

TITLE

Multibeam Water Column Data Processing Techniques to Facilitate Scientific Bio-Acoustic Interpretation

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BIO

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ABSTRACT

One component of the Gulf of Mexico Research Initiative's (GoMRI) Consortium for oil spill exposure pathways in Coastal River-Dominated Ecosystems (CONCORDE) project is focused on examining water column acoustic return data from a Reson Seabat 7125 SV2 within the Mississippi Bight. The multibeam system was mounted on board the RV Point Sur, and data was collected at three times of year (fall, spring and summer). The goal was to identify and map spatial and temporal variations in biomass throughout the region by correlating the water column data with imagery from a towed profiling high resolution in situ ichthyoplankton imaging system (ISIIS) (with CTD, dissolved oxygen, PAR, and chlorophyll-a fluorescence). There are many technical challenges associated with correlating the two datasets, as the multibeam data are in three dimensions, and they operate on different temporal and spatial scales. Overcoming issues with receiver sidelobe interference and developing a filtering algorithm to identify objects and signal patterns of interest, which might normally be considered noise, is investigated. The development of these filtering algorithms allows the water column data to be correlated to the reference imagery data from the ISIIS, and other sensor information, expanding the usefulness of the dataset.

INTRODUCTION

Acoustic water column data from a 400 / 200 kHz Reson Seabat 7125 SV2 multibeam sonar was collected during three Gulf of Mexico Research Initiative's (GoMRI) Consortium for oil spill exposure pathways in

COastal River-Dominated Ecosystems (CONCORDE) cruises in 2015 and 2016. The system collected water column, bathymetry and seabed backscatter data simultaneously with a towed, high-resolution profiling In Situ Ichthyoplankton Imaging System (ISIIS). The data collected from the ISIIS will be used to validate and compare with the water column acoustic return data of the multibeam sonar.

Formed after the Deepwater Horizon oil spill disaster in April 2010, CONCORDE consists of an interdisciplinary group of researchers from 10 universities across North America. The consortium was tasked with examining the physical interactions in the northern Gulf of Mexico with a goal of improving our understanding of the transport of oil in the coastal environment and its interaction with plankton communities and the coast itself. CONCORDE scientists are addressing three objectives: 1) spatio-temporal characterization of vulnerable plankton distributions that are subject to nearshore physical environmental controls; 2) spatio-temporal characterization of physical, geochemical, and bio-optical fields influenced by pulsed river discharge to identify potential 3-D pathways for oil exposure to the coastal region's lower trophic level constituents; and 3) modelling physical transport pathways spanning the nearshore to continental shelf domain.

Funding to support the efforts of CONCORDE was provided by GoMRI over three years starting in 2015. The project included three, two-week cruises aboard the University of Southern Mississippi research vessel, the Point Sur. The cruises were focused on collecting data along three corridors stretching across the continental shelf of the northern Gulf of Mexico, as shown in Figure 1. The corridors covered an area north of the Deepwater Horizon oil spill location and are framed by three variable sources of fresh water: the Mississippi River, Mobile Bay and Lake Pontchartrain.

