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# Deconstructing a polygenetic landscape using LiDAR and multi-resolution analysis

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ABSTRACT

It is difficult to deconstruct a complex polygenetic landscape into distinct process-form regimes using digital elevation models (DEMs) and fundamental land-surface parameters. This study describes a multi-resolution analysis approach for extracting geomorphological information from a LiDAR-derived DEM over a stabilized aeolian landscape in south Texas that exhibits distinct process-form regimes associated with different stages in landscape evolution. Multi-resolution analysis was used to generate average altitudes using a Gaussian filter with a maximum radius of 1 km at 20 m intervals, resulting in 50 generated DEMs. This multi-resolution dataset was analyzed using Principal Components Analysis (PCA) to identify the dominant variance structure in the dataset. The first 4 principal components (PC) account for 99.9% of the variation, and classification of the variance structure reveals distinct multi-scale topographic variation associated with different process-form regimes and evolutionary stages. Our results suggest that this approach can be used to generate quantitatively rigorous morphometric maps to guide field-based sedimentological and geophysical investigations, which tend to use purposive sampling techniques resulting in bias and error.



## 1. Introduction

There are numerous stabilized aeolian landscapes scattered throughout central North America ranging in size from localized patches of dunes on abandoned fluvial terraces in Oklahoma (Cordova et al., 2005; Lepper and Scott, 2005), to large continuous sand seas such as the Nebraska Sand Hills (Loope and Swinehart, 2000; Mason et al., 2004) and the South Texas Sand Sheet (Houser et al., 2015). Periods of aeolian instability (characterized by active dune migration) and stabilization occurred throughout the Holocene in response to complex changes in climate and vegetation (Madole, 1994; Cook et al., 2004; Halfen and Johnson, 2013). This results in a polygenetic landscape characterized by a mosaic of ephemeral streams and ponds, interdune wetlands, silt and dust deposits, and relict and active sand dunes (Fig. 1; Fulbright et al., 1990; Forman et al., 2001). Historical patterns of erosion and deposition have resulted in a complex geological framework that affects evolution of the modern surface by altering local hydrology, vegetation cover, and sediment transport, such that certain portions of the sand sheet represent zones of aeolian erosion, aeolian deposition, and non-aeolian hydrological dynamics and vegetation succession (see Fulbright et al., 1990; Fay et al., 2008; Houser et al., 2015). The diverse process-form regimes define a surface morphology that is partially inherited; areas with a prolonged aeolian or hydrological control tend to remain that way, resulting in unique topography representing aeolian or non-aeolian regimes. Piecing together localized histories of activation and stabilization is crucial for understanding how these systems have evolved in response to changes in the climate through the Holocene (e.g., Woodhouse and Overpeck, 1998; Hugenholtz and Wolfe, 2005a; Sridhar et al., 2006; Xiadong et al., 2007; Mason et al., 2009), and how they may react to future changes in climate (Muhs and Volliday, 1995; Thomas et al., 2005; Thomas and Wiggs, 2008; Thorpe et al., 2008; Ashkenazy et al., 2012; Bhattachan et al., 2014). Characterizing multi-scale topographic variation associated with historical process-form regimes is required to map polygenetic landscape evolution (Bishop et al., 2012).

Studies of aeolian landscape evolution over the Holocene rely on the collection of sediment cores that are analyzed for characteristic texture and geochemistry, representing previous stages in the evolution of a system (i.e., arid/humid or stabilized/activated). Selection of sampling sites introduces bias and error, unless the sampling is done in a manner that is reflective of the underlying geological and geomorphological framework that causes spatial autocorrelation. Without a significant number of appropriately spaced samples, assumptions of continuity across a landscape may not hold true. For example, collecting core samples at the floor of a buried interdune surface versus an active dune will reflect different histories. A number of studies have investigated

