Latest generation multibeam echo sounder application and the evolution from bathymetry to more complete ocean mapping.

Authors: GEE Lindsay[1], RAINEAULT Nicole[2], KANE Renato[2], JOHNSON Paul[3], HEFFRON Erin[3], and DOUCET Maurice[4],

1. Acoustic Imaging, PO Box 902, Cooroy, QLD, Australia
2. Ocean Exploration Trust, 215 South Ferry Road, Narragansett, RI USA
3. Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM-JHC), University of New Hampshire, 24 Colovos Road, Durham NH, USA
4. Quality Positioning Services, Inc., 104 Congress Street, Portsmouth NH, USA

Abstract

Recent years has seen the evolution in use of multibeam echo sounders from primarily bathymetric mapping, to observing backscatter variations for characterizing the seabed, and most recently imaging the water column. The overall use of multibeam sonars as full ocean mapping sensors broadens their application with new users continuing to develop and adapt the processing and analysis of the data.

Survey standards and processes for bathymetry are well established, however they continue to evolve for both backscatter and water column data. Seabed backscatter data are commonly used for seabed geological interpretation. However it was only recently that the GeoHab BSWG generated guidelines for best practice in the acquisition and processing of backscatter data.

Initial hydrographic use of water column data was to allow comparison against the bathymetry from conventional bottom detection over wrecks to ensure least depth determination over protruding structures like masts. Tools developed for this purpose also proved useful in assessing and optimizing sonar performance.

There has been significantly broader use in geophysical surveys for research and oil and gas exploration, where integrated mapping of the seabed and water column has provided a more complete view of the geologic processes in a region. This paper will examine the use of this integrated approach to mapping with the EM302 multibeam sonar during a number of surveys undertaken by Exploration Vessel (E/V) *Nautilus* during the 2016 expedition season off the U.S. Pacific Coast.

Presenting Author Biography - Lindsay J. Gee

Lindsay has over 35 years of broad experience in hydrographic surveying and ocean mapping. In recent years his work has focused on the technology used in the ocean mapping industry, and the strategic planning and business development required to identify and transition innovative technology to products, services and solutions for general operational use.

INTRODUCTION

Mapping and charting of the seafloor underwent a revolution nearly thirty years ago with the introduction of multibeam sonars -- sonars that provided complete, high-resolution coverage of the seafloor rather than sparse track-lines of observations. Subsequently there has been an evolution in their use resulting from the ongoing upgrade of capabilities, research to fully utilize new functionality, commercial development of software, and application by the users in the seabed mapping community.

The new multibeam capabilities, including backscatter and water column data, continue to broaden the base of multibeam users beyond those mapping the seabed for bathymetry. However, this expansion does not come without challenges and continues to require a transfer of knowledge in the community through development of guidelines and standards for operation of multibeam sonars in various applications.

The evolution of multibeam sonars to acquire the water column data has extended their use above the seabed, and already made significant contributions to scientific research, such as the expeditions of E/V *Nautilus* [1]. However the exploitation of water column data is still in the early stages with early adopters, and it presents further challenges to ensure the capabilities of the systems, applications and operations are standardized and documented to maximize appropriate multibeam use.

BACKGROUND

While the industrial sector led the development of the multibeam sonar hardware, it was collaboration between academic researchers and industry that created much of the software that is now used for multibeam sonar processing. The initial focus of these systems was the mapping of depths in support of safety of navigation, geologic mapping and offshore exploration. Subsequent innovations in processing software (again derived from the academic research) led to approaches to characterize seafloor type and thus opened up new markets for mapping seafloor habitat in support of fisheries research and further expanded use in offshore industry surveys.

There are many examples of research projects that have underpinned the progress of multibeam applications and the resultant technology being successfully transitioned to industry. Three from the Center for Coastal and Ocean Mapping, University of New Hampshire (CCOM) illustrate this successful collaboration. The Concurrent Uncertainty and Bathymetric Estimator (CUBE) algorithm addressed the bottleneck in hydrographic bathymetry processing, and for the associated transition to a navigation surface, CCOM was a focal point in leading government, industry and researchers in the definition of an open format (Bathymetric Attributed Grid – BAG). The GeoCoder tool was developed to simply generate a seafloor mosaic of the sonar imagery; a critical first stage in analyzing the seafloor character. The outcomes of these research projects have been transferred to many of the leading international commercial multibeam-processing software products.

