Advanced Mid-Water Tools for 4D Marine Data Fusion and Analysis

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ABSTRACT

Mapping and charting of the seafloor underwent a revolution approximately 20 years ago with the introduction of multibeam sonars -- sonars that provided complete, high-resolution coverage of the seafloor rather than sparse measurements. The initial focus of these sonar systems was the charting of depths in support of safety of navigation and offshore exploration; more recently innovations in processing software have led to approaches to characterize seafloor type and for mapping seafloor habitat in support of fisheries research.

In recent years, a new generation of multibeam sonars has been developed that, for the first time, have the ability to map the water column along with the seafloor. This ability will potentially allow multibeam sonars to address a number of critical ocean problems including the direct mapping of fish and marine mammals, the location of mid-water targets and, if water column properties are appropriate, a wide range of physical oceanographic processes. This potential relies on suitable software to make use of all of the new available data.

Currently, the users of these sonars have a limited view of the mid-water data in real-time and limited capacity to store it, replay it, or run further analysis. The data also needs to be integrated with other sensor assets such as bathymetry, backscatter, sub-bottom, sea-floor characterizations and other assets so that a "complete" picture of the marine environment under analysis can be realized.

Software tools developed for this type of data integration should support a wide range of sonars with a unified format for the wide variety of mid-water sonar types. This paper describes the evolution and result of an effort to create a software tool that meets these needs, and details case studies using the new tools in the areas of fisheries research, static target search, wreck surveys and physical oceanographic processes.

1. INTRODUCTION

Modern, commercially available, multibeam sonar technology has advanced to the stage of providing high-resolution acoustic return information not only from the seabed or sub-seabed, but also the intervening column of water. To exploit these data, an efficient means of reading, processing and analyzing the data is required. This paper describes the results of a project undertaken to make a commercial tool (FM Midwater) available to scientists, researchers and engineers interested in visualizing water column data in a multi-mode, 4D environment. FM Midwater is primarily a feature extraction tool used to export Fledermaus SD objects for visualization in 4D.

2. INITIAL RESEARCH

The system we describe in the bulk of this paper has its roots in GeoZui4D, a research prototype developed at the University of New Hampshire to investigate methods for interactively visualizing time varying geospatial data [Arsenault et al, 2004; Ware et al, 2001] [1][2]. GeoZui4D stands for Geographic Zooming User Interface 4D, and one of its primary objectives has been to develop ways of rapidly navigating in both space and time. Its spatial zooming interface has been adopted by Fledermaus as have some aspect of its method for navigating in time. GeoZui4D currently has two time bars as illustrated in Fig. 1. The top bar shows a small interval of time centered about the time being displayed in the visualization with the amount of time being related to the speed of playback. The lower bar shows a temporal overview that encompasses all of the life spans of the data objects that have been loaded.

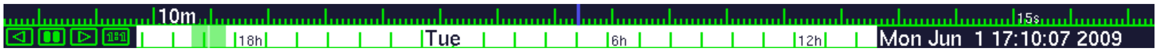

Fig 1: The GeoZui4D time bar. The top section animates as time passes. The lower section gives an overview.

A recent focus in GeoZui4D development has been the investigation of ways of visualizing both single and multibeam sonar data in both real time and playback modes. The two main abstractions for displaying sonar data are the fan and the curtain plot. Fans are primarily used for the instantaneous display of multibeam water column returns, and curtains are used to show the returns from single beam sonars such as the Simrad EK60. GeoZui4D can also display one or more beams of a multibeam sonar in the form of a curtain. Fig 2 shows a screen shot from a visualization of a project to observe the underwater behavior of humpback whales using sophisticated tags (DTAG) that record the animal's depth pitch, roll and heading [3]. An Imagenix DeltaT multibeam and an EK60 single beam sonar were used to map prey fields. In the image shown, cross sections of three whales can be seen in the multibeam. In addition, the ascending path of one of the whales can be seen in the single beam. The path of the whale, shown as a line, was only available after recapture of the tag and given the fact that the whale's position was only derived through dead reckoning, the correspondence of the reconstructed whale position with the image in the multibeam is remarkable. GeoZui4D can currently display Simrad ME70 & EK60 sonars data in real-time.

