A System for Visualizing Time Varying Oceanographic 3D Data

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Abstract **- Most data visualization systems only show static data or produce "canned" movies of time-varying data. Others incorporate visualization in real-time monitoring but these are generally customized to the particular application. The ability to interactively navigate through geospatial data is common but interactive navigation along the time dimension is not. And yet, visualization of data from interacting dynamic systems is increasingly necessary to interpret biological process, physical oceanographic processes, the motion of instrument platforms (such as ships, ROVs and AUVs), and the interactions between all of these. To address this need, we have enhanced our GeoZui3D system so that it seamlessly handles multiple time varying data sets: anything can be handled that can be represented through time varying surfaces, curved colored lines, curved colored tubes, arrow arrays, or color-, shape-, and size-coded points. The system can be used in both real-time and replay modes and data sets that have different sampling rates can still be visualized together. GeoZui3D can visualize events over a wide range of time scales from sensor readings at the millisecond scale to glacial movements evolving over tens of thousands of years. The system is illustrated with examples from collaborative research projects including modeled ocean and estuarine currents, tides, ship movements, changes in surface topography, AUV and ROV movements and the movements of marine mammals.**

I. INTRODUCTION

One of the greatest challenges facing oceanographers is interpreting data from multiple heterogeneous sources. Such data can be sensed from a variety of static or moving instrument platforms, or it can be modeled. Examples of such data sets include changing water levels; changes in currents and salinity; the movement of ships, autonomous underwater vehicles (AUVs), and remotely operated vehicles (ROVs); the tracking of animals, such as whales; or the growing and receding of glaciers. In the field of geographic information systems (GIS), a considerable effort has gone into constructing spatial-temporal (4D) databases capable of handling both spatial and temporal queries on all this information [1, 2, 3].

Less attention has been paid to the problem of how to create a user interface supporting rapid spatial and temporal navigation through such a 4D data set. The most common approach is still to generate a video file by specifying a time interval and a camera path. But this is a laborious process that precludes the kind of rapid interaction that is most useful in exploratory data analysis.

To meet the need for a flexible system that allows for the interactive viewing of multiple time varying data sources we have enhanced our GeoZui3D system [4]. This is a 3D geo-referenced data visualization system that has a zooming user interface allowing the user to rapidly zoom in and out with respect to points of interest. Prior to the developments reported here, GeoZui3D already had the capability of showing a wide range of static objects including digital bathymetric modes, ROV tracks, point glyphs of various types, and water-column 'ribbon' plots derived from high frequency sonars.

In this paper we describe how time is handled internally in GeoZui3D followed by a description of the features we have added to support time varying data. The remainder of the paper is devoted to four case studies that illustrate the applications of this enhanced system.

II. Handling Time in GeoZui3D

GeoZui3D internally represents time in a similar fashion as the Unix operating system. Time is converted to the number of seconds since midnight, January 1st, 1970. The one major difference is that GeoZui3D represents time as an IEEE double precision floating-point number. This representation allows for sub millisecond precision in the few hundred years surrounding the year 1970, while also providing the flexibility to represent times in the millions of years, albeit with reduced accuracy.

A. Interface

In GeoZui3D, time is viewed as a fourth dimension. Spatial navigation is always done by moving part of the scene to the center of the workspace in 3D. Similarly the current instant in time is represented as a point on the time bar, although this generally progresses forward. The current moment in time on the time bar (see Fig.1) corresponds to the spatial center of the workspace (see Fig.2). Like space, time also has a scale, namely the rate at which the visualization progresses. Similar to the way one would zoom into a three-dimensional scene to view more detail, one can zoom into time—slowing it down to see dynamic processes in more detail. Conversely, just as one would zoom out of a three-dimensional scene to gain a sense of context, one can zoom out of time—speeding it up to get an overall feel for dynamic processes. This is done using the scroll wheel commonly available on many computer mice. Buttons are also available on the time bar to support operations unique to time, namely pausing time,