The thirty years of multibeam sonar use for bathymetry surveys has seen the parallel development of procedures and standards across all survey sectors – nautical charting, offshore surveys supporting engineering activity (pipeline installation and monitoring, site assessment) and habitat mapping. The initial standards and procedures evolved from those based on single beam echosounders (IHO S-44 "IHO Standards for Hydrographic Surveys" [2]) while other guidelines have been specifically developed for use of multibeam sonars in a specific industry sector (IMCA S-003 Guidelines for the Use of Multibeam Echosounders for Offshore Surveys [3]).

One of the challenges as research is transitioned to industry and operations, is to evolve or establish standards, guidelines, or procedures to stay relevant with the latest technology. The IHO S-44 is currently in the 5th Edition (2008) and the International Hydrographic Organization has established a project team to begin the process for the preparation of the next edition. However the broader use of both backscatter and water column data from multibeam sonars has resulted in issues related to inadequate understanding of research in the broader mapping community, and sometimes inconsistent and premature transfer from research to commercial applications that can result in inappropriate or inconsistent use of the technology.

A good example of the seabed mapping community responding to these types of limitations is the initiation and development of guidelines for using multibeam backscatter. As these data became more commonly used for seabed geological interpretation, a number of issues were hindering the progress of scientific and industry uses of multibeam backscatter data; there was a lack of standard procedures, poor or absent calibration, and a limited understanding and documentation of processing methods. It was concluded at a seafloor backscatter workshop at the GeoHab meeting in 2013 that there was an overwhelming need for better coherence and agreement on the topics of acquisition, processing and interpretation of data. The GeoHab Backscatter Working Group (BSWG) was created with the goal of documenting the state-of-the-art in sensors and techniques available, and proposing methods for best practice in the acquisition and processing of multibeam backscatter data, and the resulting document (Backscatter measurements by seafloor-mapping sonars: Guidelines and Recommendations) was completed in May 2015 [4]. The Guidelines were developed with contributions from a broad cross-section of the seabed mapping community; researchers, sonar manufactures, software producers and multibeam mapping users. This no doubt contributed to them being widely accepted across the seabed mapping community, in addition to being a significant contribution to the overall understanding and use of backscatter data.

MULTIBEAM SONAR WATER COLUMN APPLICATIONS

Just over ten years ago a new generation of multibeam sonars was developed that had the ability to map the water column concurrently with the seafloor. Utilization of water column data allowed a number of research areas to be investigated, including better detection of complex hard targets (wrecks, etc.) above the seabed, mapping fish and marine mammals and a wide range of physical oceanographic processes. However suitable software tools were not available to open up the range of new applications for users of the data from these types of multibeam sonars. Some of the techniques could be transferred from the established water column processing from fisheries sonars, but differences in the hardware and operational use also required new approaches and software [5]. At the beginning the users of the multibeam sonar water column data sonars had a limited view of the data in real-time, no simple way to replay it, or run further analysis. Although research software was being developed, there was certainly no commercial application to extract the data from the various sonars or allow detailed analysis in the geo-spatial and time domains.

An early stage of the research of multibeam water column data was to assess the performance of the sonars and analyze their operation, and an initial application in hydrographic surveys was to provide improved quality control over hard targets such as wrecks to ensure the regular bottom tracking was properly defining the least depth [6]. The initial commercial implementations of using water column imagery for this type of application took two paths – integrating the water column data with the bathymetry processing [7] or in a separate and more generic water column application [8]. Both approaches provided tools to the users undertaking surveys for nautical charting to modify their procedures in the investigation of wrecks and obstructions, and to reduce the use of sidescan sonars or wire sweeping. This change in approach has also seen the evolution of operational guidelines and standards for least depth determination at a number of national hydrographic authorities.

Importantly the water column imagery has also been shown to provide additional qualitative and quantitative indicators of general MBES performance. The Multibeam Advisory Committee (MAC), funded by the U.S. National Science Foundation, conducts a number of visits each year to vessels of the U.S. Academic fleet. These visits include conducting sea acceptance trials (SATs) of newly installed multibeam systems as well as regular quality assurance tests (QATs) to the fleet's research vessels. These ship visits aim to ensure that the multibeam sonar systems are properly installed, calibrated, configured consistently, and are operated with best practices in order to maximize data accuracy and quality so that they can meet the defined scientific requirements that fund their use. As part of each MBES test, the water column imagery has proven to be incredibly useful in supporting the MAC's assessment of multibeam performance and determining the needs for further analysis or adjustments to the systems. Problems revealed through these tests include indications of noise and/or interference from other acoustic systems, the ship's engine or operational noises, propeller cavitation, bubble sweep down over the MBES array faces which also affects bottom tracking, and oceanographic features that affect the overall performance of the system.

