New Mapping Tool and Techniques For Visualizing Sea Level Rise And Coastal Flooding Impacts

National Oceanic and Atmospheric Administration (NOAA)
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Abstract

It is one thing to have a discussion or write about a one- or two-foot rise in the ocean surface and potential impacts to a local community; it is another to show someone a map highlighting the areas that would potentially be impacted. The ability to visualize the potential depth and inland extent of water gives us a better understanding of the corresponding impacts and consequences. Mapping sea level changes in a geographic information system (GIS) gives the user the ability to overlay the potentially impacted areas with other data such as critical infrastructure, roads, ecologically sensitive areas, demographics, and economics. Providing maps on the Web via Internet mapping technologies enables the user to have an interactive experience that truly brings out the "visual" part of the map definition.

Over the past several years, the lessons learned from investigating pilot sea level change mapping applications have led to the development of a next-generation sea level rise and coastal flooding viewer. In addition, new mapping techniques have been developed to use high-resolution data sources to show flooding impacts on local public infrastructure, mapping confidence, flooding frequency, marsh impacts, and social and economic impacts from potential inundation. This paper will provide a brief history of previous sea level change visualization pilot projects, detailed discussion of new methods, current status of new tool development and outputs, and future plans for expanding to the rest of the U.S.

Introduction

In the last 5 years, all levels of government (federal, state, local) have begun to undertake what might seem like a monumental task of developing strategies for adapting to climate change, including sea level rise (SLR). At the federal level, a multitude of initiatives are ongoing to address climate adaptation. Executive Order 13514 addresses the energy efficiency and carbon pollution of the various agencies within the President's control. The Climate Change Adaptation Task Force makes recommendations to the President on how Federal Agency policies and programs can better prepare the U.S. to respond to the impacts of climate change. Individual federal agencies like the U.S. Army Corps of Engineers have issued engineering guidance for incorporating the direct and indirect physical effects of projected future climate change impacts (sea level change) in managing, planning, engineering, designing, constructing, operating, and maintaining federal projects (USACE, 2009). At the state level, states like California have issued executive orders directing their state agencies to plan for climate impacts such as SLR (State of California, 2008). To date, 12 states have climate adaptation plans in progress or completed, and another 8 states have had an adaption plan mentioned in their climate action plan. At the local level, many counties are beginning to develop individual climate task forces or equivalents to address climate change and SLR. In South Florida, for example, Monroe, Miami-Dade, Broward, and Palm Beach Counties have entered into a climate change compact in 2009 to ensure consistent methods and strategies for a regional approach to climate change adaptation.

In many cases, the foundation for adaption planning is an assessment of what is at risk from climate change impacts such as SLR. This usually involves mapping different SLR scenarios and overlaying socio-economic data from the U.S. Census or local parcel databases to determine consequences. Such an analysis can lead to a cost-benefit comparison of various adaptation strategies. Therefore, consistency in how the mapping is performed becomes a critical element to maintain comparable results across municipal, county, and state boundaries.

In November 2008, the U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA) held a workshop to develop a community initiative focused on the needs of national, regional, and local coastal decision makers for tools and information to anticipate, plan for, and adapt to climate change and variability. One outcome of the workshop was an agreement by the USGS and NOAA to work together to complete two "climate demonstration" pilot projects focused on visualizing SLR scenarios in two separate geographies (Wilmington, Delaware, and Mississippi-Alabama coastal counties). A second outcome was to assess and present lessons learned from each pilot at a community workshop a year later (December 2009) and make recommendations to the SLR and inundation community for how to proceed with future work. The first pilot was developed in cooperation with the Delaware Coastal Program in preparation for the State's initiation of a climate adaption planning effort. The second pilot was developed in cooperation with the Mississippi-Alabama Sea Grant Consortium to begin climate adaption efforts in the Northern Gulf. Both pilots generated Web-based map viewers using different methods of mapping and visualizing SLR scenarios. The viewers can be accessed on the Web. (Turnipseed et al., 2010)

- Delaware – http://www.csc.noaa.gov/digitalcoast/tools/slrviewer-de/index.html
- Mississippi and Alabama – http://gom.usgs.gov/slr/index.html

Community Needs

In December 2009, a community workshop was held by the USGS and NOAA in coordination with the Ocean Research and Resources Advisory Panel. Lessons learned from the above mentioned "climate demonstration" pilots were presented and data and tool needs and recommendations were made by over 60 experts from all levels of government and from academia, nonprofits, and the private sector. The proceedings from the workshop (Culver et al., 2010) list several data and tool needs, roles and responsibilities, and findings and recommendations. Some of the highlighted needs were as follows:

- Communication of uncertainty
- Societal and economic impacts
- Natural resource impacts, scenario approaches
- Mapping on the best available topographic data
- Mapping using latest techniques in datum transformation
- Accounting for error

In summary, the community wants visualization and scenario tools that are easy to access, have transparent methods, and have actionable output. One of the sets of tools necessary for adaptation planning that was emphasized in the proceedings was visualization and scenario-building applications—specifically, ones that show, "visualizations using familiar viewers (such as Google Earth) for different SLR, storm frequency, and inundation scenarios that are interactive, offer planar and oblique views, and show critical infrastructure, relevant landmarks, and other information that allows communities to understand impacts" (Culver et al., 2010).