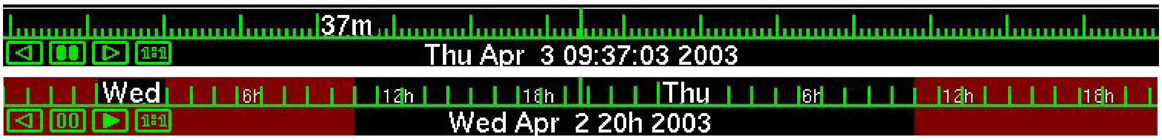

Fig. 1. Two screen captures of the time bar, showing time paused at a 1:1 scale (above) and time playing at the rate of about 3 hours per second. The centerline above the textual time display indicates the GeoZui3D's notion of "now". The shaded area indicates time that is outside the bounds of the data being displayed in the scene—data is only available for times in the unshaded region.

reversing time, and making time flow at 1:1 (real-time) speed.

B. Issues in time varying data.

The addition of time in an interactive GIS poses interesting challenges both conceptually and in terms of implementation. At a conceptual level, some situations may warrant displaying data from various times at once. One such situation would be where current (real-time) and planning (future) information are juxtaposed, as in a system that displays tide data for planning a ship's future passage (described in detail in Section III.C.). As a leg is plotted, it would be ideal to show the tide along the leg at the planned (future) time of transiting the leg. How does one show a continuously different tide along the leg, without it being confused with the (real-time) tide at the current time shown elsewhere on the display?

Another conceptual issue is how to treat views on 3D data that changes through time. In a stationary scene, users can investigate objects by clicking on them. This centers the view on that object and allows users to rotate or scale the view about the new center (see Fig. 2). In time-varying data environments, the object that the user clicks on may be moving. Should the display center on the geographic location the object was in at the time of user interaction, or should the view remain centered on the object? GeoZui3D does the latter, continuously updating the view so that all viewing operations are with respect to the reference frame of the moving object of interest [5].

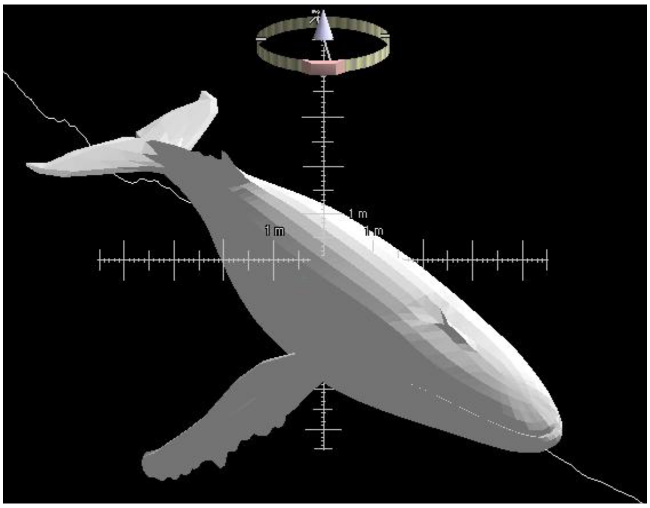
Fig. 2. The GeoZui3D rotation widgets attached to a moving object.

A more technical issue that arises with time varying data is the massive increase of data storage necessary. Data that varies in time might be represented with 100 time slices, requiring up to 100 times the storage space needed for a static scene. Although typical data sets visualized with GeoZui3D easily fit on a hard disk, main memory can easily be overwhelmed. In order for data to be visualized in an interactive display, the data must reside in main memory.

One way to address this problem is to leave most of the data on the hard drive and load into memory only what is needed, using a just-in-time strategy. Such an approach is used to visualize 30,000 particles flowing in and out of an estuary (see Section III.A.). With the help of the efficient NetCDF file formatting mechanism, only a few time slices are resident in memory. As time moves along, new data are read into memory as old data are discarded from main memory, all at speeds sufficient to support smooth animation.

Another way to address the storage problem is to compress the data in some way. One example is the display of water levels changing with tides (see Section III.C.). Instead of having multiple grids of water level each representing a time slice, a continuous tide model could be used to generate tide values on the fly, such as a single grid of phase offsets and amplitude multipliers applied for a single tide station. Of course, this type of approach takes advantage of properties of the data to determine a plausible compression strategy.