Another significant application area for water column data, integrated with the bathymetry and backscatter, has been the detection of gas seeps. Researchers identified this capability as being able to increase the general knowledge of the ocean environment, by mapping the bubble plumes from gas seeps and the simultaneous mapping of communities that are often in the vicinity of the seeps. The offshore industry has been quick to recognize the benefits of the integrated mapping for the detection of seeps of hydrocarbons, and Fugro has conducted a significant number of seep hunting surveys globally, with large regional area surveys in Indonesia, Brazil, and most recently Mexico. The number of this type of seep-related surveys is expected to grow, despite the general downturn in the offshore oil and gas industry. [9].

EXPLORATION VESSEL NAUTILUS SEEP RELATED EXPEDITIONS

E/V *Nautilus* is a dedicated exploration ship with an annual program exploring the ocean focusing on the fields of geology, biology, maritime history, and chemistry, while simultaneously pushing the boundaries of engineering, technology, education and communications. In 2013, a Kongsberg EM302 multibeam sonar was installed on *Nautilus*, and the ship collects data for identifying areas or features of interest, creating bathymetric charts for remote operated vehicle (ROV) dive planning and situational awareness, and locating hydrothermal vents and gas or oil seeps. The EM302 multibeam mapping system is always recording water column data in addition to bathymetry and backscatter. The 1x1^{o} beams are mostly fixed to 65^{o} for seep detection surveys as a result of trials and recommendations of the Multibeam Advisory Committee [10].

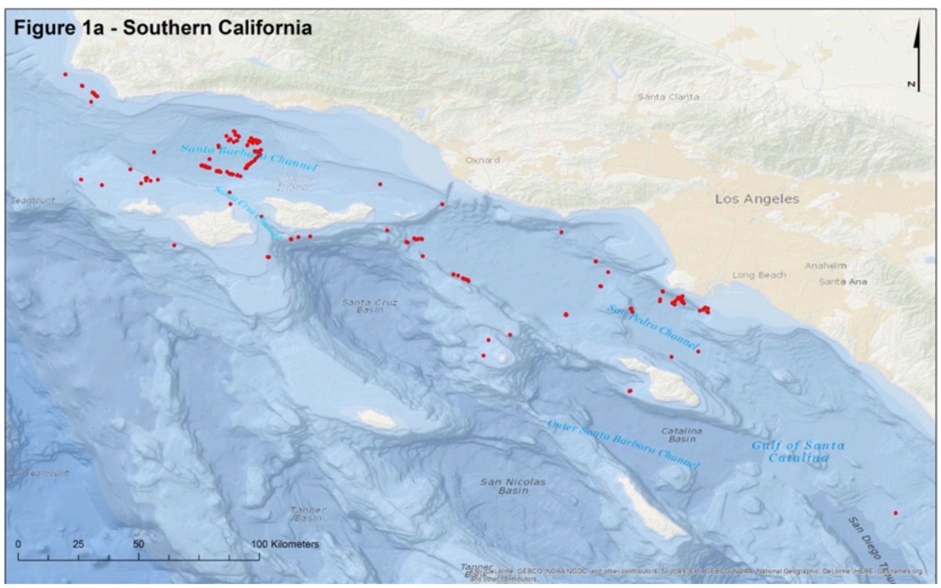
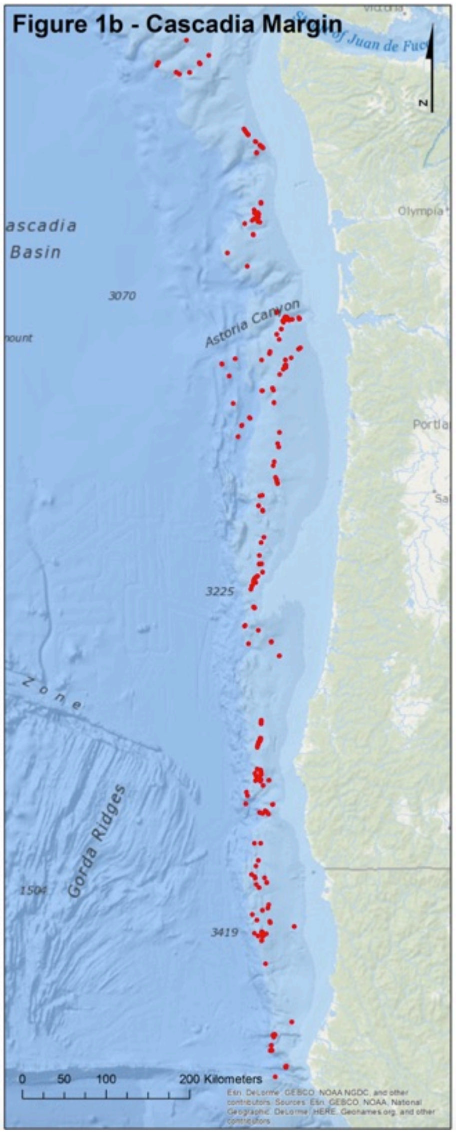


