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Final Project

Introduction

In the past, research in the field of geomorphology, or the study of landforms and the ways and processes by which they change, primarily involved direct measurement by means of surveying and other ‘on the ground’ data collection methods. Such methods, though labor-intensive, allowed for the study of rivers, hill slopes, sediment movement and erosion, for example, and allowed scientists to develop predictions of the past and future conditions of the landscape. In recent years, developments in technology have made capturing and analyzing landform data and modeling patterns of change much easier. One of these relatively new technologies is Light Detection and Ranging (LiDAR) data, collected by an airplane which sends out laser pulses and records when they return to obtain information on the terrain elevation. Multiple return LiDAR technology is able to record multiple reflected signals from the same initial laser pulse, which creates a point cloud that includes both returns from vegetation and the last, ‘bare earth’, return. Such data can then be used to create a Digital Elevation Model (DEM), generally using only the bare earth returns, or a Digital Surface Model (DSM), which includes all the returns, thus depicting the vegetation and structures on the surface as well.

New techniques for visualizing these DEMs and the features they contain are currently developing that move beyond traditional 2D maps and take advantage of 3D visualization software and animations. Scientists are applying these techniques to study landform change, especially in areas in which change happens quickly and more dynamically, such as coastal areas.

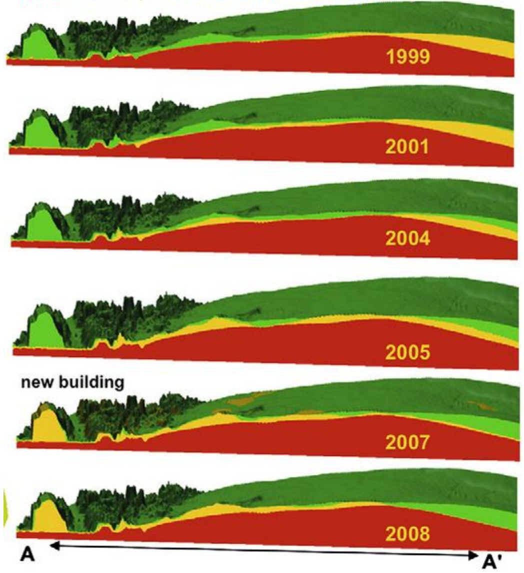
Literature Review

Dr. Helena Mitasova has conducted a variety of research on modeling landscape processes and changes in coastal topography, especially focused on the dunes of North Carolina barrier islands. In calculating and displaying her results she discusses novel methods of visualizing time-space data to show the evolution of 3D features over time.

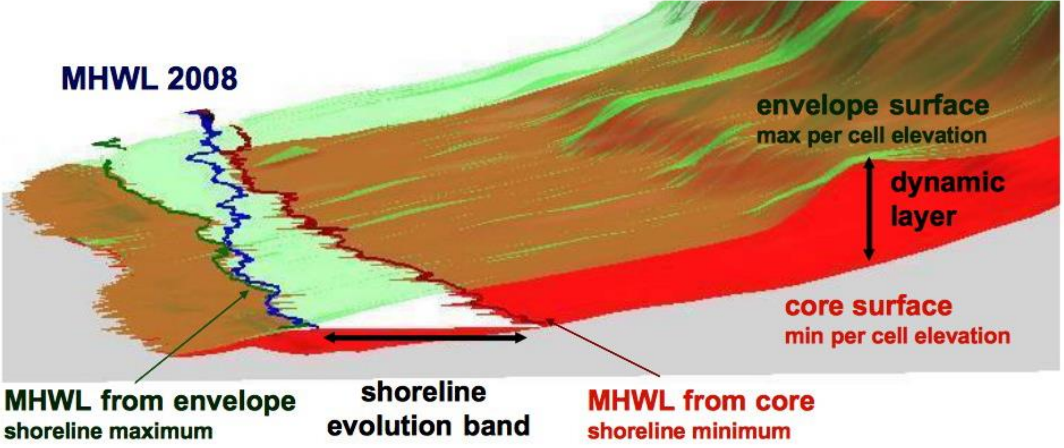
The analyses described in this review are done using the open source GIS Geographic Resources Analysis Support System (GRASS GIS), rather than ArcGIS, but many of the processes are transferable. However, GRASS GIS has more 3D analysis and visualization capabilities than ArcGIS. First, from LiDAR data, some method of interpolation is used to create raster DEMs for each year to be included in the study. A frequently used interpolation and smoothing method is a regularized spline with tension. From these rasters a wide range of statistics can be calculated and visualizations created. A few will be detailed here.

Some of the 2D maps that are often created include rates of elevation increase or decrease, the year within the time series of maximum or minimum elevation at each cell, and maps displaying houses that have been built or destroyed. All of these are created using raster calculator or cell statistics. More involved statistical calculations are also often performed and displayed, including linear regressions of the slope change and calculation of the standard deviation across the years of the study as a measure of variation in elevation.

A useful way of contextualizing the display of an individual year’s data is to calculate the dynamic layer defined by the core and envelope surfaces. The core surface is defined as the minimum elevation in each cell over the time period of the study. This is the layer below which the land did not move, and is calculated through cell statistics. The envelope surface is defined as the maximum elevation in each cell over the time period of the study. All changes to the topography therefore are contained within these two surfaces in the dynamic layer. A clear way of displaying this is through a cross-section of the 3D display of the core and envelope surfaces, within which the data for a particular year can be displayed to see where it fits into the multi-year picture. Such a cross-section can be generated for each year in the study and then animations can be created that allow for the visualization of where sediment is gained and lost over the time series, as displayed in this image, from Mitasova et al, 2012. Numerical data extracted from the dynamic layer can also be used, such as to calculate the volume of sand that has been displaced. The analysis of new and destroyed houses also used the depth of the dynamic layer as a means of determining where the elevation had changed by at least 10 feet to select areas in which houses might have been created or destroyed.



