

New Tools for Water Column Feature Detection, Extraction, and Analysis

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Lead author biography: Erin Heffron has been a Product Specialist for QPS (formerly IVS 3D) for almost nine years, with a primary focus on the Fledermaus software. She has a B.S. in Environmental Studies from Slippery Rock University. Her academic and career background is in geology, GIS, and habitat mapping, and she has a strong interest in the backscatter and watercolumn modalities of multibeam sonars.

Abstract:

The water column capability of multibeam sonars has widened the applications for their data. However, this presents a challenge in developing applications that can address all of the potential user requirements. The design of the FMMidwater application has thus focused on providing a platform for processing water-column data, with the flexibility to extend the baseline capabilities to meet specific user requirements by adding plugins. The latest tools for improved feature detection utilized this architecture to transfer research code developed by CCOM UNH into the FMMidwater application. These tools incorporate Normalization, Despeckling, and a Clustering Object to help identify and visualize gaseous seafloor seeps.

Until recently, seeps were manually detected in a time consuming and subjective procedure by viewing water column returns in FMMidwater. The NOAA Office of Exploration and Research *Okeanos Explorer* Program tested the new tools in an effort to reduce this subjectivity and time commitment. The initial results show potential for meeting the *Okeanos Explorer* Program goals to increase water-column exploration through reduced processing time and increased detection accuracy between data processors working on the ship or ashore. NOAA and its partner CCOM UNH continue to work with QPS to refine the implementation and operational procedures; several suggested improvements are currently being implemented.

Introduction:

Mapping and charting of the seafloor has evolved over the last few decades since the introduction of hydrographic multibeam sonars. The initial focus of these sonar systems was the charting of depths in support of safety of navigation and offshore exploration; more recently this has extended to the development of approaches to characterize seafloor type and for mapping seafloor habitat and geohazards. The software tools to process and analyze the bathymetry, and more recently characterize the seabed from the backscatter, are available in commercial software, and support the majority of the modern sonars.

The latest generation of hydrographic multibeam sonars now has the ability to map the water column, along with the seafloor. Utilization of the water column data has the potential to address a number of research areas including detection of complex hard targets (wrecks, etc.) above the seabed, mapping of fish and marine mammals, and a wide range of physical oceanographic processes. However, users have a limited view of the mid-water data in real-time, and until recently they mostly relied on their own in-house software tools to study the water column data. The variety of applications for the water column data is one of the complications to developing commercial tools to process and analyze the data. It is essential to ensure that flexibility is incorporated in the commercial tool to allow for both the simple addition of evolving data types as more multibeam sonars provide water column data, and to address the many emerging uses and users for the data. For some applications, the variation of these data through time is also important and this 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 associated with water column data.

Initial FMMidwater Development and Manual Feature Extraction

The initial development of the FMMidwater module at QPS, over four years ago, was built on research from the Center for Coastal and Ocean Mapping, University of New Hampshire (CCOM UNH) to investigate methods for interactively visualizing time-varying geospatial data (Arsenault et al, 2004; Ware et al, 2001). The water column data required a number of new visualization metaphors to be created in order to address the geospatial and temporal aspects required for analysis; additional development was also required to extract fully refracted and adjusted detections in order to allow for fusion of the information with seabed detections from the multibeam processing and visualization.

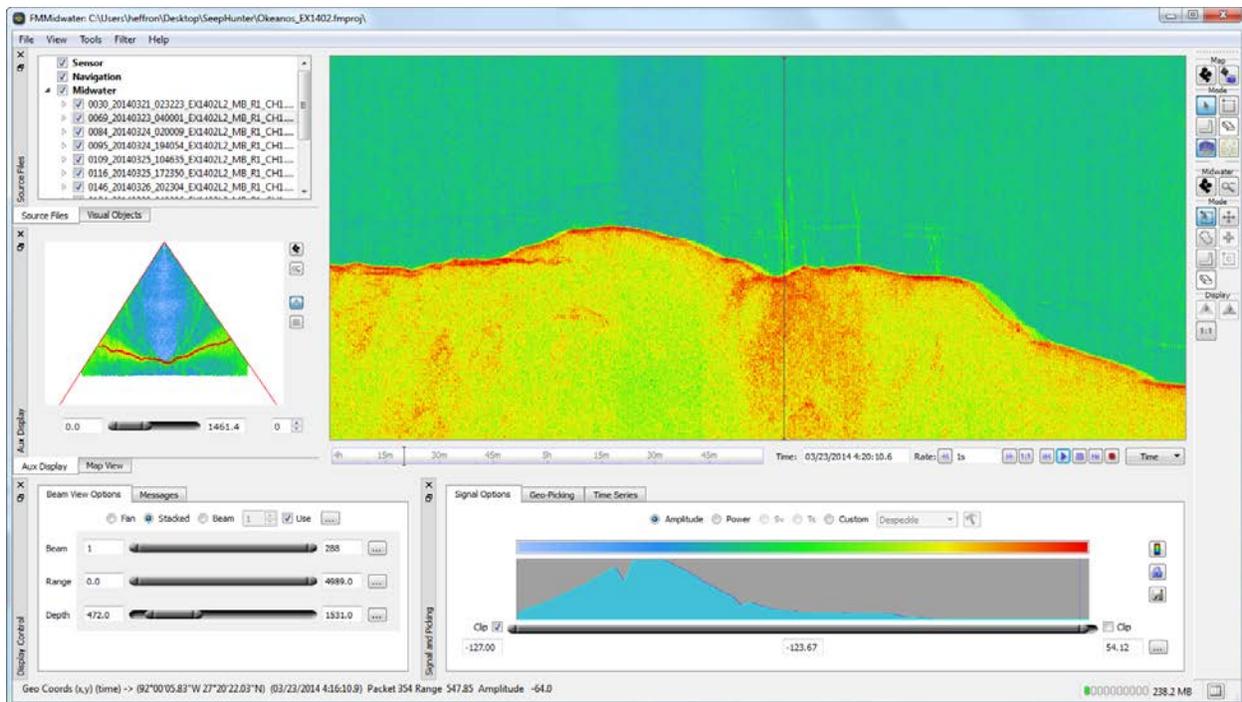


Figure 1. – Image of unprocessed NOAA ship Okeanos Explorer EX1402 EM302 multibeam sonar data in the FMMidwater module. Seeps are shown in the main window Stacked View and in the Fan View of the left; the black line in the Stacked View indicates the position of the Fan View. Red points in the Fan View show the bottom online detection.

