Approach to a methodology for the generation of backscatter products with the technological infrastructure of the National Hydrographic Service - CIOH

Aproximación a una metodología para la generación de productos de backscatter con la infraestructura tecnológica del Servicio Hidrográfico Nacional – CIOH

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ABSTRACT

The complete and detailed knowledge of the sea bottom properties in the present time is fundamental for handling, monitoring, profiteering and education of the national marine spaces. The technological development in sea bottom exploration has circled around echo sounders, systems that deliver not only bathymetry information but acoustic backscatter information. The proper measurement and analysis of *backscatter* information from the current multibeam echo sounders is useful for determining sea floor characteristics and sedimentary processes. Observation of various factors that influence the measurement of backscatter intensity was made, for finally obtaining an effective methodology for the acquisition and analysis of this information, taking it into a real scenario with the actual capacities of the National Hydrographic Service (CIOH Caribe).

KEYWORDS: sound, backscatter, echo sounder, multibeam, hydrography, sonar, hydroacoustics, noise.

RESUMEN

El conocimiento completo y detallado de las propiedades del fondo marino en la actualidad, es fundamental para el manejo, monitoreo, aprovechamiento y educación de los espacios marinos nacionales. El desarrollo tecnológico en la exploración submarina ha girado alrededor de las ecosondas, sistemas que entregan además de la información de batimetría, la información de retrodispersión acústica o backscatter. La apropiada medición y análisis de información de backscatter de las actuales ecosondas multihaz es útil para determinar características del fondo marino e identificar procesos sedimentarios. Se realizó una observación de varios factores que influyen en la medición de la intensidad de backscattering, finalmente con el objeto de llegar a desarrollar una metodología efectiva para la adquisición y análisis de esta información, llevándola a un escenario práctico con las capacidades actuales del Servicio Hidrográfico Nacional (CIOH Caribe).

PALABRAS CLAVES: *sonido, retrodispersión, ecosonda, multihaz, hidrografía, sonar, hidroacústica, ruido.*

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Introduction

It is striking to find mainly echo sounders, which were invented at the beginning of the 20th century, and whose development has been largely driven by military applications, once observed the follow-up to the technological development that has occurred in the last decades in the methods of marine exploration. Right from that moment, numerous types of echo sounders have been built and perfected, allowing the seabed to be studied with different levels of detail (OHI, 2005).

In addition to providing georeferenced depth data, multibeam systems provide acoustic backscatter data, better known by its English name *backscatter*. If these data are appropriately reduced, they provide a measure of the *backscatter* force as a function of the elevation angle (of the beam or acoustic beam) or angular response (Lark *et al.,* 2015).

A practical application of *backscatter* analysis is the identification of seabeds. Traditionally, the surface conformation of the seabed is determined by the collection of a series of samples, analyzing them to determine grain size or type of rock, and then plotting the results on a map, interpolating or extrapolating the gaps between the samples (Dartnell & Gardner, 2004). In recent years, the integration of bathymetry and backscatter information has led to a revolution in the understanding of seabed characteristics and sedimentary processes (Medialdea *et al.,* 2008).

It should be clarified that the detailed analysis of the *backscattering* signals of multibeam systems is the main topic of current research and development activities at the international level. These studies are aimed at obtaining more information about the properties of the seabed and benthic habitats from acoustic information (Parnum, Siwabessy & Gavrilov, 2004).

At present, the General Maritime Directorate, through the National Hydrographic Service (CIOH Caribe), has the oceanographic platforms ARC Malpelo and ARC Providencia (Figue 1), scientific research vessels that have multi-beam systems of the latest technology, recently updated in search of the highest international standards in terms of capacity and quality of information collection of the seabed. However, despite the best skills acquired, it is important to emphasize that there is no effective methodology for the acquisition and analysis of backscattering data, which prevents optimization of the use of equipment and information that can be exploited more efficiently with a view to better understand jurisdictional maritime spaces; and it is precisely this, the research problem that arises and develops in the present investigation.

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Figure 1. Oceanographic vessels ARC Malpelo (right) and ARC Providencia (left), recently modernized in their hydrography equipment technology.

Materials and methods

By reviewing the development of the methodology, a preliminary study of the state of the art in the subject was carried out, where more than 40 bibliographical sources were investigated in which various methods for obtaining, analyzing and validating *backscatter* data were proposed. Thus, for the most part, the revised methods converge in the relationship of different ranges of backscatter intensities with the sediment classification proposed by Folk, Andrews & Lewis (1970).