By extracting the contour for the mean high water level, the shorelines corresponding to the core and envelope surfaces can be extracted to delineate the shoreline evolution band, or the area within which the shoreline existed during the time period of the study. As with the cross-sections, individual yearly shorelines can be displayed within this band and then animated to show the water level change.



Data and Methodology

LiDAR point data was obtained from the USGS Center for Lidar Information Coordination and Knowledge (CLICK) web server. The data downloaded was collected for a strip of Southern California coastline from Dana Point to Point La Jolla, an area from just south of Irvine to just north of San Diego. The data analyzed in this project is one tile from three separate survey years – May 2002, April 2004, and March 2006. LAS data files were downloaded in UTM zone 11N North American Datum 1983 coordinate system with North American Vertical Datum 1988 (NAVD88) with units in meters.

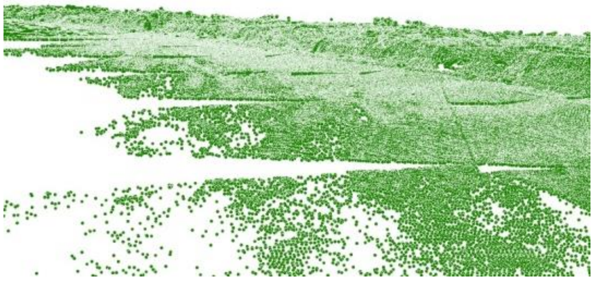
The ArcGIS programs ArcMap and ArcScene were used for all analysis and visualization. The LAS files were converted to Multipoint objects to import them into ArcMap. The points were interpolated to a raster DEM using Inverse Distance Weighting. The points from all returns were used, and a 5m grid was created. The rasters were masked to the footprint of the LiDAR data points.

From these three rasters, various additional rasters were derived. Core and envelope surfaces were created by taking the minimum and maximum elevation values, respectively, that occurred in each cell over the three years of data. The total depth of the dynamic surface at each cell was calculated by subtracting the core surface from the envelope surface. A raster of the total net change in elevation over the four year period was created by subtracting the 2006 values from the 2002 values.

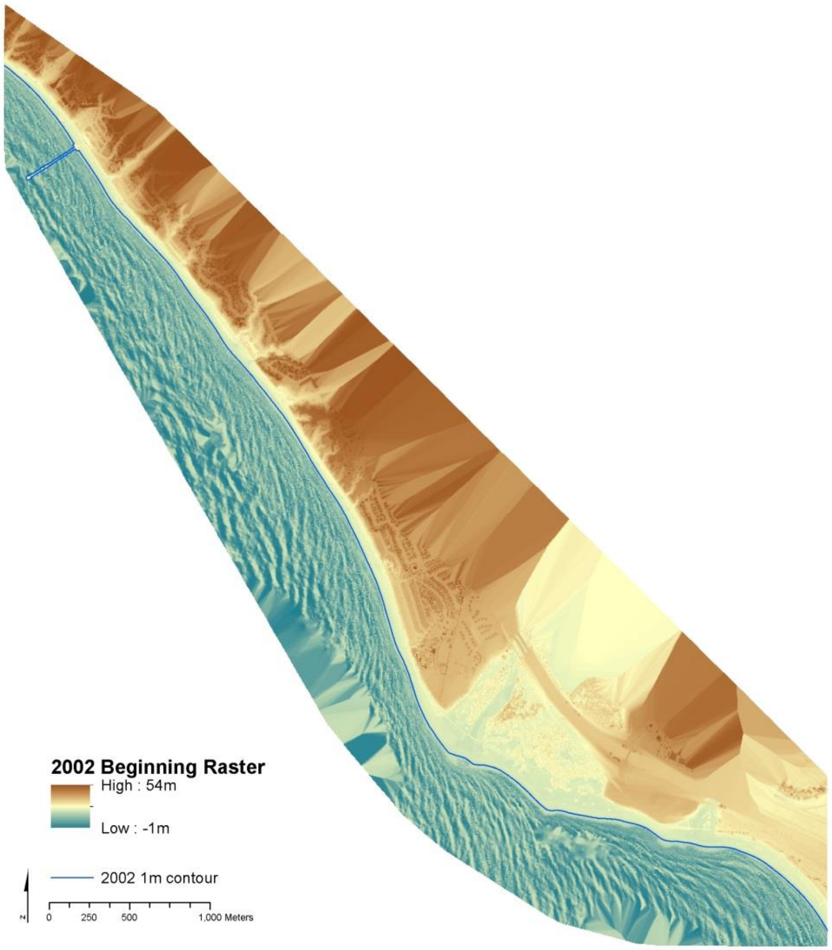
A contour was created at an elevation of one meter for each of the three years of data as well as for the core and envelope surfaces. This contour is estimated to represent the mean high water level. A one meter elevation was chosen visually from where the pier and other landmarks seemed to define a reasonable shoreline location. The contour of the core surface defines the minimum and the contour from the envelope the maximum of the shoreline evolution band.