The original intent of the USGS and NOAA "climate demonstration" pilots was to take the lessons learned and community needs and work to build a next generation SLR viewer. The rest of this paper describes a new SLR visualization tool and mapping techniques that attempt to address the needs outlined above and build on the previously described efforts.

New Tool to Visualize Sea Level & Coastal Flooding Impacts

Being able to visualize potential impacts from SLR is a powerful teaching and planning tool, and the SLR and Coastal Flooding Impacts Viewer (Figure 1) brings this capability to coastal communities. A slider bar is used to show how various levels of SLR will impact coastal communities. The initial project areas include Texas' Houston and Galveston coasts and Mississippi, with additional coastal counties to be added in the near future. The purpose of this viewer is to provide coastal managers and scientists with a preliminary look at SLR and coastal flooding impacts. The viewer is a screening-level tool that uses nationally consistent data sets and analyses. Data and maps provided can be used at several scales to help gauge trends and prioritize actions for different scenarios.

The tool is presented in a Web mapping application format using ESRI's ArcServer and Adobe's FLEX technology and can be accessed here (http://www.csc.noaa.gov/digitalcoast/tools/slrviewer/). Features of this tool include the following:

- Displays potential future sea levels
- Provides simulations of SLR at local landmarks
- Communicates the spatial uncertainty of mapped sea levels
- Models potential marsh migration due to SLR
- Overlays social and economic data onto potential SLR
- Examines how tidal flooding will become more frequent with SLR

Because of many assumptions made in map layers in the viewer, disclaimer information appears when the user launches the tool from the main tool webpage. The data and maps in this tool illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future man-made alterations of the shoreline. Water levels are shown as they would appear during Mean Higher High Water (MHHW). The data, maps, and information provided should be used only as a screening-level tool for management decisions. As with all remotely sensed data, all features should be verified with a site visit.

Figure 1. SLR and Coastal Flooding Impacts Viewer showing 4 feet (1.2 meters) of SLR above MHHW in Galveston, TX. Local impacts of this amount of water at local landmarks can be seen in simulation photos. This is one of 5 features of the tool. The tool can be accessed at the following URL: http://www.csc.noaa.gov/digitalcoast/tools/slrviewer/.

Mapping Sea Level Rise

The Sea Level Rise feature, accessed by clicking on the "Sea Level Rise" button, enables the user to use a slider bar to see how various levels (0-6 feet or 0-1.8 meters) of SLR will impact the zoomed-in area. These levels represent inundation at MHHW. Areas that are hydrologically connected (according to the digital elevation model used) are shown in shades of blue that represent depth of inundation. Low-lying areas, displayed in green, are hydrologically "unconnected" areas that may flood. They are determined solely by how well the elevation data capture the area's hydraulics. A more detailed analysis of these areas is required to determine susceptibility to flooding. The user can click on visualization locations to view simulation photos of selected inundation levels on selected landmarks (Figure 1, inset at bottom right).

Generally, the process used to map sea level inundation can be described as a modified bathtub approach or linear superposition method. The criteria used for mapping the various sea levels in the tool were developed to enable consistent mapping on a national scale. They are as follows:

- Use publicly, best available and accessible elevation data
- Map literature-supported levels of SLR
- Map SLR on top of MHHW
- Incorporate local or regional tidal variation of MHHW for each area
- Evaluate inundation for hydrological connectivity
- Preserve hydrologically unconnected areas greater than one acre in size, but display separately from hydrologically connected inundation

For inundation studies for which increased water level scenarios are required to determine the amount of land affected by sea level inundation, the elevation of a tidal datum (such as mean high water, or MHHW in areas with diurnal tides) is often used as the base elevation. This is because the high water datum represents the elevation of the normal daily excursion of the tide where the land area is normally inundated. Taking this normal extent of inundation into account is important when trying to delineate land areas inundated by abnormal events such as storm surge, tsunami run-up, or sea level change (NOAA, 2010).

As with any mapping process, there are caveats and assumptions made with regard to future sea level and the elevation data used in the mapping. The digital elevation models used to map SLR do not incorporate a detailed pipe network analysis or engineering-grade hydrologic analysis (for example, culverts and ditches may not be incorporated, resulting in incorrectly mapped areas). The mapped SLR levels do not incorporate future changes in coastal geomorphology and assume present conditions will persist. Geomorphologic changes associated with natural processes and human actions will, of course, be vital in controlling future SLR inundation extents. Failing to consider these processes is a significant limitation of this mapping component. As the scientific community continues to increase its understanding of and skill in predicting these critical process, the functionality of the tool can be updated. In the interim, however, our experience with coastal managers, floodplain managers, and other users indicates that the current functionality (with disclaimers) meets their needs for a screening-level assessment.

The mapping process uses the best elevation data available for a region of study that most closely meet the criteria outlined in Gesch (2009) for 1-foot mapping intervals. In most cases, lidar-based digital elevation data do not exist at this resolution (~9.3 centimeters root mean square error, or RMSE). More typically 18 centimeters RMSE vertical accuracy data exist. To address this issue and to give the user a more thorough picture of the accuracy of the data, we portray the uncertainty in mapping a projected MHHW shoreline inland in the mapping confidence portion of the tool, as described in the next section.

