GIS and Remote Sensing Application in Coastal Inundation

Evidence for the first oceans places their birth no later than 3.8 billion years ago. Since that time the oceans have been subjected to a myriad of forces ranging from scales as grand as the astronomical and the global and to, as small as, the regional and local. These forces have driven the continual advance and retreat of the seas throughout time, leaving the world arranged as seen today. It is the rich diversity of the coasts that has brought humans to it since earliest days of our ancestors. But, this proximity to the coast is not without its perils. Any manmade structure or natural habitat near the coast is in a dangerous place, subject to inundation due to storm surge, sea level rise, and wave action among others.

Simply put storm surge is the inland movement of water from the ocean due meteorological and local conditions which creates increase in the water surface. Storm surge, in and of itself, poses a great amount of risk; the situation becomes even more complex when fluctuating sea level surfaces are taken into account. Sea level rise occurs for global reasons: eustatic, the warming of the oceans and melting of ice, or for relative reasons such as isostatic adjustment and land subsidence. Current data supports the notion that on average, sea levels are rising and will continue to do so into the foreseeable future. Wind driven waves have always battered the coastlines of the world. Their effects can be exaggerated with changes in tide and meteorological forces. With near-constant development, investiture, and explosive population growth in coastal areas the understanding and prediction of coastal inundation is a necessity of the modern world.

Numerous numeric models have been developed to determine the effect of coastal inundation from sea level rise, storm surge, and wave action. One of the most widely used models is the National Oceanic and Atmospheric Administration’s (NOAA) Sea Lake, and Overland Surge from Hurricanes (SLOSH) model. The SLOSH model relies on physical equations to develop a deterministic model. These methods can be combined into composite models that develop Maximum Envelopes of Water (MEOW’s) and Maximums of MEOW’s (MOM’s). SLOSH is a two-dimensional model and does not account for wave action or inland precipitation and consequent riverine flooding. Additionally, the results are only viewable. NOAA’s Sea Level Affecting Marshes Model (SLAMM) is another model often employed. SLAMM models the effects of long term sea level rise (5-25years) on shorelines and coastal marshes and wetlands. A third model, concentrated more on smaller scales, is the U.S. Army Corps of Engineer’s (USACE) Coastal Modeling System (CMS). CMS is a two-dimensional model. CMS uses two components CMS-WAVE and CMS-FLOW to develop a comprehensive model. Due to this approach, CMS is able to take into account the effects of wave action and morphological change, however including storm surge and sea level rise is difficult.

All models require the development of reliable input data. A common theme of data need for coastal inundation modeling regardless of modeling type is a Digital Elevation Model
Traditionally, detailed topographic information was difficult and time consuming to obtain. This was especially true in dynamic coastal zones. With the advent of LiDAR and advanced sonar systems topographic and bathymetric data began to reach a level of accuracy and density to fully utilize numerical modeling techniques. Despite these advances in technology problems still exist in collecting data in the near shore environment. This area is generally characterized by shallow, turbulent, and sediment laden waters. Seaborne measure are impossible to use in this zone due to access. The limitation of seaborne measures has made LiDAR the primary alternative. To combat the problems associated with the coast zone dual laser LiDAR systems are often used. This type of system incorporates a NIR laser and blue-green laser. The NIR laser is used to determine the water surface and the blue-green laser the sub-surface. There are still difficulties in collecting data even using a dual LiDAR system due to wavelength, and pulse duration as well as the signal interaction with the water (Raman scattering). In many cases some difficulties with LiDAR collection can be dealt with directly via planning. Some planning considerations to be taken into account could be high vs. low tides, current, wave action, and sediment load of the water.

GIS and remote sensing systems are of great benefit in organizing and collecting data to perform inundation modeling. An even greater ability of those systems may be to calibrate, verify, and represent data from the various models. Several studies have focused on gathering data from RTK GPS points and comparing them to SLOSH modeled predictions. These have been done to evaluate the risk of these points to current and predicted inundation. In cases where historic coastal inundation information is available these points have also been used to check the accuracy of the model in question. In another case, RTK GPS points where collected along with aerial photography to evaluate the performance of a CMS model. In this case ground truth GPS points could be compared to predicted water surface elevations, and the extents of the predicted inundation could be compared to the actual inundation shown in aerial photographs. These cases demonstrate the ability of GIS to convey the risk of inundation, as well as, check the performance of the model in use.

In the study of coastal inundation the use of remote sensing techniques, and GIS in combination with analytical modes has proven its value in innumerable ways. The use of high-accuracy LiDAR, RTK GPS, aerial photography, and others has provided the ability to more accurately model the extents and risk of inundation. As more information becomes available, more detailed models will be able to be developed. As these technologies and methodologies advance several areas of additional study will become more prevalent. One, new area of study will be to move away from modeling coastal inundation in the standard one- and two-dimensional spaces will move the more complete 3-dimensional and time dependent models. A second, area will be probabilistic modeling as more data becomes available and GIS systems are used to usefully manipulate that data and determine what variables are of importance and which are not. Additionally, more complete/complex models that include hydrodynamics, storm surge, meteorological factors, and upland flooding will be developed. GIS will continue to provide the ability to manage, store, and manipulate the data needed to complete these models. GIS will also communicate the often complex factors involved in inundation mapping making the visualization and understanding of coastal dynamics far more accessible to those impacted, involved with the management, use, and development of coastal zones.

In studying any natural system it is important to remember that scientists and engineers can never solve the actual or "true" system. It is not possible to know precisely the value of all
the variables of a system or how exactly they interconnect. The best solution is to solve a model of a particular system that mimics nature as closely as possible. Remote sensing and GIS technology allows for the collection of data that once was not available, and the ability to organize and manipulate that data in meaningful ways that have and continue to extend our knowledge and ability.