The data was also examined in ArcScene by setting the base heights of the rasters to be the elevation values of their own cells, also refered to as draping the raster over itself. Contours were added to these 3D surfaces, draping them as well. ArcGIS does not have the same 3D visualization possibilities as GRASS GIS, and in particular there is no way to create cross sections of a 3D surface. In ArcMap, however, it is possible to extract 2D profiles of a raster by drawing a line on the surface and using the Profile Graph tool. 2D cross section was created by extracting the profiles of a variety of the surfaces.

Results



The LiDAR point data was visualized in 3D to make first cursory observations. There is a lower elevation further west near the ocean and then some hills and vegetation as well as residential areas further east.


2002 Beginning Raster
High : 54m
Low : -1m
2002 1m contour
N
0
250
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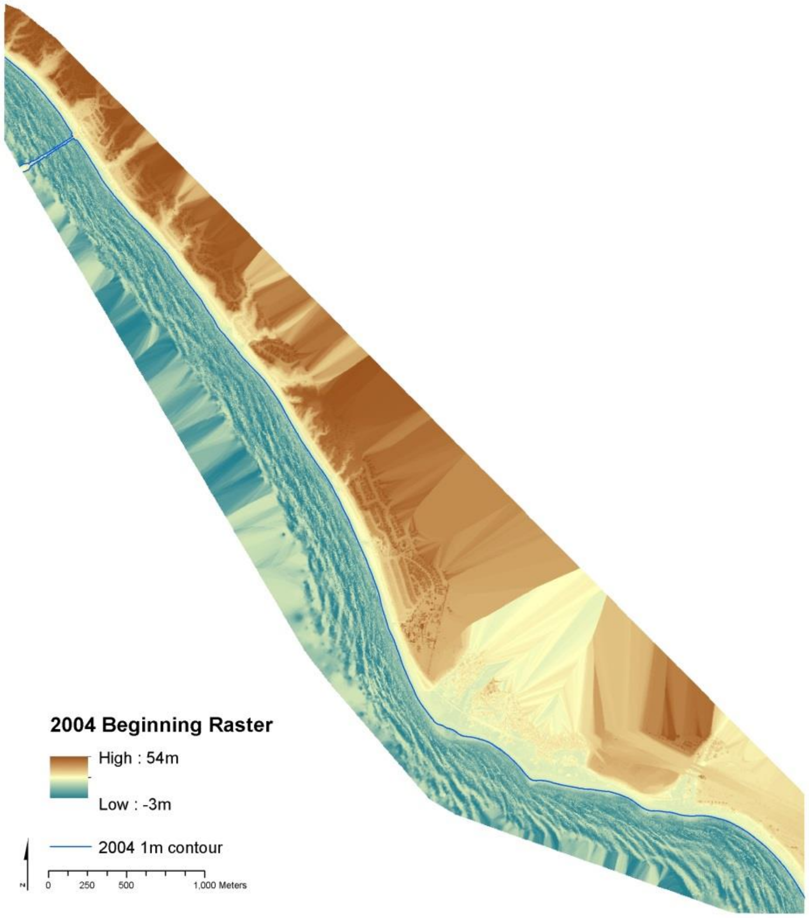
1,000 Meters