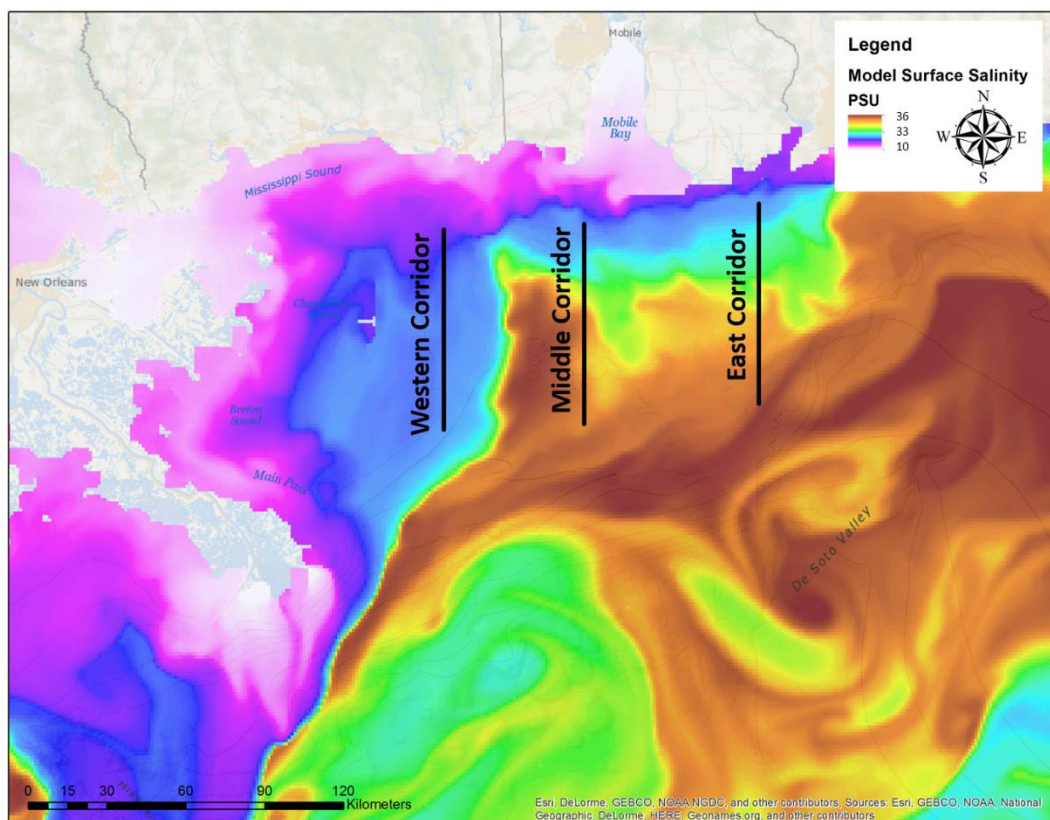


Figure 1 - CONCORDE Corridors and Surface Salinity

Multibeam water column data have been shown to provide useful information for a number of oceanographic and biologic variables including zooplankton, bubbles, suspended sediment, mixing and internal waves (Colbo, Ross, Brown, & Weber, 2014). The Seabat 7125 SV2 used as part of this project was not calibrated to provide true target strength measurements of water column backscatter; therefore, the water column data only provides a relative intensity measurement of scattering, like most other hydrographic multibeam sonar systems. The relative nature of the returned signal makes it difficult for the multibeam alone to provide an estimate of the target strength associated with water column scattering due to imperfect estimates of transmitter source level, receiver sensitivity and transmission losses, along with other internal processing, making independent classification very difficult (Colbo et al., 2014; Urlick, 1983). To overcome this limitation, the data is compared to the output variables and analysis of the ISIIS system, giving reference to the relative measurements.

The ISIIS provides real-time output variables of conductivity, temperature, pressure, dissolved oxygen, PAR, and chlorophyll-a fluorescence, along with shadowgraph imaging of plankton and zooplankton from digital line scan cameras (Cowen & Guigand, 2008). The system uses its imaging capability to measure suspended particles and organisms from a size range of 500 μm – 13 cm over a 13cm x 13 cm field of view with a 40-cm depth of field (A. T. Greer, Woodson, Smith, Guigand, & Cowen, 2016). The system samples a one-metre cube of water approximately every seven seconds at standard tow speeds of 2.5 m/s. Environmental data is recorded at 6 Hz and is sent back to the operator in real time with the line scan camera feed.

The nature of the multibeam water column scattering from groups of individual small targets, like zooplankton, traditionally means that any analysis is performed in a qualitative sense over small spatial scales. Individual target areas of interest must be identified in the dataset and analysed. This method was not practical for this project as the concurrent collection of multibeam water column data and ISIIS imagery data translated into over 50 TB of raw data covering a large area. The collection of full multibeam water column data from the Seabat 7125 SV2 resulted in raw data files divided into approximately 30-second-long segments with file sizes of 1 GB each, making processing 6-hour transects of water column data time consuming and very difficult with standard computer hardware. Automated algorithms were developed, and continue to be improved, to analyse the ISIIS imagery for zooplankton abundance counts along the data collection corridors (Cowen et al., 2013). Therefore, an automated method of comparing the multibeam water column data and the ISIIS outputs was required to facilitate further analysis.

An example of the multibeam water column beam fan data from one of the CONCORDE corridors is provided in Figure 2. Certain features of the data are clearly visible in the figure. The seafloor, as indicated by the red bottom detection points, is shown along the bottom of the figure and represents the depth limit of useful data for this project. The minimum slant range, beyond which receiver side lobe interference is present, is also clearly visible as a ring which stretches up from the nadir seafloor at a common range from the transducer. Both these signals are considered noise in this investigation, and the focus is instead placed on the area highlighted by the red circle in Figure 2. This area includes the water column scattering response from various targets. As the scattering targets are not continuous features, a method was developed to extract the average scattering amplitude from the water column data and remove the unwanted signal noise, for comparison to the ISIIS output variables and to facilitate automated comparisons and analysis.