To incorporate tidal variability within an area when mapping SLR, a "modeled" surface (or raster dataset) is needed that represents this variability. In addition, this surface must be represented in the same vertical datum as the elevation data, which is typically the orthometric North American Vertical Datum of 1988 (NAVD88). Once created, this surface can be used as a current conditions surface upon which SLR can be superimposed. Currently, there are two primary ways this surface can be created. The first and simpler approach is to interpolate a surface using tide gages and their associated vertical datum conversions. The second and more accurate approach is to use NOAA's vertical datum conversion software, VDatum (http://vdatum.noaa.gov/). Both approaches have been used in this tool.

Where VDatum was available, the MHHW VDatum grid for the study region was first converted to NAVD88 and then subtracted from a NAVD88 10 x 10 meter digital elevation model (DEM) in ESRI's ArcGIS. The resulting depth grid was then used in the viewer as a raster dataset representing 0 foot SLR. This process was done using a linear superposition method of adding one foot increments to the MHHW surface, up to 6 feet (1.8 meters). Because tidal datum transformations in VDatum extend only slightly beyond the MHHW shoreline, interpolation and extraction routines to extend the MHHW surface inland were done according to methods suggested in NOAA (2010).

Where VDatum was not available, methods outlined in NOAA (2007) were used to interpolate between NOAA tide gages where the tidal-to-orthometric datum relationship existed. Then the procedure described above was used to create sea level inundation layers.8

Once the depth grids were created, they were evaluated for hydrologic connectivity using the eight-sided connectivity rule as suggested in Poulter and Halpin, 2007. Hydrologically connected areas were used to mask out unconnected areas in the original depth grids. The unconnected areas were preserved in a separate grid and are displayed as low-lying areas in the viewer.

Mapping Confidence

The Mapping Confidence feature, accessed by clicking on the "Confidence" button, illustrates that the inundation areas depicted in the "Sea Level Rise" feature are not as precise as they may appear. Levels of confidence are depicted in this feature, with blue areas denoting a high confidence of inundation (80%), orange areas a low confidence (20%) of inundation, and unshaded areas a high confidence (80%) that these areas will be dry given the chosen water level (Figure 2). There are many unknowns when mapping future conditions, including evolution of the coastal landforms (e.g., barrier island overwash and migration, man-made alterations), as well as the data used to predict the changes. The presentation of confidence here only represents the known error in the elevation data and tidal corrections and not the uncertainty associated with these other physical processes or the selected SLR projections.

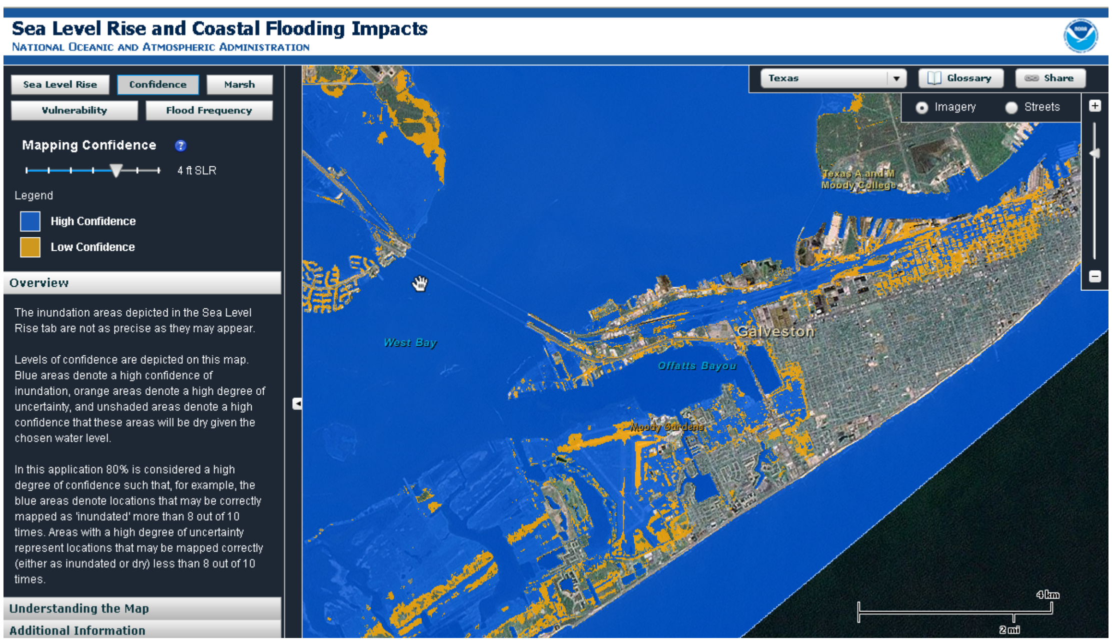

Figure 2. Mapping confidence depicting uncertainty in the elevation tidal surface used to depict 4 feet (1.2 meters) of SLR in the viewer. Blue areas indicate high confidence (80%) of being inundated and orange areas indicate low confidence (20%) for inundation. Unshaded areas (gray) have high confidence (80%) of remaining dry in the selected SLR scenario.