2004 Beginning Raster
High : 54m
Low : -3m
2004 1m contour
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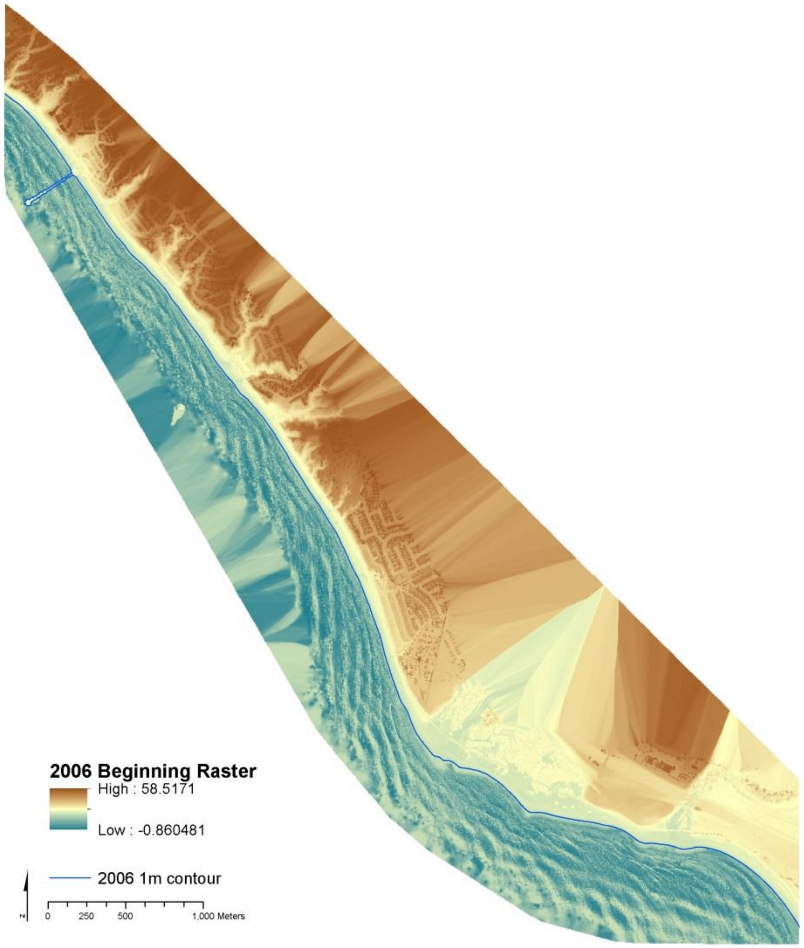
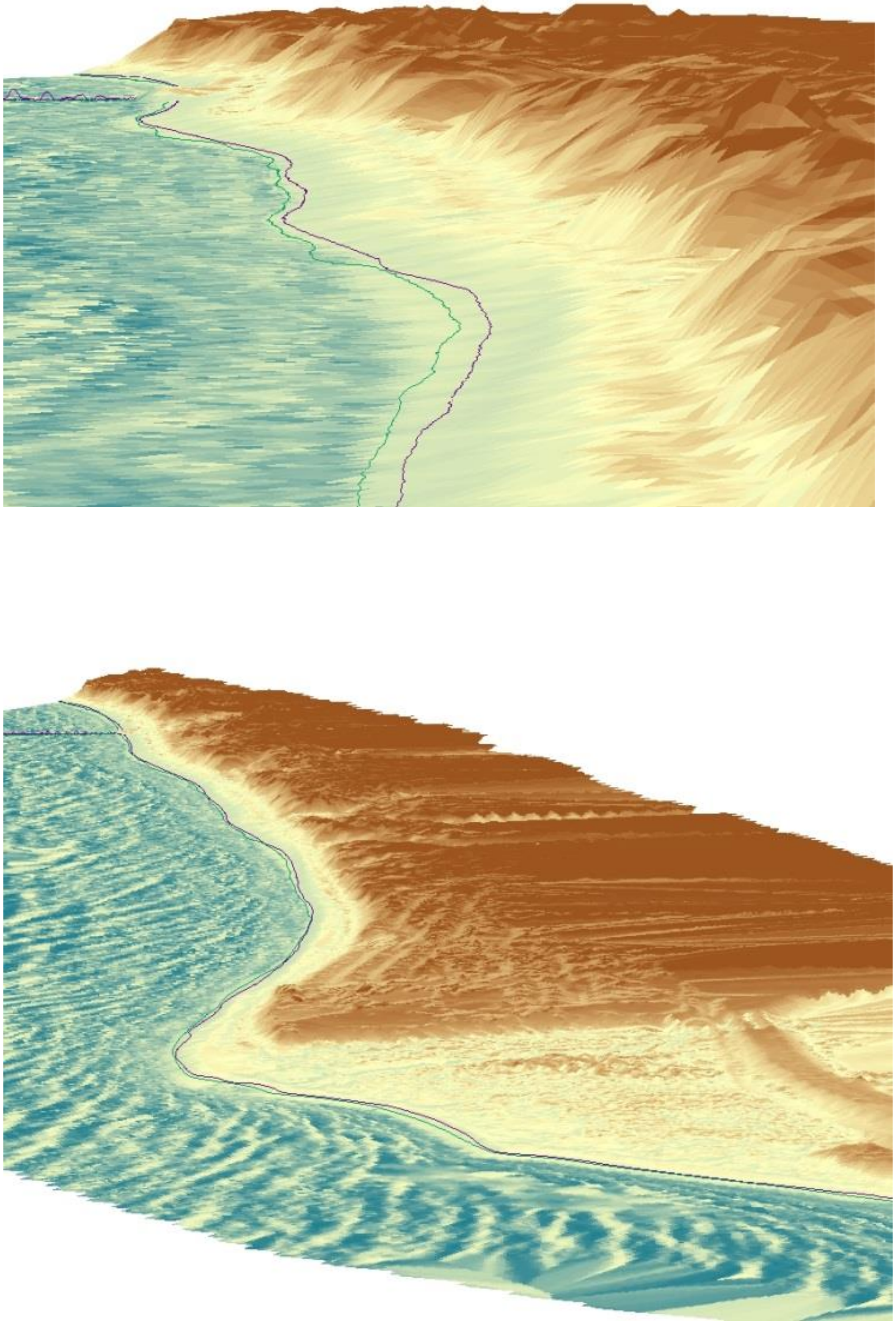
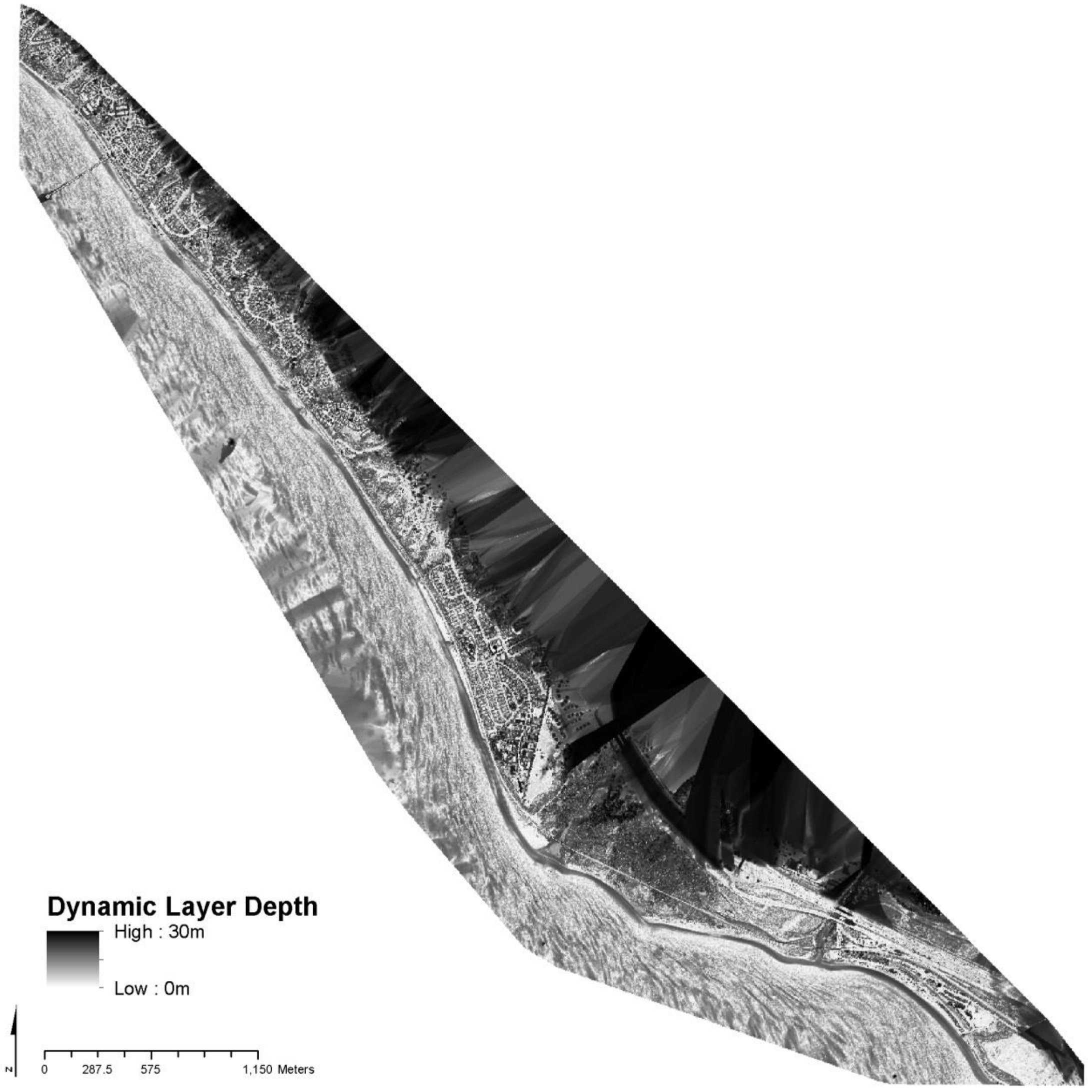