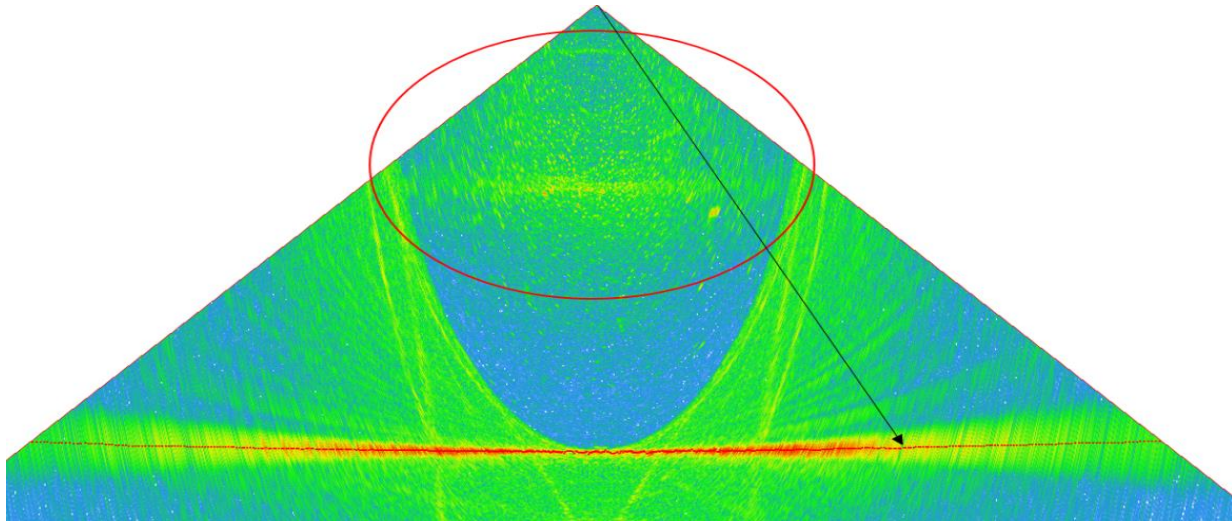


Figure 2 - Multibeam Water Column Data Example

METHODS

Multibeam Sonar

Multibeam sonar data were collected along each of the CONCORDE corridors, as shown in Figure 1. Each corridor is approximately 50 km long with depths ranging from 10 to 50 metres. The multibeam was run with consistent settings along each of the corridors to limit variations in the returned signal, and the system settings were chosen for the primary purpose of collecting water column data, as shown in Table 1. Absorption and spreading, which affect the Time-Varied Gain (TVG) curve, were set based on frequency and the temperature and salinity of the local environment, as outlined in Reson 7125 SV2 operators manual (Reson, 2011).

Table 1 – Reson Seabat 7125 Settings

Sonar System Setting	Value
Frequency	400 kHz
Power	220 dB
Gain	83 dB
Pulse Length	100 μ s
Maximum Ping Rate	5 Hz
Beams	512
Beamwidth	Tx: 1 Rx: 0.5
Swath Width	140 degrees
Beam Spacing	Intermediate Beam Mode
Absorption	110 dB/km
Spreading	30 dB

Water column data from the Reson Seabat 7125 was logged through the Seabat software to an S7K file, along with position and attitude data from an Applanix POSMv augmented by CNav 3050 corrections. The water column data samples are recorded along each beam as 16-bit amplitude and phase data. To facilitate processing within the Ocean Mapping Group Swathed code base, the water column amplitude

data are converted to a dB value. Along each beam, approximately 4500 intensity samples were collected between the sonar and the user specified maximum range setting.

Ray tracing Water Column Sample Data

To extract depth and geographically reference the water column data, each of the data samples must be ray traced through the local water column to convert the time-based sample and beam launch angle to a latitude, longitude, and depth point. The sonar provides the intensity of the samples along the beam at a constant sampling rate together with the initial array relative beam pointing direction. The sample number and sample rate provide a one-way travel time. The conversion from an array relative pointing angle and one-way travel time to a depth and position are done using several well-known steps to convert the array relative angle to a beam pointing vector. This process takes into account the orientation of the vessel at the time of transmit and receive, the transmitter and receiver mount angles, and the transmit and receive steering angles (Beaudoin & Hughes Clarke, 2004).

