Interacting with 4D oceanographic volume data using GeoAnalytics tools

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1 INTRODUCTION

The need to turn environmental statistical data into knowledge and make decisions based on large amounts of multivariate, time-varying and geospatial information represent a major challenge for the analyst. These information streams, often in time-critical situations, demands efficient, integrated and interactive tools that aid the user to explore, present and communicate large information spaces. This approach has been encapsulated in the idea of Geovisual Analytics (GeoAnalytics), an emerging interdisciplinary field based on the principles from Visual Analytics (VA) [20].

This abstract does not claim any novel technique but instead try to demonstrate the potential synergy of integrating volume visualization (VolVis) with popular InfoVis and GeoVis interaction techniques and exploit joint usage in an intuitive and usable manner. VolVis will benefit from InfoVis' explorative data analysis (EDA) applied in a multiple-linked and coordinated views interface [16]. Research in VolVis has been directed towards efficient rendering algorithms. In this abstract the focus is on the analysts and important tools for human-information discourse – dynamic data manipulation [13] through a visual user interface (VUI) perspective [14,21] that provides facilities to "see" and "interact" dynamically in 3D space with volume data. Although advances have been made, a VUI that supports explorative insight in 3D space with immediate response defined as less than 200 milliseconds [20], have substantial room for improvements and in particular for spatio-temporal large volumetric data. The effectiveness of our geovisual analytics approach is demonstrated in a tailor-made, environmental-oriented volume data explorer (VDE) application [19] that facilitates the advantage of a VUI through screen space focus and dynamic interaction in a context of perceptual reasoning that enables the analyst to take a more active role in the overall EDA process. A sense of immediacy interaction is achieved and demonstrated through its ability to coordinate simultaneously time-linked views for large volume data.

The main contributions can be summarised:

- Means to interact dynamically with large-scale 4D volume data with immediate response time are demonstrated;
- Demonstrate how VolVis can benefit from generic 2D visual interaction techniques to facilitate exploration and discovery;
- Proposed interaction mechanisms to support VA for spatio-temporal and multivariate volume attribute data;
- A research toolkit platform for evaluating and implementing synergies between InfoVis, GeoVis and SciVis methods;
- Public VDE application for NetCDF volume data formats;

2 RELATED WORK

Methods to visualize volume data such as isosurface extraction [3,4,5,6] have been extensively studied in many research scenarios. Interaction science and VUIs for space-time and multivariate volume data exploration is a rather unexplored research area. Focus has been on interfaces for volume rendering but [7] introduces an interesting approach that also demonstrates the synergy between the commonly used InfoVis method parallel coordinates and volume rendering. They implement parallel coordinates as a VUI that emphasizes how parameters and their relationships will be useful for exploring data and compare different renderers. However, the parallel coordinates VUI devotes a large portion of the screen to parameter visualization and is used to drive the rendering process. InfoVis of time-oriented spatial and multivariate data has been the subject of many research papers [9,10,11,12].

Researchers tend to focus on visual representation while interaction design is not assigned the same significance. The mantra by Shneiderman [2] "Overview first, zoom and filter, details on demand" is well-accepted and also applied in our VDE application, but a "science of interaction" is needed that supports VA reasoning and should be entrenched in a deep understanding of the different forms of interaction methods and their benefits [20]. The continued discussion about the need for framework and taxonomies in [22] was an important source of stimulation to our development of VDE. Interaction and related performance are the essential contributions in this paper and here applied to temporal and multivariate volume data. VDE also reveals the effectiveness and the synergy between InfoVis, GeoVis and SciVis methods based on the approaches of our previous works [17]. We demonstrate through our component and coordinated views architecture how VolVis components integrate and correlate seamless with 2D InfoVis and GeoVis components.

We revise our used interaction techniques from three ways. First, because the nature of our volumetric data is 3D, we consider what the users are perceptually capable of doing when interacting with data, for example, multiple-views and time animation. Second, we look at how interaction is used to accomplish tasks such as data manipulation (brushing, time animation, correlation, cut-away, etc). Third, we look at minimum human response acceptance.