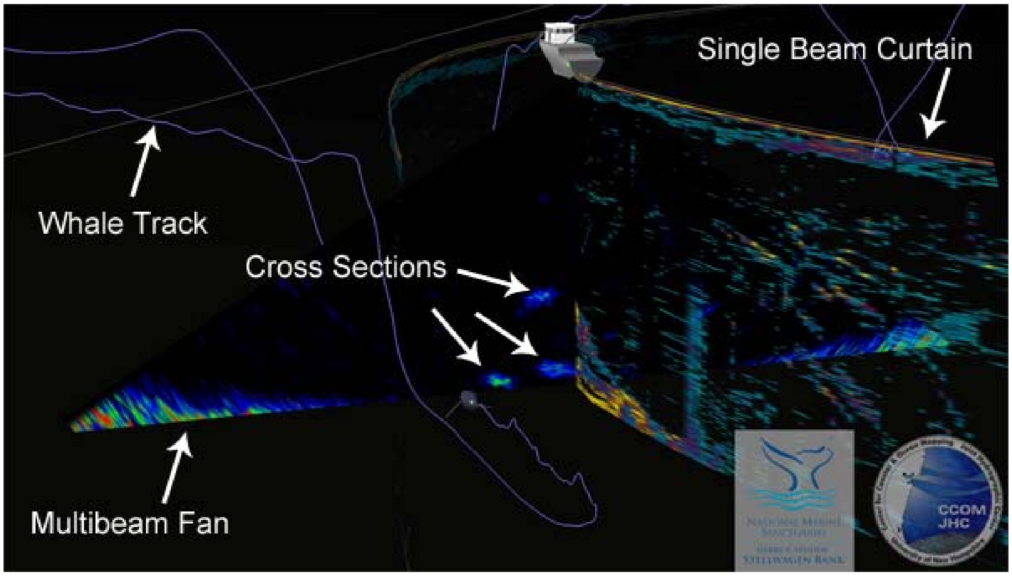

Fig 2. GeoZui4D screen shot from an animated reconstruction. The sonar fan shows three humpback whales from a multibeam sonar. The line is the reconstructed trajectory of a tagged whale. The curtain plot shows the ascending pattern of one of the animals in EK60 single beam data.

3. DEVELOPMENT CHALLENGES

Before considering which types of visualization to use for the water column data, we must first address some of the basic challenges present in efficient exploitation of this data.

The first challenge is the lack of sonar format standardization that exists in the marine industry. Each sonar manufacturer has a specific data logging file format that they use to capture water column data. Within each logged file are discrete packet types that represent data from a specific component within the system such as navigation, attitude, backscatter, multibeam and water column data. Also due to Ethernet bandwidth concerns during acquisition, some of these packets are broken up into sub-packets to ensure that all data is captured for a single ping. For example, during Kongsberg EM3002 water column acquisition, a single ping worth of data is broken up into a number of packets representing groups of beams for this ping. This causes a single water column ping to be fragmented across multiple packets.

Navigation and attitude information can also be logged in separate packets and not integrated into the water column packet. In some system configurations, this data can also be logged to a completely separate file. This results in further fragmentation of an instantaneous snapshot of the water column. In order to compute where each sample from the water column of a single ping exists in time and space, we need to integrate information from multiple packets and sometimes multiple files. These considerations must be factored in for each sonar of every manufacturer supporting water column acquisition.

Another challenge is the high data rates that exist in some sonar types such as the Reson 7125 and Simrad EM Series sonars. Extrapolating the sounding collection rates shown in Fig. 3, water column data capture rates can also be expected to continue to increase. This is due to the fact that water column data is a time series sampling from each beam of the sonar. Sounding collection rates increased because maximum ping rates and number of beams increased. By following this trend, one can assume that water column data capture rates will continue to increase.

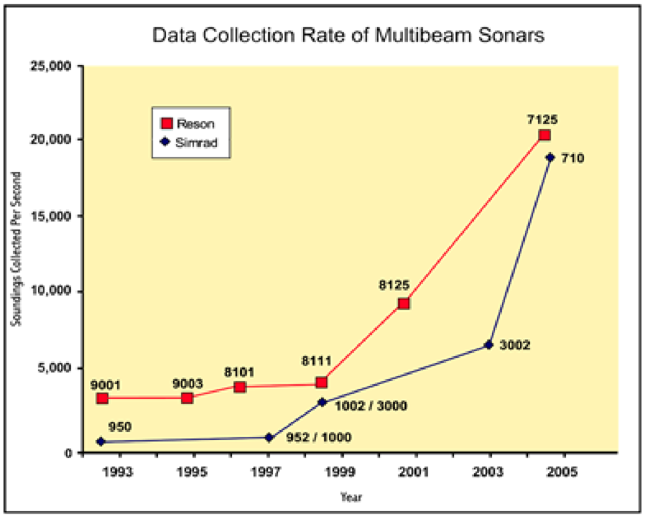

Fig. 3 – Multibeam Sonar Sounding Data Rates

In order for any type of visualization to be efficient and interactive, data loading for the visualization must be fast with a minimum amount of disk seek time and read delays. Good interactive visualization can be completely limited by slow inefficient disk access. As one can see from the above challenges, loading data from very large fragmented files can seriously impact the performance of an interactive visualization system.

