# Real-Time Visualization of 4D Scalar Data using Hardware Accelerated Volume Rendering

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***Abstract*—We present a visualization framework using direct volume rendering techniques that achieves real-time performance and high image quality. The visualization program runs on a desktop as well as in an immersive environment. The application is named HurricaneVis, and it uses OpenGL, GLSL and VTK. For immersive visualization VRJuggler is added.**

**The initial use was visualization of scalar data from numerical weather model simulations of tropical cyclones, namely Hurricanes Isabelle and Lili. We are expanding that to include visualization of other types of scalar and time-varying data sets.**

## I. Introduction

The latest developments in graphics hardware offer new possibilities in the field of visualization. Computationally expensive techniques like volume rendering can now be implemented directly on the GPU and offload this processing from the CPU. This heterogeneous computing holds great promise, not only for entertainment applications but also for scientific visualization.

We present a visualization framework using direct volume rendering techniques with real time performance and high image quality [1]. The visualization is designed to run on the desktop as well as in an immersive environment. The application named *HurricaneVis* is based on the Visualization Toolkit (VTK) [2], a powerful and comprehensive framework for visualization. Additionally, HurricaneVis uses a framework for hardware accelerated ray casting by Ralph Brecheisen [3]. We extended this framework to include further visualization techniques, namely object-aligned and view-aligned texture slicing [4]. We store the transfer functions as well as the 3D volume of scalar data on the GPU in texture memory.

Additionally, we provide user interaction for modification of the transfer function. The portion of the software that does the volume rendering is implemented through shader programs written in GLSL. This results in rendering that is significantly faster than CPU-based algorithms. VRJuggler [5] enabled us to move the HurricaneVis application from a desktop to an immersive environment.

## II. Results

The hardware accelerated rendering on the GPU provides real-time interaction to the user. Interaction provides meteorologists with the possibility to investigate the time-dependent 3D data in arbitrary views. Also, properties of the visualization can be changed in real-time. Therefore the space-time visualization is more dynamic and compelling than the commonly used static 2D slices.

The application started with visualizing hurricane data, but it is flexible enough to adapt to any type of 4D data set, either computed or measured. We demonstrate this by visualizing ocean data as a second type of scalar data.

### A. Hurricane Data Set

We present results of working with a hurricane data set created from a numerical weather model. Hurricane Lili was unique as it dramatically weakened from a category 4 hurricane to a category 1 in a period of just over 13 hours. The Hurricane Lili data come from the Four-Dimensional Variational Analysis (4DVAR) sensitivity run outputs of Zhang, Xiao, and Fitzpatrick [6].

### B. Ocean Data Set

Barbara Reed, NAVOCEANO provided access to a data set of ocean data. The data was generated by the Navy Coastal Ocean Model (NCOM) and includes temperature, salinity, eastward currents, northward currents, and surface elevation.

### C. User Study

We conducted a user study to evaluate this statement: "'Volume rendering and isosurface visualization can both be used to examine hurricane data, but volume rendering is more easily and effectively understood"' [7]. Subjects may have been able to answer questions more quickly with HurricaneVis because the interface is easier to use. However, the results do indicate a significant advantage of direct volume rendering compared to the representation with isosurfaces.

### D. Sample images from HurricaneVis

Figures 1 and 2 are screen shots from HurricaneVis on a desktop computer. Figure 1 is the scalar variable labeled CLW (Cloud Water Mixing Ratio) in hurricane Lili. Figure 2 is a screen shot of the NCOM ocean data set. In the lower lefthand of each display is the area of the display where the user can interactively modify the transfer function.

Figure 3 is HurricaneVis in the Mississippi State University Virtual Environment for Realtime Exploration (VERTEX).

