Visualizing Katrina - Merging Computer Simulations with Observations

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Abstract. Hurricane Katrina has had a devastating impact on the US Gulf Coast, and her effects will be felt for many years. Forecasts of such events, coupled with timely response, can greatly reduce casualties and save billions of dollars. We show how visualizations from storm surge and atmospheric simulations, was used to predict how strong, where, and when flooding would occur in the hours leading up to Katrina's landfall. Sophisticated surface, flow and volume visualization techniques show these simulation results superimposed with actual observations, including satellite cloud images, GIS aerial maps and LIDAR showing the 3D terrain of New Orleans. We have developed efficient data layout mechanisms to ensure fast and uniform access to the multiple time-varying datasets. The visualization that emerged from this nationwide multidisciplinary effort was showcased at Supercomputing '05.

1 Background and Previous work

Katrina was one of the most powerful hurricanes ever to hit the US, and was certainly, the most devastating. This catastrophe has highlighted the need, not only for timely and accurate observations and forecasts from simulations, but for meaningful visualizations that upon a range of available data sources, enabling coordination and information transfer between domain experts, policy makers and emergency responders. The Center for Computation & Technology at the Louisiana State University (LSU) together with the LSU Hurricane Center is part of the SURA Coastal Ocean Observing and Prediction program(SCOOP) [1], a national community that currently engages in distributed coastal modeling across the southeastern US on an operational basis. Advisories from the National Hurricane Center(NHC) about impending storms are used to trigger automated workflows that start with the generation of high-resolution wind fields around the center of activity which then initiate the ADvanced CIRCulation hydrodynamic model[1] (ADCIRC) on LSU's 1024 processor cluster, SuperMike. ADCIRC accurately models a wind-driven storm surge - its formation, movement across

[1] `http://www.nd.edu/~adcirc/`

the ocean and morphology as it impacts land. The SCOOP data archive [2] housed at LSU aggregates the model outputs from multiple sources and is the source of data for our visualization efforts.

The domain of the ADCIRC simulation used to model Hurricane Katrina's storm surge covers the southeast US, resolving from the Atlantic ocean to the channels within New Orleans, showing the increasingly intense surge that ultimately breached the levees and flooded the city. We have created an interactive visualization of the events leading to the flooding pulling together models showing the development of the hurricane's wind and temperature fields, the storm surges, 3D terrain views from LIDAR and GIS data, combined with comparisons to what actually happened using time-varying atmospheric imagery from the GOES-12 weather satellite. Facing these challenges required new partnerships between coastal modelers, engineers and computer scientists. Given the sheer size and complexity of the data, this application also motivated research in efficient data access mechanisms and rendering algorithms. The result was demonstrated at Supercomputing 2005 in Seattle, both as an interactive stereoscopic visualization and a remotely streamed high-resolution movie.

Previous work at the LSU hurricane center has focused exclusively on 2D representations of the storm surge results. In the computational science community, much work is confined to scientific visualization methods such as isosurfaces or volume rendering for 3D atmospheric model outputs. On the other hand, the geoscience community has concentrated on visualizing, generally in 2D, data from remote sensing and GIS mapping sources. While geovisualization softwares like vGeo[2] allow for isosurface display with GIS data, the drawback is the lack of extensibility to incorporate new data formats, limited rendering functionality and in some cases, platform-dependence. For our purpose, we decided to use Amira [3] as the visualization framework as it runs on most common platforms, allows for custom data loading, sophisticated hardware-accelerated rendering as well as display to multiple devices such as stereoscopic and multi-tiled systems.

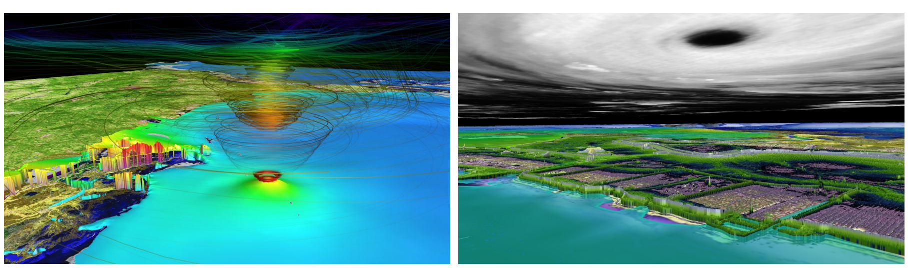

Fig. 1. a) Composite view of wind-fields from MM5 model with surge heights as Katrina approaches the coast. b) Zooming in to New Orleans - Real-time satellite imagery of the hurricane eye overlayed on the 3D terrain

