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MANAGEMENT APPLICATIONS OF LIDAR-DERIVED MEAN HIGH WATER SHORELINES IN NORTH CAROLINA

Patrick W. Limber, North Carolina Division of Coastal Management
Jeffrey H. List, U.S. Geological Survey, Woods Hole Science Center
Jeffrey D. Warren, North Carolina Division of Coastal Management

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INTRODUCTION

The accuracy of shoreline change analysis is dependent on how the shoreline is defined and the consistency of the technique(s) used to define it. Using a concurrent lidar (light detection and ranging) and orthophotography dataset from August and September of 2004 covering North Carolina's 516 kilometers of barrier island oceanfront, Limber et al. (2007) examined the spatial relationship between two common shoreline definitions used in shoreline change analysis, mean high water [MHW] derived from lidar data and the wet/dry line digitized from orthophotography. Here, we summarize this work and extend the analysis with a comparison between two different methods of MHW shoreline extraction from lidar data: a profile-based method (Stockdon et al., 2002) and a method based on correction of the lidar data to a MHW datum (Hess et al., 2005). Potential bias generated by using these different shoreline types together can affect not only the accuracy of shoreline change analysis, but also the coastal management policies and decisions that rely on it. Therefore, the implications of this study potentially extend far beyond North Carolina and Atlantic Coast of the United States.

BACKGROUND

Every five to six years, the North Carolina Division of Coastal Management (DCM) calculates the State's oceanfront erosion rates, which have been required for the establishment of oceanfront development setbacks since 1979. Traditionally, the wet/dry line interpreted from aerial photography (e.g. Dolan et al., 1980; Martin, 1997; Overton and Fisher, 2003) has been used to delineate the shoreline and calculate long-term shoreline change rates. The wet/dry line is defined simply as the boundary observed on the beach between wet and dry sand and is affected by factors such as tides, wave run-up, sediment characteristics (e.g. grain size and permeability), and groundwater levels (Martin, 1997). These physical factors can affect the lateral stability of the wet/dry line (Dolan et al., 1980; Martin, 1997), and interpretations of the wet/dry line from aerial photography, as with other visual shoreline proxies, can vary due to the different skill or knowledge levels of the digitizers (Ruggiero et al., 2003). Such uncertainties can introduce error into shoreline change rates, as a given rate may reflect inconsistencies rather than a true measure of shoreline change (Ruggiero et al., 2003).

Recently, topographic lidar surveys have been used to generate shorelines based on the elevation of mean high water (MHW) calculated over an 18.6-year tidal epoch (e.g. Stockdon et al., 2002; Ruggiero et al., 2003; Moore et al., 2006). In contrast to the wet/dry line, MHW shorelines can shift only in response to sediment transport, and any

lateral instability due to wave run-up and/or tides, for example, is eliminated. Also, there is no interpretation necessary and the shoreline extraction procedure is relatively objective and repeatable. Currently, there are two general methodologies for deriving a MHW shoreline from lidar data: 1) a profile-based method employing a linear regression through scattered foreshore lidar elevations that generates a shoreline at an operational MHW elevation (Stockdon et al., 2002; Weber et al., 2005) and 2) a method of extracting a base topographic contour from a lidar digital elevation model (DEM) that has been vertically referenced to MHW using NOAA's VDatum software (explained below; Parker, 2003; Hess et al., 2005).

DCM is considering using lidar-derived, MHW-based shoreline positions in conjunction with existing wet/dry lines to populate its shoreline database. Accordingly, the degree of consistency between the two types of shoreline in North Carolina must first be tested so that any bias to shoreline change rates introduced by using two different shoreline indicators together, or as surrogates, can be quantified.

METHODS

Between 27 August and 3 September 2004, MD Atlantic Technologies (Huntsville, AL), under contract with the U.S. Army Corps of Engineers, collected a concurrent lidar and aerial photography dataset covering the entire 516 km-long ocean coastline of North Carolina. As described in Limber et al. (2007), a profile-based method similar to that presented by Stockdon et al. (2002) was used to extract a MHW shoreline. Every 20 m alongshore, a linear regression through a selected profile of scattered foreshore lidar data points was used to locate the intercept of a MHW elevation with the beach profile. Given a vertical accuracy of ±0.15 m for all data points (Sallenger et al., 2003), beach slopes were used to convert the vertical error into horizontal error. This term was then added in quadrature (i.e. the square root of the sum of the squares) to the 95% confidence interval of the MHW intercept on the regression line to produce a composite horizontal error estimate for each MHW data point. The elevation of MHW was determined using MHW zones for North Carolina mapped by Weber et al. (2005). (Note that "MHW shoreline" will hereafter refer to the statewide shoreline derived using the Stockdon et al. [2002] method unless otherwise noted).

A supplementary 81 km-long MHW shoreline was extracted from the lidar surveys along the North Carolina's northern Outer Banks (Nags Head study area) using NOAA's VDatum software (Hess et al., 2005) so that two different extraction methods could be compared. In contrast to the method described above, which is accomplished using MATLAB software, the VDatum method can be completed within a GIS framework. Because DCM does not currently have direct access to MATLAB (in this case, the MHW shoreline was produced through a DCM/USGS partnership), developing an acceptable method using existing GIS software (ArcGIS) would allow DCM to extract datum-based shorelines when needed in-house. In general, using ArcGIS, a lidar DEM that was vertically referenced to NAVD88 was converted to XYZ points and re-referenced to MHW using VDatum. These new points were then re-interpolated (using a triangular irregular network, or TIN), and the zero contour was extracted to represent the elevation

of MHW. VDatum is not yet available for the entire North Carolina coast (specifically all points south of Onslow Beach), so its statewide application was not possible in this study.