The inventory of equipment and multibeam capabilities of the Oceanographic and Hydrographic Research Center of the Caribbean was carried out as a national hydrographic service, and it was established that high standards are met in terms of updating the technology of its equipment.

Two days of field work were carried out on board the oceanographic vessel ARC Malpelo. Thus, in the first, the environmental and platform variables that affect the performance of the multibeam echo sounder were observed; the noise levels were mainly checked by subjecting the unit to different types of course, speed and incidence of the waves; this taking into account the physical configuration of the ship and its multibeam system. On the second day, a detailed record of the operating conditions of the Kongsberg EM 302 multibeam echo sounder was made during a real campaign, verifying the backscatter intensities (oblique and normal) and observing its behavior according to the environmental and dynamic factors of the ship. We tried to establish some kind of correlation between the axial movements of the boat with the intensity of the *backscatter*, which is a variable highly dependent on the angle of incidence and therefore on the movements of the sensor. However, it was observed that not all movements are directly related to the intensity of *backscatter*.

A bibliographic compilation of some practices to be taken into account during the planning and collection of *backscatter* data was carried out, with the experience of experts in the field, confronted with the data collected in the campaigns on board the ARC Malpelo. Likewise, various existing processing methods were verified to work with backscatter signal data from multibeam systems. This reference, together with the it and technological capabilities of the Hydrographic Service (CIOH Caribe), was fundamental for the determination of the best tool to be used in obtaining an analysis of the acoustic signal.

Finally, the practical application of the proposed methodology was carried out in a previously raised area complying with the standards required for backscatter processing. The processing was carried out in the CARIS HIPS and SIPS software, using its capabilities for the processing of this type of data. After incorporating the backscatter data into the software and separating them from the bathymetry, a mosaic was generated where a preview of the data is appreciated. From this mosaic a new surface was generated in which a generalization of the data was applied in order to smooth the dispersion of the graphic data and finally an identification of colors by ranges of intensity, where they were isolated in a more defined way, the types of fund that correspond to the classification made by Carreño *et al.,* (2011).

Results

The CIOH-Caribe has different types of multibeam echo sounder systems (MBES - Multibeam Echosounder Systems), which are regularly used for bathymetric surveys within the campaigns for the permanent updating of the country's nautical cartography. The systems are the following, with their respective platform and characteristics (Table 1).

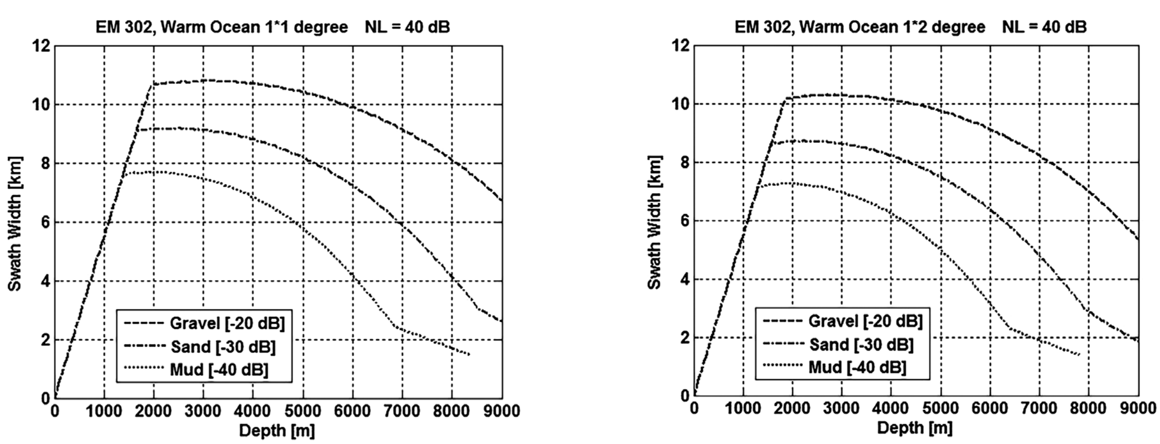
The echo sounders of the ARC Malpelo and ARC Providencia vessels were installed in a "gondola" type assembly in which a structure similar to a delta wing protrudes below the hull by approximately one meter, moving the sensors away from the ship's structure with the In order to minimize interference due to the noises generated by the bow thruster, sacrificial anodes, welding cords, sensors, bulbs and other accessories that affect the behavior of the water in the vicinity of the hull during the displacement of the vessel (Figure 2).