4. GWC - A MORE UNIFIED FORMAT

Addressing the primary challenges that exist in exploitation of water column data, a generic water column format (GWC) was designed as a unified way of storing water column data in a compressed or sub-sampled, integrated manner to be used for efficient interactive visualization. The GWC can be considered analogous to the GSF format [4] that is used for storing processed and raw bathymetry.

During the source conversion process in the FM Midwater tool (Fig. 4), the water column packets are re-integrated along with proper time-based navigation and attitude such that the visualization environment will have access to all the relevant data of any particular ping. Each file is first indexed, which enables fast non-linear lookup and extraction of any packet type or packet type collection in the source file. The decoding process is where every packet type from supported sonars is extracted for relevant information so that it can be reformatted into the new GWC file format. This same process is again used by the visualization system in that the GWC can be indexed and decoded for presentation in a visualization system. This key process enables the visualization system to be essentially format independent. Currently, the source conversion system supports a wide variety of hydrographic and fisheries sonars such as the Kongsberg EM3002, EM302, EM122, ME70, EK60, EK500 and Reson 7125.

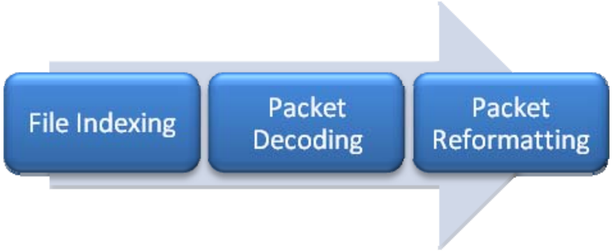

Fig. 4 – Source Conversion

5. SUB-SAMPLING FOR VISUALIZATION

The high data bandwidth of some sonar types requires a means of either sub-sampling or compressing the data during format conversion. A single logged water column file from a high-resolution sonar can easily exceed 1GB in size. For example a ~7 minute file from a Reson 7125 in ~200m of water resulted in a logged file size just over 6GB. This can be problematic when you are trying to have fast, interactive playback of water column pings within a 4D environment.

Since the data is meant primarily for visual interpretation on a nominal screen size of 1280x1024 pixels, simple sub-sampling can provide a reduced data set for visualization that maintains the salient features needed during interpretation. Given that the source data was indexed during the conversion process, correlation between the visualized sub-sampled data and the original source data is easily achieved. In other words, an individual GWC ping record has all of the information necessary to get directly back to the original beam packet of the original source data at full resolution.

6. FEATURE EXTRACTION

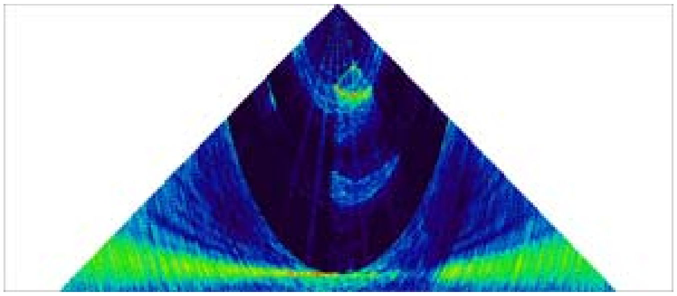

Fig. 5 - Swath View

Although the raw data rates of water column data collected from multibeam sonars can be very high, the information content is generally much smaller. An important aspect of any tool used to examine this type of data is the ability to rapidly review the data and extract features of interest. In FM Midwater, this is done by providing multiple ways to view and threshold the data prior to displaying it in a 4D environment. In Fig. 5 we see a "swath view" display of the water column data. Using the timeline control within the tool, we can move through the data reviewing each ping in sequence or use our index to review the data in a non-linear manner.

However, if this is our only display mode, we would still need to review every ping to look for interesting features which is a time consuming way to extract data.