Figure 1a: Highlight of gas plumes found around the Channel Islands.

During expeditions off the west coast of the United States between July 2015 and September 2016, *Nautilus* mapped more than 30,000 km^2 of seafloor [11]. Most mapping efforts were concentrated along the Cascadia Margin and the Southern California region, and examination of the water column data revealed hundreds of distinct vertical features, presumably plumes of methane gas released from the seafloor The locations of seeps are shown in Figures 1a and 1b.



The initial processing used the FMMidwater tool to locate the seeps and determine their size and location. This was achieved using a number of different modes: the single fan, stacked fan (10-20 pings) to improve detection of faint seep returns in noisy environments, and stacked range mode for a chronological view. Each line of data was viewed in playback mode and water column processing was normally able to be completed in 25 to 30% of the time taken to acquire the data. Extraction of useful information from the sidelobes was inconsistent, particularly in the Southern Californian area. This precluded the use of the automatic detection tools in FMMidwater even when the sidelobe signal was suppressed. When a seep was detected, the locus of the seep at the seafloor (bottom pick) and maximum height above the seafloor (rise) was geo-picked and saved. Geospatial distribution of the detected seeps was reviewed during processing in 3D scenes with Fledermaus to relate the seeps to features in the multibeam bathymetry and backscatter. (see Figures 2a and 2b).

The results of the mapping efforts revealed an unexpected number of methane seeps. ROV dives were then used in a number of areas to provide geological context to the seeps and determine associated unique biological communities. (see Figure 2c).

Figure 1b: Highlight of gas plumes found off the coast of Washington and Oregon.

A number of significant discoveries were made from the exploration:

- Most mapping efforts were concentrated along the Cascadia Margin and the Southern California region, and over 800 clusters of seeps were identified.
- The majority of seeps were identified along the 500 m depth contour, which coincides with the upper limit of methane hydrate stability, but also represents the depth zone with the greatest mapping effort. Low mapping efforts in the 200-400m depth range (and in the central California region) may account for low seep discoveries in those areas.

- There were often fields of seeps found in the 100 m depth zone, but further research is required to identify the cause that may be from increased detection resolution or higher seep concentrations/more diffuse vent sites.
- Similarly, there were relatively few seeps found in greater than 1200 m depth, and it remains uncertain if this may be accounted for by geophysical limitations or lower detection resolution.