The wet/dry line was digitized from concurrent orthophotography. Several DCM personnel familiar with coastal processes interpreted the wet/dry line to ensure consistency. Eleven morphologically diverse study areas totaling a distance of 244 km were chosen in which to compare the horizontal positions of the wet/dry and MHW shorelines. All shoreline comparisons were made using ArcGIS 9 and the Digital Shoreline Analysis System (Thieler et al., 2005) with transects spaced 20 m alongshore.

RESULTS

Summarizing Limber et al. (2007), the wet/dry line was landward of the MHW shoreline by an average of 2.82 m (st. dev. = 5.31) over a distance of 244 km (positive numbers indicate the wet/dry line was landward of MHW). The mean landward offset varied by study area, reaching a maximum at Ocracoke Island (15.61 m) and a minimum at Oak Island (0.05 m). The variations in offset magnitude potentially were due to differences in beach slope between (and within) study areas and fluctuations in water level (i.e., tides and wave run-up) over the five days spanning concurrent lidar and aerial photo acquisition. Results suggest that beaches with lower slopes and/or higher water levels (at the time of photography) experienced greater offset (e.g. Ruggiero et al., 2003). The bias to long-term (42-71 years) end-point erosion rates caused by using the MHW shoreline instead of the wet/dry line ("rate shift") was on average 0.05 m/yr.

Comparisons conducted here between the different types of MHW showed that the VDatum MHW shoreline was landward of the MHW shoreline generated using Stockdon et al.'s (2002) technique by an average of 2.27 m (st. dev. = 0.71) and landward of the wet/dry line by an average of 1.62 m (st. dev. = 2.41).

DISCUSSION AND IMPLICATIONS

Several studies have previously addressed the relationship between the high water line (HWL; visible markings on the beach left by the previous high tide) and MHW. Results from these investigations showed that the HWL was found to be landward of MHW by approximately 50 m in Washington (Ruggiero et al., 2003), 18.8 m on Assateague Island (Maryland and Virginia; Moore et al., 2006), and 13.4 m in North Carolina (Pajak and Leatherman, 2002). Because the wet/dry line is located lower on the beach face than the HWL, the offsets and rate shifts presented in this paper are, on average, much less than in previous studies. This investigation suggests that in North Carolina, lidar-derived, datum-based shorelines can be used as a supplement to, or a substitute for, the wet/dry line with minimal bias to shoreline change rates. However, the importance of noting morphologic and oceanographic conditions at the time of photography cannot be understated when considering shoreline interchangeability.

As discussed above, there are two prevailing approaches to extracting a MHW shoreline from lidar data: the Stockdon et al. (2002) technique and NOAA's VDatum software. VDatum uses elevations that constantly vary alongshore from the current tidal epoch (1983-2001), averaging approximately 0.38 m (st. dev. = 0.01; relative to NAVD88) in

the study area. The Stockdon et al. (2002) shoreline uses a 0.26-m MHW elevation from the previous tidal epoch (1960-1978) that remains constant alongshore. Potentially, the mean 2.27 m horizontal offset between the different MHW shorelines generated from each of these methods is due to inconsistent MHW definitions. However, converting the 0.12 m vertical datum offset to a horizontal offset using mean beach slope from the study area (0.085) results in a difference of 1.41 m, not 2.27 m. To test for additional bias, a 0.26-m contour line derived from several NAVD88-referenced DEMs was compared to the 0.26-m Stockdon et al. (2002) shoreline. The contour line was landward of the MHW shoreline by an average of 0.59 m, which helps to explain the total 2.27 m offset. The cause of this offset is unclear, but because the same raw lidar dataset was used for each method, it is likely an artifact of the processing procedure used (i.e. gridding the raw data into DEMs versus linearly regressing the raw data to find the MHW intercept). Re-interpolating the DEM data points using a TIN after processing in VDatum (as discussed in the Methods section) could cause additional horizontal error; however, this merits further review.

Although the mean 2.27 m offset between the different MHW shorelines suggests that they are relatively analogous, the VDatum shoreline continuously reflects topography alongshore and was considerably noisier than the Stockdon et al. (2002) shoreline. In addition, it is more difficult to check the consistency and uncertainty of the VDatum shoreline than the MHW shoreline derived from the raw lidar data using Stockdon et al.'s (2002) profile-based statistical method.

With several lidar datasets spanning the past 10 years available for North Carolina coast, the potential exists for DCM to augment its existing shoreline database (predominantly wet/dry shorelines) with MHW-based shorelines. Analysis of a more complete time series including both MHW and wet/dry shorelines will allow for the identification of short-term fluctuations that currently cannot be resolved using a long-term end-point approach. A better understanding of shoreline trends will help identify shoreline response to coastal processes (natural and anthropogenic) and create additional tools for coastal policy development.

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Patrick Limber
NOAA Coastal Management Fellow
North Carolina Division of Coastal Management
1638 Mail Service Center
Raleigh, NC 27699-1638
(919).733.2293 ext251
patrick.limber@ncmail.net