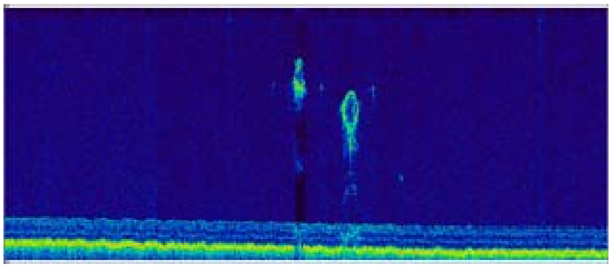

Fig. 6 – Beam View

Fig. 6 shows another way to easily look at the data as a single beam along-track plot. Here we are viewing the data through the water column as if we were an observer perpendicular to the track line. The X-axis represents pings along track and the Y-axis represents beam range from zero to maximum range, top to bottom. The display allows us to cycle through each beam to reveal features in the water column as if our viewpoint was moving across the track line. We can also simply click and drag a selection window on the display to zoom in to interesting features (Fig. 7).

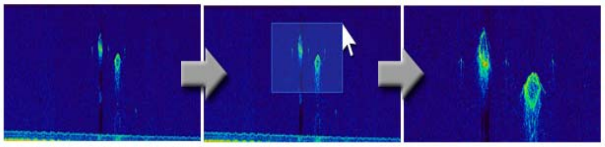

Fig. 7 – Zooming to Features

The final and most useful way to review that data is shown in Fig. 8. This is an along-track "stacked" view of all the data for a single line. The X-axis represents the pings along track and the Y-axis represents beam range.

We are still looking through the water column from a perpendicular viewpoint, but this time all the beams have been combined using a "maximum" filter so that we can see the highest return targets in the water column for the entire line. This view is also intentionally distorted and not corrected for beam angle so that we can see the maximum amount of information provided by all the beams.

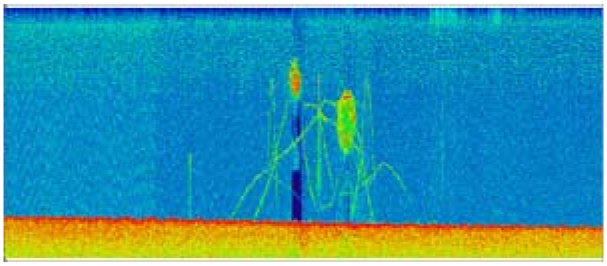

Fig. 8 – Stacked View

7. THRESHOLD FILTERING

The previous section shows how we can easily get to the relevant features in any water column file. But before we export to our 4D environment, we may want to further reduce the amount of undesired data within the water column. This can easily be achieved by some straightforward threshold techniques.

The first filter we can apply is to which beams we specifically want to focus on. If we are passing by the side of a wreck for example, we may not need over half the beams in the water column packet. Those unused beams can contain quite a bit of data that is irrelevant to our visualization. To manage this, the tool provides a “composite slider” control as a means of easily setting the range of beams we want to look at (Fig. 9). The swath view updates when the control is changed so that the user is instantly aware of the area of focus (Fig. 10).

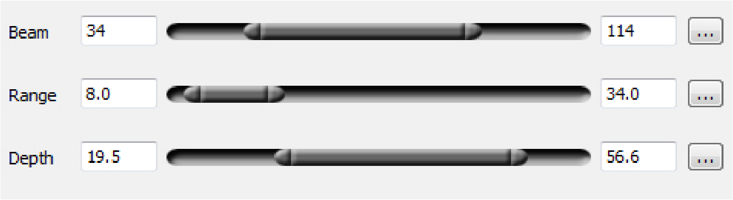
Beam 34 114
Range 8.0 34.0
Depth 19.5 56.6