The techniques used to generate "confidence areas" in the viewer are similar in principle to previous techniques described in Gesch (2009) and Gesch et al. (2009). They both use the reported RMSE of the data in most cases and its relationship to a normal error distribution. Some major differences are the use of an 80% confidence level instead of a 95% confidence level, the use of a cumulative percentage in determining the uncertainty (one tail vs. two tail), and mapping this interval both above and below the inundation extent. Water level surface inaccuracies are also included; for many parts of the U.S. where VDatum coverage exists (http://vdatum.noaa.gov/about/availability.html), the standard deviation of the water level errors have been documented. In areas without VDatum, the errors may be greater and may have to be estimated.

In the simplest case, without any water level inaccuracies included, the inundation from a single-value water surface model is dependent only on the elevation uncertainty. Errors in elevation data are typically reported as either the RMSE or the Accuracy_z and inherently incorporate horizontal errors (Maune, 2007). The Accuracy_z is computed from the RMSE by multiplying the RMSE x 1.96 when the data are normally distributed; Accuracy_z is the same as the 95% confidence level in these cases. In addition, RMSE is equivalent to the standard deviation (SD) when the data are not biased (De Smith et al., 2007). This is an important point for our method; this paper assumes that the RMSE is analogous to the SD (i.e., the data are not biased), which allows for the generation of a 'standard-score' from the data.

Mapping of the uncertainty takes on the same basic equation used to compute a standard-score (Eq. 1) but substitutes RMSE for SD. The standard-score is simply the number of standard deviations a particular value falls from the mean.

$$\text{Standard-Score}_{(\text{value})} = (\text{Value} - \text{Mean}_{(\text{population})}) / \text{SD}_{(\text{population})} \quad (1)$$

This equation is rewritten to substitute the inundation level (water surface) and the specific elevation at an X,Y location and RMSE of the elevation data set (Eq. 2).

$$\text{Standard-Score}_{(X,Y)} = (\text{Inundation}_{(\text{water surface})} - \text{Elevation}_{(X,Y)}) / \text{RMSE}_{(\text{Elevation Data})} \quad (2)$$

Using this equation (Eq. 2), the standard-score can be defined for any elevation in relationship to a certain water level. For example, the standard-score at a given location with an elevation of 1.2 meters, which is based on a lidar data set that has an RMSE of 20 centimeters (0.2 meters) and an inundation level of 0.75 meters, would be as follows:

$$(0.75 - 1.2) / 0.2 = -2.25$$

This standard-score (-2.25) can then be used to find the percentile rank (Cumulative %). In this case the percentile rank, using a look-up table, would be 1%. So one could say, given the quality of this elevation data set, that this location has a 1% rank (chance) of being inundated by a water level of 0.75 meters.
The differences between this process and the process outlined in Gesch (2009) and Gesch et al. (2009) are the continuous nature of the standard-score computations (i.e., each elevation value has its own standard-score) and the use of the 1.96 x RMSE value to attain a 95% value. A standard-score of 1.96 above the level of inundation (what would be called -1.96) would equate to a 2.5% rank of flooding in this equation, not a 5% rank, since a cumulative or single tail approach is used (i.e., there is an assumption that values at the lower extreme are going to be inundated). The cumulative approach uses the entire area under the normal distribution (Figure 3), not the discrete area between the standard deviations from the mean (i.e., the area between 1.96 and -1.96).