Rasters were created for each of the three years using Inverse Distance Weighting and displayed using a histogram equalized stretch. There are a some visible differentces, especially in the developed residential areas, but generally all three look very similar.

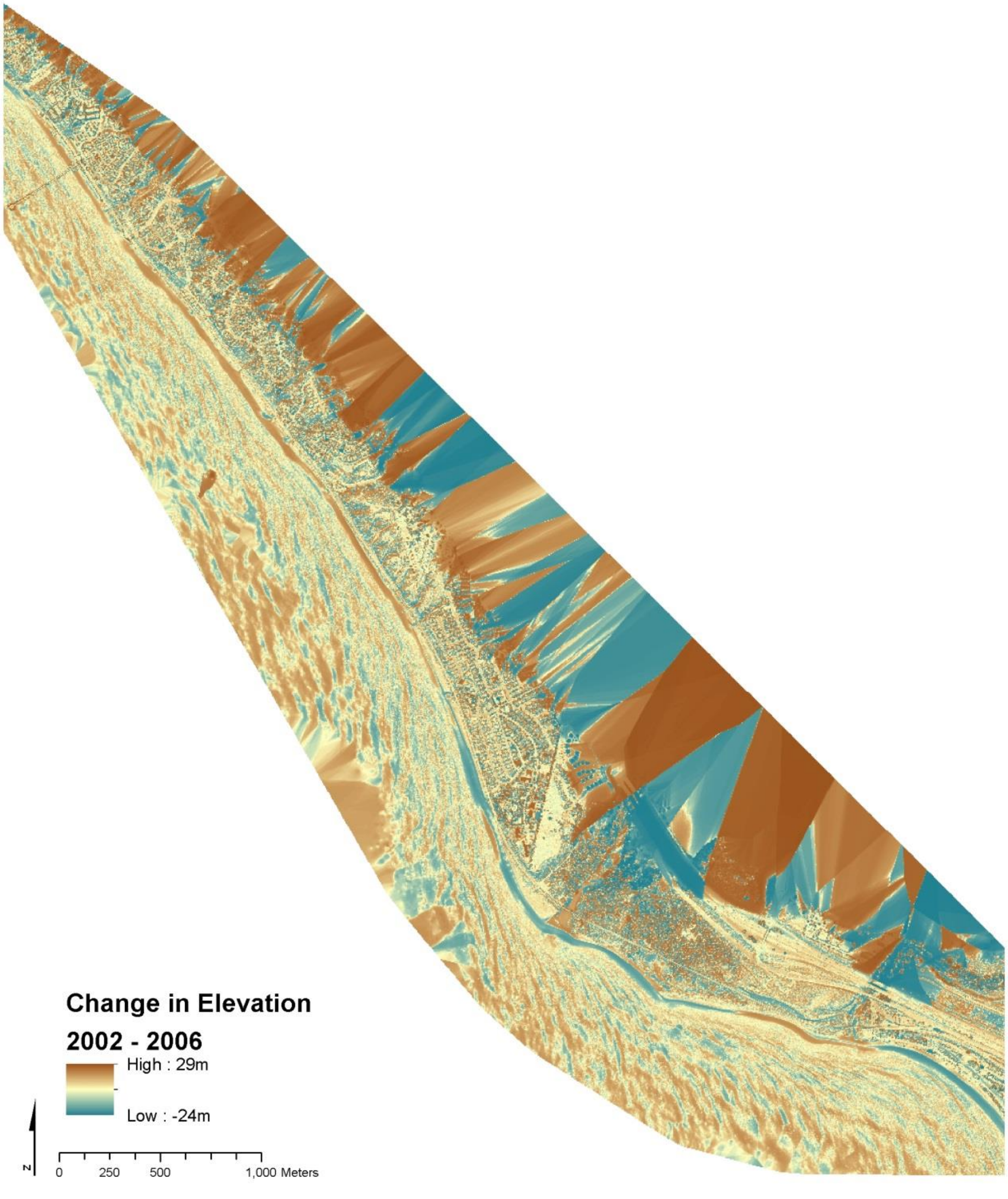


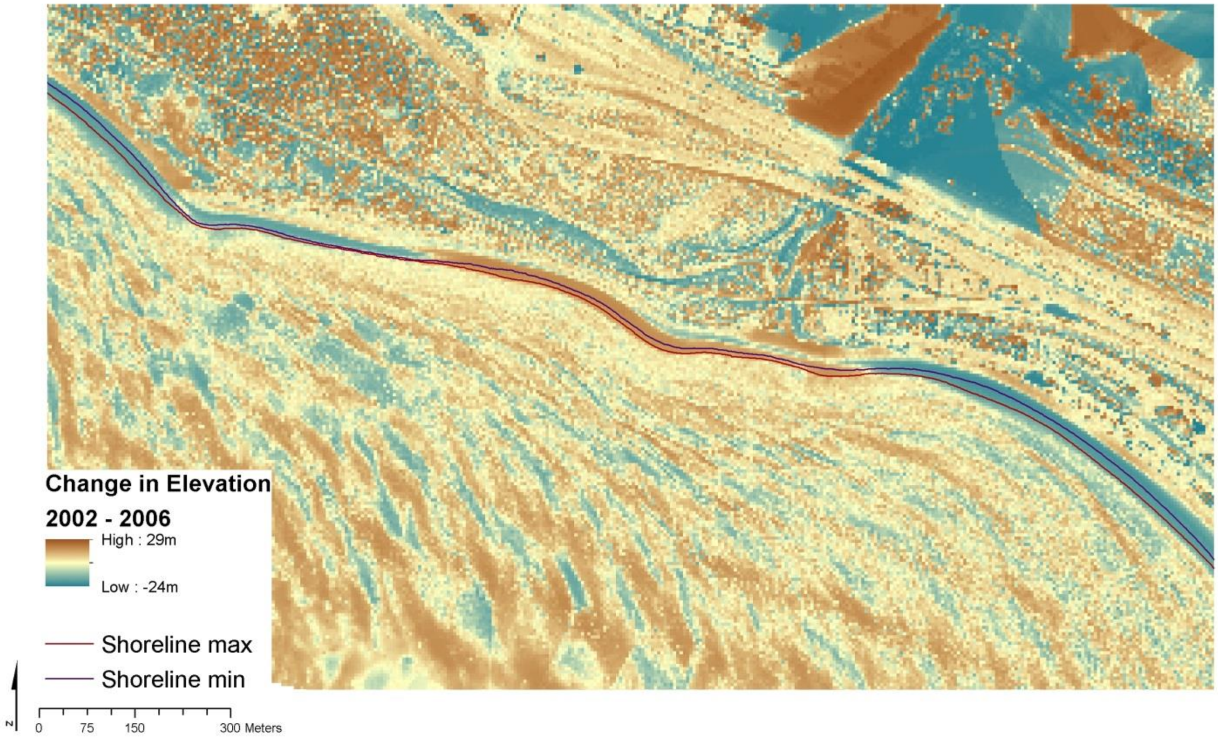
Two 3D visualizations of the 2006 raster with the contours that define the shoreline evolution band.

To begin to examine how the elevation has changed, the core and envelope rasters were subtracted to find trends in the areas that were more or less dynamic. While there is a lot of variation in the residential areas further inland, likely because of construction and vegetation, the area of the beach has a fairly uniform, relatively high dynamic layer depth, indicating that all along the beach there has been a fair amount of sediment movement.