Fig. 9 – Composite Sliders

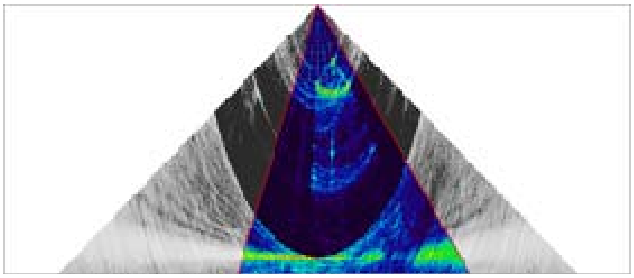
Fig. 10 – Beam Limiting

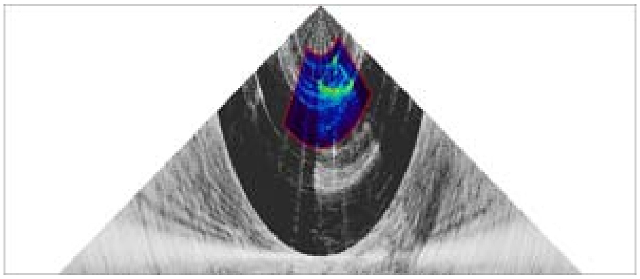
Fig. 11 – Range Limiting

Another obvious threshold that can be applied is for beam range. Typically there can be near transducer noise that is not desirable for visualization and alternately far range returns, data past the seabed interface is also not desirable. Using the same type of threshold control used for beams, the user can limit both the beam range and an overall cutting plane depth. This further eliminates unnecessary data appearing in the 4D visualization (Fig. 11).

The next threshold adjustment is in the sonar signal itself. Each GWC file generates a histogram of the data during the load process. A control is provided (Fig. 12) such that the user can eliminate low-level noise and either clamp or clip the data at either end of the threshold limits. The cyan plot of the signal is the initial signal histogram. As the user moves the composite control, the magenta plot shows the “stretched” part of the signal that will be the focus. This stretched signal is mapped across the range of the color map. The histogram can display raw amplitude, power, volume scattering or target strength depending on the capabilities of the sonar.

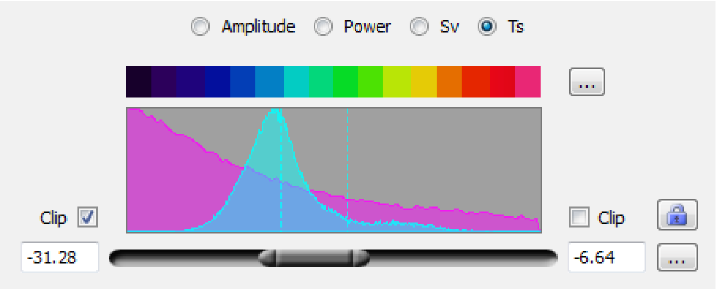
○ Amplitude ○ Power ○ Sv ● Ts
Clip ☑ -31.28
☐ Clip -6.64

Fig. 12 – Histogram Limiting

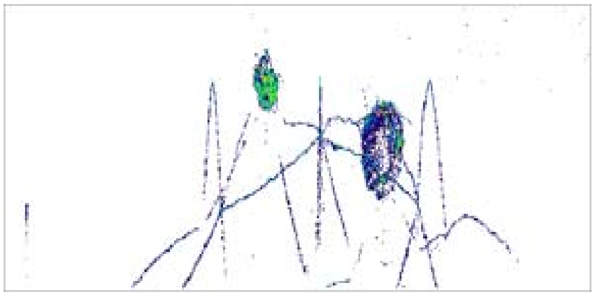
Fig. 13 – Histogram Limited/Stacked View

Finally, when the user zooms in on a particular part of a stacked or beam view, they are automatically limiting which pings they are interested in. This provides our temporal limit to the data that will be used for exporting to the visualization environment.

Fig. 13 shows the final result of the threshold limiting with a bit of zooming added in. Here we can clearly see the water column features that are available for export to our visualization system. These are the fish traps and associated mooring lines that we have passed over with our survey.

8. VISUALIZATION METAPHORS

Now that we have appropriately focused our attention on the features of the water column that we want to visualize, it is time to export these objects into our 4D environment. To accomplish this, four primary visualization metaphors were developed to provide the most effective means of reviewing water column features. In the following examples, we use data from an EM3002 that was acquired off the coast of New Hampshire. The survey passed over some suspended fish traps in the water column.

8.1 BEAM FAN OBJECT

The Beam Fan object (Fig. 14) is an along track view of the water column swath. This object is temporally aware and is rendered in the 4D environment dynamically from the GWC file. As time is played back in the scene, or the user moves the time control point, the Beam Fan object updates from the GWC. Control of this object also mirrors capabilities in the feature extraction tool in that the user can control beam, range and signal histogram thresholds. The Beam Fan is colored using the sample values transformed by a color map. Additionally, when using a calibrated sonar, the sample values can be mapped as computed target strength (Ts) or volume scattering (Sv).