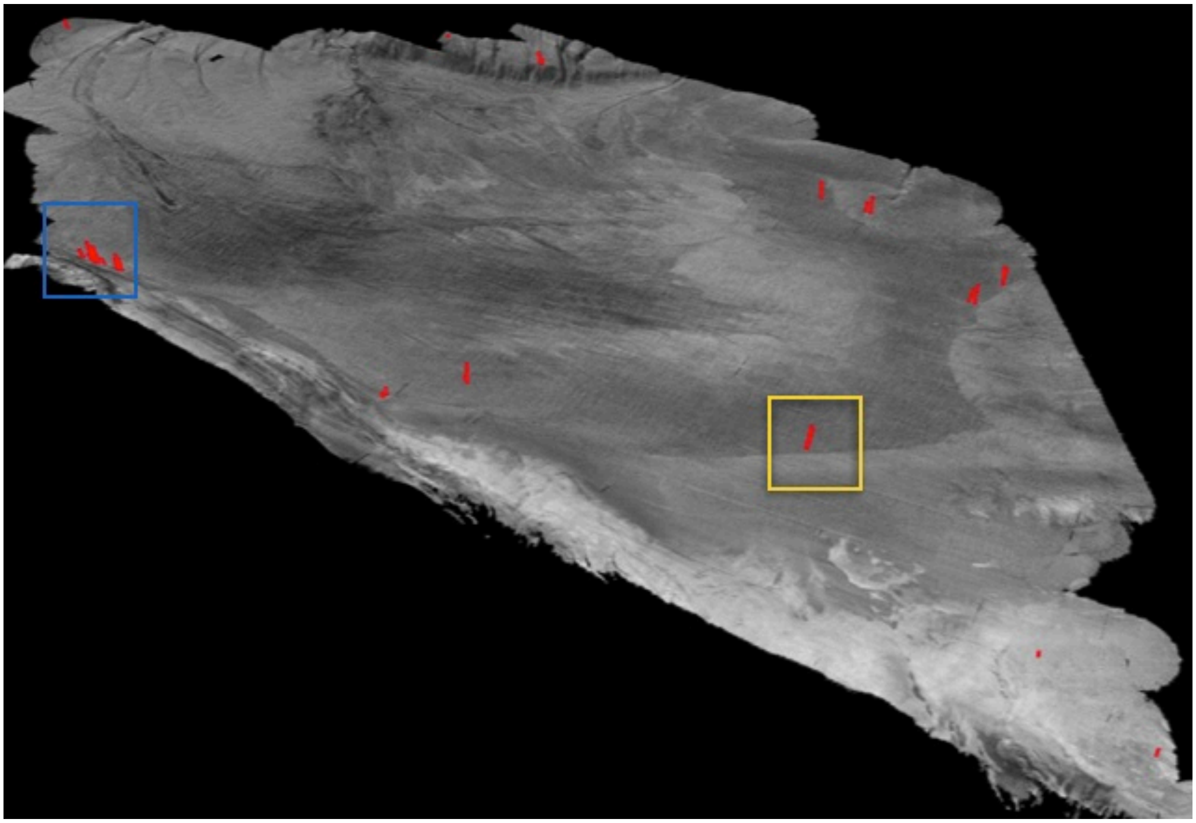


Figure 2a: Overview of Santa Monica Basin, (viewed to North and 2x vertical exaggeration). Boxes indicate location of figures 2b and 2c.

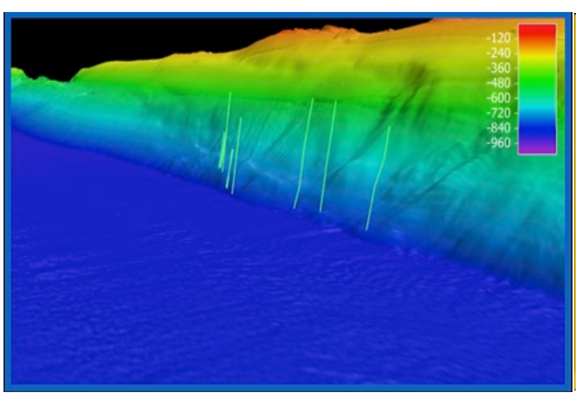


Figure 2b: A number of seeps located along the break in slope at base of Pilgrim Bank. (view to South and 3x vertical exaggeration)

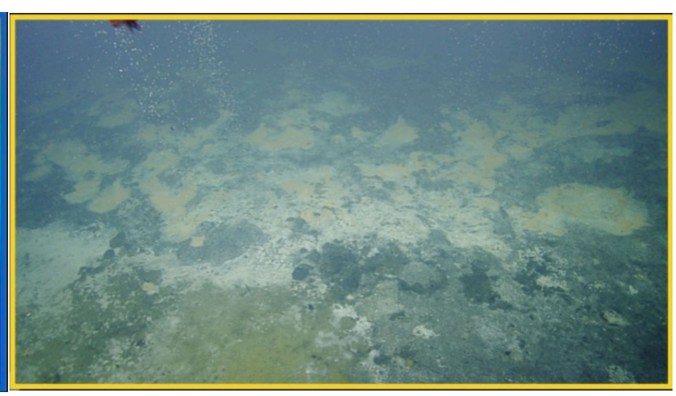


Figure 2c: Seep located at 896 m depth amongst hummocky terrain with white, grey, and orange bacterial mats. (Nautilus Cruise NA075, Dive H1548)

Altogether it is noted that these findings contribute significantly to the baseline inventory of seeps along the continental margins of the United States [11]. In future work, it is planned to gain insight from these data through further analysis of seep location in relation to backscatter, slope, depth, and geological setting, with the goal of more automated detection. Analysis of the spatial distribution of seep clusters and the factors that constitute a grouping are ongoing.