While the 10 angles associated with the calculation of the beam pointing vectors are known, the unknown variable with the greatest uncertainty for the ray tracing calculation is the sound speed profile. Several alternative solutions are considered to account for changes in the speed of sound through the water column. As the multibeam data was collected while towing the ISIIS, stopping to perform sound speed casts along the CONCORDE corridors was not an option. Sound speed in this area is quite variable due to the influences of multiple sources of fresh water and therefore must be accounted for (Church, Williamson, Quas, & Jacobs, 2016). Sound speed data can be obtained from the ISIIS CTD measurements or from numerical hydrodynamic models of the area (Church et al., 2016). This project extracted temperature and salinity estimates from the three-dimensional Gulf of Mexico Navy Coastal Ocean Model (NCOM) and generated sound speed solutions for ray tracing along the corridors (Barron, Kara, Martin, Rhodes, & Smedstad, 2006).

Processing of each individual water column sample along each beam of every ping within a specified time range was completed over a user specified maximum range. For this exercise, only data within the minimum slant range is considered as valid data, which speeds up processing time. The result is a water column acoustic sample with a latitude, longitude, depth and across track distance.

Enhancing the Signal

As the features of interest for this project are the persistent scattering response patterns within the multibeam sonar water column data, the data must be processed to extract and emphasise that signal, while suppressing individual target responses. To accomplish this, the resulting data from the ray tracing exercise is added to a running average in a two-dimensional array encompassing the stated maximum swath extents at a user specified vertical and horizontal resolution, as shown in Figure 3. The averaging is completed within the minimum slant range and only for data above the seafloor. The large data volume associated with the original water column data file, approximately 2.3 million samples per ping, is reduced to an easily manageable two-dimensional array. For example, in a water depth of 20 meters at a vertical and horizontal resolution of 0.5 metres, the resulting processed data is only 1600 points.