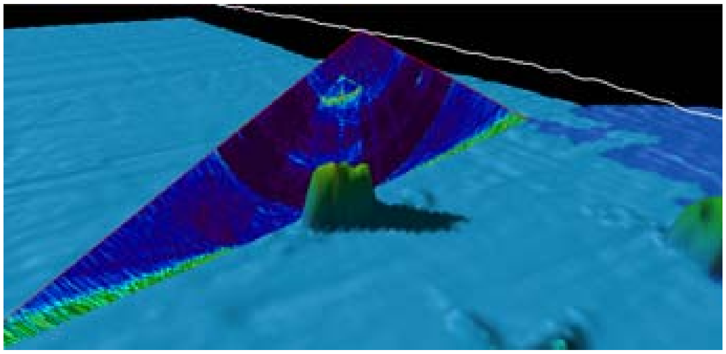

Fig. 14 – Beam Fan Object

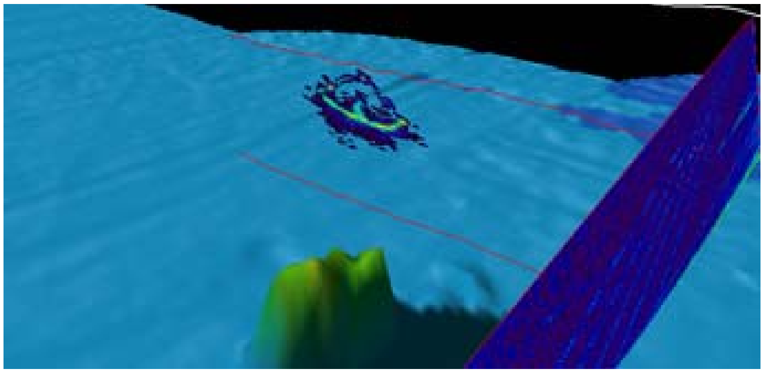

Fig. 15 – Beam Line Object

8.2 BEAM LINE OBJECT

The Beam Line object (Fig. 15) is an along-track curtain similar in nature to a seismic curtain in the Fledermaus environment. The only difference is that the curtain is aligned to the beam angle. One advantage of this metaphor over the Beam Fan is that you get an image based slice of the water column without the across-track distortion inherent in the Beam Fan. Each vertical ping is also time-aware in this metaphor so a time-window can be setup to visualize only a temporal portion of the entire line. In Fig. 15 we can see a view from beam 94 of the fish trap data in the water column. Multiple Beam Line objects can be exported to give a better sense of the overall structure of the target. The Beam Line object is also useful for display of water column data from a single beam system.

8.3 POINT CLOUD OBJECT

The Point Cloud object (Fig. 16) contains 3D points that represent the bore sight location of a sample that passed the threshold filters. It is the transformed location of the beam sample and can be visualized as any number of atomic objects in the 4D environment including points, cubes and spheres. In Fig. 15 we see the entire fish trap field which includes the traps, fish and mooring lines. The individual points can be viewed with a color map that represents sample signal level, height in the water column, beam number or line number. The points are also time aware so a time-window can be used to visualize only a temporal portion of the entire line

