Modeling Coastal Change Using GIS Technology

In the past few decades, coastal communities around the world are being threatened by accelerating rates of sea level rise, a climate-change induced issue that has caused increased frequency and severity of storms, coastal flooding, erosion, and land loss. Coastal erosion, where shoreline is lost through processes of wave action and tidal currents, is a natural process that is historically accompanied by periods of accretion, in which the shoreline builds back up. However, in more recent decades, the issues mentioned above and coastal development has exacerbated erosion rates. Studying rates of coastal change, therefore, has been on the forefront for coastal engineers, scientists, and coastal managers who are working to find ways for social and economic development to adapt along with the coast. Using GIS and remote sensing technologies have proven to be beneficial for these fields, as historical rates of change can be determined and, in some cases, extrapolated into the future, which is beneficial for long term planning.

The first step in shoreline change mapping is to define a shoreline indicator and choose a source for data (Boak and Turner 2005). Typically, there are two methods for shoreline definition: using visible information on digital imagery such as the high water line, or using a tidal datum for mean high water. However, other common shoreline indicators include bluff toes, storm-water lines, wrack lines, and dune crests. After defining a shoreline indicator, a data source must be chosen for the analysis. Data sources commonly used in shoreline analysis include historical photos, charts, aerial photography, GPS, and other remote sensing technologies (Boak and Turner 2005). The United States Coast and Geodetic Survey (now NOAA), has been producing topographic images of the US coastline since the 1830s! The indicator and data source used will depend on the objectives and goals of the project; for example, if the study is focusing on short or long-term rates of change, the extent of the study area, sheltered vs. exposed coastlines, etc. Interestingly, the choice of shoreline indicator is typically subjective for the researcher- and may cause complications when trying to compare results to other studies that do not use the same indicator. For long-term planning and management, it is important to have many studies that compliment each other so that results can be easily understood by a wide range of practitioners.

The interplay of geologic composition, human development, storm action and other physical oceanographic factors is important in studying dynamic shoreline change, as these factors do not work singularly to determine shoreline structure (Lentz and Hapke 2011). Two methods for collecting data to study this interplay are LiDAR, often referred to as Light Detection and Ranging, and RTK, or real time kinematic GPS surveys. LiDAR is a relatively new technology in the GIS world, and works by emitting laser pulses from an airborne system that are reflected from the ground and returned to the sensor.
The data collected from LiDAR is often used to create high-resolution elevation models; in recent years the accuracy has been increased to 1 meter or less (resolution of imagery produced). Reconciling the aerial data with RTK GPS surveys, taken at a sampling of points along the ground, help to further increase the accuracy. Using these two methods, one study of shoreline change over a ten-year period on Fire Island, NY, produced 3D maps that displayed volumetric changes in the shoreline, as well as 2D maps that showed planimetric shoreline and dune changes.

Another data collection method used by researchers in North Carolina was a hot air balloon sensing system, which was also the technology used to capture the first aerial photography in the 1800s (Eulie et al. 2013). In this specific study, researchers used images captured by tethered balloon and reconciled ground position with RTK GPS to study short-term shoreline changes in an estuarine system. The benefit of this method was that it was much less expensive than acquiring fly-over aerial photography; however, constraints included the weather conditions and the limited coverage that a tethered balloon can provide.

There are many GIS methods to carry out shoreline change analysis, including the transect-from-baseline method and the change-polygon method. Both have benefits and challenges; however, one study determined the change-polygon method to be the superior (Smith and Cromley 2012). The transect-from baseline method is used by FEMA to define their flood zones and as the standard for measuring long-term change. This method involves measuring the distance between two time-lapsed images of the same shoreline and dividing it by the time elapsed. The transects are measured from a given baseline, which as discussed above are often subjectively chosen by the researcher, and sometimes intersect each other rather than the shoreline (Smith and Cromley 2012). The change-polygon method measures the total area of the coastlines in question at two different times, and overlaps them to show areas of erosion and accretion, which can be more useful in visually displaying and analyzing shoreline change.

While many studies focus on long-term shoreline change rates along exposed coasts, such as the shoreline change maps produced for Rhode Island Coastal Resources Management Council, which study shoreline change from the 1930s through the present, there have also been a number of shorter-term studies conducted along sheltered shorelines (Cowart et al. 2011, Eulie et al. 2013). One study conducted in the Neuse River Estuary in NC used a point-based approach to analyze the rates of erosion (Cowert et al. 2011). An interesting benefit to this approach is that the user can associate other variables such as shoreline vegetation, elevation, and wave exposure with the erosion rates, which is important as the shoreline is dynamic and affected by many factors, as discussed above. One of these factors could be the damage caused by hurricanes. Another study examined how Hurricane Ivan affected the dune systems on Santa Rosa Islands in Florida (Houser et al. 2008). Using LiDAR from two different sources as the basis of the model: the Compact Hydrographic Airborne Rapid Total Survey and the NASA sensor EAARL (Experimental Advanced Airborne Research LiDAR), inverse distance weighting was used to extrapolate the points into elevation models for carrying out the pre and post storm comparison of the dune system.
The use of GIS and Remote Sensing technologies for studying shoreline change has increased over the past few decades, and is becoming more important than ever. Many coastal areas (including Rhode Island) are experiencing increasing rates of sea level rise and increasing frequency and intensity of coastal storms, which is causing erosion and loss of the shoreline. Some areas of Rhode Island have experienced almost 250 feet of shoreline erosion in the past 50 years, although there are areas in the world that are experiencing even faster rates such as Byron Bay in Australia. Coastal managers and planners, along with engineers and scientists, must continue to study shoreline change in order to adequately and safely plan for future social and economic development along coastlines, development that is hopefully more resilient to the dynamic nature of the coast. Recent advances in high resolution digital elevation models, created from LiDAR sensing systems, has helped to increase the accuracy of present models and future predictions, and future advances in this, and other, technologies will help to further increase this accuracy. In Rhode Island, the data gathered by LiDAR and other collection schemes are available as public sources online, so a wide variety of practitioners (and the general public) can use them in planning and research. This is important because if many studies are conducted that use the same data sources, they can compliment each other and be a part of the whole instead of overlapping efforts and products. This will also require increased coordination among agencies, academia, municipalities, etc., which can be beneficial to save resources, decrease overlapping and conflicting solutions, and get more people involved in holistic planning for the future.