Table 1. Platforms and multibeam systems installed on board the platforms of the DIMAR.

Platform	ECOSONDA						
	Brand	Model	Version	Frequency of operation	Number of beams	Maximun coverage angle	Depth range (m)
ARC Malpelo ARC Providencia	Kongsberg	EM 302	1 x 2 1 x 1	30 kHz	288	140°	10 - 7.000
ARC Isla Fuerte	Reson	Seabat 7125	1 x 0,5 2 x 1	400 kHz 200 kHz	512 256	128°	0,5 - 500

Figure 2. Gondola of the arrangement of sensors of the multibeam systems in the lower part of the hull of the vessels ARC Malpelo and ARC Providencia.

The MBES of the two vessels differ only in their angular arrangement in the reception sensor. While in the ARC Providence, the receiver has an angle of 1 ° with respect to the horizontal, in the ARC Malpelo has 2°. This influences the sweeping width of the beams in reception, being the angular arrangement of reception of the ARC Providence, more effective in that the reception is better (Figure 3).



a. b.

Figure 3. Performance of the different arrangements of the Kongsberg EM 302 echo sounders in the oceanographic vessels of the CIOH-Caribe: a) ARC Providencia b) ARC Malpelo. Source: Kongsberg Maritime AS.

The *RESON Seabat 7125* echosounder on board the ARC Isla Fuerte pilot boat is installed in a retractable mount on the bow of the boat (Figure 4).

Figure 4. MBES on board the ARC Isla Fuerte boat. The arrangement (right) is deployed towards the bow and is submerged in the water when the system operation starts.

In the first campaign carried out on board the *ARC Malpelo*, the objective was to reach a depth of more than 2000 m depth, in order to verify the work of the echosounder in optimal operating conditions. The information began to be recorded from the last section of the exit channel of the Cartagena Bay and until the return to it at the end of the day. When reaching the depth required to perform the coverage tests of the beams, changes of course and speed were made, running the tests of the system where the different levels of noise were shown, dependent on the vessel-environment interaction.

During these tests, the sea conditions were from 2 to 3 on the Beaufort scale, having a height of the wave between 1 and 1.5 m approximately, enough to notice impairments in certain courses and speeds, in what refers to the generation of noise in the vicinity of the sensors.

In order to determine the reception level of the MBES, the SIS software (Seafloor Information System) generates a display window called stave display, which graphically shows the levels of echoes in all reception elements or "staves", for verification purposes about performance. In the case of EM 302 echosounder, the number of elements or staves in which the receiver is divided is 64. The range of echoes for the receiver ranges from -64 dB to 10 db, where saturation of the stave receiver is already generated.

The (Figure 5) shows the window of the stave display for the moment in which the ship is sailing in the bay of Cartagena with departure course, a depth of 31 m and a speed of 10.2 knots. The blue colors represent the absence of echoes, which is normally obtained in the water column. A few echoes can be observed a few meters from the hull, which are supposed to be generated by the vessel's machinery given the speed at which it was sailing at that moment; but without significantly affecting the performance of the system. This stave display window under relatively good operating conditions (inside the bay), was taken as a reference for the following open water performance observations.