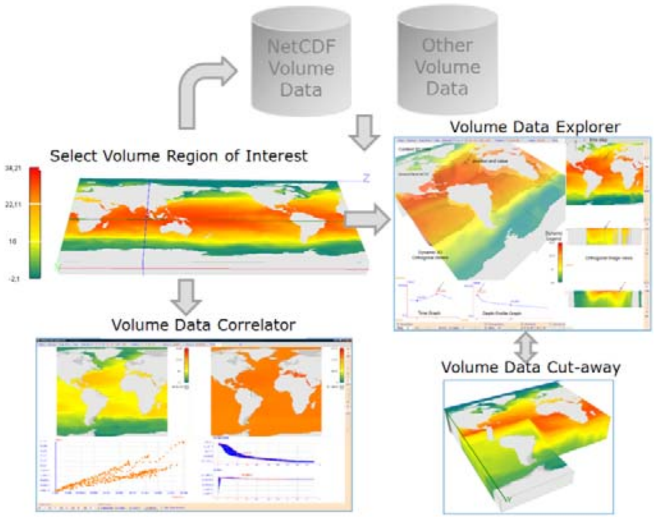

Figure 1. Volume data explorer (VDE) integrates four modules in the EDA process (Overview, Explorer, Cut-away and Correlator) demonstrated in a time-linked exploration of ocean temperature and salinity volume data at different depths levels for a time period of 12 months in 1994.

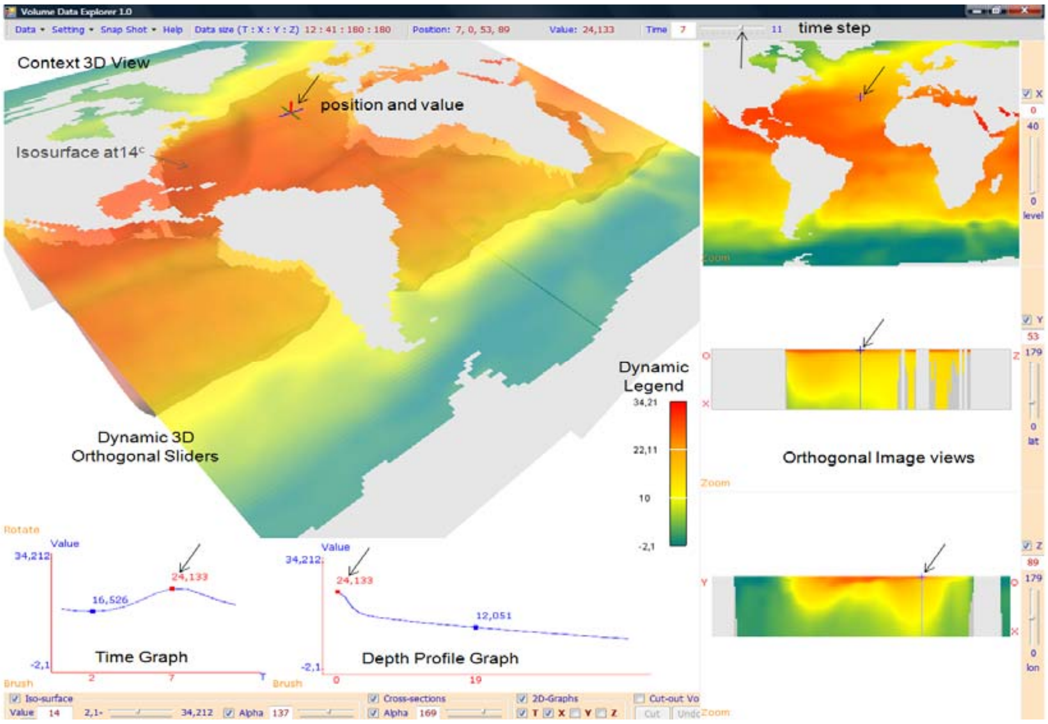

Figure 2. VDE's coordinated multiple-views interface. The VUI optimizes screen usage for visual representation. Less than 5% of the precious screen pixels are devoted to traditional GUIs. The analyst can navigate in both 2D and 3D views including zoom, rotate, pan, brush and highlight. Direct data manipulation such as dynamically moveable orthogonal planes in 3D space and interactively change isovalues and opacity. Changes occur with immediate response time simultaneously in all seven time-linked and coordinated views. The Depth Profile Graph view (middle) shows temperature along the depth profile also highlighted in the 2D and 3D image views (see arrows). The Time Graph view (lower left) shows the temperature for 12 months. The time steps are controlled by either a time range slider (top menu) or by dragging with mouse movements the red point in the Time Graph along the time curve. All views have implemented brushing techniques. Colours and scales are changed in all views by dynamically moving the splitters in the dynamic colour legend view. The isosurface embedded in the 3D view represents water temperature at the 14^c during July 1994. The figure represents a snapshot of captured events taken from a explorative scenario.

