GIS and Remote Sensing Applications for Monitoring and Modeling Storm Surge Inundation

Introduction:
“In the long term, floods kill more people in the United States than other weather-related events. Floods can destroy buildings, roads, and bridges; tear out trees; devastate agriculture; cause mudslides; and threaten human lives.” (NOAA/NWS, 2005) “Traditionally, coastal flooding due to hurricanes has been estimated by measured water levels on buoys and coastal gauges. Although these monitoring networks provide good historical data for coastal flooding, they lack spatial information because of the limited number of stations over many large areas.” (Klemas, 2015) Currently, some strategies for monitoring storm surge inundation include aerial photography and spaceborne sensing techniques. There are also two widely used models used to model storm surge heights, and levels of inundation. This paper will address the popular methods for monitoring and modeling inundation caused by storm surge.

Aerial photography:
Aerial photography includes remote sensors and camera attached to aircraft that are flown at varying levels of altitude depending on the area and resolution needed to be covered for a project. Typically, higher altitudes cover a larger area but provide less ground resolution. Low altitude photographs provide higher resolution pictures for a more site specific area. New and advanced digital cameras can be mounted to aircraft which are “capable of delivering photogrammetric accuracy and coverage, as well as multispectral data at any user-defined resolution down to a 0.1-m ground sampling distance.” (Klemas, 2013) This high resolution camera can help with accessing damage after a storm hits and can be compared to previous photographs to see how the landscape was affected. Aerial photography can also help in aiding the search and rescue process as the most severely damaged areas can be identified quickly.

Figure 1 (above) demonstrates the benefits of monitoring storm damage by taking aerial photographs. This picture was taken from Seaside Heights Pier, NJ. The above picture shows the pier pre-sandy while the bottom picture shows post-sandy. Looking at the bottom picture, you can see the destroyed pier and the roller coaster that was picked up and dropped into the ocean. There is also sediment deposited much further inland than in the pre-sandy picture. Aerial photography is widely used in monitoring damage after a storm causes damage but there is also remote sensing technologies that can provide real time data.

Spaceborne Sensing Techniques
“Satellite radar systems can provide data on sea surface height, surface winds, and wave fields with radar altimeters, scatterometers, and synthetic aperture radar.” (Klemas, 2009) The table on the right is from the Klemas, 2009 paper. This demonstrates five popular sensors used for remote sensing of the ocean. Data from each sensor can provide images and numerical data which can be incorporated into models to predict damage from storm surges. Important variables captured by remote sensing systems to predict storm surge includes barometric pressure, track, intensity, size and forward speed of the hurricane.

such as the track, intensity, size, and forward speed of the hurricane and the characteristics of the coastline where it comes ashore or passes nearby.
Storm Surge Modeling:
High resolution models have been developed to model coastal flooding due to storm surge. These models are beneficial for understanding storm surge, wave and flood dynamics, as well as the preparation, planning response and mitigation of hurricane and coastal flood hazards. These models can use remote sensing data to make highly accurate predictions of wind fields which drive storm surge. The most widely used model to predict inundation is NOAA’s Sea, Lake, Overland Surge from Hurricanes (SLOSH). The SLOSH model can estimate storm surge heights and wind from predicted or hypothetical hurricanes. This model can be combined with other remotely sensed data such as elevation. Elevation can be measured from Light Detection and Ranging (LiDAR) systems. These sensors measure distance by shooting a laser at ground targets and measurements are recorded from the reflected light. When the SLOSH model is laid upon elevation data, the elevation data can be subtracted from surge data and the output will show what areas will be inundated by a range of storm intensities. The model can be run on a region wide basis or a more localized area.

