Visualizing Hurricane Katrina - Large Data Management, Rendering and Display Challenges

Shalini Venkataraman, Werner Benger, Amanda Long *
Center for Computation and Technology
Louisiana State University
Baton Rouge, LA - 70803

Byungil Jeong, Luc Renambot †
Electronic Visualization Laboratory
University of Illinois at Chicago
Chicago, IL - 60607

Abstract

Hurricane Katrina has had a devastating impact on the US Gulf Coast. Forecasts of such events, coupled with timely response, can greatly reduce casualties and save billions of dollars.

In our effort, we use sophisticated surface, flow and volume visualization techniques show the storm surge and atmospheric simulations simulation results superimposed with actual observations, including satellite cloud images, GIS aerial maps and elevation maps 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. In particular for rendering, we focus on continuous and discrete level of detail algorithms used to render large terrains of the Mississippi basin and also remote visualization techniques to stream the rendered results across the network to large display clients.

Our primary contribution is in adapting existing state of the art research in data access, rendering and display mechanisms and devising an overall framework for application in hurricane and coastal modeling.

TODO - Redo abstract

Keywords: Scientific Visualization, Scientific Data Management, Geovisualization, Scalable Displays

1 Introduction

Katrina was one of the most powerful hurricanes ever to hit the US, and was certainly the most devastating as its accompanying wind-driven surge instantaneously impacted more than a million people by flooding major parts of the sub-sea level city of New Orleans. This predictable catastrophe has highlighted the need, not only for timely and accurate observations and forecasts from simulations, but also for meaningful visualizations that draw upon a range of available data sources, enabling coordination and information transfer between domain experts, policy makers and emergency responders. **(split)** Solving a complex problem of this nature requires a concerted effort between application experts, computational scientists and technologists. The SURA SCOOP [MacLaren et al. 2005] is one such regional effort to create a consortium of experts in atmospheric sciences, coastal modeling, GIS, grid computing, data archival and scientific visualization. Based on impending storm warnings, the supercomputers on this grid are triggered to run various forecast models and archive the results. This research environment provides the motivation our visualization efforts.

In this paper, we describe our approach to visualize scientific data that are available for hurricane Katrina, originating from computational simulations as well as from remotely sensed observations. The visualizations show the development of the hurricane in the atmosphere as it interacts with the sea to causing the deadly storm-surge. Data from remote sensing include the 3D terrain of New Orleans, land-surface satellite imagery of the region at multiple resolutions and the dynamic clouds imagery showing the actual hurricane path. These observational data serve as a geospatial reference for the simulations. The sheer size and complexity of the various data sources motivated research in

- generalizing efficient representations among diverse data types;
- Rendering methods using sophisticated flow, volume and terrain visualization techniques for the time-dependent 3D and 2D vector/scalar fields and geometry management for large height fields; and
- Display methods and systems that can show high resolution datasets without sacrificing context or detail and streaming visualizations over high-speed networks to enable remote and distributed visualization.

Figure 1 illustrates the various input data used for our visualization building from ocean to land to atmosphere and drawing from both simulation and observations.

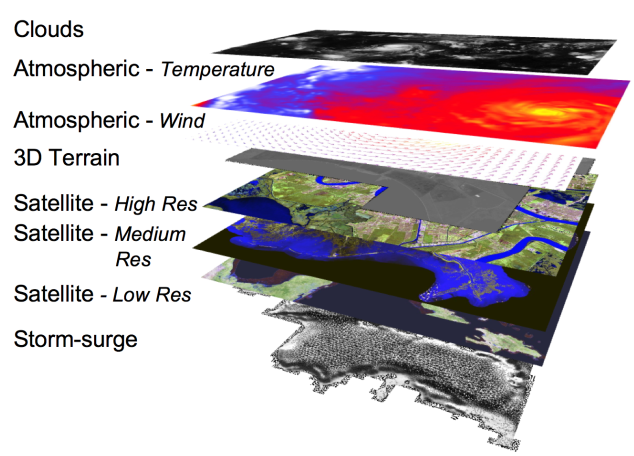

Figure 1: Superimposition of the various datasets used in the visualization building from ocean to land to atmosphere.