FMMidwater allows users to extract features from the water column data for visualization and analysis. The raw data rates of water column data collected from multibeam sonars are very high, however the information content is generally much smaller. Therefore an important aspect of a tool to examine these data is the ability to rapidly review the data and extract features of interest. FMMidwater provides multiple ways to view the data for display and analysis: swath view, beam view, stacked view, and combinations of these. The various views allow easy and rapid manual identification of features for selection, thresholding and extraction of data. Initial selection is the first stage of feature extraction – focusing (zooming in) on an area of interest disregards all data points outside of that area. Filters can be applied to specifically focus on certain beams and to limit the range of data used. Threshold adjustment is applied to the sonar signal itself. A histogram is generated of the water column data during the load process and a control is provided such that the user can eliminate low-level noise and either clamp or clip the data at either end of the threshold limits. The histogram can display raw sonar units, power, volume scattering or target strength depending on the capabilities of the sonar. The final selection allows for interactive digitizing to further restrict the area of the data to be extracted. Bottom detections from the sonar or nadir bottom detections computed by FMMidwater can be used to further filter data being exported (Gee et al, 2012).

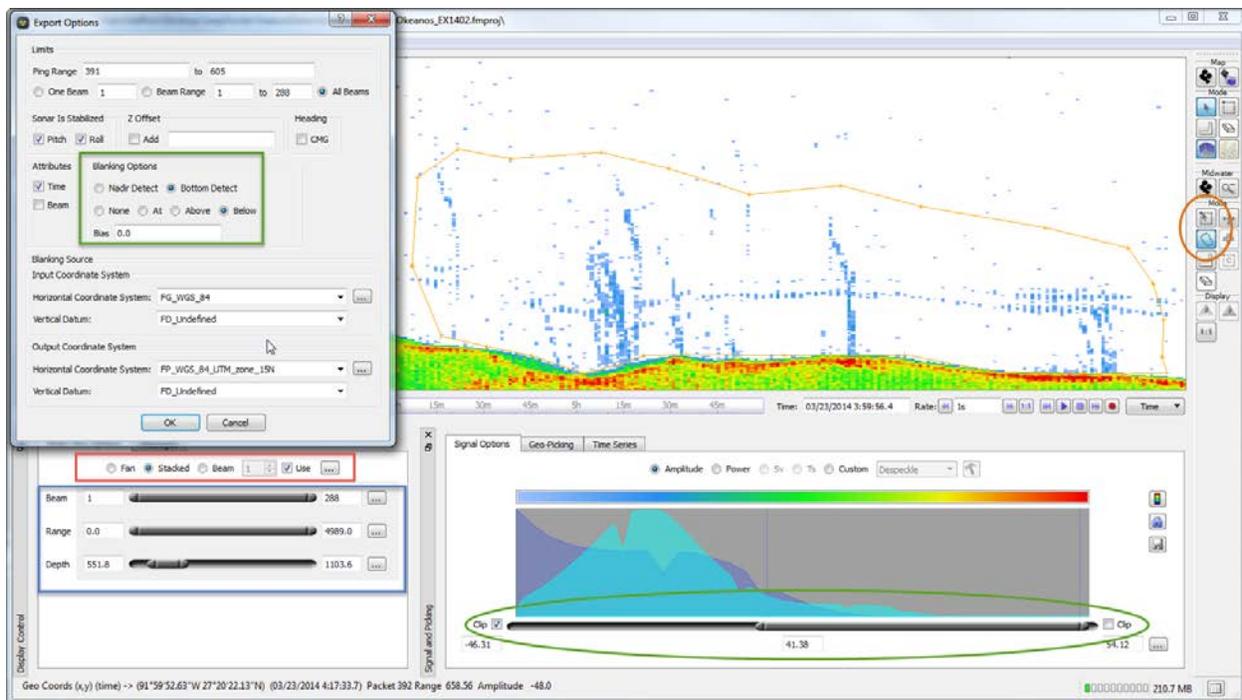


Figure 2. – Tools to filter exported data in FMMidwater. The orange circle in the Control Bar highlights the Explore/Zoom Select and Select Area Modes. The Beam, Range, and Depth filters are in a blue box. View options are surrounded by a red box. Thresholding with the histogram is highlighted with a green circle. Finally, the option to blank on export is shown with a green box.

Water Column Tools and Plug-ins

The water column capability of modern multibeam sonars has widened the applications for their data and has the potential to extend the capabilities of these systems in various fields such as resource exploration and marine habitat mapping. This presents a significant challenge in developing commercial software applications that can address all of these potential user requirements, especially since the requirements are still evolving as new uses are found for the data. The design of the FMMidwater software architecture has thus focused on providing a platform for processing water-column data, with the flexibility to extend the baseline capabilities to meet specific user requirements by adding plug-ins. Plug-ins are a means of adding specific capabilities to a larger baseline application without the need of direct integration that would require a new build or release of that application. Plug-ins can be developed by the creator of the host application, by end-users themselves or even by third-party developers.

Plug-ins within the FMMidwater platform fall under various categories to allow the addition of key additional functionality: new data import, data export, signal processing, and application specific tools. This approach enables a prototype to be rapidly transferred from research to a broader community of users without the researcher being required to develop and support an entire software application. The newest features for improved feature detection were undertaken with this approach where the research code was transferred to a plug-in for prototype, optimized, and then packaged and released in the FMMidwater application.