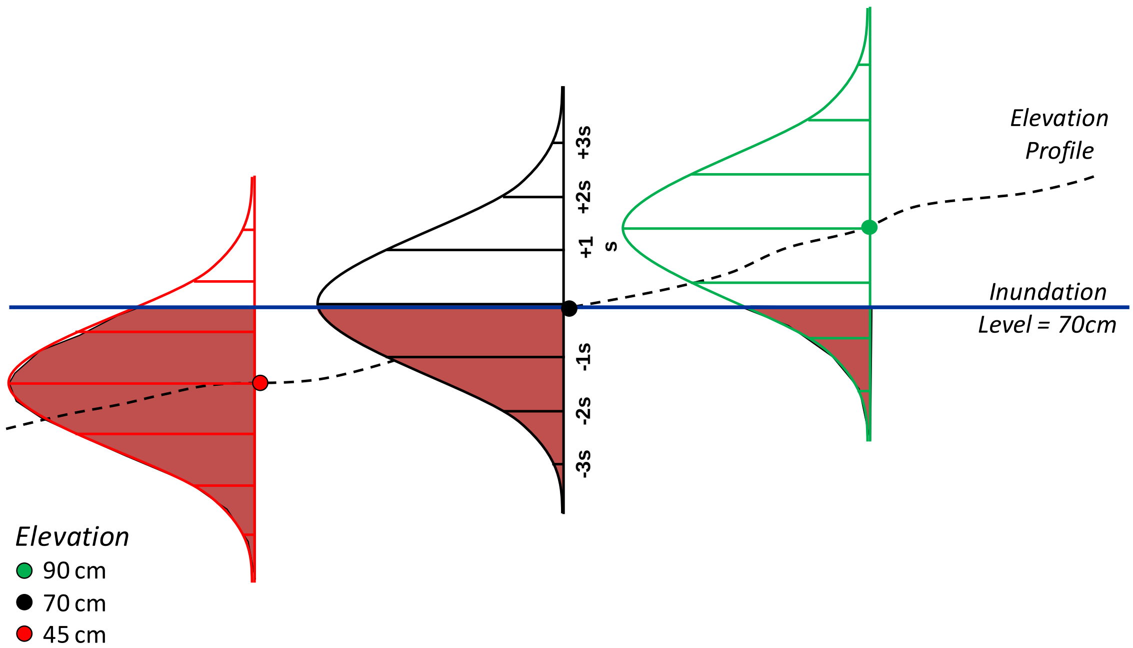

Figure 3. Example of NOAA Coastal Services Center method for computing a standard score at 20cm above and 20cm below an inundation level of 70cm.

Data errors that are directly related to elevation and water height data can be used to begin defining areas with mapped inundation that do not have the same level of confidence as other areas. The combined errors associated with most lidar and tidal data are not trivial and can approach 2 feet (0.6 meters), which is on par with some SLR estimates for 2100. The technique used in this tool only maps confidence in the elevation and tidal surface, not in the various geomorphic and man-made variables and processes.

The technique and definition of “confidence” levels in this feature of the tool are slightly different than other common methods, but the use of standard deviation to derive the assessment is similar. This tool has tentatively chosen the 80% rank as the threshold between areas that have high uncertainty and those that seem well represented by the mapped output; however, any choice of uncertainty or rank can be used with this technique.

Mapping Marsh Migration

The Mapping Marsh Migration feature can be accessed by clicking on the “Marsh” button. The user can use a slider bar to see how various SLR scenarios may impact marsh distribution. Maps represent the potential distribution of 12 marsh and wetland types (Cowardin et al., 1979) based on their elevation and how frequently they may be inundated under each scenario (Figure 4). As sea levels increase, some marshes may migrate into neighboring low-lying areas, while other sections of marsh will be lost to open water. There are advanced options where users can select an appropriate accretion rate and time interval for their area of interest. The wetland data portrayed as the initial condition within the viewer are derived from NOAA’s Coastal Change Analysis Program (C-CAP) (http://www.csc.noaa.gov/landcover).

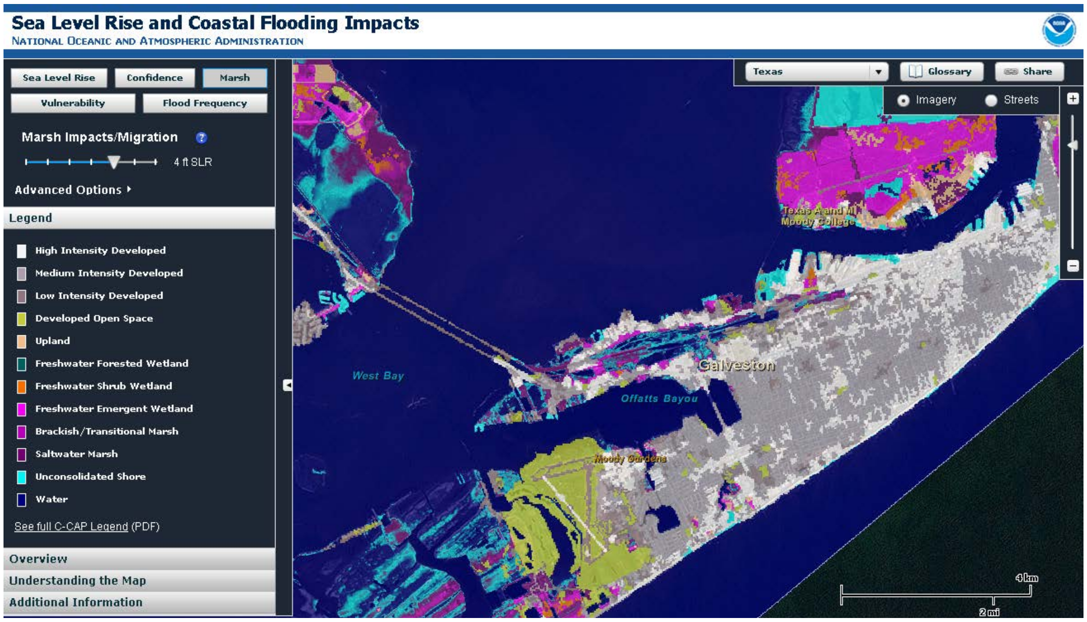

Figure 4. Potential distribution of marsh and wetland types based on their elevation and how frequently they may be inundated under different SLR scenarios (showing 4 feet, or 1.2 meters). As sea levels increase, some marshes may migrate into neighboring low-lying areas, while other sections of marsh will be lost to open water.

