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Precision, accuracy and sources of errors in multibeam data acquisition and processing for a correct interpretation of the backscatter data (both from seafloor and water column)

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Abstract **– Acoustic methods for seafloor mapping have been widely developed over the last decades. In particular, the development of swath bathymetry has allowed the creation of detailed maps of seabed topography and acoustic backscatter data; these data have been used to infer sediment and habitat types. So the Multi-Beam Echo Sounder (MBES) is a tool that allows getting information about bathymetric, morphological and compositional characteristics of the seabed surface. In addition to this, MBES can now also discriminate the acoustic imaging of the water mass by recording sampled reflectivity measurements along each beam. Infact new hardware and software modules for MBES have been developed, allowing the hydrographic community to exploit a series of powerful means to acquire water column backscatter. The aim of this paper is to present different surveys conducted by IAMC to show some examples of acquisition and processing and the results obtained to a correct interpretation of the data.**

I. INTRODUCTION

Given the significant increase in accuracy and resolution of seabed imaging techniques, recent developments in sonar technologies provide new tools for seafloor exploration and data acquisition. Through a qualitative and quantitative analysis of acoustic backscatter, multibeam echo sounder (MBES) systems have been used to infer physical, geological and biological proprieties of the seafloor, such as surface roughness (e.g. [1–3]), sediment grain size (e.g. [4–8]), substrate type (e.g. [9,10]), and distribution of seagrass meadows and other biota (e.g. [11,12]). Seafloor backscatter intensity corresponds to the amount of acoustic energy scattered back from the seafloor toward the echosounder receivers after the interaction with the seabed. The backscatter signal received by MBES systems can be influenced by various variables, which can be categorized into system settings (e.g. power, gain, pulse length), acoustic propagation conditions (e.g. absorption and spreading loss), beam geometry (e.g. range, incident angle, footprint size) and seafloor properties [12]. Accordingly, in order to derive useful information about the substrate and geomorphology of the seabed, it is important that the received backscatter signal is fully corrected so that it is invariant to system settings, propagation conditions and beam geometry, thus all backscatter changes can be related only to seafloor properties [13]. It has been shown that the variation of backscatter intensity is related to sediment properties (e.g. [14–16]): fine sediments generally exhibit low backscatter intensity due to low sediment bulk density and low acoustic impedance contrast at the water–sediment interface; whereas coarse sediments generally result in higher backscatter intensity given their higher bulk density, high acoustic impedance contrast and greater roughness of the sediment–water interface (e.g. [17,18]). Furthermore, it has been shown that, for sandy sediments, backscatter intensity decreases with mean grain size ([14]).

Each multibeam system logs the backscatter signal with different way and it's possible divide three principal sources of backscatter (Fig. 1):

-time series of backscatter strength per beam (Snippet for Reson and Beam time-series for Simrad system)

-one value of average backscatter strength per beam (Beam Average)

-two long time series of backscatter strength for each received ping (Sidescan-like with no angular information, Reson system)[19].

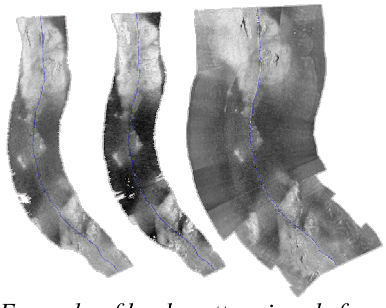

Fig. 1. Example of backscatter signal: from left to right: Snippet, Beam Average and the Sidescan-like

In the last years some multibeam systems are able to log the backscatter strength for the entire echo return along each beam, recording the acoustic response of the entire water column. This data are affected by contribution of the side-lobes, influence more or less intense depending on the geometry of the multibeam (Fig. 2), and are difficult to manage for the gigabyte amount that are acquired in a few minutes. Furthermore the echoes can be contaminated from other sonars, propeller and engine noise, bubble wash-down, and so on (e.g., [20–22]