Improved Processing and Semi-Automated Feature Extraction

FMMidwater has been used successfully on a number of projects since release, and one area of particular interest is the detection and mapping of bubble plumes or flares from gaseous seeps (note: the “seep” is used in this paper to describe both the seep itself and the visualized bubble cloud/flare that indicates the location of the seep). Even though FMMidwater provides a fast and intuitive method for manually extracting the features in the data, users quickly requested automated and objective techniques for processing and analysis of high volumes of data. As more seep data was collected, users moved beyond the “easy” seeps (easy to spot and visualize) and showed interest in locating and extracting the transient seeps that only exist over a few pings (which are particularly difficult to locate and process).



Figure 3: Bubbles of methane gas rise through a mussel bed at the Pascaguola Dome. *Image courtesy of the NOAA Okeanos Explorer Program.*

To meet these needs, QPS has worked closely with researchers at CCOM UNH to implement some of their water column processing techniques for seep detection as FMMidwater plugins. The algorithms were developed to support an offshore exploration cruise in an area of known methane gas seeps in the northern Gulf of Mexico (Weber et al, 2014). The CCOM UNH approach chains together simple signal processing techniques to isolate and extract signals consistent with methane gas seeps from multibeam water column data. The approach is summarized as:

- 1) Compute a pixel-by-pixel running average of target strength in a fan view for a series of pings
- 2) Use the average from (1) to normalize the target strength for a particular fan

- 3) Threshold the output from (2) to isolate the strongest scatterers
- 4) Apply a clustering algorithm to clump together scatterers that are nearby one another into single cluster objects (as opposed to single point scatterers)
- 5) Apply a morphological filter to remove strong scatterers that do not conform to the expected shape of a gas seep (linear and mostly vertical)

These steps are implemented in the FMMidwater module as the Normalized GWC Import and the Despeckle Filter, and in the Fledermaus module as the Cluster Data Object. The individual tools have also been combined in a semi-automatic Feature Detection tool in the FMMidwater module, which runs the Normalization and Despeckle algorithms on a selected line; from there, the user is only required to select the features from the results for export as Cluster Data Objects which are loaded in Fledermaus for further analysis and characterization.

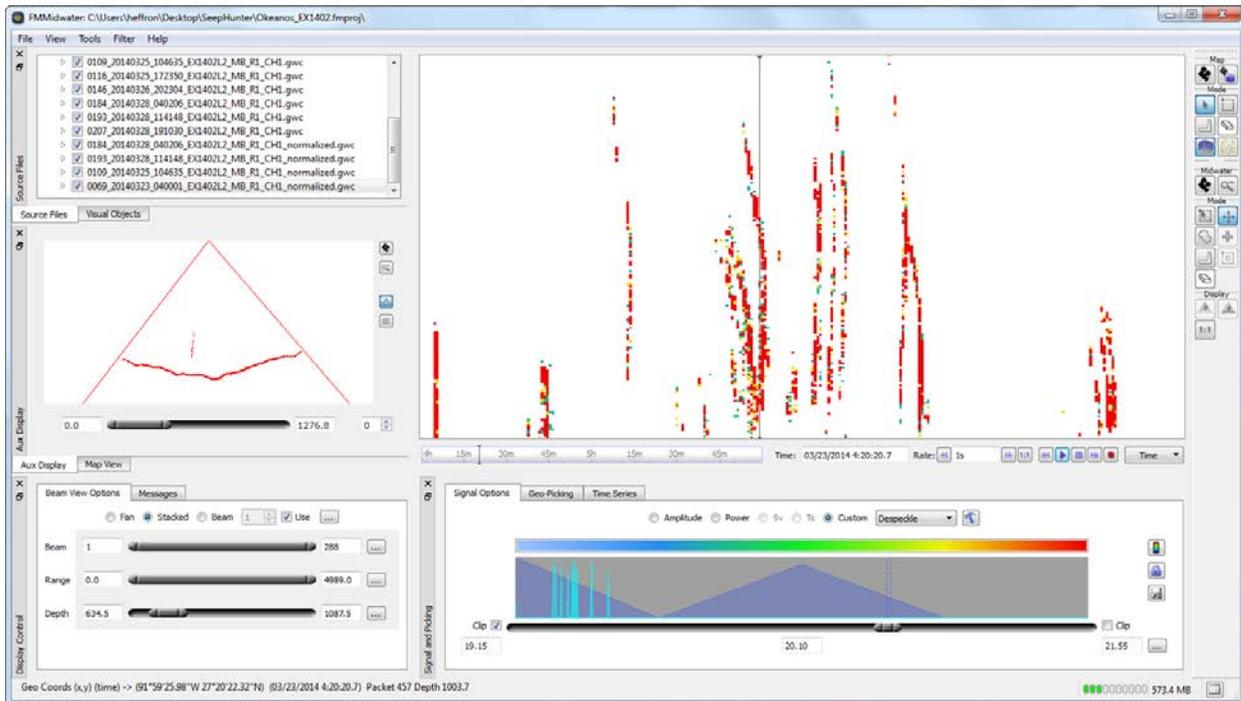


Figure 4. – Manually Normalized, Thresholded, and Despeckled *Okeanos Explorer* EX1402 EM302 data in FMMidwater. The remaining vertically-aligned points in both views are seeps; the seafloor detections are also visible in the Fan View.