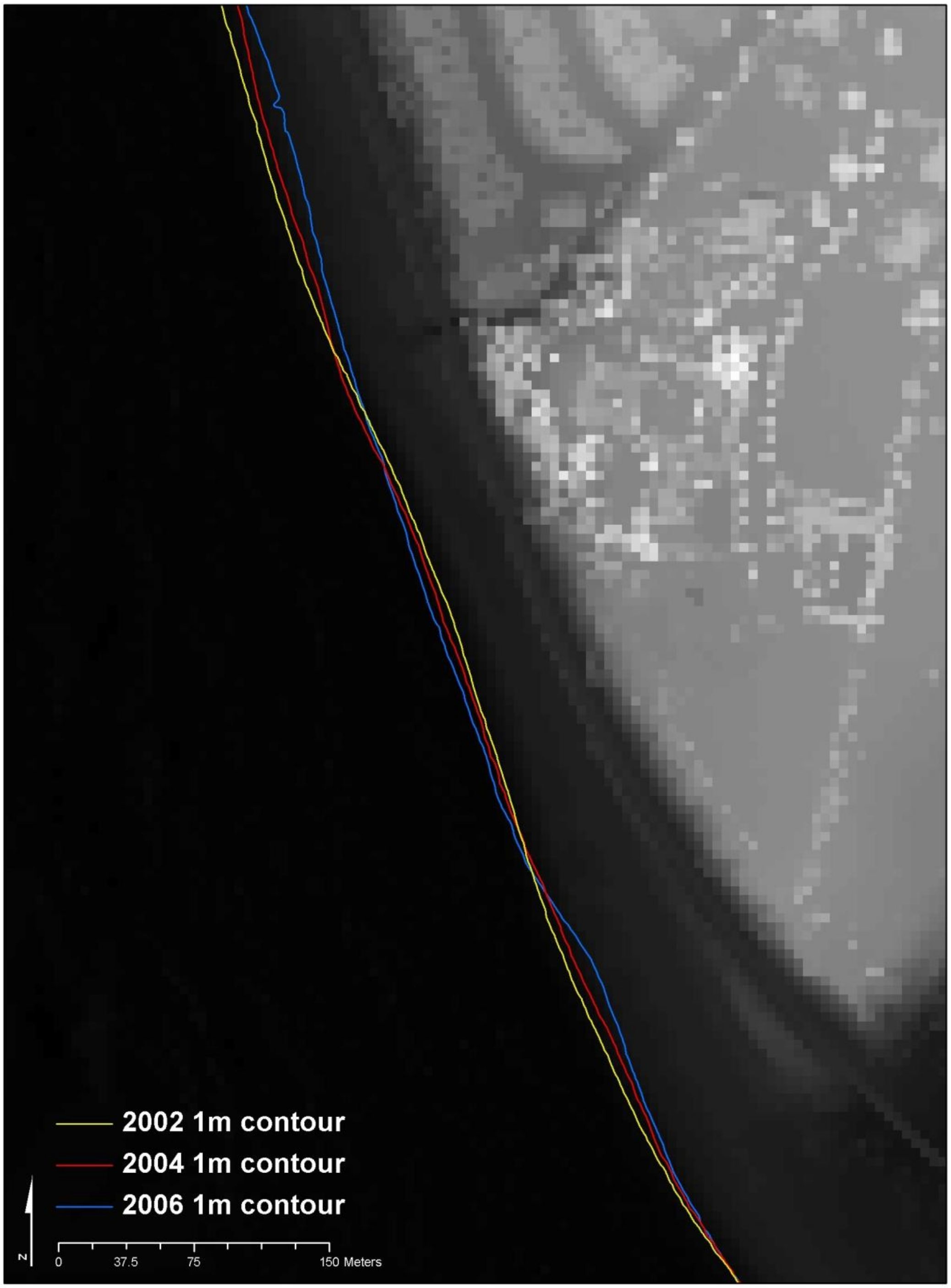
To find further patterns in the dynamics of the coastal area, particularly the beach, the net change in elevation was calculated. This depicts areas that have lost sand and areas that have gained sand, or had changes in elevation for other reasons. The migration of sand from one area of beach to another could be an explanation for the alternating strips of positive and negative change depicted in this map.