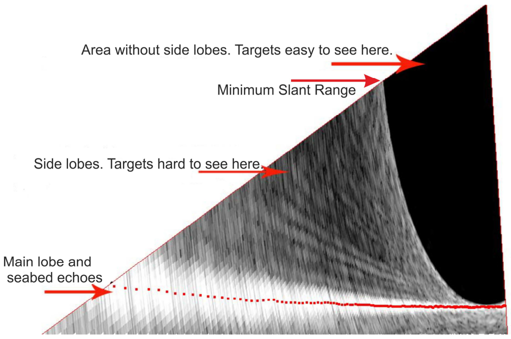

Fig. 2. Example of water column backscatter data of the Simrad EM3002D

In this work, we present a series of multibeam backscatter data acquisitions during different surveys and the relative data processing, both for the interpretation of the sea bottom and in the recognition of the schools of fish in the water column backscatter.

II. MATERIAL AND METHOD

During the CARG Project – Geological and geothematic cartography (2004-2007), the IAMC of Naples acquired bathymetric and acoustic data along the Campania coast (e.g. Naples, Pozzuoli, Ischia and Procida islands), to realize geological and geothematic sheets on scale of 1:50000. The data were acquired in a range of 10-600 meters range depth. For deeper acquisitions were used multibeam Reson SeaBat 8111 for bathymetric data, and SideScan Sonar Klein 2000 and/or 3000 for acoustic image seabed. Instead for the shallow water acquisition (5-50m) were used the multibeam Reson SeaBat 8125, a 455 kHz MBES that provides sub-centimetric depth resolution data. The SeaBat 8125 was utilized both bathymetric and backscatter data. The system insonifies a swath on the seafloor that is 120° across track by 1° along track. The receiver array forms 240 individual beams 0.5 ° wide at the center of the swath (references). All vessels utilized for shallow water acquisition were equipped with a 12-channel Landstar Differential Global Position Systems (DGPS) and with an IxSea Octans 3000 that provide positioning data (sub-meter accuracy) and attitude data (0.01° accuracy) to the navigation software. A Reson SVP-C sound velocity probe was installed near transducers, thus providing the real-time sound speed for the *beam steering*, a process that allows to examine the sounds coming from different angles simultaneously [23]. A sound velocity profiler, Reson PDS2000 software was used for positioning and for logging MBES data; during the acquisition the software receives data from the DGPS system and from the motion sensor and applies real-time corrections to the bathymetric data. During the system installation, the static positional offset were measured and a calibration (i.e. patch test) was carried out in order to measure and the correct for the dynamic sensor offsets. The survey lines were run parallel to the coast with an overlap of 50% between adjacent swaths. Some filters were applied in the PDS2000 *Acquisition Window* to remove spikes during data logging, namely the *quality filter*, which rejects beams that do not meet the quality settings based on collinearity and brightness levels and the *nadir filter*, which rejects beams outside a defined port and starboard angles and the nadir. Bathymetric data so collected produced very high-resolution (20 x 20 cm grid cell) Digital Elevation Model (DEM). The Reson 8125 was able to log the backscatter data intensity according two methods: Snippet and Sidescan-like options (see Fig.1). Snippets are fragments of the complete signal envelope that aim to contain the seafloor backscatter from each beam (references). Bathymetry beams on the port and starboard sides (respectively 0-119 and 120-239 for the sonar used here) are combined to produce the Sidescan-like images. The process combines adjacent pair of beams by averaging and then the averaged beams. The array of intensity values as a series of amplitudes, one for each sample interface for each Sidescan beam. In addition to computation differences, there is also a spatial difference between Snippet and Sidescan-like options: Snippet data range corresponds to the bathymetric data range, while Sidescan-like data include the whole acquisition range of MBES Central Unit, that includes the distance from transducer to the bottom and the range of the acquisition. This implies that the Sidescan-like data external parts out-of-range returns are included: null data have to be removed during the processing phases. For CARG Project was processed only the Sidescan-like data because at that time it was not possible to process the Snippet data. Available data were processed with Triton Elics suite programs, Isis ver. 6.6 and DelphMap 2.10. Smoothing the navigation data, adjusting the TVG (time Varied Gain), applying geometric and radiometric corrections (see [24] and reference therein, for a detailed description of geometric and radiometric corrections) and, finally, creating the acoustic mosaic, are the main steps on a processing workflow. This procedure is the same used for a standard Sidescan sonar data, except for TVG application and removing the external null-data. Isis software includes three options to apply TVG: Standard, Auto and Custom. The latter was used because it is possible to fine-tune the TVG settings. There are three independent controls expressed as a formula:

$$\{number\}*\log(R) + \{number\}*R + \{number\}$$

Where the unit R stands for range. During MBES acquisition the operator needs to modify some parameters such as power and gain according to the depth changes, thus producing incorrect seafloor acoustic response; changing the *{number}*, Isis calculates the TVG curves to apply in order to minimize the acquisition parameters changes producing a well-blended final mosaic. The outer bands of each line, characterized by null-data, were manually removed by a generic image-editing software. Finally, a mosaic was created using cartographic software.

In the years following 2007, different Snippet processing tools are available. One of the most recent ones will be described. The characteristics of the acquisition parameters are the same of the description above, while the multibeam in the last year was replaced with the most modern Reson SeaBat 7125 (400 kHz, 512 beam 0.5° across-track beam width). This MBES performing an equidistant beam spacing mode, that provides uniform sounding density and maximizes usable outer swath, increasing system productivity. Snippet data processing were carried out using FMGeocoder Toolbox (FMGT) in Fledermaus 7.6 version, made by QPS [25]. This software is able to account for system characteristics, analyses and visualize backscatter data from the MBES systems. The Snippet was corrected for receiver gain, transmit power, transmit pulse width, spherical spreading, attenuation in the water column, area insonification, beam patter, spekle noise, angular dependence and local slope. After corrections, the abrupt changes in the intensity of received signals disappeared in the backscatter image. To correct for the angular dependence of backscatter, FMGT produces an equalized backscatter mosaic.

Regarding the Water Column Image (WCI), the data were collected during an oceanographic survey carried out in the Strait of Sicily to evaluate anchovy and sardine abundance and distribution. During the survey has been used the Reson SeaBat 7125 and the WCI data were acquired on single transects during pelagic trawls to visualize and isolate high-resolution 3-D fish schools and attempt a fist study on fish school shapes. Files were analyzed with FMMidwater of Fledermaus 7.0 of the QPS Company, designed to rapidly extract relevant water column objects from a range of sonar formats. A simple graphical user interface was used to perform threshold filtering on a number of key parameters to help extracting features of interests, such as fish schools. The reader can find short development illustrations of this approach in Appendix A of [26].

III. RESULTS AND DISCUSSION

The sidescan-like processing was more time-consuming than Snippet processing, due to all the corrections manually applied on each line and, in general, to the labor-intensive mosaicking (e.g., the cutting of the external data on each line). Nevertheless, the obtained seabed image is very similar to a classical Sidescan sonar mosaic. The main difference between standard Sidescan sonar and the Sidescan-like is that, in the first case, the instrument can be towed below the surface at the lower and constant altitude above the seafloor, whereas, in the second case, the instrument is at the surface, so its resolution decreases with increasing depth because of the signal attenuation. Moreover, in shallow water area the MBES produces a narrow swath than a conventional Sidescan sonar, so a shorter distance between acquisition lines is required. However, in this study, an instrument capable to produce both bathymetric and backscatter data was employed to save survey time, considering that both bathymetric and backscatter data were required. The figure 3 shows an example of a 20 cm resolution acoustic mosaic obtained around the peninsula of Nisida (Naples, Italy). We use a grey scale, where the high backscatter levels correspond to dark areas.

