Communicating Coastal Risk Analysis in an Age of Climate Change

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14. ABSTRACT

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Communicating Coastal Risk Analysis in an Age of Climate Change

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***Abstract*—Complex science and large volumes of disparate data required for risk analysis of coastal hazards can be very difficult to communicate effectively to government and business decision makers. Including potential future scenarios as a result of climate change complicates matters further. An immersive visualization environment integrating data from high resolution imagery, sensed and measured data, model output, and more, that can scale from the desktop to large dome theater venues demonstrate promise for greatly enhancing the impact and reach of these scientific endeavors.**

Keywords- coastal hazards; coastal risk; visualization; decision support; WorldWide Telescope;

I. INTRODUCTION

A substantial percentage of the world population lives within 10-100 km of the ocean and in relatively low-lying, flat coastal regions [1], and the land, people, and supporting infrastructure are particularly at risk from coastal hazards including storm surge inundation, precipitation driven flooding, waves, and coastal erosion. This population segment will likely be exposed to increased risk as impacts of a changing climate are felt through elevated sea levels and potentially increased storm intensity and frequencies [2, 3]. The ability to understand and predict coastal changes, and effectively communicate potential future scenarios to decision makers is thus critical for adaptation to, and mitigation of increasing coastal risks and development of forward-looking plans for coastal resource management. Compelling methods for visualization of this risk analysis are required to increase public awareness of the changing environment and for combining disparate data into a consolidated framework. In this context, we are investigating the WorldWide Telescope [4] as a platform for implementing a data rich environment for visualization and decision support.

II. RISK AS A FUNCTION OF CLIMATE CHANGE

The "total" risk of living on the coast depends on many factors; the physical hazards (storm surge, inundation, waves, and winds driven by strong tropical and extratropical storm systems); the geometry and geomorphology of the area (regional and local bathymetry and topography, including rivers, marshes, and width of the continental shelf); built and natural structures including levees and dunes. All of these factors will, in some way, be modified by future climates, and storm surge levels are generally expected to increase [5]. Sea level rise, whether attributable to human activity or not, compounds the impacts of these hazards by allowing further inland penetration of surge and waves. Additionally, the actual inundation caused by a storm is a function of many variables, including: storm characteristics, low-frequency coastal water level associated with Gulf Stream transport [6, 7] and large-scale atmospheric patterns, evolution of the coastal shoreline and geomorphology, and over longer time scales, regional elevated sea levels due to global climate change. However, the NOAA Climate Change Science Program report [8] on changes in extremes concludes (among other things) that predicted magnitudes of surge increases have not been sufficiently investigated. This information gap hampers coastal resource managers and planners in their efforts to anticipate future risks in the coastal zone. Key questions of interest to coastal managers and planners include:

1. On a statewide and regional scale, do flood levels in the current climate (for example, the 100-year surge level) undergo a change in frequency such that they occur more often in a plausible future climate? Under what conditions does the 100-year

surge level (currently used to set flood insurance rates) become the 50-year surge level?

2. Given anticipated coastal land use and development changes over the next century, under which climate scenarios are impacts expected to be greatest? Which areas of the coast should expect the largest changes in risk?

3. What changes in the wind hazard from tropical storms can be anticipated under plausible future climates?

4. How do ocean wave heights responsible for substantial coastal erosion evolve in future climates?

Without compelling visualizations of information pertaining to these and many other questions, the impact and importance of such issues can be very difficult to adequately convey to key stakeholders, policy and planning officials, coastal management groups, and interested individuals.

III. DATA SOURCES

Effectively communicating the risk profile of an area to government and business decision makers requires a large and disparate set of data.