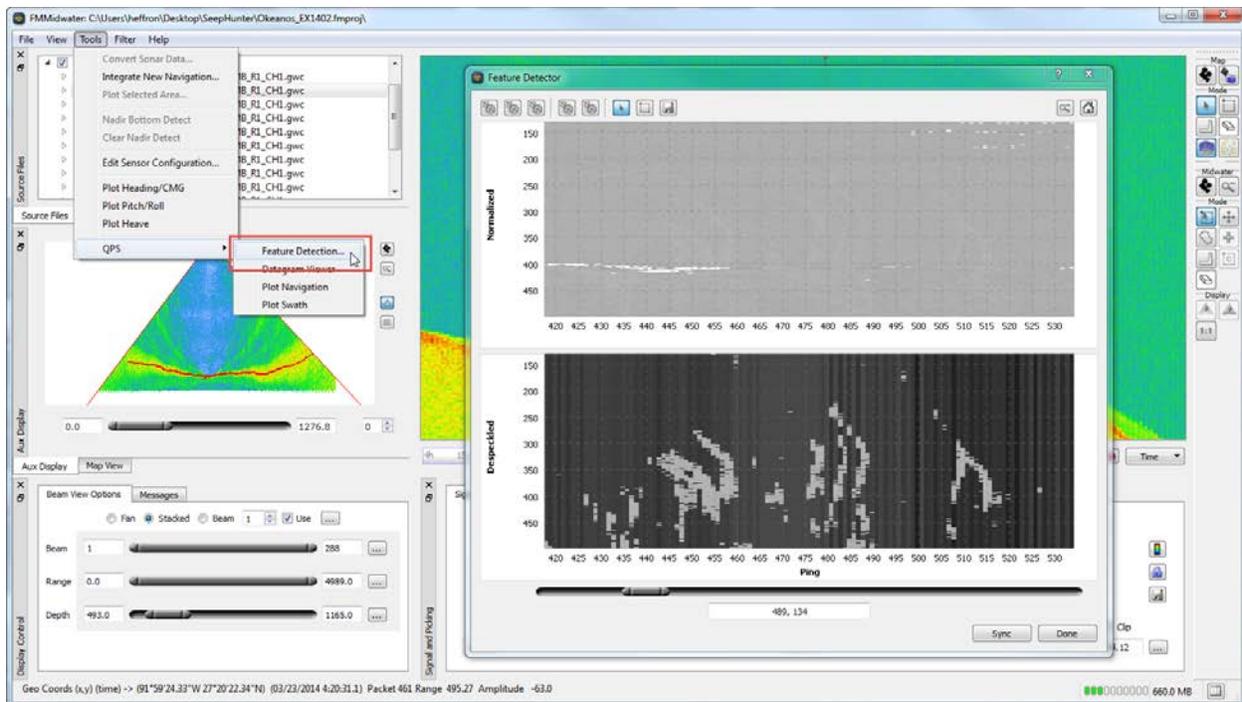


Figure 5. – Auto Normalized and Despeckled *Okeanos Explorer* EX1402 EM302 data in FMMidwater. The grey vertically-aligned points in the Despeckled Window are seeps.

The Cluster Point Object builds on the standard Fledermaus point object with a structure and tools to allow grouping of the points detected into specific clusters based on horizontal and vertical point separation and minimum group size. After clustering, a Cluster Summary Object can be generated with one XYZ point per seep; the XYZ location of the point will be that of the lowest point in the cluster and can be used to locate the location of the seep on the associated seabed surface. Cluster Point Objects and Cluster Summary Objects can be exported as ASCII for reporting and further analysis. At each stage of the cluster analysis, the results can be interactively validated against the normal FMMidwater objects: the fan, beam curtain and stacked curtain.

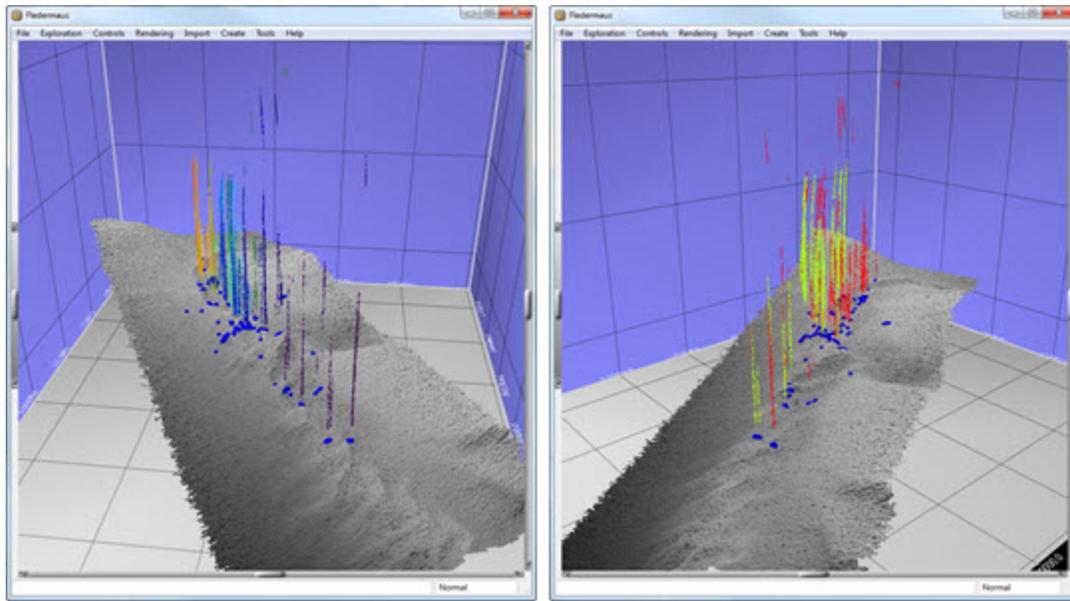


Figure 6. – Cluster Point Object and draped Cluster Summary Object for *Okeanos Explorer* EX1105 EM302 data, displayed in Fledermaus. In both images, the blue spheres on the seabed are the Cluster Summary Objects draped to show approximate seep location. In the image on the left, flares are colored by the cluster ID. In the image on the right, flares are colored by whether or not they are “Accepted”; in this instance, the minimum size for acceptance was 100 points.