3 Volume Data Explorer (VDE)

The publicly available VDE application was customized with the GeoAnalytics Visualization (GAV) toolkit [18]. VDE facilitates integrated VolVis, GeoVis and InfoVis data specific VUI methods such as dynamic moving 3D orthogonal planes, cross section graph, time and depth profile graphs, attributes correlation plot, 2D and 3D data brushing, interactive dynamic colour legend mapping and opacity control, isosurface extraction etc. VDE also integrates a second direct manipulation cut-away module (figure 1) that suppresses less important parts to reveal and focus upon more relevant information. The third VDE module analyses and correlates time-oriented volumetric variables. The fourth Select Region module reads original NetCDF formatted data, defines the area of interest for the VDE process and stores the result in NetCDF.

GeoAnalytics tools are suitable for the visual analysis and diagnosis of time-oriented weather and climate related data advancing a predictive understanding of global problems for making informed and reasoned decisions on time scales of weeks to decades [15]. In this VDE application, we demonstrate how GAV tools can aid the oceanographers during the analysis and interpretation of ocean space behaviour. Examples of parameters interesting to oceanographic researchers are salinity, temperature, density, pressure and PH. For our case study we have selected spatial, temporal and multivariate oceanographic volumetric data obtained and simulated showing how ocean-water properties change through time. Volumetric time series NODC World Ocean Atlas data for two selected attributes were downloaded from the NOAA/OAR/ESRL. These two volume oceanic data sets, described with the NetCDF format, represent temperatures and salinity values available from the sea surface to the sea floor. Data consist of 12 time steps during January - December, 1994 at disparate depth-levels and a global world grid of 1.0 degree latitude by 1.0 degree longitude (180 x 360). We extracted an area with longitudes from 0.5E to 59.5E and latitudes from 241.5E to 359.5E corresponding to grid size 180 x 180. Depth data in meters exists from sea surface down to 1000m level for the following irregular sea levels 10 20 30 50 75 100 125 150 200 250 300 400 500 600 700 800 900 1000. In a pre-computing phase, 41 steps at 25 meter's interval were interpolated. A number of positions in the data-sets have no data. They are called missing data positions and are marked by a special value.

Spatial and temporal volume data are difficult to analyze through the use of a single type of visual representation. In order to detect complex patterns and expose problems within this massive environmental data, a number of complementary visual representation methods, each of which is best suited to highlight different patterns and features are used [16]. For example, 2D image focus views in VDE (figure 2) are important for seeing details of a particular part of the ocean space and navigating or measuring distance and location precisely [15]. The 3D context view is good for gaining an overview of possible discoveries and understanding of a selected attribute's (temperature, salinity) importance. The 3D and 2D image views serve different purposes and being able to interact with them simultaneously will benefit data related tasks such as orienting and positioning. 3D is useful to gain an overall understanding of the data space, and 2D is needed for precise data access. Figure 2 and 3 demonstrates that the 2D and 3D views are not only linked but also correlated – the observed data location is updated in all views and GUI sliders. The 3D orthogonal planes can be moved dynamically through direct manipulation of the 3D planes and time space or by traditional GUI range sliders.

3.1 Select ocean space area of importance

The first pre-processing step (figure 1) in the EDA VDE process is to select an ocean space area to analyse. This module reads NetCDF data and the analyst interactively defines a suitable world projection using dynamic moveable longitude and latitude lines. 51 depth levels are then interpolated at 20 meter's intervals for all time steps. In the next step, the analyst can define regions of less importance that are cut away. Finally, the new ocean volume data is saved again in the NetCDF format.

3.2 Explore volumetric temperature data

Dynamic data navigation in 3D time-oriented volume space can be a challenging task such as in our oceanographic case study with 31,881,600 data values. By performing direct data manipulation through analyzing and seeing the data from different aspects and under different conditions the users immerse themselves in the data. If the display is updated within a pre-attentive acceptance of less than 200ms, the user gets the feeling of actually touching the data and can better understand the behaviour and structure of the observed ocean space. VDE's architecture allows you to see something in the ocean space and interact with data directly or to cut away what you don't need, drill into details, combine multiple variables for comparison. This promotes a smooth flow between seeing something, thinking about it, and manipulating it, with no distracting lags in between.