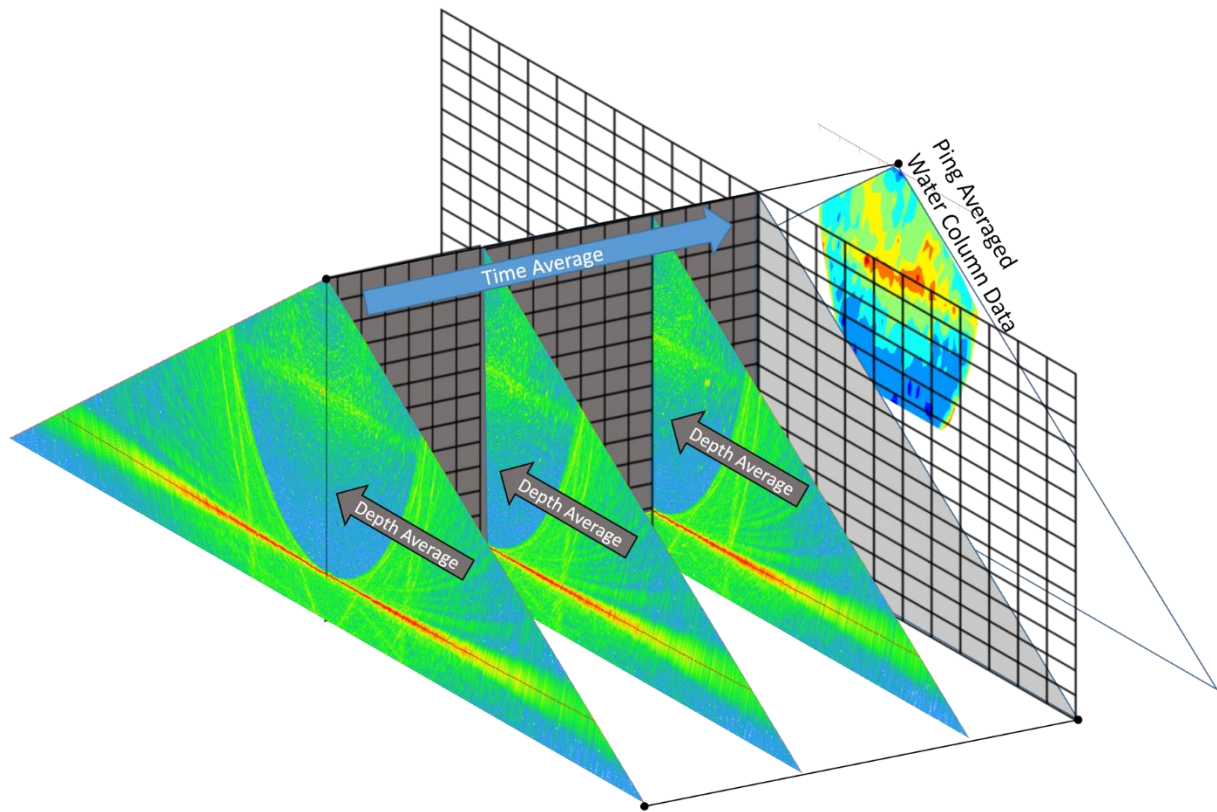


Figure 3 – Water column time and depth averaging

The resulting binned and time averaged data and associated variance is calculated for a user defined number of successive pings, or a specific time interval, as shown in Figure 4A where the colour scale represents relative water column backscatter intensity. Patches of anomalous water column backscatter data are now visible within the processed and georeferenced 2D array. Figure 4A shows a time averaged result in one meter horizontal and vertical bins over approximately 160 pings. At a ping rate of 5Hz and vessel speed of 3 m/s, this represents an along track distance of approximately 100 meters.

To facilitate comparison with the ISIS data, further processing is required to examine correlations in backscatter with ISIS variables and image analysis. The two-dimensional water column data must be reduced to form a single one-dimensional array of depth and intensity, through either extracting the maximum response at that depth or through further averaging. An example of the result of data averaging is shown in Figure 4B, where water column backscatter intensity is represented as the x-axis variable. The one-dimensional depth vs. intensity profile can be directly compared to the ISIS data to establish correlations and detect features of interest.

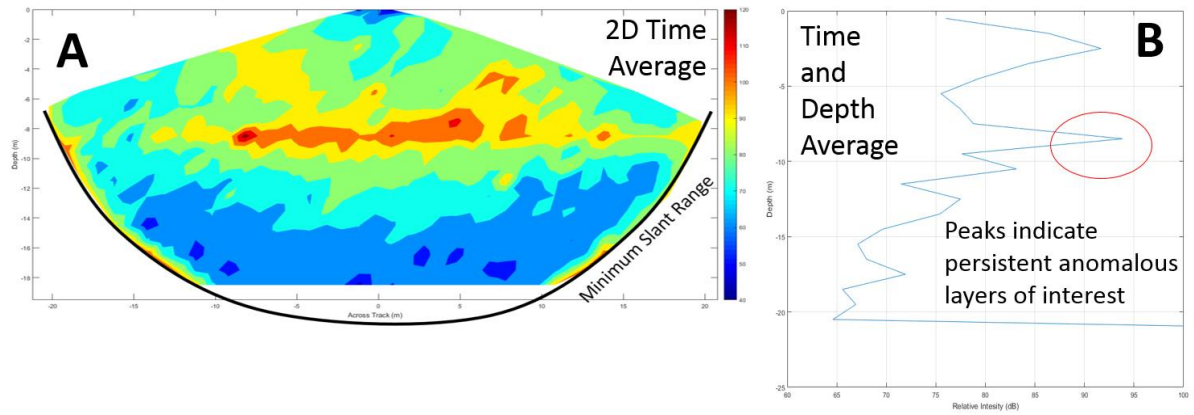


Figure 4 – A) Example time averaging over 30 seconds of data to 1 metre horizontal and vertical cells and B) depth average to generate acoustic intensity profile

RESULTS

To top pane of Figure 5 demonstrates the effect of combining the time and depth-averaged water column acoustic data along the middle CONCORDE corridor transect, as shown in Figure 1, while the centre and bottom panes represent data collected on focused studies near the western corridor. The colour scales in Figure 5 represent the average acoustic intensity calculated over 1-metre depth and 30 second time bins. The combination of the time and depth binned results into a transect of data allows for direct comparison between the acoustic data and the ISIIS output variables over the domain. The water column scattering features of the area are identified based on their average acoustic response. Some features represent persistent layers, while others exhibit a distinct patchiness in both the horizontal and vertical dimensions.