The mapping processes employed to create the layers in the marsh migration tool are similar to those discussed above in the mapping SLR section. The same assumptions are made in both, and both use a linear superposition method and incorporate tidal variability using the methods in NOAA (2007, 2010). Additional assumptions are made that marshes that cannot maintain their elevation relative to sea level will gradually become submerged and be converted to an intertidal mudflat or open water over a period of many decades (Morris et al., 2002). Titus (1988) states that because periodic flooding is the essential characteristic of salt marshes, increases in the frequency and duration of floods can substantially alter these ecosystems. Titus (1988) also states that salt marshes extend seaward to roughly the elevation that is flooded at mean tide, and landward to roughly the area that is flooded by spring tide. We make the same assumptions in this part of the tool. Our method assumes that specific wetland types exist within an established tidal elevation range, based on accepted understanding of what types of vegetation can exist given varying frequency and time of inundation, as well as salinity impacts from such inundation.

The marsh migration mapping procedure uses four tidal surfaces from the VDATUM model instead of just MHHW: mean high water spring (MHWS), MHHW, mean tide level (MTL), and mean lower low water (MLLW). The MHWS surface is a modified form of the MHHW surface but has been shifted upwards in relation to the highest tide levels in the spring. For example, if during the May-June period the highest predicted tides are 5.5 feet (1.7 meters) and the MHHW datum is 5 feet (1.5 meters), the entire MHHW surface would be adjusted upwards by 0.5 feet (0.2 meters) to generate a MHWS surface.

The fifth surface that must be derived prior to modeling the impacts from SLR is the boundary between the upper elevation of freshwater wetlands and uplands (FWUB). This boundary is determined by comparing existing wetlands to current elevation values for the study area and determining whether each elevation increment is primarily wetland or upland. The threshold of 66% is used to establish a conservative estimate for where this transition takes place. Therefore, whatever elevation is made up of at least a 66% majority of wetlands would be considered wetland, but less than 66% wetland would be considered a primarily upland elevation value. Once established, this elevation is treated like the tidal surfaces created above.

The detailed mapping process is as follows:

1. Add desired SLR amount to each of the five surface grids. This is done using a look-up table (Figure 5) based on A1B rates of SLR (see IPCC, 2007).

	Sea Level Rise (ft) in 100 years					
	1	**2**	**3**	**4**	**5**	**6**
2025	0.25	0.50	0.50	0.75	1.00	1.25
2030	0.25	0.50	0.75	1.00	1.25	1.50
2040	0.25	0.75	1.00	1.50	1.50	2.00
2050	0.50	0.75	1.25	1.75	2.00	2.50
2060	0.50	1.00	1.50	2.00	2.50	3.00
2070	0.75	1.25	2.00	2.50	3.50	4.00
2075	0.75	1.50	2.00	3.00	3.50	4.50
2080	0.75	1.50	2.50	3.00	4.00	4.50
2090	1.00	1.75	2.50	3.50	4.50	5.50
2100	1.00	2.00	3.00	4.00	5.00	6.00

Figure 5. Look-up table that has amounts of SLR (in feet) and years, based on the IPCC A1B rates. Highlighted example shows that 1.75 feet (0.5 meters) of sea level would be added to the present-day tidal surface to simulate a condition at year 2050. Increments of 0.25 ft. (0.1m) were used.

2. Add desired amount of accretion to the DEM surface. Accretion is the vertical rise of the marsh's surface caused by buildup of organic and inorganic matter. The amount of accretion is a result of sediment delivery and deposition dynamics that occur at an individual site. The net amount of accretion for a given year is determined by the accretion rate multiplied by the number of years being modeled. In the SLR and Coastal Flooding Impacts Viewer, the user can select from four predetermined rates of accretion. These rates are presented as high, at 6 millimeters (mm) per year, medium (4mm per year), low (2mm per year), and no accretion (0mm per year). These rates were determined from rates generally used in previous studies.

3. Subtract the resulting five surfaces from step 1 from the resulting DEM in step 2. The result is a new surface layer for each of the MLLW, MTL, MHHW, MHWS, and FWUB.

4. Model the land cover class transition rule set. Using surfaces created in step 3 above, a simple rule set can be instituted to model wetland habitat class transitions, based on these new tidally adjusted elevation surfaces. Within the viewer, wetland categories are assumed to exist within the boundaries between the tidal thresholds. As the amount of SLR causes an area to move down within the tidal spectrum (based on the modeled surfaces derived above), wetland categories will change from one type to the next, according to their new location. For example, as sea level rises, and the tidal threshold locations move up in elevation relative to the land, upland categories may transition into fresh marsh, and freshwater marsh areas may transition into brackish, salt marsh, or unconsolidated shore habitats. In the viewer, classes are not allowed to transition in the opposite direction (i.e., saltwater marshes are not allowed to become freshwater marshes). This would only be the case if the amount of accretion would exceed the amount of SLR being modeled, and it is assumed that this would not be likely given that the accretion rate on the upper end of the tidal spectrum would be less than optimal, and that areas not flooded regularly would have no accretion at all.

Mapping Social and Economic Vulnerability

By overlaying social and economic data on a map that depicts SLR, a community can see the potential impact that SLR can have on vulnerable people and businesses. This feature of the tool, accessed by clicking on the “Vulnerability” button, shows sea level inundation layers over social and economic data from the University of South Carolina (USC) and U.S. Bureau of Labor Statistics (BLS). By looking at the intersection of potential SLR and vulnerable population, one can get an idea of how vulnerable populations might be affected by SLR (Figure 6). The Social Vulnerability Index (SOVI) (Cutter, 2003) shows areas of high human vulnerability to hazards based on population attributes (e.g., age and poverty) and the built environment (31 variables in all). Census block group analysis of SOVI data is being shown for the first time in this tool, based on new methods developed by USC to downscale the SOVI analysis from county to block group level.