[2] `http://www.vrco.com/vGeo/OverviewvGeo.html`

2 Approach

The underlying computational mesh for the ADCIRC simulation consists of 314,442 points and their topographic or bathymetric information with unstructured grid resolution down to 100m. The output is a triangular surface with time-evolving water elevation, both wind and current directions on each vertex. To show the atmospheric conditions that led to the hurricane formation and the resulting surge, the wind and temperature fields from the MM5[3] domain-2 atmospheric model were used. Each time-step in this model is a structured 3D grid with dimensions 150x140x48 storing the wind velocity, precipitation and temperature values. Both the ADCIRC and the MM5 model outputs were at 30-min intervals, and for the dates August 15 2005 to September 1 2005, just after Katrina had made downfall.

Satellite images and GIS raster data are well representable in common image file formats such as GEOtiff [4]. In contrast, MM5 and ADCIRC data are more complex, and no standard format exists for these kind of data types. A huge number of file formats compete, each bringing unique strengths but also tend to be mutually exclusive. Even for a specific data type, such as a triangular surface, there co-exist myriads of file formats. Particularly in a Grid context where n various independent applications with no a-priori knowledge of each other need to mutually communicate and therefore support each other's file formats, the file format issue becomes a n^2 implementation effort. Ideally, we would like to use a common file format which covers all cases of types of scientific data and thus achieves maximum synergy. To find such a unified description, a common denominator is essential, which, following D. Butler's [4,5] proposition is using the mathematical concept of vector and fiber bundles to layout data. Within the classification scheme of the fiber bundle data model, MM5 outputs are dynamic scalar and vector data on a three-dimensional regular domain, while ADCIRC data are described by a a dynamic scalar field given on a static triangular surface.

We employed the widely-used Hierarchical Data Format V.5 (HDF5) [6] as underlying format, as it provides many unique features of interest particularly in a Grid context [7]. While HDF5 provides a syntax for an efficient representation of scientific data, the layout of data as a fiber bundle provides a semantic layer over HDF5. While such a layout is not unique, our version [8] intrinsically supports time and extended datatypes over arbitrary dimensions on unstructured and structured grid types. With this unified interface, writing custom file converters was a one-time effort to output the time-varying surge surfaces, wind and temperature volumes to the fiber bundle HDF5 format. As a result, loading the large time-varying ADCIRC datasets provided originally as text files now only required a fraction of a second instead of minutes. Moreover, due to the integrated caching algorithms in the HDF5 library itself, each time step is loaded on demand when accessed. Both ADCIRC and MM5 data can be loaded through the same interface and may even be stored in the same file.

[3] `http://www.mmm.ucar.edu/mm5/`

[4] `http://www.remotesensing.org/geotiff/geotiff.html`

Custom rendering modules were written in Amira to display the surge heights as a transparent surface over the ocean bathymetry, making use of the "laminae" technique [8]. Using Amira, the wind field, a vector field, is visualized using the technique of illuminated stream lines. The temperature, a scalar field can be volume rendered by itself or used as a colormap upon the streamlines. Fig. 1a shows a composite view of the surge surface and the wind-vector streamlines color-coded with the temperature values.

Fig. 1b shows a 3D terrain of New Orleans extracted from LIDAR data and overlayed with the Infra-red satellite imagery showing the eye of the hurricane looming over the heart of the city. The LIDAR[5] obtained from the Louisiana Geological Survey gives us a 5m resolution elevation grid of the New Orleans area. Rendering this grid as a height-field gives us the 3D terrain. The satellite imagery shows the infra-red channel from the GOES-12 satellite captured at the Earth Scan Laboratory at LSU every 15 min on a 4km resolution grid. This helps us visually compare with forecasted trajectories from simulation results.

The extremely high-resolution of GIS elevation models (in our case 77 million points) makes interactive rendering virtually impossible. We are currently implementing hierarchical Level-of-Detail (LOD) techniques to dynamically simplify the mesh at run-time depending on the view point. In future, we also hope to integrate the visualization components as part of the automatic workflow triggered during an emergency alert to visually aid in parameter tweaking and running multiple scenarios.

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[5] LIght Detection And Ranging `http://www.lidarmapping.com`