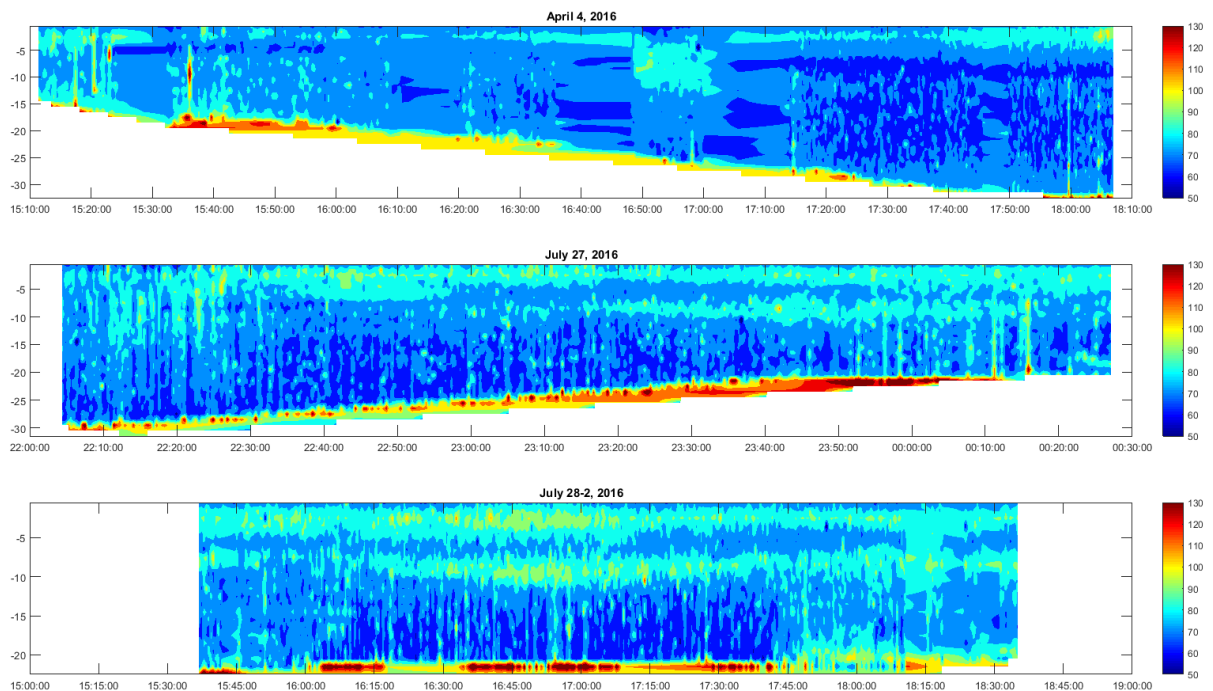


Figure 5 – Time and Depth-Averaged water column data along the CONCORDE transects

Intensity Segmentation

Once anomalous features within the water column data are identified from the comparison of the one-dimensional acoustic intensity profile and the ISIS image analysis or physical variables, the processed two-dimensional data can be revisited to view the phenomena in two or three dimensions. Once the feature of interest is tied to a specific intensity range from the water column backscatter, the data can be segmented to isolate that intensity range. When multiple two-dimensional time-averaged processing results are examined in sequence, the three-dimensional structure of the water column feature can be extracted, as shown in figure 6.

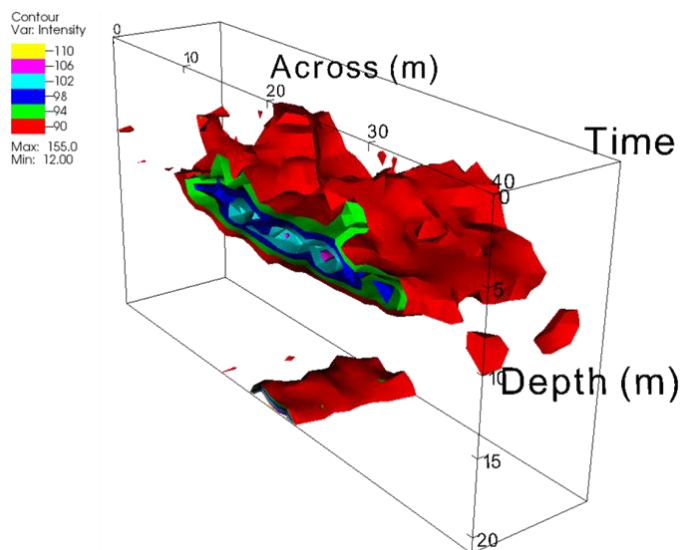


Figure 6 – Segmented 3D water column data

DISCUSSION AND CONCLUSIONS

The water column acoustic backscatter from a traditional multibeam sonar is an imperfect tool to observe water column phenomena. The systems are primarily designed to collect bathymetry data, which introduces some issues to the analysis of the weaker water column acoustic response. One of the primary challenges is associated with the presence of receiver side lobe, inherent in a mills cross configuration, which distorts the actual water column signal. This is clearly apparent in the area outside the minimum slant range, as shown in Figure 2, but also impacts and distorts the response from strong targets above the seafloor (Hughes Clarke, 2006; Marques, 2012). The correlations between the time and depth average multibeam acoustic data and other sensors must be completed after limiting the effects of side lobe interference. For this project, at this stage, the relatively simple approach of accepting only data within the minimum slant range is used to limit the influence of side lobes in the transmitter and receiver beam patterns.