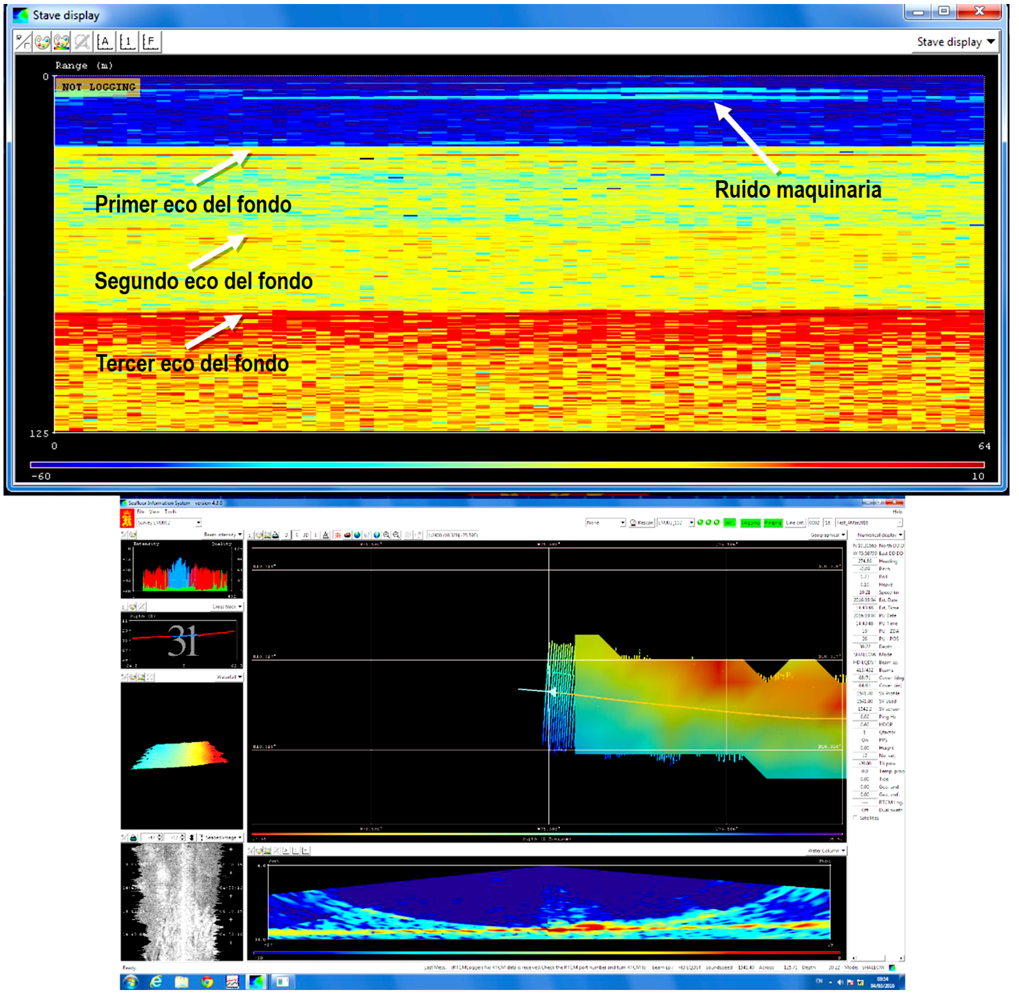


Figure 5. Stave display during transit out of the Cartagena bay of the Malpelo ARC.

The echoes were observed for different combinations of course, speed and wave incidence, obtaining different system responses for each case:

Depth of 410 m, speed 9.4 knt and heading 269T: the column of water was observed without alterations or echoes in the staves, and from the detection of the bottom a normal operation. At the time of the capture of the window, the unit sailed during the first hours of the morning, when the height of the wave was approximately 1 m.

Depth of 837 m, speed 9.6 knt and heading 251T: slight echoes are observed in the water column, since the bridge was instructed to increase the power of the machinery as much as possible. However, the detection of the bottom is much more consistent than before because the depth has increased and the vessel is sailing in the same direction as the waves.

Depth of 2274 m, speed 6.6knt and course 270T: it was requested to decrease the speed of the vessel. At this time the depth was already that of the test area (> 2,000 m) and it is clear that with that speed and the 270 ° T course (close to the direction of the swell) the water column is not significantly disturbed.

Depth of 1739 m, speed 8.1 knt and heading 088T: it was requested to increase the speed of the vessel to 8 knots (cruising speed). This time, navigating with the wave almost in the prow, we can clearly see an almost uniform noise level in the whole water column in all the staves and poorer bottom echoes than in the previous test. It can be deduced that the two effects added (increase of power in the machinery and wave incidence) generate a noisier response in the water column, affecting the data of the bottom (Figure 6).