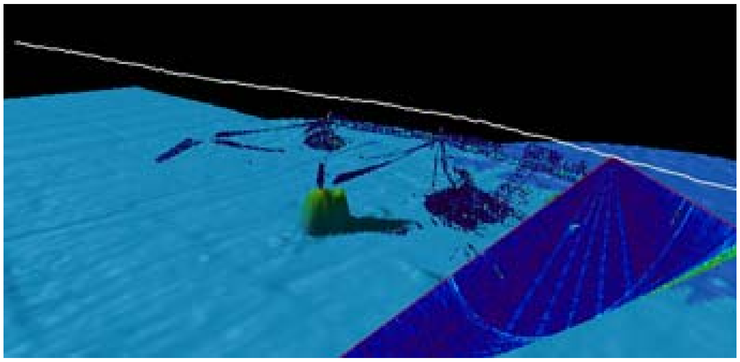

Fig. 16 – Point Cloud Object

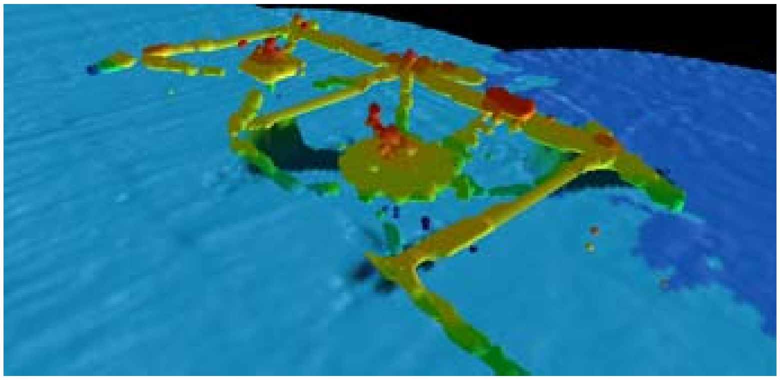

Fig. 17 – Volume Object

8.4 VOLUME OBJECT

The Volume object (Fig. 17) is a 3-dimensional grid of voxels at a user specified cell size that is loaded through ray-tracing of the selected water column data into the positioned volume. In the visualization environment, the voxel "brick" is used to generate ISO surfaces at a user selected ISO value. The ISO surface is generated using a typical marching-cubes algorithm. This visual metaphor is very useful when viewing objects such as fish schools. It can additionally be used in a nested mode to show internal structure of a complex object such as a seafloor geo-thermal vent [5].

9. THE TOOL - FM Midwater

All of these capabilities are integrated into FM Midwater as an easy to use graphical tool that enables an operator to extract the maximum amount of useful water column data in the minimum amount of time (Fig. 18). The operator can easily see the water column display along with a map display that shows the current location of the view according to the time position on the timeline control. One can easily switch between swath, beam and stacked views and can easily add or remove survey lines to the project.

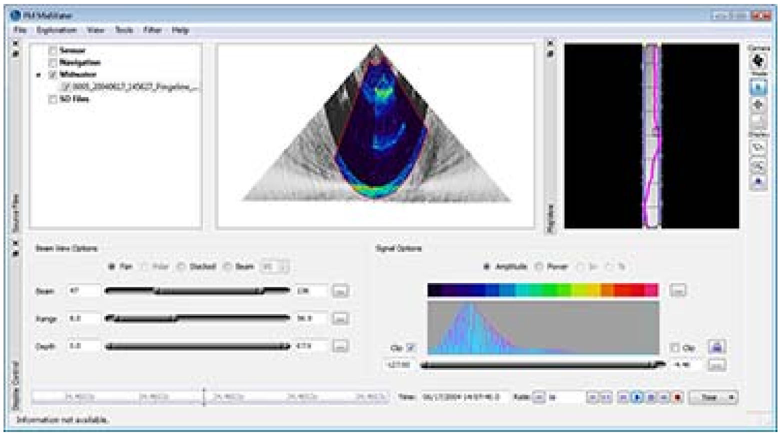

Fig. 18 – FM Midwater Tool

10. DATA FUSION – THE WATER COLUMN ADVANTAGE

The importance of data fusion using water column data is best explained visually. In Fig. 19, we see a typical visualization of a bathymetry DTM from a survey around an oilrig in the Gulf of Mexico (upper left image). With the addition of a Point Cloud Object (upper right image) of the rig in the water column, we get a more complete picture that can help us in our interpretation. The final two images show the addition of Beam Fan and Volume objects that clearly show fish schools in the water column during the survey.

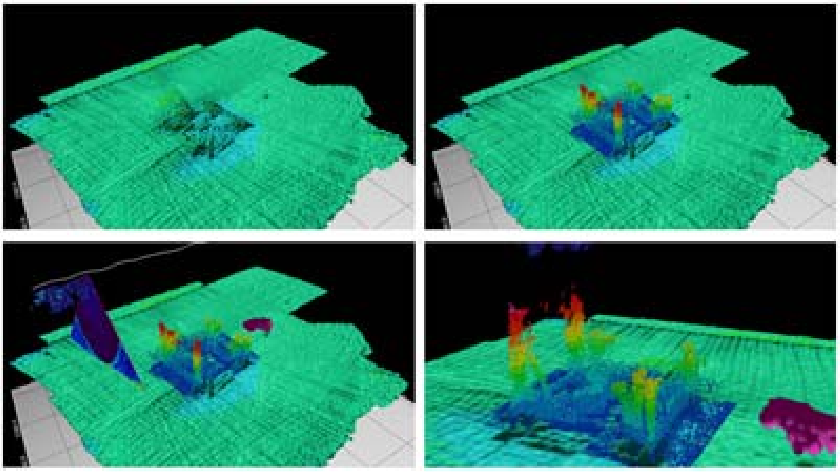

Fig. 19 – Oil Rig Investigation – Data courtesy of C&C Technologies, Inc.