VDE interacts with temperature data (figure 2) through seven linked and coordinated views (represented by GAV functional components): Context 3D View, three Orthogonal Image Views, Dynamic Legend View, Time Graph View and Depth Profile Graph view. The Depth Profile Graph shows the temperatures for a given profile position in the volume space. The user can move the cursor along the profile and see actual value for a given position. The Time Graph shows temperatures for the 12 time steps. The exact location in 3D ocean space is simultaneously displayed all views. The Image views have a blue cross hair and line segment that indicates position and profile of the temperature value. The red value "24" is the temperature value at location (0,53,89) and time step 3 (April 1994). Most screen objects can be direct manipulated, for example, by moving orthogonal planes in the 3D view, dragging 2D red focus point along the depth profile line which also moves corresponding 2D image planes, dragging the 2D red pointer in Time Graph, which immediately updates time for all views.

The Depth Profile Graph (figure 2) shows how a certain water property changes with depth. For instance, a depth profile of sea water temperature shows how temperature varies from the sea surface to the sea floor. The depth profile is drawn with the depth along the horizontal axis. The sea surface (0 meters) is represented at the left of the x axis, and the deepest water (e.g., 1000 meters) at the right end and 25m intervals. The vertical axis shows temperature in degrees Celsius. Individual points on a depth profile provide two pieces of information: the depth of the water, and the value of the property being examined.

3.3 Cut-away volumetric data

The amount of relevant information is often relatively sparse as compared to the overall amount of ocean space data. More interesting regions could therefore be visually emphasized by using a cut-away technique integrated into the EDA process. The popularity of this technique (also known as cropping) is demonstrated by the fact that it can be found in almost any book about medical visualization and has already been researched for many years in computer graphics [8].

Our implementation of the cut-away method emphasizes direct manipulation VUI technique such as interactively define and remove less important volume space, and integration with the overall EDA process. After first exploring the context data structure, the user may then enter into the VDE cut-away module (figure 1) and remove parts of less importance. User then returns to VDE for further exploration with maximized visual information in focus.

3.4 Correlation between two volume data variables

Interactive scatter plots and line graphs are frequently used visual representations in InfoVis to search for patterns and trends when comparing multivariate attributes. We propose that these methods can be used efficiently in a multiple-linked-view environment together with volume visualization (figure 3) and thus demonstrate a synergy and joint usage between InfoVis and SciVis. Our aim is to correlate two important oceanographic variables temperature and salinity while maintaining control over both the spatial and temporal dimension in an interactive explorative data analyse. We link coordinated Scatter Plot and Depth Graphs views with 2D Volume Map views.

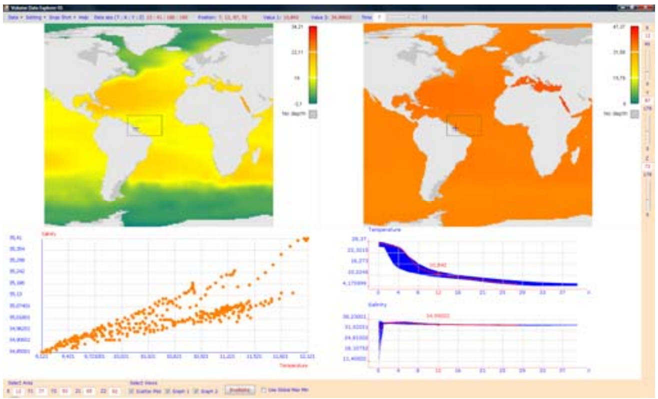

Figure 3. A snapshot of a time-correlated and multiple-linked five views event comparing Temperature and Salinity using 2D image maps, 2D scatter and 2D depth graph views. A comparison of Temperature vs. Salinity inside a defined area is presented for time step August (7). The user has selected an area of special interest with high salinity values outside the coast of South America. Volume data inside the selected area are shown simultaneously in five coordinated views. Correlation between the two attributes for a time step is analysed in a 2D scatter and two depth profiles. The value at position (0,86,69) is highlighted in all views. A dynamic time slider updates all views with immediate response time.

The user first interactively selects an area of importance in a 2D Volume Map view. The Scatter Plot shows the correlation between temperature and salinity for selected depth and time within the selected region. The Map and Scatter Plot are coordinated both ways and picking a grid cell in the Map will highlight corresponding glyph in Scatter Plot and reverse. The two Depth Graphs display for each grid cell in the given area a line of measurements (temperature and salinity) along the X-axis for all 25m's levels. Differences between adjacent grid cells can be found by visually comparing the strings representing them. When you move the depth or time range slider all views are automatically updated. These InfoVis methods facilitate a dynamic and intuitive understanding of the distribution of temporal volume data and of the relationships between data attributes.

