Visualizing Terrestrial and Aquatic Systems in 3D

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Abstract

Better visualization tools for environmental science is a well documented need, and the Visualization for Terrestrial and Aquatic Systems project (VISTAS) aims to help scientists produce effective environmental science visualizations and to determine which visualizations are most helpful to scientists and their stakeholders. Focusing on 3D topographical visualizations, aiming to visualize across spatial and temporal scales, VISTAS software currently superimposes measured or modeled data on digital elevation models and allows side by side viewing of single frames, animations, or multiple images. This paper and poster present visualizations of three collaborators whose data might be enhanced by visualizing each other's data in "cross-scale visualizations". VISTAS is an interdisciplinary project among computer, environmental, and social scientists; we work jointly with create effective software and evaluate visualizations. VISTAS source and executable are freely available (http://blogs.evergreen.edu/vistas).

Keywords: Visualization in Earth, Space, and Environmental Sciences, Knowledge Externalization, Geographic/Geospatial Visualization, Coordinated and Multiple Views.

Index Terms: J.2 Physical Sciences and Engineering; I.3.4 Graphics Utilities, I.3.7 Three-Dimensional Graphics and Realism; I.6.4 Model Validation and Analysis

1 Introduction

Our prior work suggested visual analytics could help scientists more effectively use large data sets and models to understand and communicate complex phenomena [2,5], so we hypothesized that spatially and temporally explicit visualization of ecosystem states and processes across topographically complex landscapes would enhance comprehension of relationships among ecological processes. Scientific visualization is not a new field and current applications produce 3D topographics, but ecologists do not typically use existing visualization tools in spite of perceived need [3,4]. We thus collaborate with environmental scientists who believe that seeing the same phenomena at different scales across space and time will improve intuition and forge new hypotheses and explain results; we work collaboratively to create new software, design visualizations and explore barriers to use.

The VISTAS project thus focuses on visualizing 3D representations of natural phenomena over time at various spatial scales from the output of environmental sensors and of land use and process-based models that simulate cycling and transport of water and nutrients within plots, hill slopes, and watersheds. VISTAS' environmental science goal is to gain insight into and communicate land use and ecosystem services in terms of natural and built components and underlying topography.

This paper and poster showcases recent VISTAS visualizations for our collaborators. Each presents modeled or sensed data at a different scale, and elucidates one or more concepts that might be better conveyed using VISTAS than with prior tools: 1) 2D data superimposed on 3D terrain, i.e., topography; 2) interactive perspective browsing; 3) side-by-side coordinated images of attributes or scenarios; and 4) animation over time. Immediate next steps are: add analytics coordinated with animation, improve the user interface, formally evaluate visualizations, and validate VISTAS extensibility. In the future we aim to scale domain objects to view phenomena at different scales on the same canvas.

2 Sample VISTAS Visualizations

In this section, we briefly describe the domain areas of our three collaborators, and show example VISTAS visualizations for each.

2.1 Hydrological-Biogeochemical Processes (VELMA)

McKane and Brookes use VISTAS to demonstrate results from their ecohydrological model VELMA [1]. Given a set of drivers (eg, temperature, precipitation) and disturbance (eg, fire, harvest, fertilization), VELMA models the interaction of stream flow and biogeochemical processes, and carbon and nitrogen dynamics in plants and soils. Running on a daily time step across thousands of pixels, VELMA generates multiple gigabytes of output for multi-century simulations of large landscapes, and results are difficult to tune, interpret and communicate without visualization.

The U.S. EPA currently studies nitrogen deposits at multiple sites and scales. For example, VELMA was run to investigate the feasibility of using an ecohydrological model to help bound uncertainties in difficult-to-measure nitrogen fluxes – a critical problem near croplands and in wetlands because agricultural pollutants and eutrophication are critical water quality problems, and many bays, estuaries, and tributaries exhibit high nitrate levels. VISTAS visualizations (Fig. 1) were generated from VELMA by McKane for an EPA webinar (July 2014).

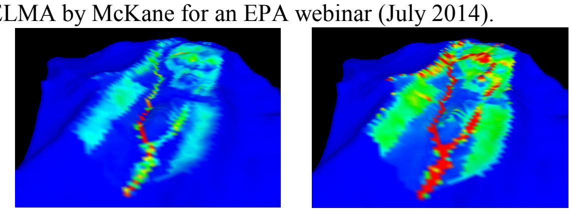

Figure 1: Nitrate in Chesapeake Bay, left 2000, right 2003.

After two weeks exercising the newest VISTAS prototype McKane reported he could demonstrate that VELMA successfully quantified and dynamically mapped ecohydrological (riparian) processes controlling nitrogen pollution to the Chesapeake Bay given extreme climatic conditions. Process-level interactions "popped out" in 3D, and helped identify biogeochemical hot spots and conditions that reduce or contribute to nitrate pollution. Figure 1 illustrates to stakeholders how green infrastructure helps limit nitrogen pollution and protect water quality. McKane also developed a clearer conceptual approach for improving the model, and could better prioritize his priorities for VISTAS enhancement.