Annotated Bibliography


This paper by Allouis T. et al. discusses the use of LiDAR for gathering bathymetric data. The paper was written with the idea that LiDAR techniques for shallow coastal zones could be used for gathering bathymetric data for riverine systems. Due to the focus of the paper the conclusions of the paper do not directly relate to costal inundation. However, because the case study for the paper was a shallow coastal zone, a great deal of information was available concerning LiDAR and coastal bathymetry. Particularly interesting was the discussion of using green laser light in conjunction with the NIR spectrum to determine the water surface and the depth of the water, and the inclusion of Raman scattering as a way to determine depth was also interesting. The use of Raman scattering by the authors own admission is in need of further development and has drawbacks in its use due to physical factors of the water affecting the returns. The paper was well written and clear despite its lack of describing some of the more complex underlying mathematics.


This paper by Eakins, B.W. and Grothe, P.R. presents topics and issues in dealing with Coastal Digital Elevation Models (DEM’s). The paper covers a wide range of difficulties in assembling and building DEM’s with particular focus on coast DEM’s. The paper breaks these difficulties down into six categories of potential error: Source Data, Processing, Gridding/Interpolation, Qualitative or Quantitative Assessment, Morphological Change, and DEM Uncertainty. The paper has very good discussions on topics such as source error, scales, datum and processing that extend to DEM’s other than just coastal DEM’s. Particularly interesting was the discussion of data issues at the land/ocean (coastal) interface and the inability to collect useful or accurate data in this region due to environment conditions or physical limitations of the data gathering platforms. Additionally, the segment on morphologic change and its associated Figure 4 was interesting due to the topic of temporal scale. Over all the paper was well written and especially well organized making it easy to reference.

In this paper Klemas demonstrates the importance of obtaining near shore bathymetry data and the difficulties of obtaining it have been reduced primarily through the use of LiDAR systems. The author discusses the use of blue-green laser light as the optimum wavelength for penetrating the water surface as compared to blue, and the use of dual band LiDAR utilizing a NIR laser to determine the water surface. Also mentioned and of some interest is the use of Raman signal from the interaction of the blue-green light and water as method of determining the water surface. The author also uses three case studies to illustrate the uses of LiDAR. This was particularly valuable and supportive of the paper. The paper is well written and clear and interesting to anyone involved with LiDAR and the coastal terrain mapping.


In this paper Murdukhayeva, A. et al. present an analysis of the risk of inundation due to storm surge and sea level rise for Cape Cod National Seashore and Assateague Island National Seashore. The authors used three models to describe sea level rise and storm surge. These models are: “bathtub inundations”, Sea Level Affecting Marshes Model (SLAMM), and Sea, Lake, and Overland Surges from Hurricanes (SLOSH) models. The first two models are used for seal level rise while the third is used for storm surge. For the risk analysis of inundation and model creation high accuracy elevation data was need and obtained from LiDAR and RTK GPS. The paper analyzes the risk for Categories 1-4 Hurricanes and sea level rises of 0.6m, 1m and 2m. Only the 1m and 2m scenarios could be modeled at Cape Cod National Sea Shore due to uncertainty in the LiDAR data. The most interesting aspect of this paper is the discussions of the statistical procedures and the use of the SLAMM model to discuss the changes on habitat as sea level rise occurs. Additionally, the inclusion of site inspection after Hurricane Sandy was of interest. The paper was well written and generally more engaging than similar papers because it contained an environmental component not often mentioned in other papers.


This paper by Reid et al. addresses methodologies for evaluating model performance for coastal inundation. The Army Corps of Engineers CMS model was used to create an inundation prediction for a low lying mud flat and navigation channel on the Gulf Coast of Texas. The model was calibrated using in-situ data and its performance evaluated using high resolution imagery, field survey GPS and GIS methodologies. The paper concerns itself with the evaluation of the performance of the model and not the calibration of the model. The most informative section of this paper discusses the use of high resolution imagery and associated GIS processes to evaluate the horizontal extents of model vs. actual extents. This is supplemented with GPS field surveys of actual extents. This was well written paper providing information on methods for using imagery to evaluate the horizontal performance of an in-situ calibrated inundation model.

In this paper by Tate, C.A., and Frazier, T.G. is case study of Sarasota County, Florida to evaluate exposure of infrastructure (specifically public freshwater well heads, and electric substations) to sea level rise and storm surge. The National Hurricane Centers SLOSH model is used to develop an inundation map for the county for all five categories of Hurricanes on the Saffir-Simpson scale. Using the vector data from SLOSH and DEM data, a raster flooding depth was created for present conditions and SLR at 0.3m, 0.6m, 0.9m, and 1.2m. Depth of flooding was then compared infrastructure elevations. The discussion of flooding depth data along with flooding extents data was of particular interested and addresses the complexity of modeling hydraulic systems. The paper was concise, informative of the procedures used, and explained the importance and usefulness of flood depth data, with its own discussion on limitations, advantages, and further research.


In this paper, Thomas, and Frazier present a discussion on risk and vulnerability of communities to coastal inundation based on Sea Level Rise, Storm Surge, and Inland Precipitation. As well as, a discussion of the differences between deterministic modeling and probabilistic modeling. Sarasota County Florida is used as a case study for the discussion. Two topics in this paper are particularly interesting. The first is the discussion of deterministic models versus probabilistic models, and the limits and benefits of both models and how they can be combined to address aspects of vulnerability. The second topic of interest is the addition of inland precipitation to coastal inundation. Coastal inundation is usually accompanied with large rainfall events, however in most cases the effects of rainfall upslope of coastal areas is usually neglected. The paper raises many interesting points but, it was difficult to read with a large section of the paper being devoted to the statistical analysis of the data. The section was needed but was cumbersome.