3.5 Time

We demonstrate that dynamically exploring time-oriented data could provide important insight and knowledge about how temperature or salinity changes over time and at various depth levels. VDE provides many interactive means for exploring and interacting with time-oriented ocean space data in a coordinated and linked-views interface. VDE views with integrated isosurfaces, 2D and 3D images, time and profile graphs, are time-linked so that all of these views are synchronized to the same point in time at immediate response. Animating linked views simultaneously through time is also a common feature in many GeoAnalytics tasks and enables users to dynamically compare spatio-temporal data [10,11,14]. Time animation is achieved by either moving the red focus point in the Time Graph along the X-axis or moving the time step range slider in top menu (figure 2 and 3). The animations run at interactive speed and the analyst can step back and forth through time frames and change viewing and isovalues exploring individual volume data items.

3.6 Performance

There are many ways to improve performance in a component toolkit. For example, we try to minimize the number of data calculations by applying the two following key principles. The first one is to use pre-calculation as much as possible. During an EDA process, data items are re-used many times, such as the min/max values of a volume datasets, 4D time-oriented datasets or the results of comparing an isovalue against values at grid points of a volume data. We have applied this technique to components such as isosurface, scatter plot, correlation and time graph etc. and found that pre-calculation increases the performance of the components. The second one is to avoid execute a process or a function call if its inputs do not change. This scenario occurs frequently in coordinated views where objects interact with each other by sending and receiving messages or function calls to interchange data objects. Processes that are executed repeatedly on the same inputs and return the same output reduce performance. To avoid this we have implemented an input checking mechanism that checks change on the inputs of a process. If the input doesn't change, the process must not be executed. To avoid executing the process many times we also implement a "lazy calculation mechanism". We wait until all inputs are changed and then execute the process only one time. This technique is applied to linking and coordination of objects in our framework. We also take advantage of the GPU on the graphics adapter to enable high rendering performance required for immediate interactive performance between the views. Another GPU-based optimization is the use of DirectX "mesh" object to calculate the normals of the isosurfaces. This approach includes an unexpected positive effect; the isosurfaces are produced without artefact that often occurs in the intersection between sub-volumes.

4 Conclusion

The GeoAnalytics approach focuses on presenting VUI techniques through direct data manipulation and coordinated multiple-linked views applied to a large ocean space volume dataset. Coordination is implemented using a data linking method where all visualization components are connected to the same data model and colouring scheme, and where any time classification or highlighting made in one of the linked visualization components propagates to all the others. Immediate interactive response defined as less than 200 milliseconds is achieved by combining this approach with performance improvements including 1) pre-calculations 2) "lazy calculation mechanism" that avoids repeating a function execution if the input to a component is not changed and 3) rendering performance optimized e.g. texture mapping for the GPU graphics adapter.

We demonstrate synergies between VolVis and SciVis with InfoVis emphasizing representation and visual interaction. The advantage to "see" and interact with time-oriented oceanographic volume data simultaneously from different perspectives, scenarios and views are established. We have carried out usability studies confirming that by applying direct data manipulation techniques to volume data, the users will become more engaged in the analytic process and thus gain deeper understanding of its utility and value of interaction in this domain. When all views were updated immediately during a dynamic time slider event, the user got the feeling of almost touching the data and thus gaining insight into the behaviour and structure of the two correlated attributes. Experience learned from this project can be summarized:

- Analysts working with large oceanographic data want to first obtain a global understanding of the data and then focus on particular regions and their attributes;
- Volume visualization can benefit from generic 2D visual interaction techniques used in information visualization to facilitate exploration and discovery;
- Integrated spatio- temporal analytics and reasoning with volume data benefits from coordinated and multiple-linked views;
- Dynamic interactions and performance provide significant productivity improvement for the analyst.

Our next step includes a more comprehensive user task analysis. Task-appropriate methods for integrating spatial and temporal dimensions of data into interaction are needed. Our case study, for example, involves changes over time. We have applied an interaction approach to view these changes. Could an alternative be a visual representation for each time step? A trade-off exists between one interactive representation and the space required to view multiple static images. Interaction enables analysts to have multiple perspectives and gain insight into the volume data. This signifies a synergy and contribution from InfoVis to the more static VolVis.

Finally, we recommend the reader to visit the VDE's web site [19], download software and experience in real-time the proposed VUI techniques that permit the volume data analytical process to become more interactive and interesting.

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