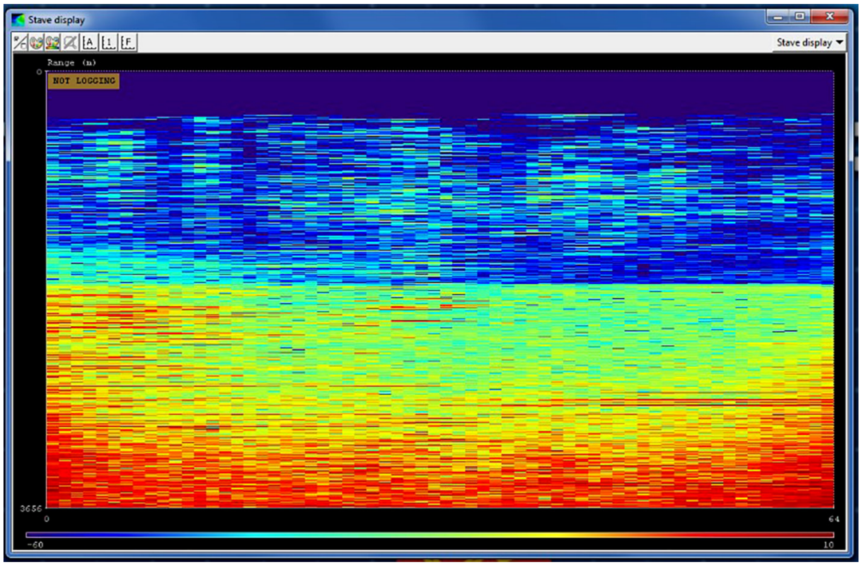


Figure 6. Stave display during the test at a depth of 1739m, speed 8.1knt and heading 088T.

Depth of 2195 m, speed 7.0 knt and course 262T: the course was changed again to one in favor of the swell, maintaining the same power of the machinery, verifying that effectively increase the reception levels of the bottom in all the staves and reduce the noise in the water column (Figure 7).

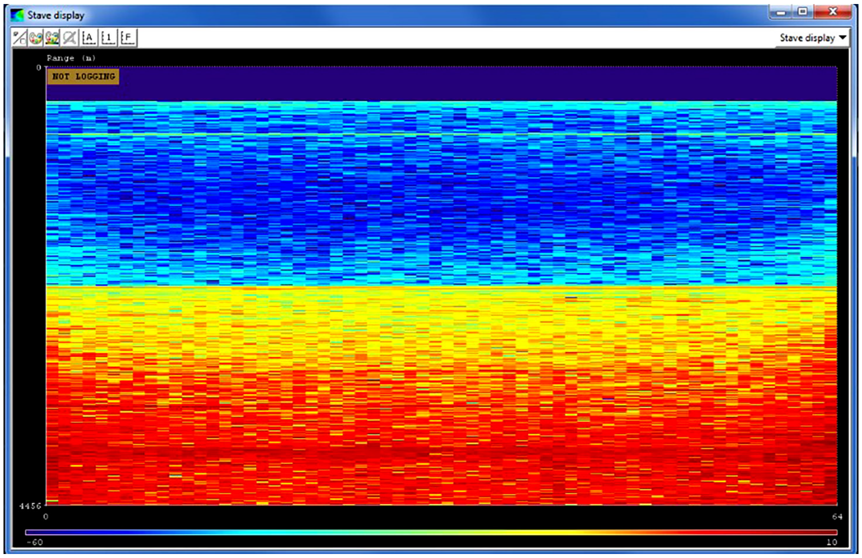


Figure 7. Stave display during the test at a depth of 2195m, speed 7.0knt and heading 262T.

As a result of the performance tests through the stave display function, it was possible to determine that the environmental noise factors caused by the ship - ocean interaction can be mitigated by knowing the performance of the vessel by this method and varying components such as speed and course.

The second campaign was carried out aboard the Malpelo ARC during a multibeam bathymetric survey operation in the smaller islands of Serrana and Roncador, in the San Andrés and Providencia archipelago. Environmental, platform, and oblique and normal backscatter intensity data from the Kongsberg EM 302 echosounder were collected for 96 hours. From this time series, the axial movement data of the sensor (roll, pitch and heave) and the backscatter oblique (OB) and normal (NIB) intensities were analyzed.

The movements of roll, pitch and elevation (roll, pitch and heave) are commonly used by the MBES to make the corrections in each of the axes, calculating other movements such as yaw (yaw) and deviation (sway). The NIB (Normal Incidence Backscatter) parameter shows the level of backscattering at normal incidence. The level of echo sounder received from the first impact (normal incidence), depends largely on the type of background and frequency. The OB (Oblique Backscatter) parameter shows the strength of the oblique backscatter. It is an average of the average backscattering level for beams placed outside the normal incidence region and within 60 ° of the vertical (Kongsberg, 2013).

