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An automated approach for extracting Barrier Island morphology from digital elevation models

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ABSTRACT

The response and recovery of a barrier island to extreme storms depends on the elevation of the dune base and crest, both of which can vary considerably alongshore and through time. Quantifying the response to and recovery from storms requires that we can first identify and differentiate the dune(s) from the beach and back-barrier, which in turn depends on accurate identification and delineation of the dune toe, crest and heel. The purpose of this paper is to introduce a multi-scale automated approach for extracting beach, dune (dune toe, dune crest and dune heel), and barrier island morphology. The automated approach introduced here extracts the shoreline and back-barrier shoreline based on elevation thresholds, and extracts the dune toe, dune crest and dune heel based on the average relative relief (RR) across multiple spatial scales of analysis. The multi-scale automated RR approach to extracting dune toe, dune crest, and dune heel based upon relative relief is more objective than traditional approaches because every pixel is analyzed across multiple computational scales and the identification of features is based on the calculated RR values. The RR approach out-performed contemporary approaches and represents a fast objective means to define important beach and dune features for predicting barrier island response to storms. The RR method also does not require that the dune toe, crest, or heel are spatially continuous, which is important because dune morphology is likely naturally variable alongshore.

1. Introduction

The response and recovery of a barrier island to extreme storms depends on the elevation of the dune base and crest, both of which can vary considerably alongshore and through time (Houser et al., 2008, 2015; Houser and Mathew, 2011). Based on the storm impact model of Sallenger (2000), the impact of elevated storm surge depends on the ratio of the total water level elevation (tide + storm surge + wave run-up) to the elevation of the dune base and crest. Even a weak hurricane or tropical storm can overwash or inundate low elevation dunes, moving sediment to the back of the island where it is unavailable for dune recovery. Conversely, larger dunes are scarped and the sediment is transported to either the beach or the nearshore, where the eroded sediment is eventually returned to the beach through the landward migration and welding of the innermost nearshore bars. Nearshore bar welding creates a beach with sufficient volume and fetch to initiate dune recovery, assuming dune-building vegetation is present in sufficient density and extent (Houser et al., 2015). Whereas erosion of the beach and dune occurs over hours and days, it can be years to decades before the beach and dune are able to recover to their pre-storm state (Houser et al., 2015). Quantifying the response to and recovery from storms requires that we can first identify and differentiate the dune(s) from the beach and back-barrier, which in turn depends on accurate identification and delineation of the dune toe, crest and heel. Predicting the resiliency of barrier islands to changes in sea level and storminess ultimately depends on our ability to estimate the rate of post-storm dune recovery.

LiDAR-derived digital elevation models (DEMs) are increasingly used to assess the response and recovery of barrier islands to elevated storm surge, but there are no simple morphometric definitions for the beach and dune. Additional information about more general theory and application of geomorphometry to characterizing features can be found in Dragut and Eisank (2011, 2012), Evans (2012), Fisher et al. (2004) and Matsuura and Aniya (2012). Contemporary methods for extracting morphological features from LiDAR data include visual interpretation from aerial and satellite imagery (*e.g.* Fletcher et al., 2011; Hapke et al., 2010; Lentz and Hapke, 2011), manually adjusting a series of inflection points derived from smoothed topographic shore-normal transects (*e.g.* Stockdon et al., 2007, 2009), and least-cost flow path (LCP) algorithm (Mitasova et al., 2011). Each approach is based on a different definition of the dune base and dune crest (Table 1), which affects estimates of the dune height and volume. Since the development of coastal dunes depends on the ability of vegetation to trap sediment transported landward from the beach by the wind, it is reasonable to assume that the boundary between the beach and dune is associated with

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Table 1
Traditional definitions of the "dune toe" and "dune crest".

	Dune toe	Dune crest
Lentz and Hapke (2011)	"Delineated from elevation and slope changes observed landward of the berm"	"Traced using the maximum elevation of the seaward-most dune crest"
Stockdon et al. (2009), Stockdon et al. (2007)	"The location of maximum slope change within a region around a coarsely digitized line"	"Highest-elevation peak, where the slope changes sign from positive (landward facing) to negative (seaward facing)" "Highest elevation peak landward of the shoreline and within a user-defined beach width"
Mitasova et al. (2011), Mitasova et al. (2009)	"The location where the beach meets the foredune" "The location where the cross-shore profile deviates the most from a line connecting the dune ridge and shoreline"	"The least cost path between two given end points of the ridge"

a change in slope that is dependent on the seasonal pattern of vegetation growth and beach and dune erosion and scarping over a sequence of storm events.