After the data of interest have been extracted from the water column acoustic return signal and the sample points have been georeferenced, the data must be binned to allow for comparison with the ISIS data. The choice of bin size and time averaging length can have a significant impact on the resulting signal. For this project, the across track and depth bins were kept equal in size. Depth bin size was chosen to compare with the ISIS zooplankton count bin size, and the time averaging window was chosen as the duration of a single ISIS profile (approximately 30 seconds). Selecting different time averaging windows

and depth and across-track bin sizes will impact the resulting processed data. Further testing is required to examine the effects of spatial and temporal averaging scales.

Providing exact correlations between the multibeam water column signal and the ISIIS output can prove difficult when looking at individual profiles, as the acoustic signal correlates with several observed variables. An example of this is shown in Figure 7 (A. Greer et al., 2017). Strong correlations will likely be calculated through comparison with multiple variables at each profile location; therefore, any attempt to isolate a single correlation signal is difficult. Rather than looking at a single profile, the comparison should be completed through examining time-varying correlations and the intensity of the response signal as zooplankton counts and environmental variables change. This analysis method will be the focus of future research.

Initial correlations between the ISIIS and the processed multibeam water column show promising results. From the example shown in Figure 7, the multibeam water column acoustic backscatter data profile can be seen to show a near surface peak, which does not correspond to zooplankton but may correspond to a peak in fish larvae; a middle peak, which demonstrates correlation with several overlapping groups (fish larvae, marine snow, zooplankton, and salinity); and a deep peak which correlated to shrimps with horizontal patchiness at a correlation coefficient of 0.65 ($p < .001$) (A. Greer et al., 2017).