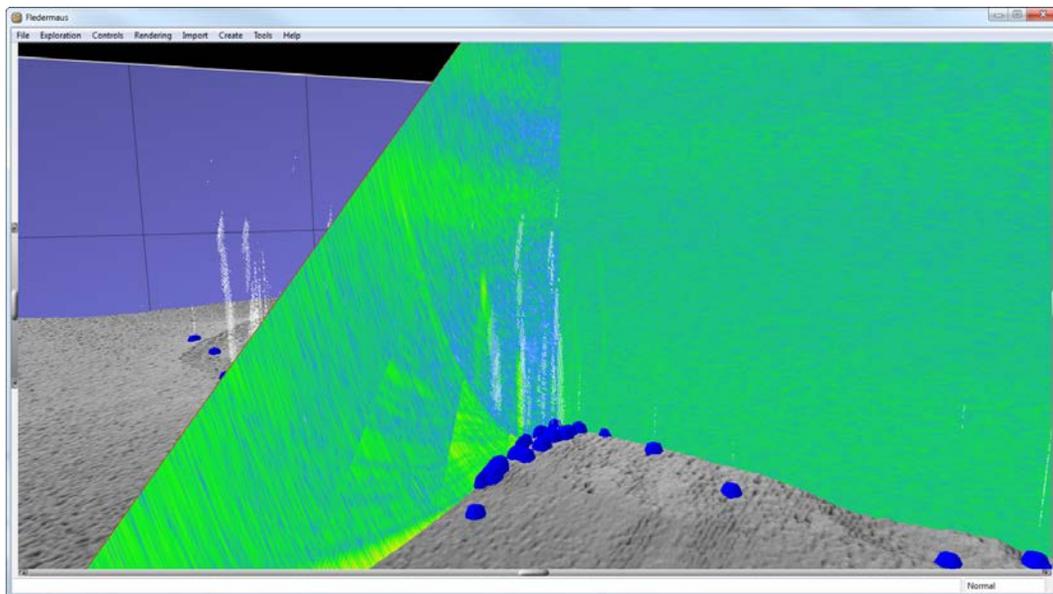


Figure 7. – Visualization and validation of *Okeanos Explorer* EX1105 EM302 data in Fledermaus. In this image, the seep clusters are white and can be compared to the appearance of the seep in the Fan and Stacked Curtain Objects. Note that the Stacked Curtain object is a view of all beams compressed to nadir and is used to provide an overview; the seep locations in that object are not truly geospatially correct.

NOAA Ship Okeanos Explorer Seep Detection

The NOAA ship *Okeanos Explorer* is the only United States federally funded vessel dedicated exclusively to ocean exploration and is utilized as a platform for testing innovative mapping technologies. The ship collects bathymetry, seafloor backscatter, and water-column backscatter using a 30 kHz Kongsberg EM 302 multibeam sonar. The system generates a 150° beam fan containing up to 432 soundings per ping in waters deeper than 3000 meters. In waters shallower than 3000 meters, the system is operated in multi-ping, or dual swath mode, and obtains up to 864 soundings per ping by generating two swaths per ping cycle. The NOAA *Okeanos Explorer* Program makes all of the data collected aboard available to the public.

Seeps identified in water-column backscatter during an expedition aboard the *Okeanos Explorer* could be used to influence future scientific research and policy decisions. Until recently, the sole method of locating seeps was using manual detection when viewing water-column backscatter returns in post-processing software. This manual procedure is time consuming and inherently subjective; results depend on individual experience and expertise, as well as environmental conditions, and therefore can vary significantly between individual observers. The Okeanos Explorer Program is interested in developing best practices with the EM 302 to enhance ocean exploration. Therefore, the Program supports examining user variability and developing improved processing methods to ensure that seep detection is accurate and consistent.

During an expedition aboard the Okeanos Explorer in the Gulf of Mexico from March to April, 2014, a NOAA Physical Scientist spent over 40 hours processing 300 lines of mid-water backscatter data using FMMidwater. Seeps were manually detected in the water-column from over 17,000 sq. km of seafloor using the swath, beam, and stacked views in FMMidwater, and seep locations were manually geo-picked in the fan view, creating a point dataset of seep coordinates. Over 600 seeps were identified, although several of the picks could be identical seeps detected in overlapping beams. This manual procedure is time consuming and subjective.