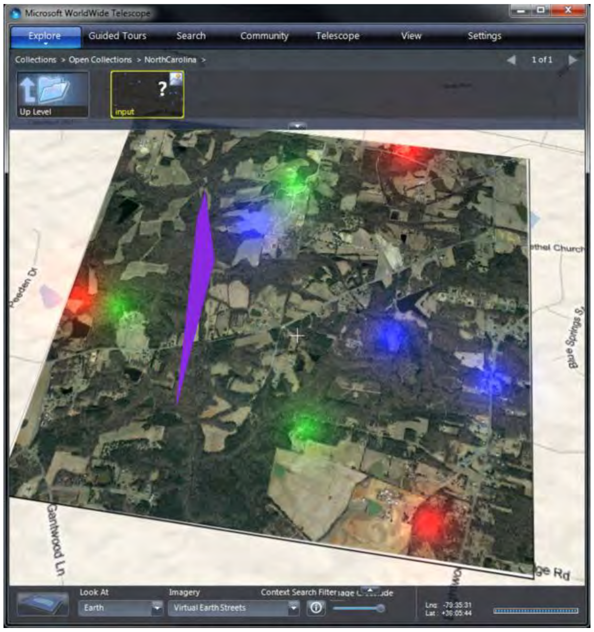

Figure 1. Custom tile overlay with point and polygon data

The state of North Carolina acquires and maintains high-resolution data assets such as orthophotos and LIDAR from across the entire state, covering approximately 805 x 298 kilometers. The resolution of the orthophoto set is 0.15 meters/pixel, requiring 17TB of disk storage, while the LIDAR data is typically about 3 to 6 meters per pixel comprising 40GB. To serve this data in place of the stock aerial photography and topology provided by WWT, we have deployed a tile server [8] and used the WWT SDK to render the orthophotos and LIDAR data.

For the prototyping effort, we have ingested into the WWT environment data from sources including: the Open Geospatial Consortium (OGC) Sensor Observation Service (SOS); Open Data Protocol (OData); and NetCDF. We plan to also leverage a recently developed .Net client API for the Integrated Rule-Oriented Data System (iRODS) to access many terabytes of geospatial contained within that system. Figure 1 above shows the WWT application with Bing Maps as the background, overlaid with an orthophoto tile from the custom tile server, along with point and polygon data.

The first scientific model brought into the environment is for coastal storm, a common and damaging natural occurrence. The simulation of storm surge on the North Carolina coast, due to either extra-tropical winter/spring storms or to tropical (hurricane) summer/fall storms, is done with the ADCIRC storm surge and tidal model [9]. This model is used by the research community to investigate fundamental physical processes controlling storm surge and coastal impacts, as well as federal agencies and industry for coastal flood simulations and risk analysis. The Federal Emergency Management Agency (FEMA) has approved the use of ADCIRC for coastal flood insurance studies, and the model output used herein was computed for such a study for the North Carolina coastal counties.

Computing storm surge for complex regions (like the North Carolina coastal zone) involves numerical simulation of the ocean. This ocean is a thin layer of fluid on a rotating sphere. The ADCIRC model thus solves the hydrodynamic equations for fluid flow on a thin, rotating shell, suitably modified for regional-scale problems. The governing shallow-water wave equations are represented using linear triangular finite elements of arbitrary size, a consequence of which is highly variable spatial resolution of the region of interest. In this North Carolina prototype, the ADCIRC region of simulation is shown in Figure 2. The complexity of the region (topography, geometry of inlets and shallow marginal bays and sounds) typically demands such resolution, with a substantial cost associated with computing the storm surge simulations. The latter is particularly relevant when considering that hundreds of simulations are needed to adequately compute the statistical risk associated with coastal storms.

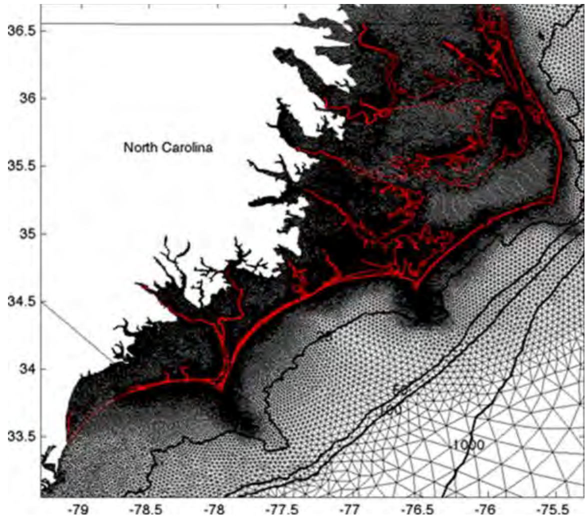

Figure 2. The ADCIRC finite element grid for North Carolina. This grid is used for coastal flooding simulations for storm surge forecasting systems and for FEMA flood insurance studies. The red line is present-day mean sea level. Depth contours are drawn at 25, 50, 100, and 1000 meters. Higher grid resolution is indicated by the denser finite element triangles, which is higher in shallower water and around water and land features. The offshore resolution relaxes to about 50 km. There are 589K nodes in this grid, 95% of which are in the North Carolina area shown in this figure. Note that the entire domain of the grid includes the Atlantic coastline of North and South America, however only the portion around the NC coastline is shown.

An example of a storm surge solution is shown in Figure 3 for Hurricane Isabel, which made landfall on the North Carolina coast on 16 September, 2003. The figure shows the maximum water level over the simulation (in meters above mean sea level). This type of visualization, a 2-dimensional plot of a model result, with no user-level interactivity is common in the domain scientific context, and while this method of showing model results is both useful and common, it does little to convey the impacts of storm surge and risk to other audiences, and can be difficult to include other important data such as photos, sensor data, and critical infrastructure. Figure 4 shows the finite element grid as a point data set within WWT.