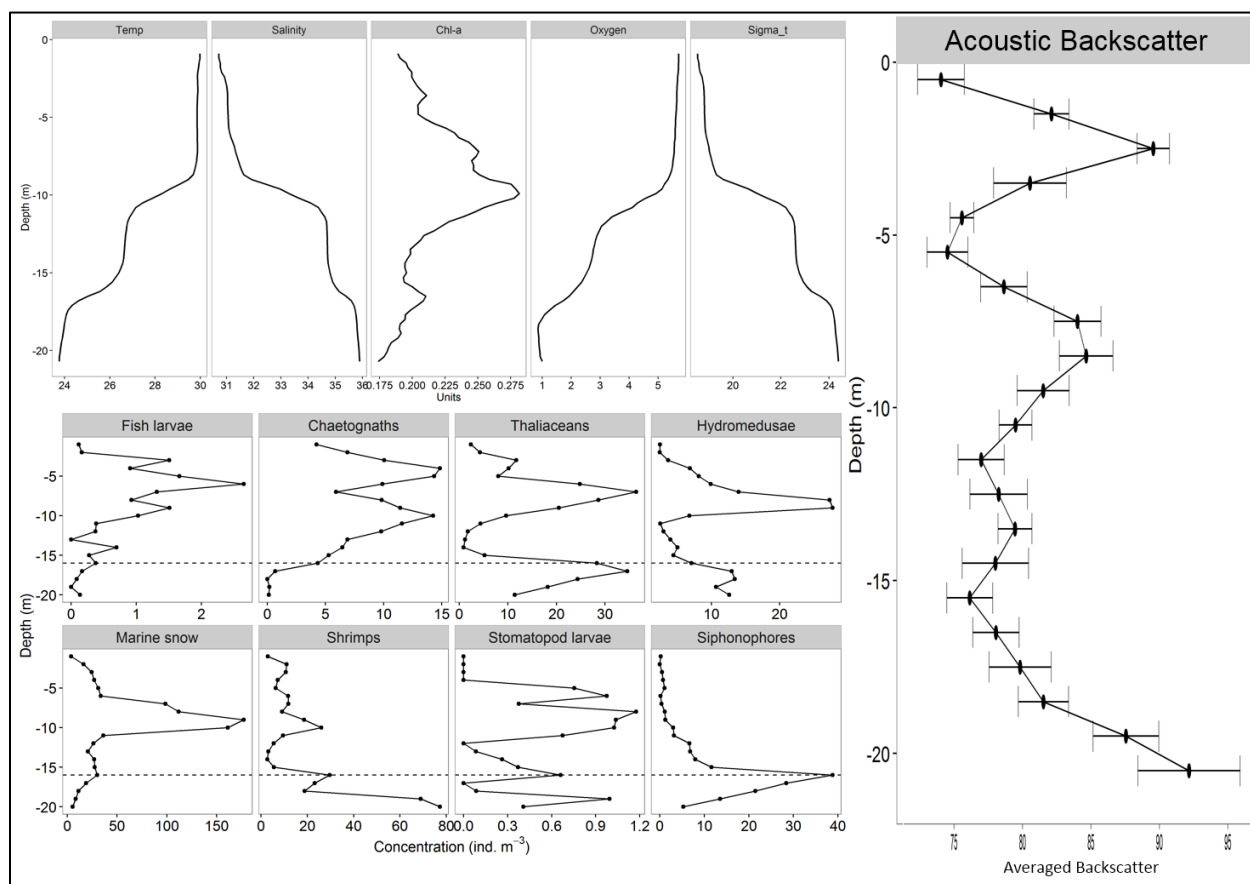


Figure 7 - Sample ISIIS Variables and Corresponding Processed Acoustic Backscatter (A. Greer et al., 2017)

Future Work

This paper describes a single component of an ongoing collaborative project founded on establishing links between the hydrographic and scientific communities. Several ongoing research topics and future work opportunities have been identified to support the development of this project. These include, but are not limited to, improving multibeam water column processing efficiency using parallel processing and high-performance computing, continuing the calculation of correlations between acoustic intensity and observed ISIS variables throughout the entire CONCORDE domain, performing further image segmentation and analysis to automate extraction of acoustic masses throughout each of the CONCORDE corridors, examining an area of strong salinity stratification to visualize the stratification of a freshwater plume, and continuing to investigate the removal of side lobe interference using beam pattern modelling.

ACKNOWLEDGEMENTS

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REFERENCES

- Barron, C. N., Kara, A. B., Martin, P. J., Rhodes, R. C., & Smedstad, L. F. (2006). Formulation, implementation and examination of vertical coordinate choices in the Global Navy Coastal Ocean Model (NCOM). *Ocean Modelling*, 11(3–4), 347–375. <http://doi.org/10.1016/j.ocemod.2005.01.004>
- Beaudoin, J., & Hughes Clarke, J. E. (2004). Retracing (and re-raytracing) Amundsen's Journey through the Northwest Passage. In *Proceedings of the Canadian Hydrographic Conference 2004*. Ottawa, Canada.
- Church, I., Williamson, M., Quas, L., & Jacobs, G. (2016). Reducing uncertainty in multibeam sonar depth estimates through integration with high resolution numerical models. In *Gulf of Mexico Oil Spill and Ecosystem Science Conference*. Tampa.
- Colbo, K., Ross, T., Brown, C., & Weber, T. (2014). A review of oceanographic applications of water column data from multibeam echosounders. *Estuarine, Coastal and Shelf Science*, 145, 41–56. <http://doi.org/10.1016/j.ecss.2014.04.002>
- Cowen, R. K., Greer, A. T., Guigand, C. M., Hare, J. A., Richardson, D. E., & Walsh, H. J. (2013). Evaluation of the In Situ Ichthyoplankton Imaging System (ISIS): Comparison with the traditional (bongo net) sampler. *Fishery Bulletin*, 111(1), 1–12. <http://doi.org/10.7755/FB.111.1.1>
- Cowen, R. K., & Guigand, C. M. (2008). In situ ichthyoplankton imaging system (ISIS): system design and preliminary results. *Limnology and Oceanography: Methods*, 6, 126–132. <http://doi.org/10.4319/lom.2008.6.126>
- Greer, A., Chiaverano, L., Church, I., Williamson, M., Briseno-Avena, C., & Cowen, R. (2017). Combining Multibeam Acoustics and In Situ Imaging to Resolve Patch Structure of Shrimp Aggregations and Gelatinous Zooplankton in Relation to Hypoxia. In *Gulf of Mexico Oil Spill and Ecosystem Science Conference*.
- Greer, A. T., Woodson, C. B., Smith, C. E., Guigand, C. M., & Cowen, R. K. (2016). Examining mesozooplankton patch structure and its implications for trophic interactions in the northern Gulf of Mexico. *Journal of Plankton Research*, 0, 1–20. <http://doi.org/10.1093/plankt/fbw033>

- Hughes Clarke, J. (2006). Applications of multibeam water column imaging for hydrographic survey. *The Hydrographic Journal*, (1992), 1–33.
- Marques, C. (2012). *Automatic Mid-Water Target Detection using Multibeam Water Column*. University of New Brunswick.
- Reson. (2011). *SeaBat 7125 SV2 Operators Manual*.
- Urick, R. J. (1983). *Principles of underwater sound*. New York: McGraw-Hill.