**Annotated Bibliography**


This paper is a fantastic review for defining a shoreline and the different detection measures that are used for shoreline change analysis. This is essential background for coastal engineers, coastal managers, scientists, and other people that study the dynamic interplay between the ocean and land, such as rates of shoreline change. First, it discusses the two main ways to define a shoreline, either from digital imagery and the visible high water line, or using a tidal datum for mean high water. However, there are also over 20 other ways to define a shoreline, such as by a bluff or storm line. Then, it talks about sources of imagery and data that have been used in shoreline change analysis, including historical photos, charts, aerial photography, GPS, and other remote sensing technologies. Then, it discusses the technique of shoreline detection, which includes choosing one of the many shoreline indicators and then detecting it with the chosen data source. I thought this was interesting, because the choice of shoreline indicator is often subjective, and may not match up well to other studies, which could have management implications. The most commonly used shoreline detection method is manual visual interpretation from aerial photography or in situ.

This study focuses on shoreline change along sheltered coasts, differing from most studies that focus on the coastline directly adjacent to the ocean. The study used a point-based approach to analyze the rates of erosion that were happening in the Neuse River Estuary in NC. One interesting benefit of using this approach is that the user can associate other variables such as the ones used in this study (vegetation, elevation, fetch, and wave exposure) with the shoreline change analysis. They analyzed the shoreline change at two different scales, regional (the whole estuary) and local (8 specific study areas). The rates of change were determined using 1998 DOQs and 1958 aerial photography that was put into digital form. Other, interesting GIS tools that were used included a wave exposure model, which calculated the exposure to waves, and the fetch. The bathymetry data used was from NOAA’s TopoDigital Elevation Model.


Unlike many aerial shoreline change studies conducted today, this study was carried out using a balloon-based sensing system called Aerostat paired with Real Time Kinematic (RTK) GPS. This system provides high resolution (0.3 m pixel size), but unlike using satellite imagery, it is limited in the area it can cover and is subject to weather conditions. This study also conducted a short-term shoreline change analysis over the period of a year rather than decades. Several ground control points were set up, and their locations were measured using a Trimble RTK GPS for geo-referencing use with the aerial imagery. Shorelines were digitized from orthophotos, and compared to the aerial photos taken by the balloons. Interestingly, shoreline positions from the balloon aerial photos were more accurate than the orthophotos, when reconciled with the GPS data.


While many studies of shoreline change focus on long-term rates of change, this study focused on the changes to the Santa Rosa Island, FL dune system directly preceding and following Hurricane Ivan. Variation in dune morphology was then linked to offshore topography, and historical trends. This study used LiDAR data from two different sources: the Compact Hydrographic Airborne Rapid Total Survey and the NASA sensor EAAIRL (Experimental Advanced Airborne Research LiDAR). Then, inverse distance weighting was used to extrapolate the points into elevation models for carrying out the pre and post storm comparison of the dune system. Erosion rates were calculated using
on shore transects. One of the most important findings of this paper was that areas with larger, better-established dune systems experienced less destruction and less long-term erosion than areas with smaller dunes, which is an important implication for coastal management.


This paper discusses the interplay of geological structure, storms, and development as it affects the shoreline along the coast of Fire Island, New York. The paper documents shoreline changes from 1998-2008 using topographic data from LiDAR and RTK (real-time kinematic) GPS surveys. Both techniques produce high-resolution images that are ideal for measuring small and large coastal changes. LiDAR also helps with the formation of 3D imaging. This study took the data from NOAA and USGS and converted it to TIN’s for analysis (they also used kriging). The methodology for this study was rigorous in that it compared 3D, volumetric changes to 2D, shoreline and dune changes to piece together a complete picture of the changes happening. It also compared changes between the eastern and western end of the island, which are responding in different ways to sea level rise and coastal storms.


This paper analyzes and compares two methods for measuring shoreline change: the transect-from-baseline method and the change-polygon method. The transect-from-baseline method is used by FEMA as the standard for measuring long-term change, and involves measuring the distance between two shorelines and dividing it by the time change (between when the images were taken). The transects are measured from a given baseline, which does not always fit well with the study, and often intersect each other rather than the shoreline. The change-polygon method measures the total area of the coastlines in question, at different times, and overlaps them to show areas of erosion or accretion. They determined that the change polygon method was better at measuring the difference between shoreline positions. One of the most interesting factors mentioned in this paper is that the United States Coast and Geodetic Survey (Now NOAA), has been producing topographic images of the US coastline since the 1830s. However, errors in measuring coastal change arise from positional error in encoding process, and the choice of methodology for measuring the changes in coasts, which is why the study focused on comparing the two methodologies.