*e-mail: {shalini,werner,along}@cct.lsu.edu
†e-mail:{bijeong,luc}@evl.uic.edu

2 Approach

2.1 Data Management

The ADvanced CIRCulation hydrodynamic model[1] (ADCIRC) accurately models the formation, movement and morphology of a storm-surge driven by wind fields as it impacts land. In our model it operates on an adaptively refined triangular mesh connecting ca. 600,000 vertices. Each vertex provides fixed topographic (or bathymetric) information as well as time-evolving water elevation, wind and water flow directions. This output corresponds to a physical time interval of every 30 minutes from August 15 2005 to September 1 2005, which is just after Katrina's downfall on Aug 28^{th}. The atmospheric conditions (wind velocity, pressure and temperature) of the hurricane formation during the same time period where obtained from an atmospheric model known as "MM5[2]". Here, each time-step is a regular grid with dimensions 150x140x48, given hourly.

The clouds imagery shows the infra-red channel from the GOES-12 geostationary weather satellite[3] every 15 min on a 4km resolution grid. The elevation data of New Orleans was obtained from LIDAR[4] with a unform resolution of 5m. We used satellite imagery of the land surface from the MODIS and LANDSAT instruments at 500m and 250m resolution respectively. Common image file formats such as GEOtiff [5] are well suitable for these remote sensing observational data.

In contrast, there is no standard file format format exists the more complex atmospheric and storm-surge simulation data types outside of their specific domain. Supporting each possible file format in a generic-purpose visualization environment is not only a tedious task, it also reduces the benefits of synergy effects among I/O routines. Following [Butler and Pendley 1989], the path to a general scheme is given by the global language of mathematics in the form of fiber bundles that is inherently common in all models of scientific data, although usually implicit in the diverse implementations, not explicitly exposed. *The proper abstractions for scientific data are known. We just have to use them* [Butler and Bryson 1992]. Here, we adhere to this vision and impose the semantics of fiber bundles upon the widely-used Hierarchical Data Format V.5 [6] as the underlying layer. The details of the classification scheme and implementation through grouping into five major hierarchy levels are described elsewhere [Benger 2004]. In this organization scheme, the atmospheric data used constitute a dynamic uniform regular grid with three fields given on the vertices, the surge data is a triangular mesh with a scalar field given on the vertices denoting elevation. Figure 2 illustrates the application of the five-level organization scheme to our data types for a certain time step.

The unified handling of uniform grids and triangular surfaces in our context enabled us to re-use, among other features, caching techniques that are mandatory for huge time-dependent datasets to allow interactive navigation in time. Also, rather complex cases of *partial time dependency* (a certain component of a dataset does not change through a certain time interval) could be handled nearly trivially via the HDF5 built-in feature of *symbolic links*, which we utilized to express relations among different components of data sets.

[1] http://www.nd.edu/~adcirc/
[2] http://www.mmm.ucar.edu/mm5/
[3] http://www.nnvl.noaa.gov/
[4] LIght Detection And Ranging http://www.lidarmapping.com
[5] http://www.remotesensing.org/geotiff/geotiff.html
[6] HDF version 5 http://hdf.ncsa.uiuc.edu/HDF5/

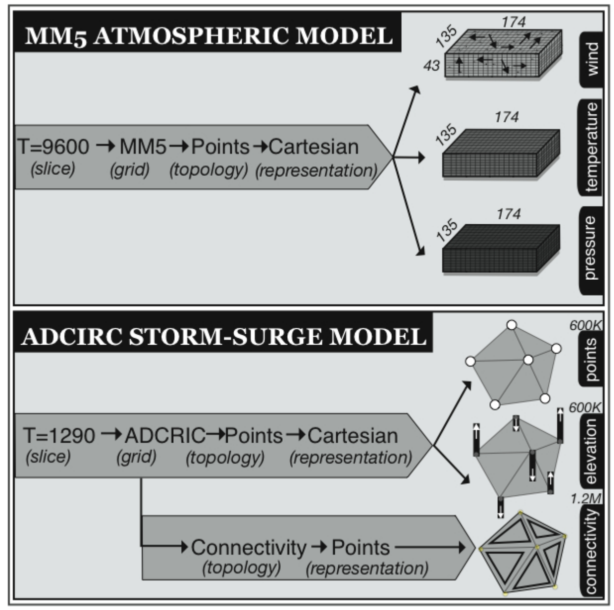

Figure 2: The 5-level organization scheme used for atmospheric data (MM5 model data) and surge data (ADCIRC simulation model), built upon common topological property descriptions with additional fields.