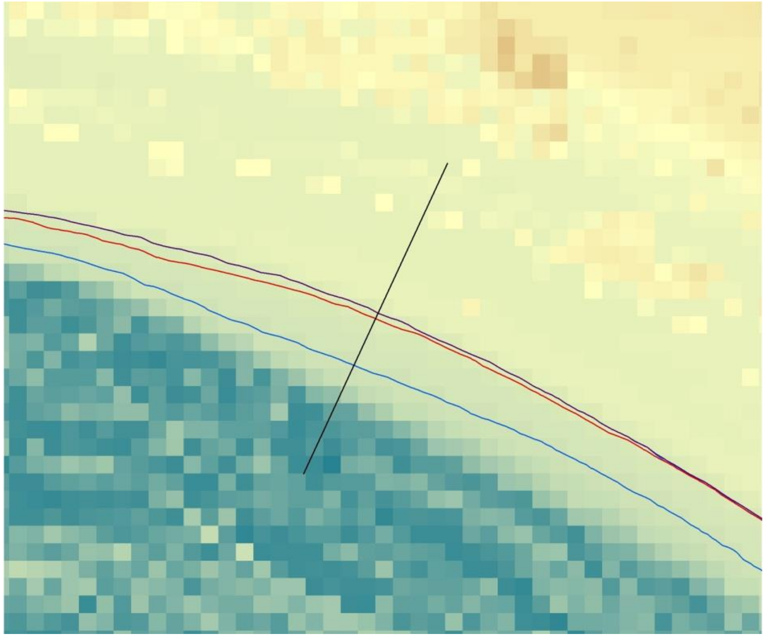


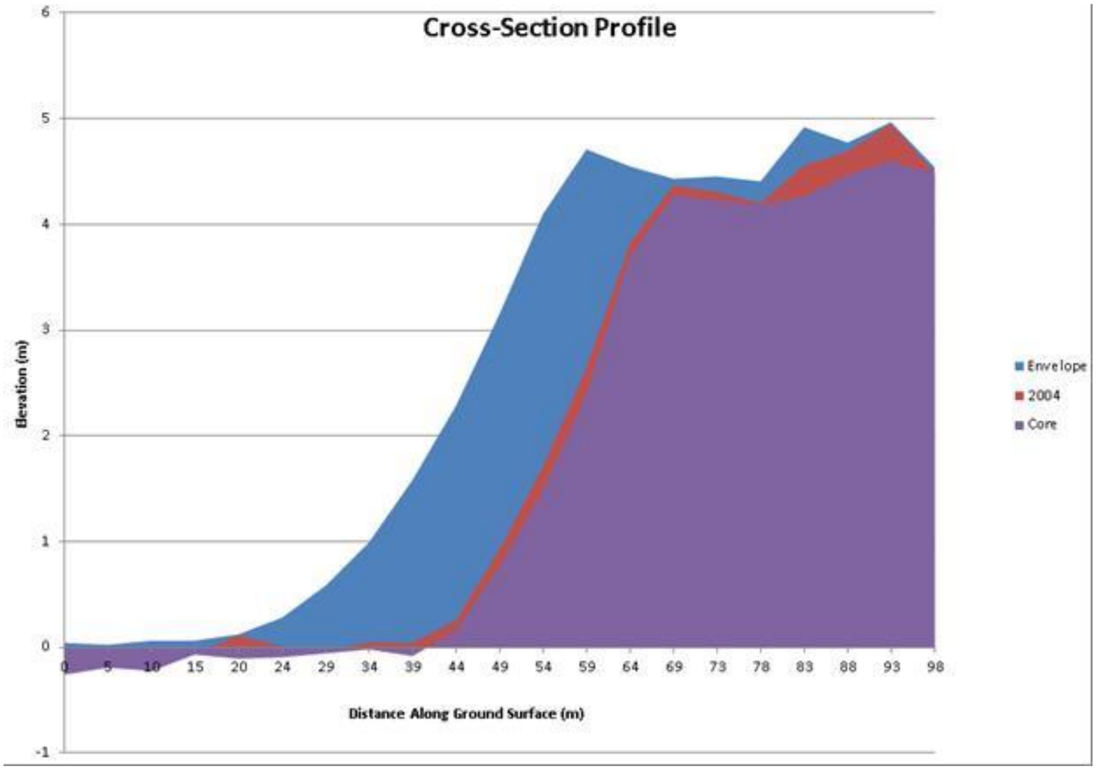
Looking more closely at a section of the beach reveals the relationship between the net change in elevation and the width of the shoreline evolution band: areas of greater change in elevation correspond to areas with a wider shoreline evolution band. However, depending on where the shoreline evolution band lies in relation to the beach area, it may not fully reflect the amount of change, as can be seen in far eastern edge of the left blue section. There the shore is losing sediment from further inland than the 1m elevation band.

Within the shoreline evolution band, the areas losing and gaining elevation can also be seen in the relative positions of the 1 meter contours for each of the three years. In some locations they move inward, in others they move outward, and in others, not depicted here, they do not just progress in one direction but both in and out.



Finally, in lieu of a 3D cross section, a profile was taken of the envelope, 2004 and core surfaces on a line perpendicular to the coastline. At this location, the 2002 contour was aligned with the envelope contour and the 2006 contour was aligned with the core contour, so they are not depicted.





The shoreline evolution band is the distance along the 1 m elevation line from the envelope to the core.

Discussion

This analysis displayed the dynamic nature of coastal landscapes. Even over a period of only four years the elevation along sandy areas can change significantly. Along this portion of the Southern California shore there are alternating sections of the coastline that have decreased or increased in elevation. These areas seem to be concentrated around a bend in the coast where the shore juts further out into the ocean, perhaps exposing it to more tidal forces, and especially to currents moving in directions other than perpendicular to the shore that might carry away sand more quickly. Even with these trends, however, the actual change in the shoreline location is very unpredictable, as adjacent secitons move in different directions and large changes may occur in one location one year followed by hardly any change the next year.

There are many ways to further this analysis of the dynamics of the coastline, including using more data; completing more rigorous interpolations, smoothings, and verifications; conducting statistical analysis; and creating more sophisticated visualizations. There are many more LiDAR surveys of the same area of coastline – this analysis only used three of about ten available because of downloading and processing time. With further data to fill in, the jumps between years would not be as significant and a more continuous picture of the shoreline change would be created. The method of interpolation could also be further developed. An inverse distance weighting was chosen because other methods of interpolation were timing out due to processing constraints. A spline method would probably produce more accurate results, which could be compared to an invariant elevation such as that of a highway to check the accuracy. It should also be considered whether it would be more appropriate to only use the last return LiDAR data, though since this analysis focused only on the beach area there would not be too much of an effect from vegetation or buildings. However, if the first return data were used, analysis on changes in the residential areas might be able to be performed, if the raster resolution were high enough. There are many more mathematical opperations that could be performed to quantify the changes observed in this analysis, which was focused primarily on qualitative observations. These qualitative observations could also be improved by further visualization techniques, especially those using 3D. Due to lack of time and software capabilities, such techinques as 3D cross sections, time-space cubes, voxel graphics, and 3D isosurfaces could not be explored. There are many posibilities for further visualization of change using these techniques.

References

Mitasova, H. “Scientific visualization of landforms.” *Geomorphology.* 137.1 (2012): 122-137.

Mitasova, H, et al. “Geospatial analysis of vulnerable beach-foredune systems from decadal time series of lidar data.” *Journal of Coastal Conservation, Planning, and Management.* 14.3 (2010): 161-172.