C. Real-time data input.

There are two ways to drive the passage of time within GeoZui3D. In playback mode, the computer's internal clock controls the passage of time, as modified by user interaction with the time bar as described in Section II.A. Playback mode is useful for exploring data sets that have already been collected, modeled, or planned. Another mode of operation is real-time mode, useful for the real-time collection and display of data. In this mode, the time signal comes from an external data source, such as a global positioning system (GPS) input or a sensor's clock. This eliminates discrepancies between the computer's time and the external data source's time. While collecting and monitoring real time data, it is possible to quickly switch back and forth between playback and real-time modes. This makes it possible to go back in time to review and replay previously collected data, and then jump back to the external data source's concept of "now" and continue monitoring the data in real time.

III. Examples of Time Control in GeoZui3D

A. Case 1: Visualizing Flow Fields

In the past few years, flow modelers have begun running forward simulations of estuarine currents on a regular basis. For example, the CBOFS model is currently providing a 24-hour forecast for the Chesapeake Bay area [6]. Such data may be useful for yachtsmen, emergency response management, and as supplementary information for navigators. We have been developing support within GeoZui3D to provide an easy to use interface to CBOFS and other estuarine and ocean flow models. This allows for the model to be viewed in a number of different ways as it evolves over time. It can be viewed as a scale-dependent grid of tracers with different color-coded layers. Alternatively, the user can interactively place "floaters" into the flow model and watch as they are advected along path lines, computed in real time and displayed with tails in order to better show the paths. This capability is illustrated in Fig. 3. Hundreds of particles can be easily handled in this interactive mode.

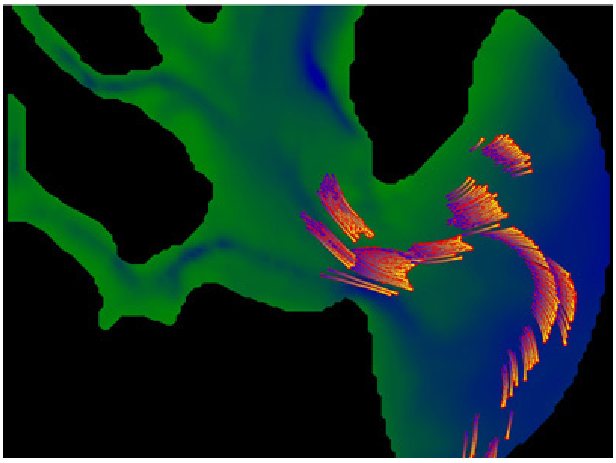

Fig. 3. Sets of tracers have been interactively dropped into a running model of Chesapeake Bay.

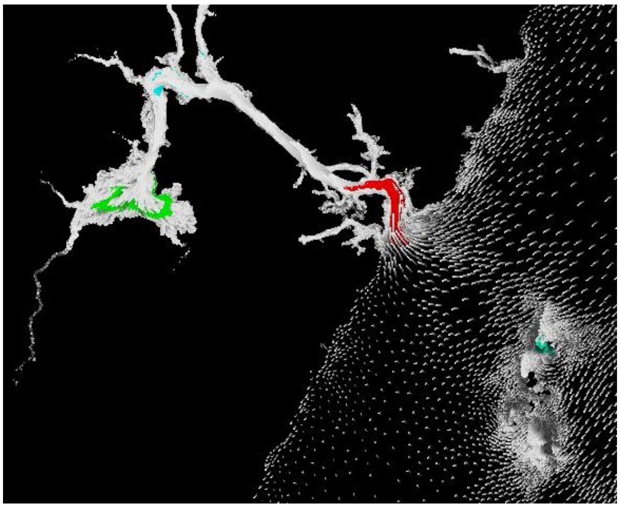

Fig. 4. A snapshot of 30,000 tracers being moved through the Great Bay and Piscataqua estuary in New Hampshire. The color-coded regions are particles that have been marked to keep them visually distinct.