2.2 Rendering

The focus of our visualization techniques was toward methods that allow intuitive depiction of the phenomena, in contrast to more advanced tools that are only of used to the trained scientist. Interactivity was another mandatory issue to explore the full complexity of the combined data sets, allowing rapid changes among global and local views as well as random access to each time step. These techniques were implemented as extensions to the Amira framework [Stalling et al. 2005]. The wind field, a vector field, is visualized using the technique of illuminated stream lines [Zöckler et al. 1996] as it better highlights global features of the hurricane than just plain vectors. Closer to the eye wall, the pressure begins to fall more rapidly while the wind speed simultaneously increases. Mapping this pressure field to the transparency of the streamlines thus avoided visual clutter by emphasizing the vortex. The temperature field was used to colorize the streamlines, thereby yielding a fully five-dimensional representation of the entire atmospheric data set (wind: three components, pressure and temperature: one component each). Fig. 3 shows a composite view of the surge surface and the wind-vector streamlines color-coded with the temperature values.

The interaction of the surge with topographical features is especcially crucial. Custom rendering modules were written to display the surge heights as a transparent surface to yield a water-like appearance over the underlying GIS and and LIDAR data. As each surface time-step comprises about 1.1 million triangles, we employed the OpenGL Vertex Buffer Object extension to speedup the rendering above 20 frames per second on decent PC graphics hardware. This technique allows to cache the large number of triangles in the graphics memory using an indexed vertex representation . Overlaying the GIS/LIDAR representation with the evolving clouds imagery as a transparent grey-scale image allows to picturize the correspondence of the observed and simulated hurricane data. Fig. 4 shows the eye of the hurricane (obtained from GOES-12 data)

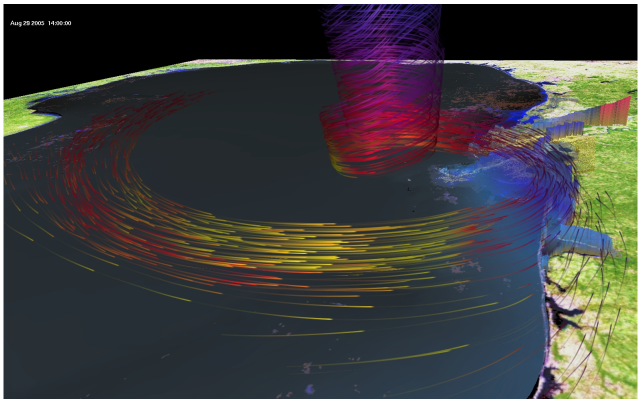

Figure 3: Streamlines of the hurricane wind vector field at landfall. The streamlines are color-coded by temperature showing higher temperatures above sea surface than at land indicating loss of energy after landfall.

looming over the heart of the city, rendered via the 3D terrain of New Orleans overlaid with the water levels from storm-surge simulations just before Katrina passed and the surge levels raised to their unbearable maximum.

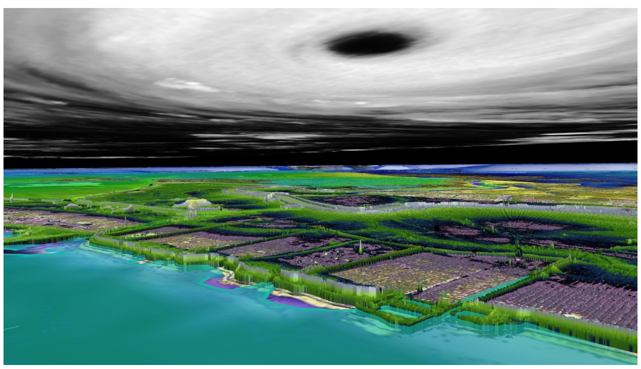

Figure 4: Zooming in to New Orleans - Clouds imagery of the hurricane eye over the 3D terrain of New Orleans that is overlaid with the surge surface.

The extremely high-resolution of the LIDAR data of 11,000x7,000 points, results in 154 million triangles using a brute-force triangulation method. This is beyond the capabilities of interactive rendering and alternative approaches are thus limited to display downsampled subsets. In order to still be able to depict the full quality of the dataset, we have implemented both continuous and static Level-of-Detail (LOD) techniques to dynamically simplify the mesh depending on the view point. For both cases, we use the automatic texture coordinate generation functionality in OpenGL that maps texture coordinates to the vertices to allow additional aerial photography on top of the full-resolution 3D representation.