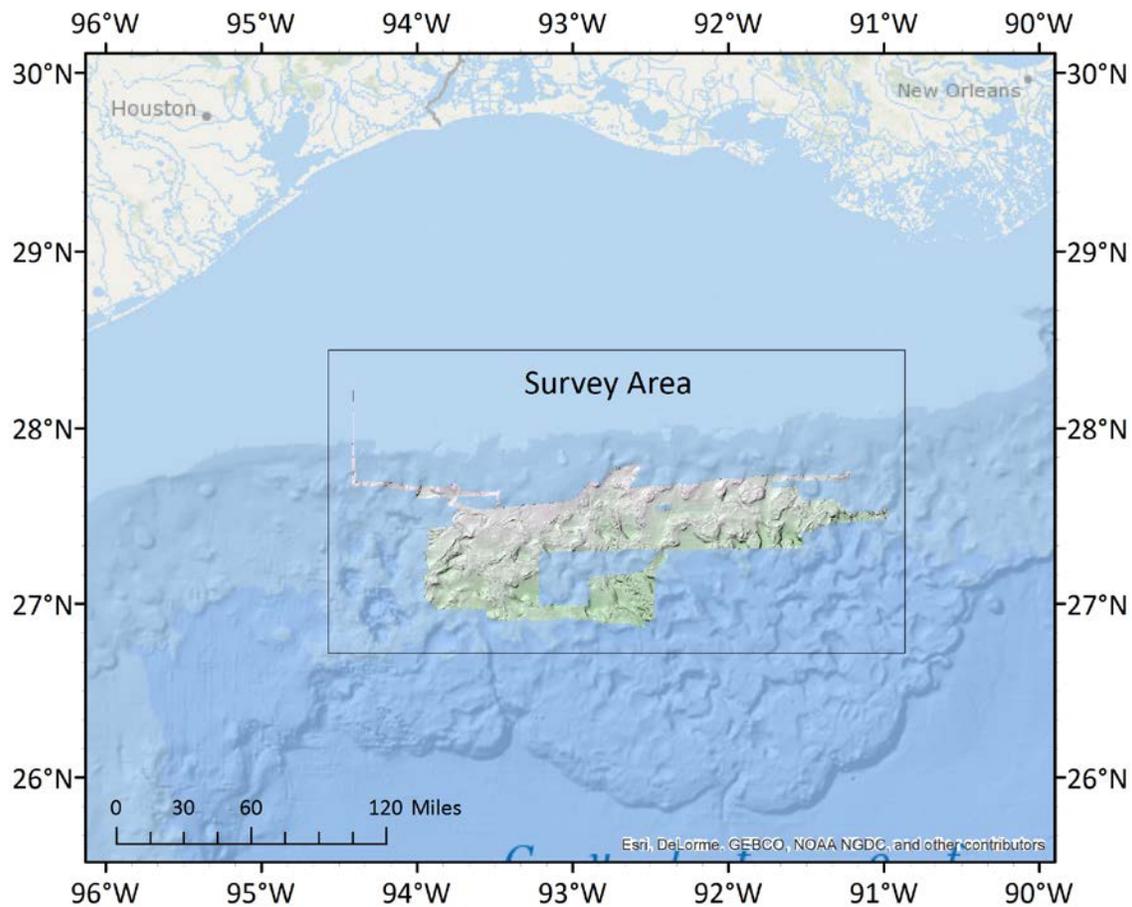


Figure 8: Overview of Gulf of Mexico showing coverage from NOAA Ship Okeanos Explorer expedition EX1402, March-April 2014.

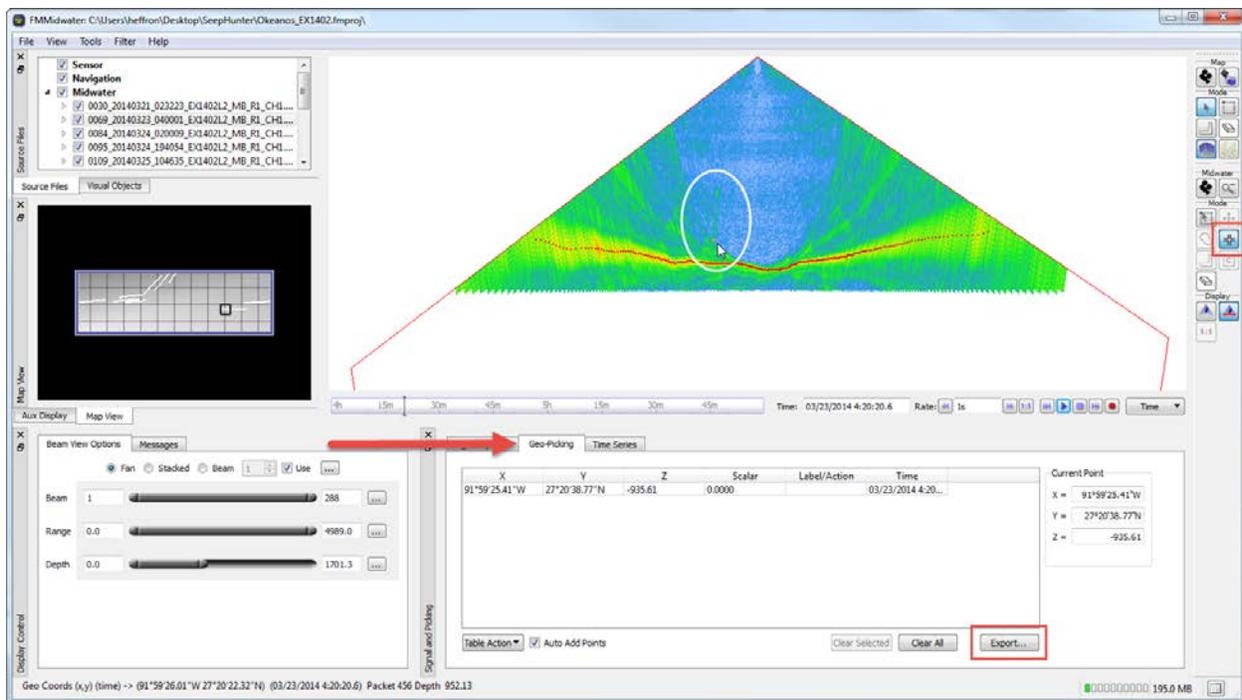


Figure 9. – Manual Geo-Picking using the Fan View and the Select Mode in FMMidwater. The operator scrolls through the data in Fan View, looking for indications of seeps (white circle). They then use the Geo Pick mode (red box, Control Bar) to mark a potential seep. The x, y, z location of this pick is recorded in the Geo-Picking tab (red arrow) and can be exported as Fledermaus SD or ASCII XYZ points (red box, Geo-Picking tab).

To examine manual detection subjectivity, the NOAA Office of Exploration and Research conducted a quality control using the data collected in March-April of 2014. Ten percent of the original survey lines were independently re-processed onshore by a different observer using the same manual detection methods by an Okeanos Explorer Program intern in the summer of 2014. Results showed that manual seep selection can be highly variable between two different individuals. For seeps with very strong acoustic signals in the near-nadir beams, the two independent geo-picks consistently overlapped. However for acoustically weak seeps and seeps that occur in the noisy outer beams, the results were more inconsistent, and geo-picks between observers only matched about half of the time. Overall, there was a 41% success rate of two independent observers selecting the same seep within a 50 m radius (McKenna et al, 2014).