To support real-time tracing and animation of large numbers of particles we found it necessary to modify the structure of the data from the original model format. We transform the irregular mesh sigma coordinate data structure into a regular mesh sigma coordinate structure and store it in NetCDF. GeoZui3D loads the NetCDF file according to the specifications provided by a supplementary XML file. The latter allows the user to specify which layers are to be loaded as well as display parameters, such as the number, density, and color of flow arrows.

GeoZui3D can also show larger numbers of tracers if their paths have been pre-computed. Figure 4 shows a snapshot of 30,000 passive water particles released in a flow field simulated by a 2D hydrodynamic model [7]. These particles were tracked over a period of one month in order to study the mixing intra-estuary and ocean-estuary exchanges in the well-mixed Great Bay Estuarine System in New Hampshire. Lagrangian particle tracking methods, such as this, allow statistically-significant large particle releases [O(500,000)] to quantify transport processes in a Markovian framework [8, 9]. These, in turn, hold great promise in ecosystems modeling when combined with contaminant transport simulations of active organisms and environmental modeling of pollutants. The combination of the complexity of variables involved in these processes with the large number of simulated particles, however, make the analysis of these results somewhat difficult and visualization becomes an important tool to convey information. Tasks such as color-coding particles as a function of space and/or time and conveniently interacting with them in both space and time makes understanding of these results a much simpler task

B. Understanding whale behavior

As stated in our introduction, our main focus has been to develop a set of interactive techniques that enable rapid navigation in both time and space to support the interpretation of data from multiple time streams. A recent whale-tagging project, led by David Wiley of the Stellwagen Bank National Marine Sanctuary, allowed us to prove this concept with several independent data sources. The goal of the project was to understand humpback whale behavior through the use of a tag [10] attached to the whale with suction cups. This tag can remain attached to the whale for a period of up to 24 hours and it can be programmed to release at a preset time. The tag contains depth and angular acceleration sensors, as well as a hydrophone for continuous sound recording.

An attempt was made to follow a tagged whale with a fast boat. Whenever a surfacing event occurred its position was visually recorded through the use of range-finding binoculars. Photographs were also obtained wherever possible. In addition to monitoring the whale, the positions of vessels in the vicinity were also monitored, as was the position of the fast chase boat. The researchers hoped to use these data to determine if the whale behavior was influenced by the presence of boats in the vicinity. GeoZui3D has the capability to place the still images in correct geo-referenced locations, and it can also play back sound recorded from the whale tag.

When researchers used GeoZui3D to review data, the unique ability of GeoZui3D to attach a view—with a single click to a moving object—was found to be especially useful. This enabled a researcher to zoom out, obtain an overview of the ship traffic in a particular area, then to zoom back in, find where the whale was at a particular point in time, and attach the view to the whale for a while. This allowed for rapid switching between whale-centered and world referenced views. Using both frames of reference, the time controller could be used to move backwards and forwards in time and to speedup and slow down the animation in order to examine behaviors on different time scales.

Fig. 5 illustrates a zoomed out overview showing the whale track combined with the locations of a number of vessels in the vicinity. Circular discs surround each boat to represent estimates of the sound fields the vessels produce. Fig. 6 shows the viewpoint attached to the moving whale. In this case it became easy to observe the detailed interactions with the seabed. In this view, individual fluke strokes could be discerned through dynamic changes in the attitude of the whale.

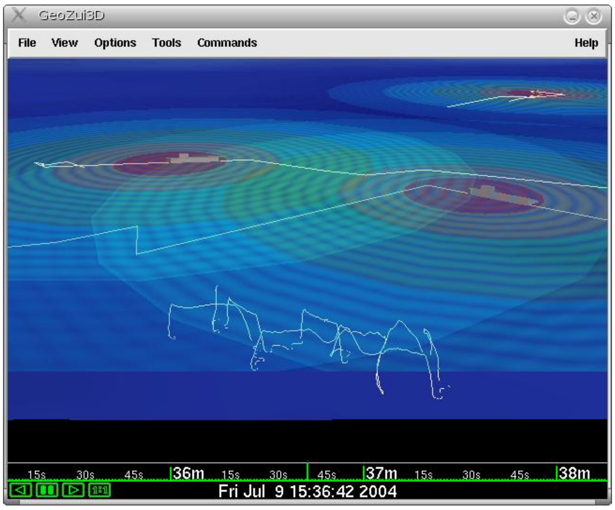

Fig. 5. An overview showing the sound fields from fishing vessels in the vicinity of the whale.