Traditionally, terrain rendering techniques attempt to create a "perfect set" of triangles by performing extensive LOD computations on the host processor. One simple and very popular example of this class of techniques is the ROAM algorithm [Duchaineau et al. 1997] . ROAM is based on a binary triangle tree hierarchy where each patch is a simple isosceles right triangle. The basis of the algorithm is formed by the notion of splitting and merging triangles to refine or coarsen a terrain triangulation. At every frame, ROAM recursively tessellates the terrain generating triangles depending on the distance to the viewer criteria (or one could also use surface roughness). For a static height-field, the variance values can be precomputed recursively and stored in a variance array. The results of the algorithm on our terrain are shown in Figure. 5. More weight is attached to the variance than the distance criterion so that the levees in the distance can still be distinguished and highlight the Mississippi river. Although such hierarchical techniques are capable of generating accurate representations of a terrain using considerably fewer triangles, we found that the CPU computations required for each triangle makes them unsuitable for recent graphics hardware.

WB: What is surface roughness? What is variance? Definition please

With the advent of modern graphics processing power, the new dogma has been to push as many triangles as the hardware can handle with the least amount of CPU overhead. Static level of detail also coined as Geomipmapping [7] can be understood as texture mipmap technique in geometry. In the preprocessing stage, terrain patches are compiled with different levels of detail. At rendering time, the detail level rendered is based on the distance from the camera and a screen-pixel error to guarantee visual fidelity. As our terrain does not change, we use static vertex buffers that can store the geometry onboard the graphics card proving to be very efficient. The one drawback of this approach is the graphics memory consumption that is directly propotional to the number of levels used in the mipmap. This can quickly saturate the on-board memory that also houses the other other data for the application. Nevertheless, we regard this as a promising approach as we continue dealing with even larger terrains.

get frame rate for both

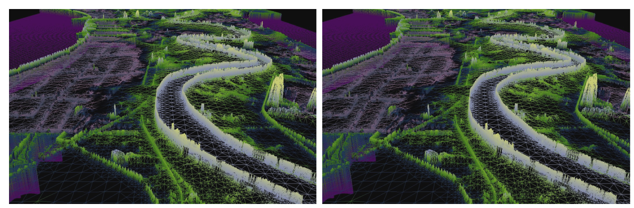

Figure 5: Wireframe rendering of the New Orleans terrain showing the results of the CLOD algorithm.

2.3 Display and Collaboration

Emergency response management such as planning evacuation routes often involves collaboration between co-located and remote teams and individuals. Interaction between each other and with the information is crucial for the success. Particularly in GIS and Geoscientific fields, the ability to obtain life-like terrain representations, zoom across spatial and temporal scales and simultaneously view various model outputs and observations is of paramount importance [Ni et al. 2006]. Moreover, satellite imagery and LIDAR data can easily exceed 100 Mpixels making it impossible to have detail as well as context on a single desktop display. This motivates our research in novel multi-user display and interaction systems that go beyond conventional single-user desktop displays. One solution is to build ultra-high-resolution display walls such as those built by stitching together dozens of LCD panels. To support scientific collaboration, real-time visualizations, high-definition video and offline rendered movies are streamed from remote collaboration sites via high bandwidth optical networks and shown on these display systems.

WB: see LaTeXnote

[7] Geometrical Mipmapping `http://www.flipcode.com/articles/article_geomipmaps.pdf`

To realize this approach, EVL/UIC[8] has developed LambdaVision, a 11x5 tiled display with a total resolution of 100 Mega-pixels, and Scalable Adaptive Graphics Environment(SAGE) [Jeong et al. 2006] a specialized middleware to support real-time streaming of extremely high-resolution graphics. SAGE enables multiple visualization applications to be streamed to large tiled displays and viewed at the same time (see Figure 6). The application windows can be moved, resized and overlapped like any standard desktop window manager. For each window move or resize operation, SAGE performs non-trivial dynamic reconfigurations of the involved graphics streams. Figure 6 shows the SAGE environment running on LambdaVision. In this particular case, a scientist or a decision-maker is able to look at the visualization of the hurricane simulation (on the right) juxtaposed with aerial photography showing the flooding that resulted in New Orleans (bottom-left). She is also able to communicate her findings with with a remote collaborator using a video-conference session (top-left).