Thus, analyzing the observations of the OB and NIB it could be observed that the intensity of the first does not present any considerable trend, unlike the NIB. This could be due to the fact that the Seabed Information System (SIS), which processes the data from the echo sounder, performs an average beam intensity up to 60 ° (OB) with respect to the nadir; in this sense the variations of the farthest beams are smoothed a bit, which the SIS uses for the Time Varying Gain - TVG corrections, related to the beams outside the normal incidence zone. However, the normal incidence of the backscatter does have a tendency, so it can be assumed that there is some factor that could be affecting it.

The correlation coefficients were calculated, comparing the axial movements against the acoustic backscatter intensities, both oblique and normal, finding the results shown in (Table 2).

Table 2. Correlations of the axial movements of the platform with the backscatter intensities.

Linear correlations			
	Swinging	**Pitching**	**Elevation**
NIB	-0.1628	0.0143	-0.2106
OB	-0.1360	-0.0614	-0.0593

Pearson correlations were calculated for pitch and roll against NIB and OB; However, with respect to the elevation movement, despite not being apparently related to the intensities of OB, a Pearson r of the order of 0.21 can be observed with the NIB intensity (Figure 8).

For the sample (96 hours), the correlation of the elevation and the NIB has a level of significance of 95%, calculated for n-2 degrees of freedom; This could indicate that the distance between the bottom and the sensor, increasing or decreasing with the height of the wave, affects the beams immediately below the platform. The calculation of the standard error for the correlation of these two factors is in the order of 0.29. Although it is not strongly conclusive given the lack of data, it could be assumed that the affectations to the backscatter intensity with reference to the angular incidence, not only refers to the morphology of the bottom and the roll of the boat, but also the displacement on the nadir axis (elevation) could also be added.

This assumption should be demonstrated in more detail with longer time series on the NIB and the elevation and with more diverse sea states that allow to observe more important variations of the height of the ship with respect to the horizontal, since for the period recorded it was of 96 hours, in which the state of the sea remained at a magnitude of 1 on the Beaufort scale.

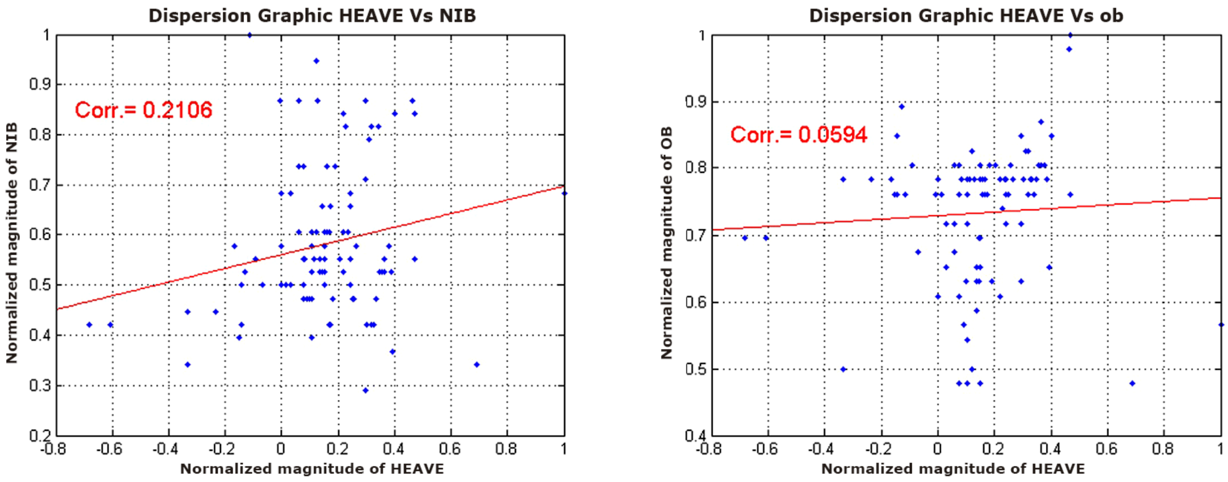


Figure 8. Graphic of the correlation of the elevation and the NIB and OB factors.

Discussion

From the performance tests of the multibeam systems carried out, it was found that acoustic backscattering, being very dependent on the angular incidence, is affected by the different axial movements of the platform. It was possible to establish a correlation between this dynamic and the intensity of *backscattering*, finding the highest correlation with the elevation movement that is the displacement of the platform only on the Y axis.