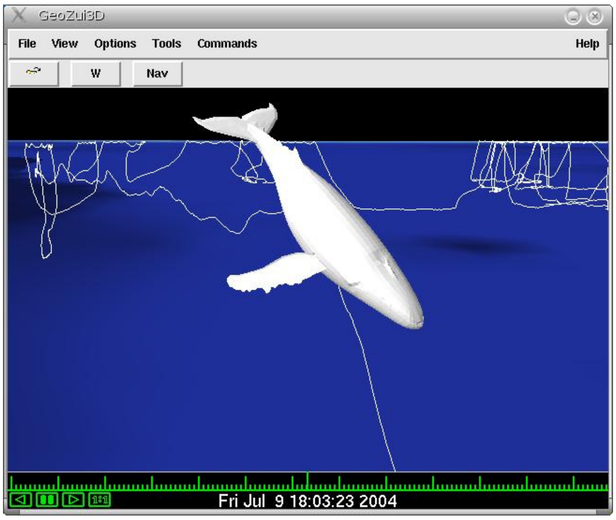

Fig. 6. The whale beginning a dive. In this snapshot, the viewpoint is attached to the whale.

C. Case 3: Planning a voyage with a tide-aware 3D chart

We have developed a variant of GeoZui3D for navigation decision support called GeoNav3D. Illustrated in Fig. 7 is a view of a GeoNav3D prototype for a tide-aware chart. GeoNav3D displays tides by continuously adjusting the color contours to take into account the estimated water surface based on modeled tides. The tide model currently in use is simply a grid of phase offsets and amplitude multipliers interpolated from tide zone information. On top of this tide-aware display of the sea bottom, the prototype allows a user to plan a path for future transit. While planning a route, a mariner may need to know the tide not only at a given time and place, but at different times for different places. A transit through a large estuary may take several hours and tidal state along the path will depend on the expected time of arrival. GeoNav3D presents such a path by displaying the anticipated tides at the estimated time of arrival at each point along the path, within a corridor surrounding the path. The mariner only needs to enter a series of waypoints and anticipated arrival times, and the system automatically computes adjusted depths along a navigation corridor. At the time of the actual voyage, the view reverts to real-time mode and shows the best current tidal information available.

The GeoNav3D interface is also capable of fusing modeled tide information with real-time positional input from various sources. GeoNav3D supports input from GPS sources, providing real-time position and course for one's own vessel. It also supports automatic identification system (AIS) input, providing near real-time position, course, and logistic information for any vessels broadcasting AIS signals in the vicinity.

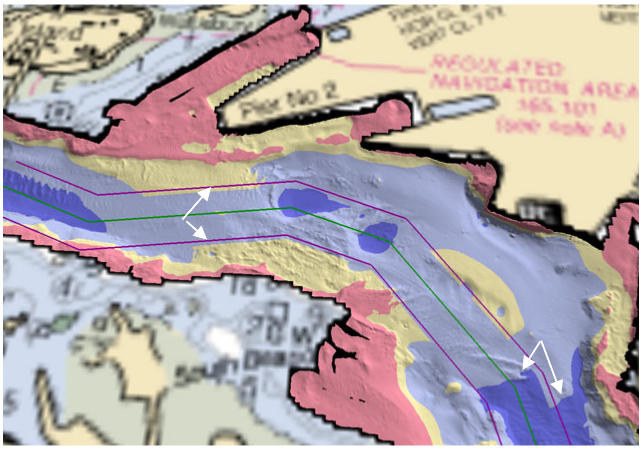

Fig. 7. Navigation path showing a transit up the Piscataqua river. At the present ("now") time, the path goes through an area where the under keel clearance is marginal as can be seen outside the navigation corridor in yellow. Inside the corridor, where depths are colored according to the tide predicted level at the estimated time of arrival at that location, under keel clearance is adequate (blue). Note the discontinuities in color near the arrows, indicating the difference in time and tide inside the corridor.