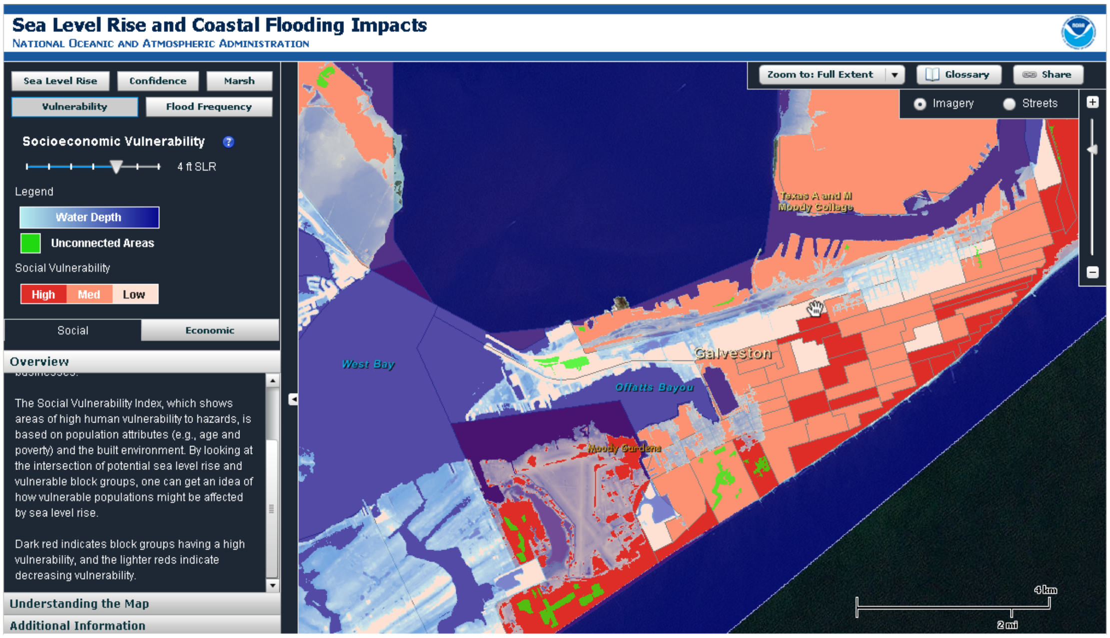

Figure 6. Sea level inundation of 4 feet (1.2 meters) overlaid on Social Vulnerability Index data. Dark red indicates Census block groups having a high vulnerability, and the lighter reds indicate decreasing vulnerability.

The economic data represent total business establishments, employment, and quarterly wages single-point data aggregated to Census block groups and are from the Bureau of Labor Statistics' 2009 Quarterly Census of Employment and Wages (QCEW) data. By looking at the intersection of potential SLR and the distribution of the economy within a community, one can get an idea of how a local economy might be affected by SLR. This viewer is the first place that these types of BLS geospatial data have been displayed. The NOAA Coastal Services Center and BLS have established an agreement to share resources to display inundation hazards with economic data.

Within GIS software, spatial joins are performed to join geocoded employer records to Census block group data. Like joining two tables by matching values in a field, a spatial join associates one layer to another based on the geographic location of the features in the layers. The resulting data are reviewed to ensure preservation of individual employer data confidentiality. Confidential data are suppressed.

Mapping Coastal Flood Frequency

The Mapping Coastal Flood Frequency feature, accessed by clicking on "Flood Frequency," demonstrates that everyday coastal flooding from tides will become more frequent as sea level rises. In a sense, today's flood will become tomorrow's high tide, since SLR will cause flooding to occur more frequently and last for longer durations. The red layer in Figure 7 represents areas currently subject to shallow coastal flooding as determined by NOAA National Weather Service criteria. These areas were mapped using a single-value threshold for each weather forecast office warning area. The user can click on a NOAA tide station to see information on the current frequency of coastal flood events and durations as compared to hypothetical half-meter and one-meter SLR scenarios (see inset in Figure 7).