Notwithstanding the results, the survey also highlighted some limitations of the still developing technology and operations for seep-related surveys. There is a lack of standardization regarding water column data acquisition, processing, and interpretation that can provide inconsistent results. There are no standard protocols for sonar configurations in changing depths or seabed type, for different types and size of seeps, or varying oceanographic conditions, or guidelines for survey design to ensure a high probability of detecting all seeps in an area. There is a need to ensure best practices are documented and shared to optimize the efficiency of using this technology across a growing number of applications. There are already a number of initiatives from the user community to assemble a multidisciplinary group to address these concerns and develop guidelines similar to the approach to the development of the BSWG Guidelines.

CONCLUSIONS

Multibeam sonars and their operations continue to evolve, and rely on a combination of hardware improvements, academic research and new software to support their utilization in more complete ocean mapping. The benefits of the new uses of water column data have already been demonstrated in a number of areas and in particular during some extensive seep surveys, and these types of operations will no doubt expand and extend the opportunity for multibeam sonar users. However, there will also need to be a broader community contribution in developing and evolving guidelines and standards to ensure the technology is used appropriately to achieve the type of consistent results required.

ACKNOWLEDGEMENTS

Research was conducted by the Ocean Exploration Trust on the E/V *Nautilus* cruises NA065, NA066, NA067, NA070, NA072, NA073, NA074, NA075, NA076, NA077, and NA078, and thanks also to funding from NOAA Office of Exploration and Research.

REFERENCES

[1] Bell, K.L.C., Flanders, J., and A. Bowman, A. (Eds.) (2017) New Frontiers in Ocean Exploration: The E/V *Nautilus*, NOAA Ship *Okeanos Explorer*, and R/V *Falkor* 2016 field season. Oceanography 30(1), supplement, 94 pp.

[2] International Hydrographic Organization (2008) IHO Standards for Hydrographic Surveys, 5th Edition, February 2008, Special Publication No. 44. https://www.iho.int/iho_pubs/standard/S-44_5E.pdf

[3] International Marine Contractors Association (2015) Guidelines for The Use of Multibeam Echosounders for Offshore Surveys. IMCA S 003 Rev. 2 July 2015.
[4] Lurton, X.; Lamarche, G. (Eds.) (2015) Backscatter measurements by seafloor‐mapping sonars. Guidelines and Recommendations. 200p. http://geohab.org/wp-content/uploads/2013/02/BWSG-REPORT-MAY2015.pdf
[5] Doucet, M., Arsenault, R., Ware, C., Weber, T., Malik, M., Mayer, L., Gee, L. (2009) Advanced Mid-Water Tools for 4D Marine Data Fusion and Analysis. IEEE Oceans, Biloxi, MS, USA, 26-29 October 2009. Conference Proceeding.
[6] Hughes Clarke, J.E. (2006) Applications of multibeam water column imaging for hydrographic survey. The Hydrographic Journal, April, 2006.
[7] Collins, C.M. (2012) The Progression of Multi-Dimensional Water Column Analysis in a Processing Environment. Hydro12 - Taking care of the sea. November 2012, Rotterdam, Netherlands.
[8] Gee, L., Doucet, M., , Parker, D., ,Weber, T., and Beaudoin, J. (2012) Is Multibeam Water Column Data Really Worth the Disk Space? Hydro12 - Taking care of the sea. November 2012, Rotterdam, Netherlands.
[9] Saade, E.J. (2016) Statement for the Record by Edward Saade, to House Transportation and Infrastructure Subcommittee on Coast Guard and Maritime Transportation and Water Resources and Environment. September 19, 2016.
[10] Beaudoin, J. (2011) Optimizing EM302 Settings for Water Column Imaging. Multibeam Advisory Committee. http://mac.unols.org/resources/cookbook-optimizing-em302-settings-water-column-imaging
[11] Kane, R., Raineault, N., Gee, L., Embley, R., Merle, S., Girguis, P., Irish, O., Lubetkin, M., German, C., Levin, L., Cormier, M., Caldow, C., Ryan Freedman, R. (2016) E/V *Nautilus* Mapping and ROV Dives Reveal Hundreds of Vents Along the West Coast of the United States, Abstract OS41A-1943 presented at 2016 Fall Meeting, AGU, San Francisco, U.S.A.