D. Case4: Real-time Data from an Oceanographic Vehicle

We have recently enhanced GeoZui3D with the capability to display scientific and navigation sensor data commonly obtained with oceanographic research submersibles in real-time as they are being operated.

Presently supported data types include the following: (a) Scalar valued sensor data, in which a sensor reports scalar valued data which varies with time and the sensor's position; (b) Vehicle trajectory data, in which a vehicle's six-degree of freedom position varies with time; (c) Target data—labeled spatial waypoints and targets selected by the user; and (d) bathymetric data, in which data from a vehicle's bathymetric sonar is gridded to produce a topographic map of the sea-floor. Geozui3D can display these data in real-time and can also display logged data from previous deployments.

The system can easily be switched from real-time mode to playback mode. Any time navigation action puts the system in playback mode allowing for the review of recent activity. A click of the RT button puts GeoZui3D back into real-time mode to continue monitoring the ROVs present position.

Figure 8 shows GeoZui3D displaying the trajectory of the Jason ROV together with bathymetric sonar data obtained by the vehicle in a deployment in the

Mediterranean [11]. GeoZui3D computes bathymetric surface as a weighted spatial average of the raw sonar ping data. The bathymetric surface is implemented as a hybrid grid data structure whose size can dynamically grow in any direction. With this interface the user can select both the spatial and temporal (i.e. real-time or a point of time in the past) viewpoint of the display.

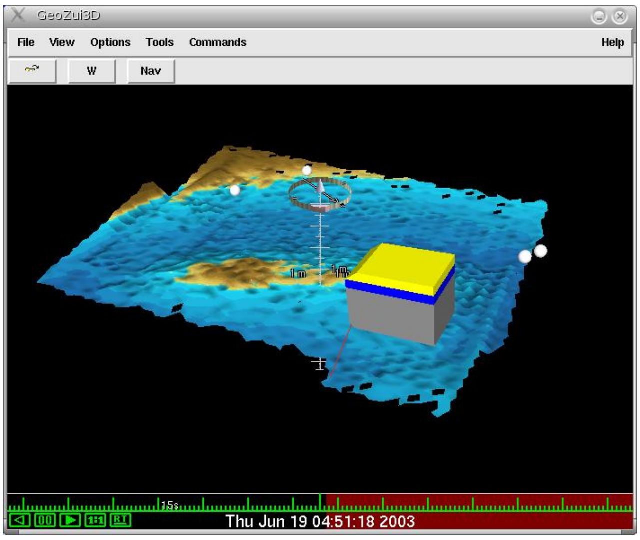

Fig. 8. Spatio-temporal display of the Jason underwater vehicle performing a benthic survey. The figure shows the trajectory of the vehicle as it evolves over time, and the growing bathymetric surface computed from Jason's scanning bathymetric sonar.

IV. CONCLUSION

We believe that the capability to interactively navigate in space and time is important in helping users to understand the complex and usually heterogeneous data sets that are increasingly important in ocean science. While many other packages are capable of constructing more sophisticated graphic representations than GeoZui3D, we are aware of none that allow for the same kind of freedom to navigate in space and time. We have only reported on a few of its uses here. Another application we have developed allows users to visualize glaciers as they evolved over millennia.

It is worth noting that all of the demonstrations we have discussed can be run on any reasonably capable PC with a 3D graphics card made within the last several years.

Acknowledgments

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Figure 8 depicts survey data obtained by Whitcomb and collaborators with the Jason 1 ROV on an expedition to the Eastern Mediterranean in June 1999, on which the chief scientists were Robert Ballard, Lawrence Stager (Archaeology), and Dana Yoerger (engineering) [11].

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