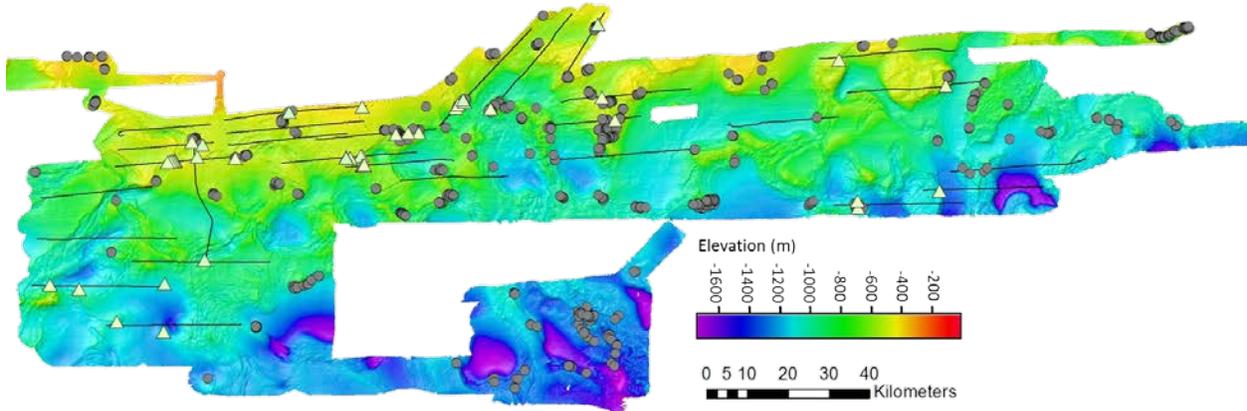


Figure 10. Overview map focusing on bathymetry mapped by the *Okeanos Explorer* in Spring 2014 and showing location of manually picked seeps. Seeps that were manually detected during the cruise are marked by circles. Tracklines used for quality control are shown in black. QC selected seeps are represented by triangles.

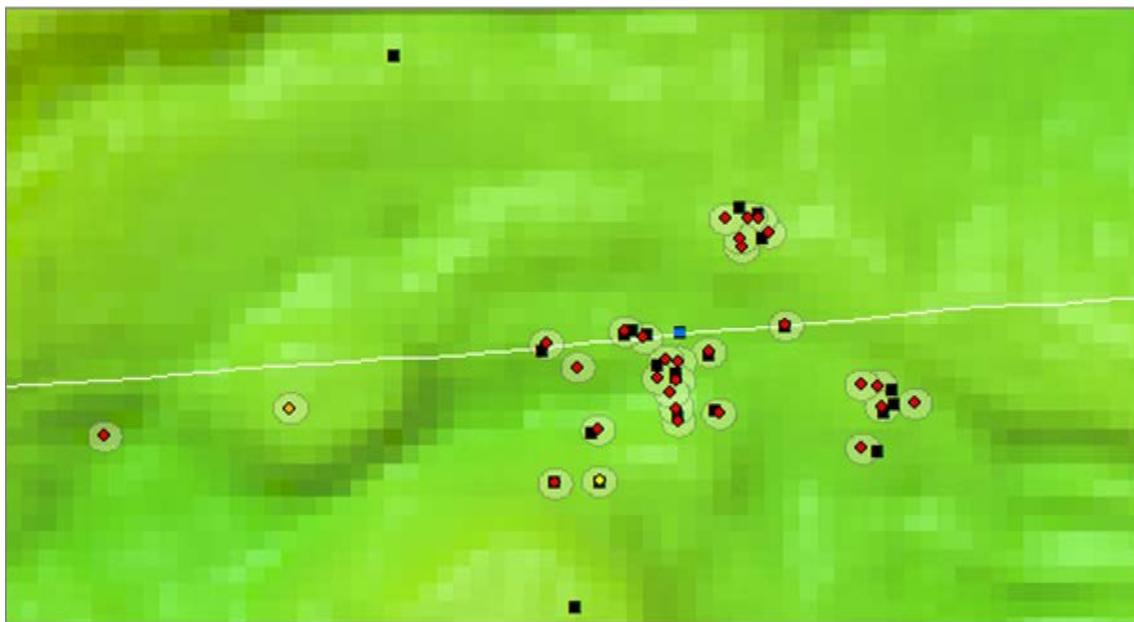


Figure 11. Comparison of the two manually detected seeps results. The original seep locations picked by the intern are shown as black squares and the QC seep location are shown as colored circles with a 50 m buffer.

In an initial test of the new FMMidwater Feature Detection tool, the 10% subset of quality controlled survey lines were run through the tool in FMMidwater, using the default settings. Automatically identified seeps were exported as clusters point objects, characterized, mapped, and compared with the manual geo-picks in Fledermaus. Not surprisingly, initial results show there can be variability between manual and algorithm seeps. Scrutiny of the automatic picks shows that the tool identified 60% of the seeps detected and verified by the independent manually-detecting observers. 32% of the seeps identified manually were missed by the tool, but

8% additional seeps were identified that had been missed through manual detection. The automatic detection showed several false positives, requiring manual intervention, but at a significantly lower level of effort than manual scrutinization of the raw data (McKenna et al, 2014). The initial results show potential for meeting the Okeanos Explorer Program goals to increase water-column exploration through reduced processing time and increased detection accuracy between data-processers working on the ship or ashore.