Future of RS and GIS:
Remote sensing and GIS applications in storm surge monitoring and modeling will become increasingly important as we move into the future where stronger, longer lasting extreme weather events are expected. Also, rising sea levels, disappearing wetlands, increased coastal development threaten to intensify the damage. Monitoring change in landscape and accurate models of storm surge can help communities become more resilient when these events take place. Providing visual images of storm inundation can be used to incorporate science into public policy and be a leading factor to influence change and protect our coasts and communities.
Annotated Bibliography


This article by Klemas examines the role of remote sensing in predicting and determining storm impacts. This article was interesting because it mainly focused on remote sensing, rather than GIS, like most of the other articles I looked into did. Klemas states satellite and airborne remote sensors can provide the required information, such as pressure, track, forward speed, etc, in a timely and reliable manner. He cites a case study of Hurricane Katrina and how remote sensing helped modelers predict the path, strength, surge level and landfall location. This article was nicely written but it would be difficult to follow if you do not have an understanding of certain remote sensing satellites and sensor systems.


This article by Klemas provides an overview of remote sensing and modeling techniques for forecasting the vulnerability to flooding of an area. He also looks into the extent, and intensity of the flooding, as assesses the damage. The paper is more about multi-temporal remote sensing image, for example, viewing images of before the storm and seeing the difference after. He discusses the popular satellite Landsat and other sensors( MODIS and ASTER) and how they are particularly useful for assessing vulnerability to flooding. The most interesting topic in this paper looks into optical RS and microwave RS. They also include what bands work the best in different landcover. This paper could be challenging to read if you do not have a prior knowledge of certain satellites and sensors.


This paper provides an analysis of the risk of inundation from storm surge and sea level rise for the Cape Cod National Seashore and other National Parks in the Northeast, US. The paper uses two models for predicting sea level rise which includes, bathtub inundations and Sea Level Affecting Marshes Model. A third model, Sea, Lake, Overland Surge from Hurricanes, was used to model storm surge inundation. The paper analyzes risks from Hurricanes ranging from categories 1-4 while incorporating rising sea levels of .06m, 1m, and 2m, as those are projected rates of sea level rise in the future. This paper was interesting because it was site specific so coastal managers would be able to use this information to plan into the future.


This article by Peek and Young talks about their study of Developed Shorelines using Microsoft Access and ArcGIS to build a national storm surge database. Their database contains over 5800 storm surge data points from 42 hurricanes. An analysis of the database was performed to examine the relationship between storm surge and storm characteristics. What I found interesting was that they found no significant relationship between surge height and the Saffir-Simpson scale, which is based on wind speed. The pressure at landfall had the most significant relationship to surge height. One negative aspect of this paper is that it suggests we use a different scale to rate storms besides the Saffir-Simpson, but they do not recommend a better way of doing so. Overall this paper was well written and flowed nicely, but it left an open ended question at the end which could be a research topic in the future.

This article by Zhang et. al., compares a more recent, Coastal and Estuarine Storm Tide (CEST) model with a well established Sea, Lake, Overland surge from Hurricane (SLOSH) model. This paper was interesting because it is using some of the most recent models to predict storm surges while using slightly different methods. The test was to model three hurricanes from the past for which they currently have data on and see which model more accurately predicts storm surge levels. This report shows that CEST model agreed better because it used field observations acquired from remote sensors while the SLOSH predicted surge without accurate measurements. This article had a nice flow and the results were written clearly. This was a good paper because it shows how advanced and accurate GIS and RS modeling is becoming.


This paper by Zuidam, et. al, discusses the use of GIS and RS applications for integrated coastal zone management. The focus of this paper is to examine three subprojects that aim to develop methodologies and tools for assessing coastal zone changes, and to evaluate scenarios for management based on GIS and RS data and other physical modeling techniques. This paper was useful as it covered a range of technologies and techniques that can be used to better manage the coast. The paper covers three projects from the International Institute for Aerospace Survey and Earth Sciences. The first project develops methodologies for optimising RS and GIS data sets, while the second project facilitates qualitative and quantitative analysis for physical aspects of coastal landscape. I believe the third project was most interesting which works to integrate the previous two projects into coastal zone management. This paper was easy to read from a non-scientist standpoint and would be a good read for a coastal zone manager.