A common approach to feature identification is to reduce a DEM to a series of smoothed shore-normal transects, and identify inflection points based on the change from positive slope gradient to negative slope gradient (Stockdon et al., 2007, 2009). The inflection points are interpreted as the dune crest position for a given transect and the dune crest line is extracted by manually connecting and adjusting the series of inflection points. The degree of smoothing directly affects the identified location of the dune crest. The results of this method are significantly limited by the transect spacing and the location of transects, as the morphometry of dune crests can change continuously alongshore. Data in the areas between the shore-normal transects is neglected from any analysis, which generates error and uncertainty. For example, a transect spacing of 1 m will yield a different result than a 5 m or 10 m spacing, depending on the natural variability of the beach and dune morphology. After an automated algorithm has determined the dune crest points from every cross-shore profile, the points are manually edited in order to "*eliminate occasional dune picks associated with spurious LiDAR points*" (p. 61 Stockdon et al., 2009). Manual editing of the extracted points can be time-intensive, requires *a-priori* knowledge of the local morphology, and injects subjectivity into the extracted location of the dune crest line.

The LCP approach can be used to identify the dune crest and dune toe by utilizing a LCP algorithm to connect two "given endpoints" (Mitasova et al., 2011). The cost function of Mitasova et al. (2011) is computed as:

$$J = e^{-bz} \tag{1}$$

where J is the cost of traversing a cell, z is the elevation of the cell, and b is a tunable parameter. There is no information on how this tunable parameter is determined or how an appropriate value is determined. Absent from this method is a clear and objective method to identify the endpoints, which are likely to come from subjective manual interpretation of the DEM or a similar data source. Another drawback to the LCP approach is its inability to identify the trailing edge of the dune (*i.e.*, dune heel), which is important for calculating dune volume. These different methods for extracting dune morphology are time-intensive for large study areas, depend heavily on the scale of analysis, and/or do not provide a means to extract the dune heel.

The purpose of this paper is to introduce a multi-scale automated approach for extracting beach, dune (dune toe, dune crest and dune heel), and barrier island morphology. The automated approach introduced here extracts the shoreline and back-barrier shoreline based on elevation thresholds, and extracts the dune toe, dune crest and dune heel based on the average relative relief (RR) across multiple spatial scales of analysis. This approach to feature extraction is not subject to error due to DEM smoothing, visual interpretation, arbitrary cost-function parameterization, and takes into account information across multiple computational scales. The effectiveness of this approach to extract coastal features and metrics is demonstrated using a LiDAR-derived DEM for a portion of North Padre Island, Texas, USA (Fig. 1) because this section of North Padre Island exhibits considerable alongshore variability in dune morphology. The sample DEM used in this paper is simply meant to demonstrate that beach, dune and barrier island features can be extracted using an automated approach in an area with variable dune morphology.

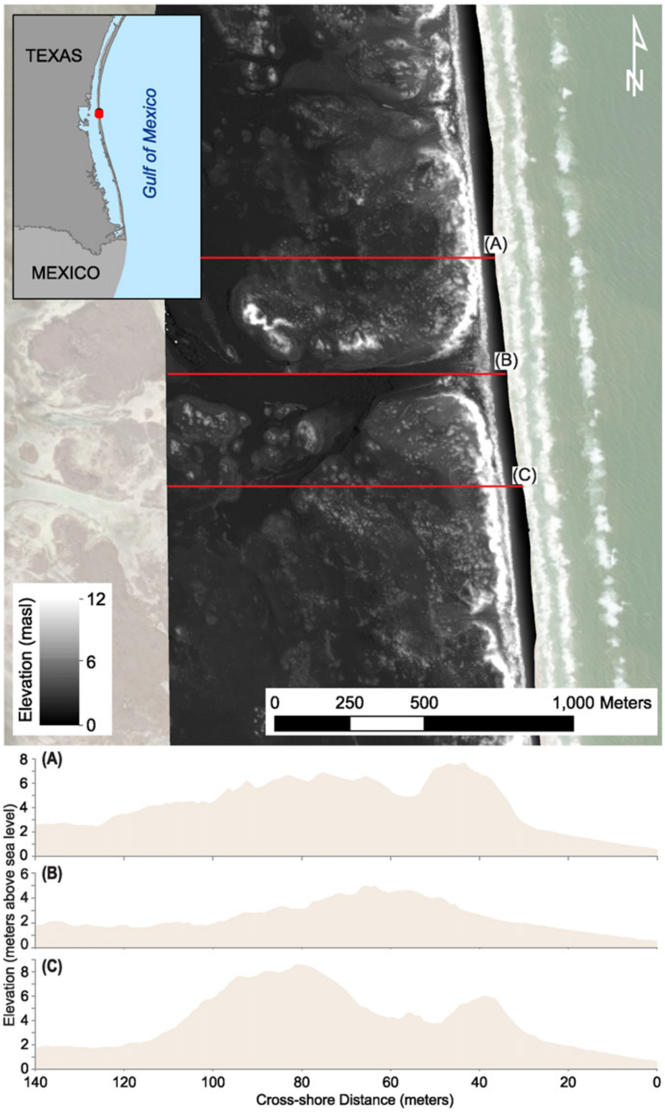

Fig. 1. The case study for the presented software is located approximately 70 km south of Corpus Christi, TX and is situated on North Padre Island between the Gulf of Mexico and Laguna Madre (inset map). The DEM clearly exhibits a highly variable morphology with a washover channel in the northern portion of the DEM.