2.2 Alternative Land Use Scenarios (ENVISION)

John Bolte and his team have worked with VISTAS developers to embed VISTAS into ENVISION, his open-source GIS-based multi-agent model for scenario-based community and regional integrated planning and environmental assessments. ENVISION integrates spatially explicit models of landscape change processes and production for alternative futures analyses. It currently produces 2D maps (as shape files) that illustrate changes over time of modelled attributes such as species habitat, ecosystem type, and disturbance. Bolte believes that 3D animations (shown as the model runs or afterwards), will help stakeholders better understand alternative futures. He also wants to view side by side "camera-position-coordinated" fly-throughs at specific points in time for different attributes or scenarios. Bolte's group had previously produced fly-through visualizations, but these have typically taken weeks or months to produce.

To exercise the most recent implementation of ENVISTAS (ENVISION with the VISTAS visualization engine as a plug-in), Bolte's team generated fly-throughs for the Central Oregon Alternative Futures Project (Forest, People, and Fire). This project focuses on better understanding how biophysical systems, management actions and socio-economic influences interact to affect sustainability in fire-prone landscapes under climate change, and aims to improve wildland fire policies in the U.S.

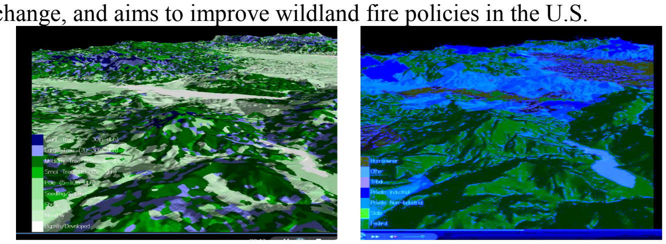

Figure 2: ENVISION vegetative cover & land use, Central Oregon.

2.3 Airflows in mountain valleys – Micrometeorology

Thomas is interested in how heat, humidity, and carbon dioxide communicate across landscapes; to that end he takes spatially distributed point-measurements of wind speed and direction to characterize the airflow, which transports these quantities. To scale up to the watershed level, he needs to develop new models, drawing on insights from viewing his data in the context of the topography. He also would like visualizations that provide more intuitive understanding than what he currently uses.

Figure 3 depicts measurements of wind speed and direction observed by a pair of ground-based acoustic remote sounders located at H. J. Andrews Long Term Ecological Research Forest in Oregon. Measurements were taken at two stations in adjoining valleys with a horizontal separation distance of approx. 6 km. Variables were continuously sampled and subsequently averaged over 5 min. for a period of 3 months and organized into daily files. Wind speed and direction are computed for 10m height increments extending from 15m to 395m above ground. The visualization shows one 5-min.vector given by wind magnitude and direction for each height interval.

Visualizing wind measurements in the context of topography was critical to identify and interpret typical flow patterns, which are strongly influenced by the position in the deeply incised, narrow valleys. Displaying and playing back observations from both stations in the same visualization provided non-quantitative, but intuitive information about spatiotemporal correlation between the two stations, which will be instrumental in diagnosing the connectivity through atmospheric transport in the adjoining valleys and thus the 'breathing' of the mountainous landscape.

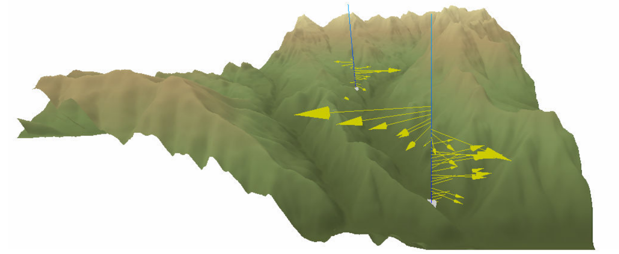

Figure 3: Airflow at two sampling locations in the HJA valley, OR.

3 VISTAS Implementation

VISTAS grew out of prior work implemented in Java and the Visualization Toolkit VTK; expertise gained there was applied to a modular, scalable design implemented in C++ and OpenGL. Adding new data and visualization types and improving the user interface then became straightforward, as did embedding the visualization engine in ENVISION. Thomas; prototypes were generated with WebGL in a JavaScript API and a digital elevation map (DEM) created from LiDAR data provided by HJA. VISTAS is freely available (http://blogs.evergreen.edu/vistas).

4 Conclusions and Future Work – Visual Analytics

VISTAS collaborators report that data previously visualized using fixed-format 2D images can now be shown to colleagues and stakeholders as 3D animations with user-controlled viewing angles, zoom and topographic amplification. McKane contends that simulation coupled with 3-D visualization is leading to new ways of thinking about how ecosystems respond to stress.

We are currently enhancing VISTAS to transition from visualization to visual analytics; priorities are 1) data aggregation, 2) dynamic charts and graphs of environmental drivers, e.g., temperature, precipitation, or the state of the atmosphere and transport (signal reflectivity and wind speed variability), 3) user interface enhancements coordinating visualizations with analytics, and 4) better metadata, e.g., scaling factors, and directional and height references. Longer term we aim to scale visualizations up or down for overlaying data at different spatial or temporal scales.

Acknowledgment

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