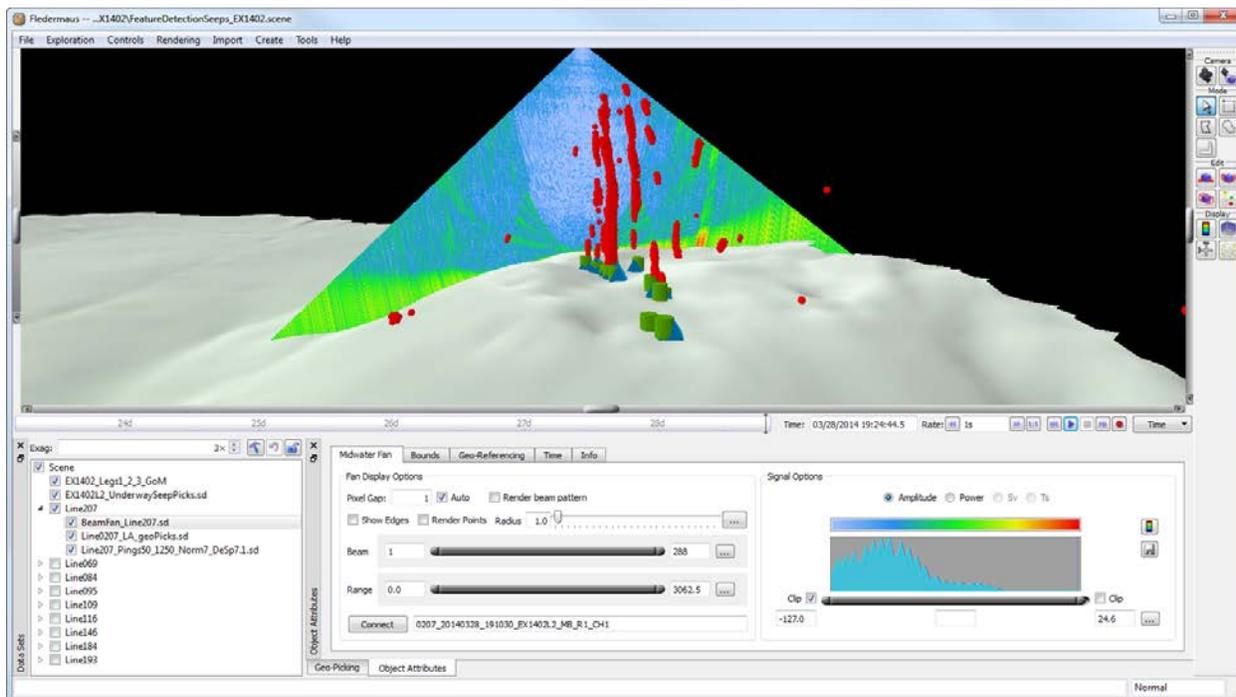


Figure 12. Image of processed water-column data in Fledermaus, EX1402 Line 207. Cluster Point Objects (red points) are the result of the Feature Detection tool. Green cylinders and blue diamonds on the seabed surface indicate manually geo-picked locations.

Ongoing Improvements

Initial testing of the Feature Detection tools in the NOAA Okeanos workflow and use of the tool in other processing workflows has yielded several suggestions for improvements. The following suggestions are currently in the development and documentation pipeline:

- 1) Direct export of Cluster Data Object from the main FMMidwater interface: many of our users have found that they prefer the interactive nature and additional tools that are available in the main FMMidwater interface over the restricted Feature Detection tool. Direct export of the Cluster Data Objects from the main interface will allow them to have the best of both worlds.
- 2) Better documentation on best practices for “dialing in” the normalization and despeckle settings for improved results: We continue to work with CCOM researchers to develop a set of guidelines on when the use of the tool is most appropriate, and how to use the tools more effectively.

3) Add batch processing to speed filtering: Once best settings are narrowed down, a batch normalization import would speed up the process.

4) Adding additional CCOM-developed algorithms to further improve feature extraction: Researchers have found that use of a side-lobe filter increases the likelihood of successful feature detection.

Summary

Many multibeam sonars now have the ability to map the watercolumn as well as the seafloor. There is a growing interest in using this ability to map the locations of gaseous seeps on the seafloor by looking for bubble plumes or flares in the watercolumn data. These features are often transient and only persist for a ping or two, making them difficult to locate and process. Additionally, data volumes are high and processing is very manual and subjective. For these reasons, users of the FMMidwater watercolumn processing module requested automated and objective tools for feature detection. QPS utilized the plug-in capabilities of FMMidwater to add algorithms for normalization and despeckling of water column data developed at UNH CCOM, which have been shown to be useful for locating and processing transient seep data in an automated and objective fashion. Testing by the *Okeanos Explorer* team shows the tools to be promising, and their feedback as well as the feedback of other users has led to a list of needed documentation and development to further improve the tool.

Acknowledgement

Thanks are extended to Dr. Tom Weber (CCOM UNH) for his continued collaboration and assistance in developing and refining the FMMidwater plug-ins, and the crew and mapping team of the *Okeanos Explorer*, and in particular Erin Weller of NOAA, and Lydia Auner of Carleton College for spending many hours manually picking seeps from mid-water backscatter data.

References

Arsenault, R., Ware, C., Plumlee, M., Martin, S. C., Whitcombe, L. L., Wiley, D. N., Gross, T., Bilgili, A. , 2004, "A system for visualizing time-varying oceanographic 3D data", IEEE Oceans, Halifax, Nova Scotia, Canada, 1 - 5 October, 5 pages. Conference Proceeding.

Gee, L., Doucet, M., Parker, D., Weber, T., and Beaudoin, J., 2012, "Is Multibeam Water Column Data Really Worth the Disk Space?" Hydro12, Rotterdam, Netherlands, 13-15 November. Conference Proceedings.

McKenna, L., Auner, L., Weller, E., Paton, M., Doucet, M., and Lobecker, E., 2014, "Preliminary Analysis of Manual and Automated Seafloor Seep Detection in Multibeam Water-Column Backscatter", Abstract OS31B-0999 presented at 2014, Fall Meeting, AGU, San Francisco, CA, 15-19 December.

Ware, C., Plumlee, M. , Arsenault, R. , Mayer, L. A., Smith, S. , House, D. H., 2001, "GeoZui3D: Data Fusion for Interpreting Oceanographic Data", IEEE Oceans, Honolulu, HI, USA, 5 - 8 November, pp. 2498 - 2502. Conference Proceeding.

Weber, T., L. Mayer, K. Jerram, J. Beaudoin, Y. Rzhhanov, and D. Lovalvo. 2014, "Acoustic estimates of methane gas flux from the seabed in a 6000 km² region in the Northern Gulf of Mexico", *Geochem. Geophys. Geosyst.*, 15, 1911–1925.