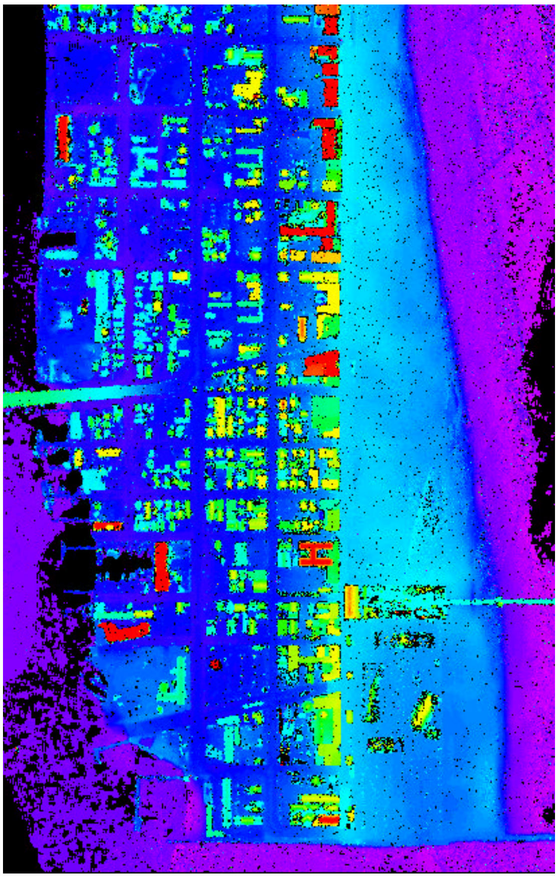

Figure 2.b Ocean City S DEM
Low elevations: blue
High elevations: red

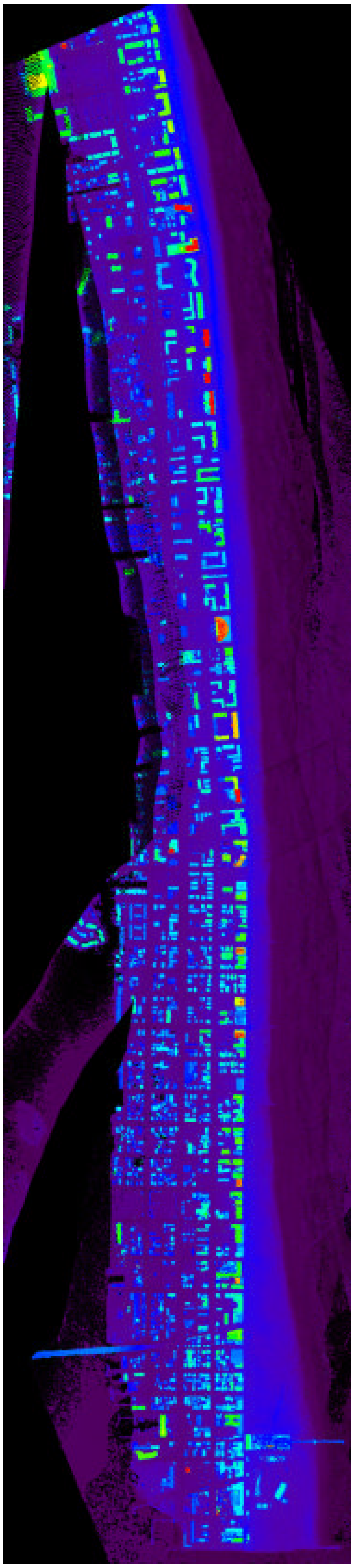

Table 1. Airborne Topographic Mapper surveys used for creating the DEMs

Date	Sensor	Frequency [Hz]	Scan frequency [Hz]	Distance along track [m]	Distance across track [m]	Swath width [m]	Number of missions	Density [points/m^2]
4/25/97	ATM-1	3000	20	5	5	300	4	0.15
4/25/97	ATM-II	3000	10	2	10	210	3	0.23
4/30/97	ATM-I	3000	20	5	5	300	2	0.15
4/30/97	ATM-II	3000	10	2	10	210	2	0.23
9/15/97	ATM-II	5000	20	4	3	310	2	0.18
10/01/99	ATM-II	5000	20	4	3	310	8	0.18