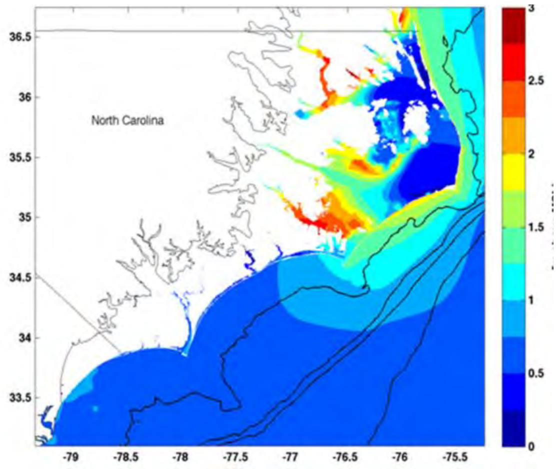

Figure 3. Storm surge levels (in meters above mean sea level) from the ADCIRC model, computed for Hurricane Isabel (2003). The largest surges are in red, showing substantial surge in the lower Neuse River. This 2-dimension visualization of model output is common and useful for the scientist and engineer, but does not convey aspects of risk and hazard to the more general audience

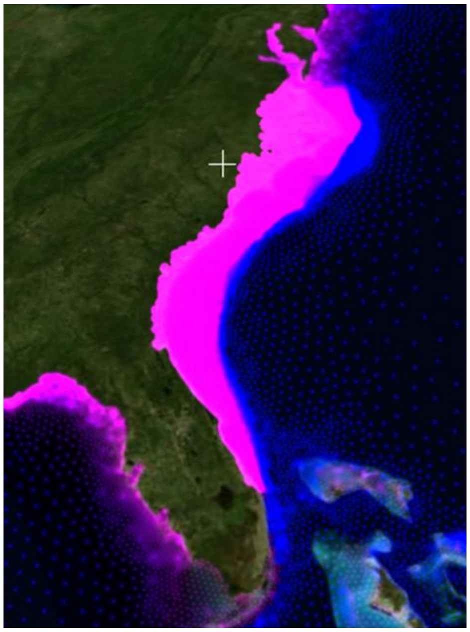

Figure 4. The ADCIRC finite element grid as shown within WWT

IV. WWT CLIENT CODE

The primary method of programmatically interacting with WWT is in the form of HTTP requests providing easy access to external data, and interesting capabilities such as injecting data into a remotely running instance of WWT (assuming the security has been configured properly). However, the HTTP based interactivity can be cumbersome from a coding perspective for high volume and fine grained control of the environment, so we have implemented a client API that encapsulates all of the WWT API functionality. We have found this client to be a valuable productivity enhancement for controlling WWT, eliminating the need to directly process the HTTP request and response. This code will be published and available for collaborative contributions under the New BSD License (BSD) policy on CodePlex.

V. HARDWARE LIMITATIONS

As powerful as today's CPU's, GPU's, networks and advanced programming environments are, the enormity of data both sensed and generated as model output quickly renders even high-end desktop machines inoperable. Loading roughly 500k data points from a NetCDF file using a Lenovo W510 with 4 cores, 8GB of RAM and NVIDIA Quadro FX880M video, the system becomes difficult to use and operate. One approach to mitigating this issue is to decrease the resolution of the solutions that are loaded into the environment. However, high resolution is often *exactly* what is needed when assessing and communicating risk related to specific communities, assets, evacuation routes, etc. Two approaches that we are pursuing to mitigating this problem: First, we will develop tools and techniques to rapidly filter incoming data limiting the field of vision to as small of an area as reasonable based on requirements. A second technique will be to "render" relatively static data into the tiled imagery.

VI. CONCLUSION AND FUTURE WORK

The WorldWide Telescope is a promising platform for integrating and visualizing the large and disparate sets of data and information related to coastal risk analysis combined with climate change. We intend to continue the prototype effort and test the validity of this approach by working directly with government and business decision makers. We plan to integrate output from additional environmental models such as the Weather Research and Forecasting Model (WRF), and utilize various display technologies such as the dome at the Morehead Planetarium and Science Center, or the UNC Social Computing Room which utilizes 12 projectors to generate a 360-degree 768 x 12,288 display across the entire perimeter of the environment. A critical challenge remains in managing the volumes of data with the capabilities of the hardware running WWT. For large venues such dome auditoriums, we expect that techniques similar to remote visualization from the High Performance Computing community may be necessary. Finally, one can imagine coupling the WWT environment directly with large scale computational resources required for ADCIRC and WRF modeling, providing interactive simulation and analysis capabilities.

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