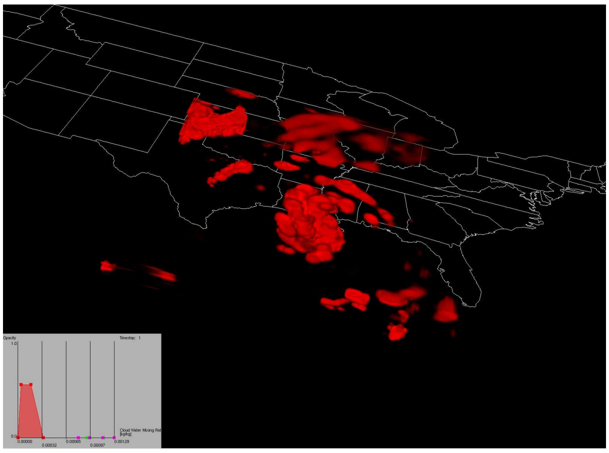

Fig. 1. Hurricane Lili, Cloud-Water Mixing (CLW) ratio

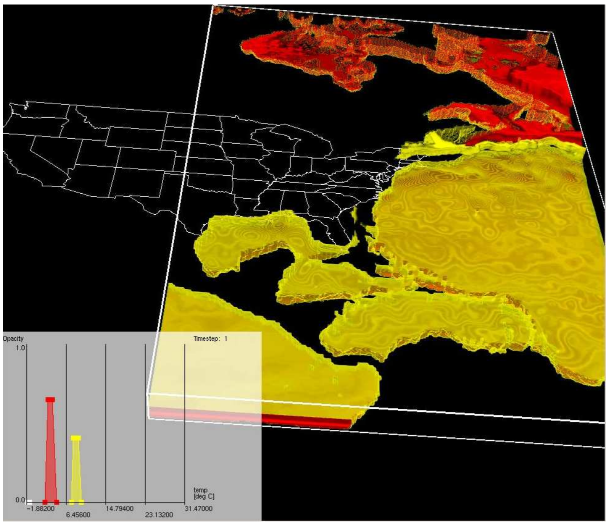


Fig. 2. Temperature from NCOM Ocean data set

## III. Conclusions and Future Work

HurricaneVis is a promising prototype that is successfully used to evaluate and investigate numerical or measured weather model data. The superior image quality from direct volume rendering presents a promising and user friendly way to evaluate extensive, 3D, time-dependent data. The interactive modification of transfer functions is very appealing to users. The user study confirmed our expectations

Fig. 3. HurricaneVis in the MSU VERTEX

We need to conduct additional user studies to quantify performance differences between using the traditional 2D methods and these 4D methods. While there is no doubt users enjoy the interactive 4D presentations, establishing the specific benefits to understanding and eventually performance when doing a task is imperative.

We implement and evaluate user interface components like the design galleries [8] for the immersive version of HurricaneVis. It is expected that ray-casting, which leads to the best visual quality, will outrun texture-slicing algorithms in the near future. We will optimize the performance of the ray-casting algorithm to meet these expectations.

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## References


[1] Berberich, Michael, Amburn, Phil, Moorhead, Robert, Dyer, Jamie, and Brill, Manfred, "Geospatial visualization using hardware accelerated real-time volume rendering," in *Oceans '09 MTS/IEEE*, 2009.

[2] Schroeder, W., Martin, K., and Lorensen, B., *The Visualization Toolkit: An Object-Oriented Approach to 3-D Graphics (4. ed.)*. Kitware, 2006.

[3] R. Brecheisen, "3D multimodal visualization techniques for tumor resection in neurosurgery," Master's thesis, Technical University of Eindhoven, 2006.

[4] Engel, K., Madwiger, M., Kniss, J. M., Rezk-Salama, C., and Weiskopf, D., *Real-Time Volume Graphics*. A.K. Peters, 2006.

[5] VRJuggler, *The VR Juggler Suite, URL: http://www.vrjuggler.org*, 2009.

[6] Zhang, X., Ziao, Q., and Fitzpatrick, "The impact of multisatellite data on the initialization and simulation of hurricane lili's (2002) rapid weakening phase," *Monthly Weather Review*, vol. 135, pp. 526–548, 2007.

[7] Berberich, Michael, Amburn, Phil, Moorhead, Robert, Dyer, Jamie, and Brill, Manfred, "HurricaneVis: Real-Time Volume Visualization of Hurricane Data," in *Posters & Demos Eurographics/IEEE Symposium on Visualization, Berlin*, 2009.

[8] J. Marks, B. Andalman, P. A. Beardsley, W. Freeman, S. Gibson, J. Hodgins, T. Kang, B. Mirtich, H. Pfister, W. Ruml, K. Ryall, J. Seims, and S. Shieber, "Design galleries: a general approach to setting parameters for computer graphics and animation," in *SIGGRAPH '97*, 1997, pp. 389–400.