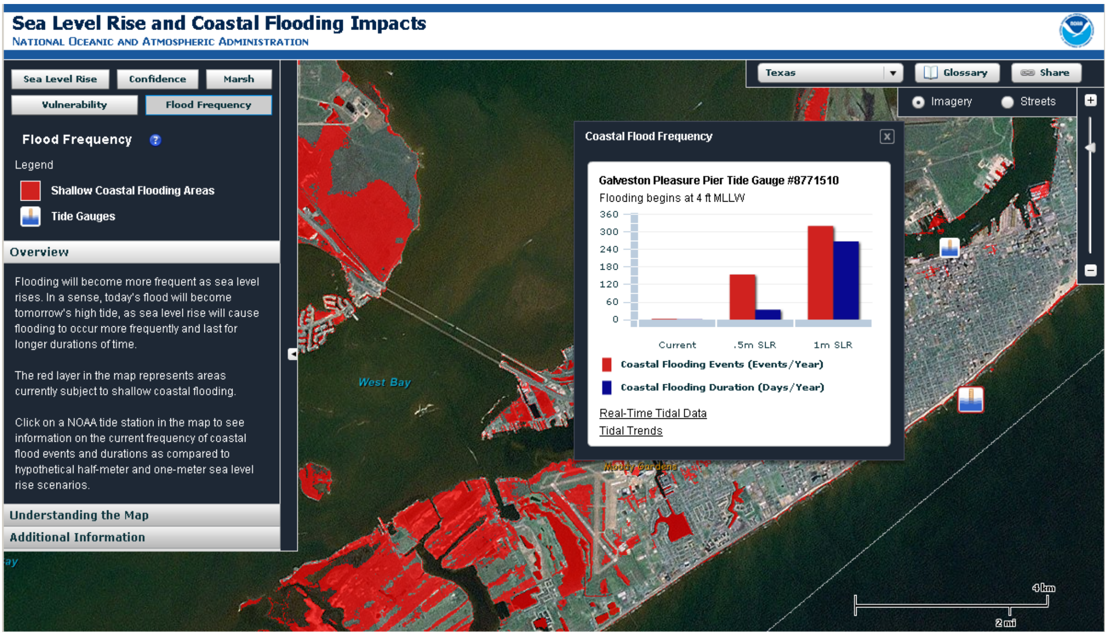

Figure 7. Areas currently exposed to shallow coastal flooding are depicted in red. The graph shows the number of flooding events and duration for 0, 0.5, and 1 meter of projected SLR at specific NOAA tide gages. Analysis is based on three years of observed tide data.

For the purposes of this viewer, an inundation analysis algorithm was developed by the NOAA Center for Operational Oceanographic Products and Services (CO-OPS). It uses the observed 6-minute water level time series and the observed times and heights of the observed high waters (tides) over a three-year period from NOAA tide gages as data input. The data output of this program is an Excel spreadsheet that takes each of the tabulated high tides in a specified time period relative to the user-specified datum reference or threshold elevations, and calculates the elevations and durations of inundation of each of the high waters above the reference datum. For analyzing various sea-level rise scenarios, the reference datum is adjusted by the estimated amount of elevation change for a given sea-level rise scenario and the statistics above are regenerated.

Future Direction and Summary

Currently, two geographies are covered in the initial release of the viewer (December 2010), central Texas and Mississippi. Additional geographies will be mapped and added to the viewer in 2011 and 2012, including most of the rest of the Gulf of Mexico, U.S. West Coast, Hawaii, Mid-Atlantic, and Southeast, with eventual expansion nationwide in following years. The Great Lakes implementation will require developing additional methods to handle the mapping of lake level drop. Partnering with regional and local entities along the way will make it possible to expand this tool and meet the needs of coastal managers who are developing climate adaptation plans or revising existing hazard mitigation plans. In addition, continued and new partnerships within NOAA, USC, BLS, USGS, and the Federal Emergency

Management Agency (FEMA) will continue to leverage valuable datasets that are used to show the SLR impacts in the tool.

The NOAA Coastal Services Center has had a history of working with partners and customers across all levels of government on inundation information and tools for years, and has used this work as a basis for this next generation SLR viewer. The SLR and Coastal Flooding Impacts Viewer contains novel datasets and approaches to looking at SLR impacts. While there are limitations inherent to the layers, feedback from the user community indicates the tool is providing a valuable service. That being said, there is much work left to be done, including a need to continue working with partners so that new and better science can be incorporated, and to ensure that the product overall continues to meet the needs of users

Data Distribution and Sharing

The NOAA Coastal Services Center's strategy for distributing data contained in the SLR and Coastal Flooding Impacts Viewer is to provide map services of the data and will expand to distribution of the actual data. Currently, the viewer displays a total of 34 map services that contain the data necessary for each of the five tabs. The map services can be accessed by external users and can be displayed in a variety of clients with both local and other remote data.

The SLR and Coastal Flooding Impacts Viewer is accessing both dynamic and cached map services through the Center's ESRI ArcGIS server implementation. Specifically, services are being accessed through the ArcGIS Server REST (Representational State Transfer) API (Application Programming Interface), which is an interface for requesting data through URLs (Uniform Resource Locator). The SLR, confidence, marsh, and flood frequency services have been cached, which allows for quick viewing of the data using the slider bar. The vulnerability and point data are accessed through dynamic services, which allow for attributes of the data to be queried and displayed.

The SLR and Coastal Flooding Impacts Viewer data will eventually be accessible via Open Geospatial Consortium-compliant (OGC, http://www.opengeospatial.org/) map services. The OGC is a standards organization that develops and oversees "open" or non-proprietary services for accessing data. The OGC services the Center will publish are Web Map Services (WMS), Web Feature Services (WFS), Web Coverage Services (WCS), and Keyhole Markup Language (KML). Each of these service types is accessible from a variety of clients. In addition to serving the data through map services, select data will be available for download via the NOAA Digital Coast website, by state, and will have Federal Geographic Data Committee-compliant metadata.

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