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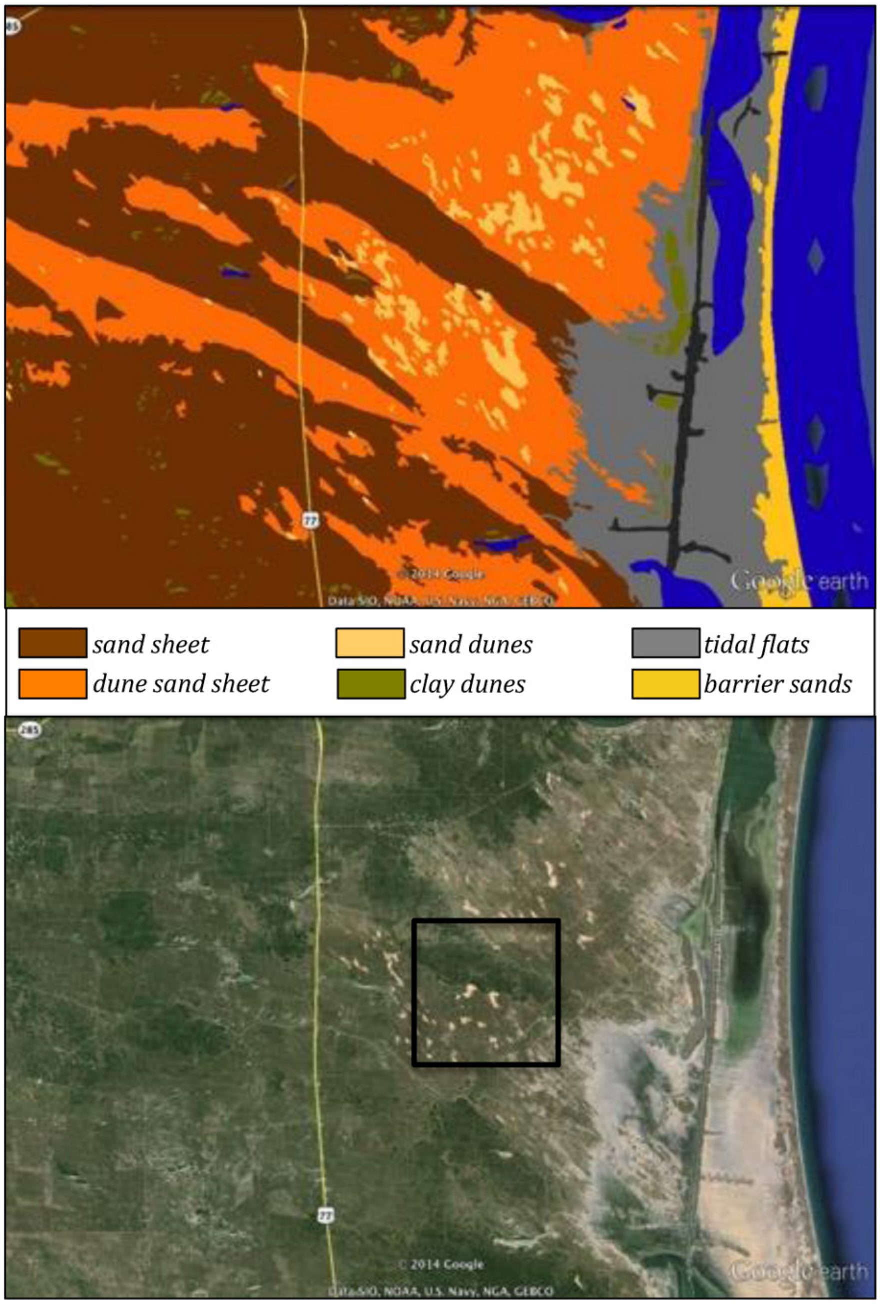


**Fig. 1.** Study area (in box) surficial geology (top; California Soil Resource Lab, 2014) and true-color imagery (bottom).

activation and stabilization histories in aeolian landscapes across central North America (Holliday, 1989; Muhs and Maat, 1993; Hugenholtz and Wolfe, 2005b; Forman et al., 2009; Telfer et al., 2010; Halfen and Johnson, 2013), and often must rely on sparse data from cores to generate landscape-scale histories. Previous research in South Texas has presented a limited selection of samples (e.g., 2 cores) and reveals valuable information about the ages of surface features across the sand sheet (Forman et al., 2001). However, research focused on correlating histories between cores can reveal disparate activation-stabilization histories across a single landscape (see Halfen and Johnson, 2013), and a number of studies have emphasized the shortcomings of field-based sampling vis-à-vis their difficulty in accounting for subsurface variations between samples (see Thomas and Wiggs, 2008; Telfer et al., 2010). Sedimentological data and dated soil samples are necessary to provide a detailed chronology of activation and stabilization at a single site, but a more rigorous methodology is needed to enable confidence in correlations between cores.

Deconstructing the land surface into characteristic process-form regimes can facilitate field sampling by reducing biases. Specifically, a quantitative methodology that links topographic variation to surface processes and permits mapping of process-form relationships could help to ensure an accurate interpretation and description of landscape evolution (Perron et al., 2008; Booth et al., 2009). This short communication describes the use of multi-resolution analysis on a LiDAR-derived digital elevation model, as part of an ongoing investigation into aeolian activation and stabilization dynamics of the South Texas Sand Sheet (STSS). Multi-resolution analysis is combined with Principal Components Analysis (PCA) to extract multi-scale topographic information that characterizes spatial variations in altitude and relief associated with different process-form regimes and polygenetic evolution.