Also, the tests on board the Malpelo ARC were used to determine the best conditions to minimize the negative effects in the measurements of the multibeam system. Checks were made with different directions and speeds, in addition to taking the standard measurement of the noise generated when navigating in calm waters (Cartagena Bay). It concludes with these tests that in a moderate sea state (2 to 4 on the Beaufort scale), the speed of the platform must be reduced to reduce the impact of the bow against the waves. In the same way, the course should not be taken directly against the waves. In the strongest sea states, it is recommended not to carry out the campaign, when the early improvement of ocean-atmospheric conditions is not foreseen and the goal of the survey is to record backscatter data.

Based on the observations of the behavior of the backscatter in relation to the conditions of the platform and the environment, various practices were generated to be taken into account during the survey stage; procedures that must be applied to obtain backscatter data of the best possible quality. It was concluded that the hydrographic service of the CIOH Caribe, if it requires carrying out backscatter surveys, must take into account certain factors, in addition to those related to a regular hydrographic campaign (Table 3).

As well as the phase of obtaining field data, in the part of data processing it was possible to establish the steps to follow to generate a quality backscatter product, using the current computer capabilities of the hydrographic service, which, as happens with multibeam equipment, they correspond to standards applied by institutions throughout the world. Thus, using the CARIS HIPS and SIPS suite, the CIOH Caribe, could enter to make part of 40% of users of multibeam systems that use this software package for backscatter data analysis; being a good reference since it shows the high level of trust placed by institutions around the world in the results obtained with this IT platform (Figure 9).

Table 3. Good practices for obtaining backscatter data.

Previous considerations	**Calibrations**	Absolute calibration	Object with known reflectivity (metallic sphere) in the background.
		Relative calibration	To compare different acoustic systems, or different configurations. By using the seabed with specific characteristics.
	Configuration changes in campaign	Dynamic range and saturatio	Power, gain and pulse length can be varied, but must be calibrated before start operation..
		Frequency	It is not recommended to modify, since the backscatter is strongly dependent.
		Additional considerations	Delays in the application of new configuration.
	Environmental factors	Energy loss BS	Minimize interference with other sources (boats or echo sounders).
Techniques to improve the quality of BS	**Superposition**	Angle of incidence	15 ° to 60 ° - angle for high quality BS. Superposition must be greater to ensure the highest quality.
	Course	Impact in BS	If complex bathymetry of the area exists, it should not be navigated in one direction.
	Direction line	Insonification	Avoid fast or very closed turns.
	Crossing lines	Data consistency	Anisotropic effects or background variability can be discovered but can be excluded from the final product.
	Incrustations	Affects BS measurement	Remove inlays from sensors to ensure optimal measurement.

At the end of the exercise the entire methodology could be applied in a real survey, obtaining a very accurate identification of sea beds in the sector of Bocachica in the bay of Cartagena being this final product of backscattering, the demonstration of the best use of technological capabilities in matter of hydrography (Figure 10).

It is possible to see in Figure 10 a combination of the two passes of the ship ARC Malpelo during the first campaign, in and out of the Bocachica area. With the CARIS software, the rasterization of the backscatter was made through its mosaic editor, making a classification of the reflectivity ranges of the seabed material according to what was consulted in Carreño *et al.,* (2011). As it is an area of which its background characteristics are known, the presence of fine and medium sands can be corroborated by the great influence of the Canal del Dique; in addition to rocky structures in a sector of cutting by dredging in the vicinity of the fort of San José. Likewise, outside the bay there are small structures of great reflectivity, which represent small coral formations present in the vicinity of Bocachica.