11. FIELD USE

A prototype version of FM Midwater was used during a recent cruise of the NOAA ship *Okeanos Explorer*. While on the cruise to test the new Kongsberg EM302 multibeam sonar in May 2009, they discovered a 1400 m high plume rising from the seafloor. An image of the plume with the surrounding bathymetry is shown in Fig. 20. The feature was noticed in the online display of the water-column data of the sonar, and further analyzed in the prototype FM Midwater tool. The ship returned to the area in July, verified that the plume was still active, and detected a number of other plumes ranging in height from 700 to 1400 m in a 15 km area around the original discovery. James V. Gardner and Mashkoor Malik , (CCOM and NOAA respectively), participated on the cruise, and provided details of the discovery in EOS [Gardner et al, 2009] [5]. The discovery of this plume is just one example of the emerging use of these types of multibeam water column data.

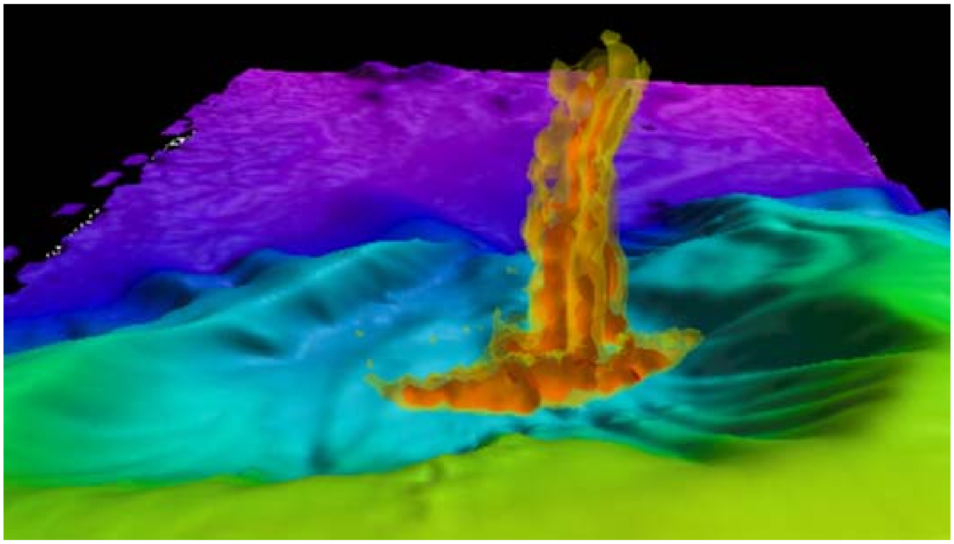

Fig 20 – Deep Water Plume

12. SUMMARY

In recent years the capability of multibeam sonars have been extended to enable them to map to the water column along with the seafloor. The development of suitable analysis tools has lagged the sonar functionality, and limited the use of the sonars by scientists investigating a number of critical ocean issues including the mapping of fish and marine mammals, water column properties and mid-water targets.

The software tools to process and analyze the bathymetry, and more recently characterize the seabed from the backscatter, are available in commercial software, and the challenge is to extend the tools to the water column data, and importantly integrate the analysis in a single environment. A significant variation for these data is their change over time that demands an addition of a temporal framework to the geospatial processing environment. Another challenge is the variety of acquisition formats and the large data volume with the water column data. An approach to unify the formats for visualization with a generic format has been developed during the project.

Initial research used the fan and vertical curtain for displaying the multibeam water column data. In this development this has been extended to include extracted points and a volume object. All objects have a temporal component to allow exploration in both space and time.

The initial approach has been developed and proved successful on a number of cruises with the research prototype, GeoZui 4D, and the FM Midwater tool, in easily allowing users to extract the water column data for visualization and analysis. In all cases the ability to integrate the water column data with the seafloor and other information, in an integrated geospatial and temporal environment, enhanced the analysis and interpretation of the data. A priority in the next phase is to refine requirements of the various users and the addition of the necessary tools to support their data extraction, visualization and analysis.

The developments from this project resulted in tools to allow scientists in a variety of oceanographic research to finally benefit from the evolution of the water column data available from modern multibeam sonars. Future research will continue to investigate optimizing the extraction of the features in the water column data, and because of the temporal nature of the data, the potential for moving these tools into a near-realtime environment.

ACKNOWLEDGMENT

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