Figure 6: The visualization of Hurricane Katrina juxtaposed with aerial photography of New Orleans and live video feeds from a remote site

3 Conclusion and Future Work

We have shown how various data sources can be used to create an effective, compelling and interactive visualization from diverse geoscientific data sources such as those describing Hurricane Katrina and her indirect consequences. These sources ranged from computational simulations of storm-surge and atmospheric models to remotely sensed data from satellites and sensors. This effort was seminal in bringing together diverse communities such as remote sensing, atmospheric and coastal modeling, grid computing and visualization. Data management techniques derived from abstract mathematical concepts have proven to be useful in practice, in both reducing implementation effort and in achieving high computational efficiency. The selected rendering techniques intuitively communicate the multiple vector and scalar fields while level of detail terrain algorithms allow for interactive manipulation. We also demonstrated the use of high-resolution display systems connected via high-speed links to see and interact with data as well as remote users.

Future investigation will go into applying techniques suitable for derived quantities, such as the Green-Cauchy tensor of the wind vector field, drawing upon experience with visualizing tensor fields [Benger et al. 2006], as well as into investigating new paradigms to interact with the visual results that broaden the audience to unexperienced users [Ullmer et al. 2003].

[8]Electronic Visualization Laboratory, University of Illinois at Chicago

4 Acknowledgements

We would like to thank Ed Seidel, Gabrielle Allen and Stephen David Beck for their visions and support. Many thanks go to our colleagues - Maciej Brodowicz, Shreekanth B, Chirag Dekate, David Gallop, Jon Maclaren and Wei He for their technical expertise. We also wish to thank folks at Earth Scan Lab, Coastal Studies Institue, LSU Hurricane Center, UNC Department of Marine Science and TAMU for access to data.

References

BENGER, W., BARTSCH, H., HEGE, H.-C., KITZLER, H., SHUMILINA, A., AND WERNER, A. 2006. Visualizing Neuronal Structures in the Human Brain via Diffusion Tensor MRI. *International Journal of Neuroscience 116*, 4, pp. 461–514.

BENGER, W. 2004. *Visualization of General Relativistic Tensor Fields via a Fiber Bundle Data Model*. PhD thesis, Free University Berlin.

BUTLER, D. M., AND BRYSON, S. 1992. Vector bundle classes from powerful tool for scientific visualization. *Computers in Physics 6* (nov/dec), 576–584.

BUTLER, D. M., AND PENDLEY, M. H. 1989. A visualization model based on the mathematics of fiber bundles. *Computers in Physics 3*, 5 (sep/oct), 45–51.

DUCHAINEAU, M., WOLINSKY, M., SIGETI, D., MILLER, M., ALDRICH, C., AND MINEED-WEINSTEIN, M. 1997. Roaming terrain: Real-time optimally adapting meshes. In *Proceedings of IEEE Visualization '97*, IEEE, 81–88.

JEONG, B., RENAMBOT, L., JAGODIC, R., SINGH, R., AGUILERA, J., JOHNSON, A., AND LEIGH, J. 2006. High-performance dynamic graphics streaming for scalable adaptive graphics environment. In *Proceedings of ACM/IEEE Supercomputing 2006, In press*.

MACLAREN, J., ALLEN, G., DEKATE, C., HUANG, D., HUTANU, A., AND ZHANG, C. 2005. Shelter from the storm: Building a safe archive in a hostile world. *OTM 2005 Workshops, LNCS 3762*, pp. 294–303.

NI, T., SCHMIDT, G. S., STAADT, O. G., LIVINGSTON, M. A., BALL, R., AND MAY, R. 2006. A survey of large high-resolution display technologies, techniques, and applications. In *Proceedings of IEEE Virtual Reality 2006*, IEEE Computer Society.

STALLING, D., WESTERHOFF, M., AND HEGE, H.-C. 2005. Amira - an object oriented system for visual data analysis. In *Visualization Handbook*, Academic Press, C. R. Johnson and C. D. Hansen, Eds.

ULLMER, B., HUTANU, A., BENGER, W., AND HEGE, H.-C. 2003. Emerging tangible interfaces for facilitating collaborative immersive visualizations. In *Proc. NSF Lake Tahoe Workshop on Collaborative Virtual Reality and Visualization*.

ZÖCKLER, M., STALLING, D., AND HEGE, H.-C. 1996. Interactive visualization of 3d-vector fields using illuminated streamlines. In *Visualization '96*, 107–113.