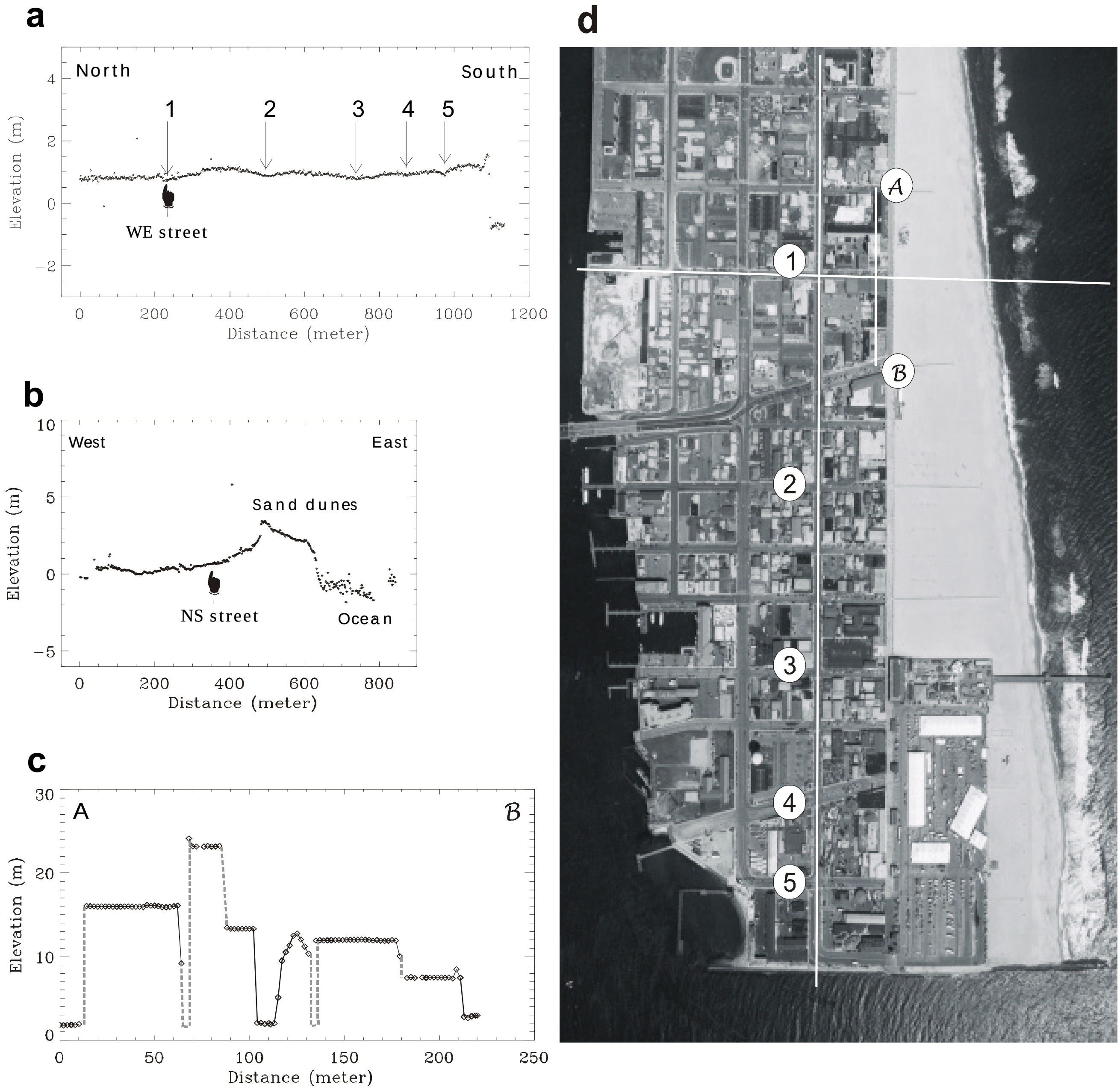

Figure 3. a-b Surface elevation profiles from DEM along streets, **3.c** Surface elevation profiles from DEM across high-rise buildings, **3.d** Aerial photograph of southern part of Ocean City. White lines show location of profiles in Figure 2.a-c.