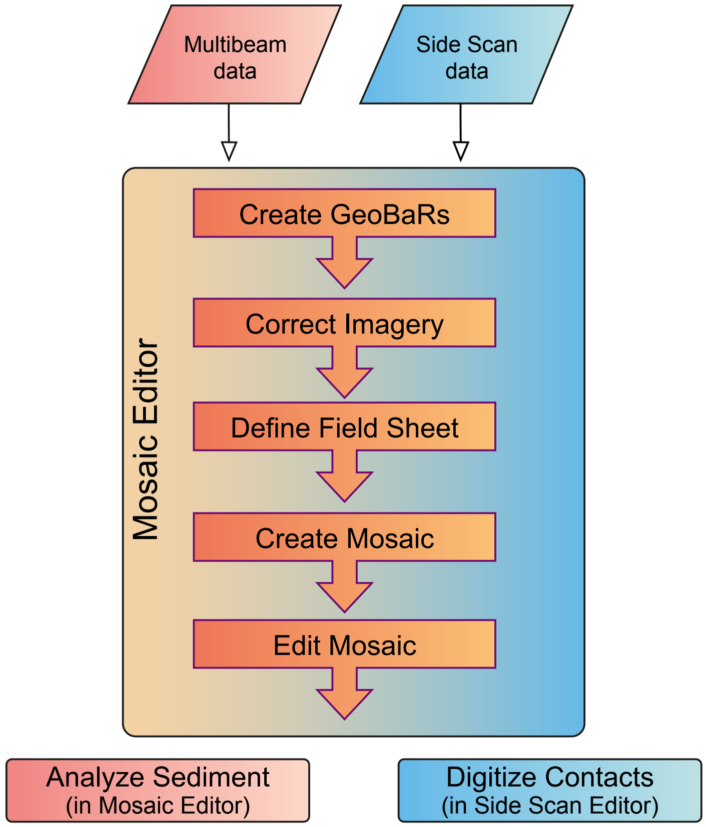


Figure 9. Basic outline of the mosaic editor of the CARIS software. Taken from Teledyne Caris Inc.

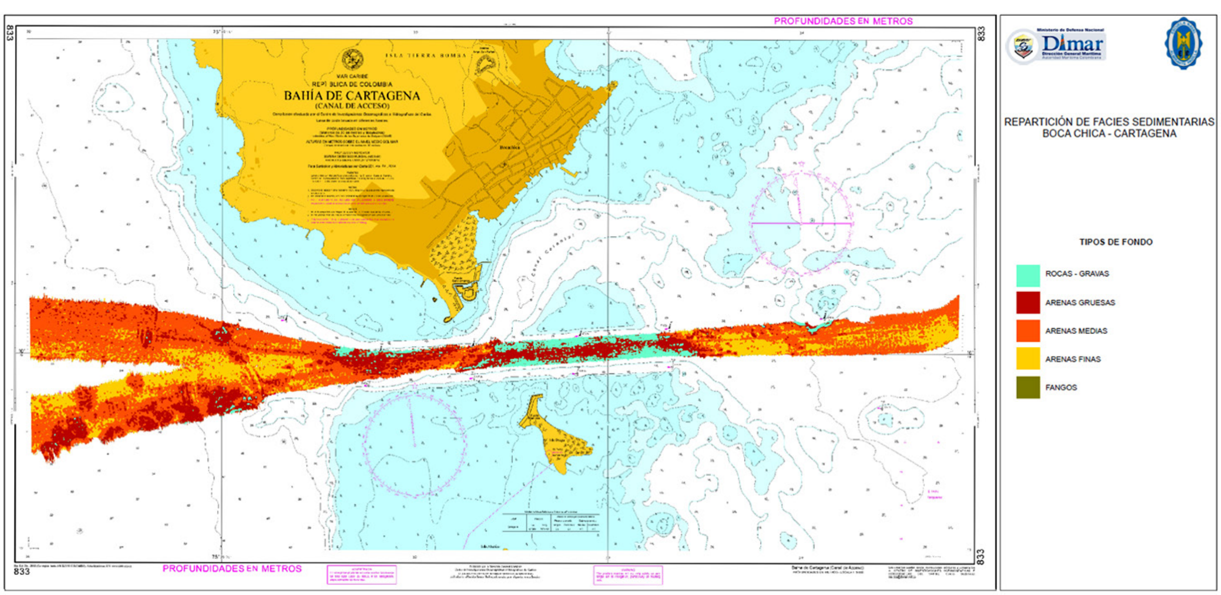


Figure 10. Characterization of funds using backscatter technology.

The final product obtained is a good approximation to the identification of sea beds made in the country based only on the collection, processing and analysis of the entire acoustic signal of a multibeam echo sounder, applying an innovative methodology in the country, thus contributing to the better understanding of national maritime spaces. Based on the above, the door is left open for the use of multibeam *backscatter* data in the development of useful products, both for the knowledge of the seas of the country and for commercial or decision-making applications by the authorities.

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