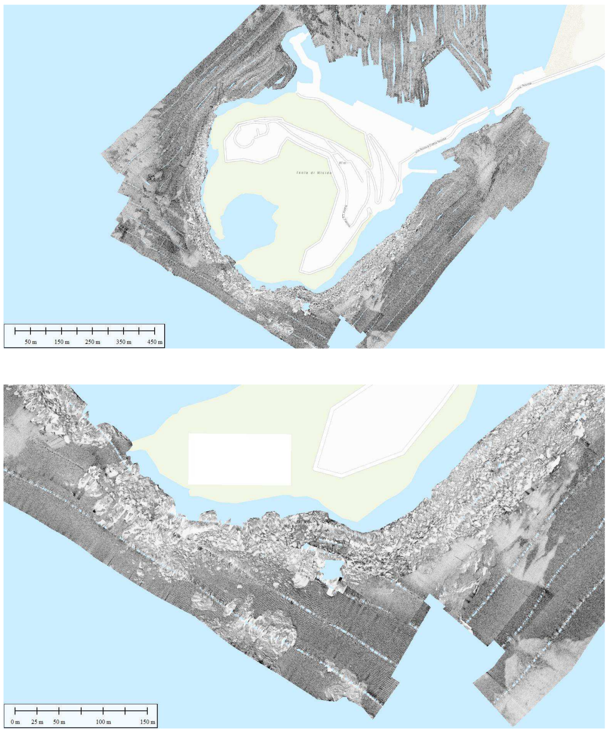

Fig. 3. An example of the Sidescan-like mosaic realized during the CARG project.

The Snippet image contained less artifacts than the Sidescan image, particularly in the across-track direction. Infact the results of the processing of Snippet data show a good discrimination among acoustic facies and the reduction in morphological information, which can be seen in the figure 4.

Fig. 4. *Above the Sidescan-like mosaic, below the Snippet mosaic realized in the same area.*

The lack of morphological information in the Snippet data compared to the Sidescan data, means that the two data layers must complement each other to construct the seabed map; in particular the sidescan-like mosaic has been useful to recognize and map the bedforms, and other morphological features as *P. oceanica* meadows. Whereas with the Snippet image it is possible to clearly define the boundaries of acoustic facies. Thanks to this characteristic and to better algorithms in processing, the Snippet is a good data to utilize automatic image classification. The figure 5 shows an example of a seabed image of Linosa island made by RSOBIA (Remotely Sensing Object Based Image Analysis). The data was acquired with the Reson Seabat 7125. RSOBIA is a new toolbox for ArcMap 10.x that segments the data layers into a set of polygons; each polygon is defined by K-means clustering and region growing algorithm, thus finding areas, their edges and boundaries in the imagery.

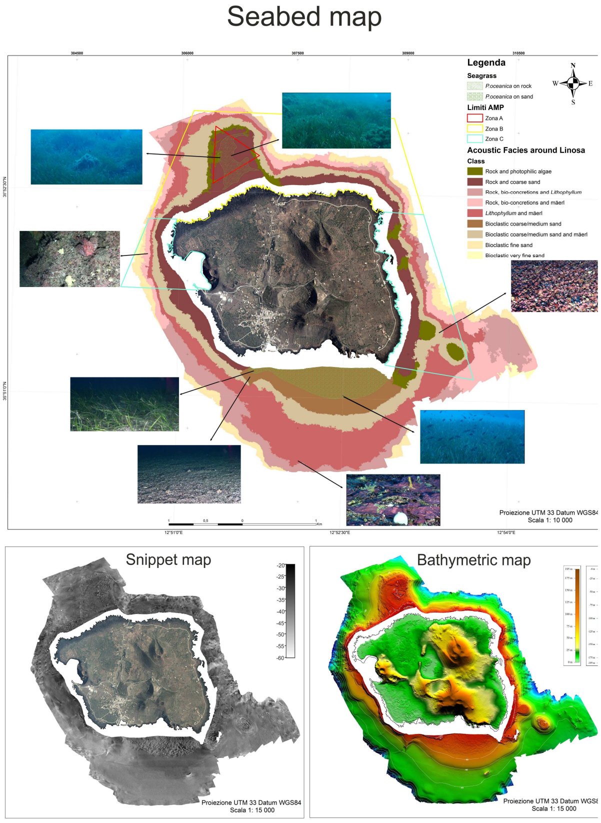

Fig. 5. *Seabed map of Linosa Island achieved with multibeam Reson Seabat 7125*

During the analysis of the WCI, about 200 schools where identified, as shown in the example of figure 6. Given that all multibeam data were acquired along with pelagic trawl catches, samples of the schools were taken aboard and fishes were identified, counted and weighted. According to such criterion, among the 200 schools identified in the WCI, 100 were sardine and 55 anchovies.

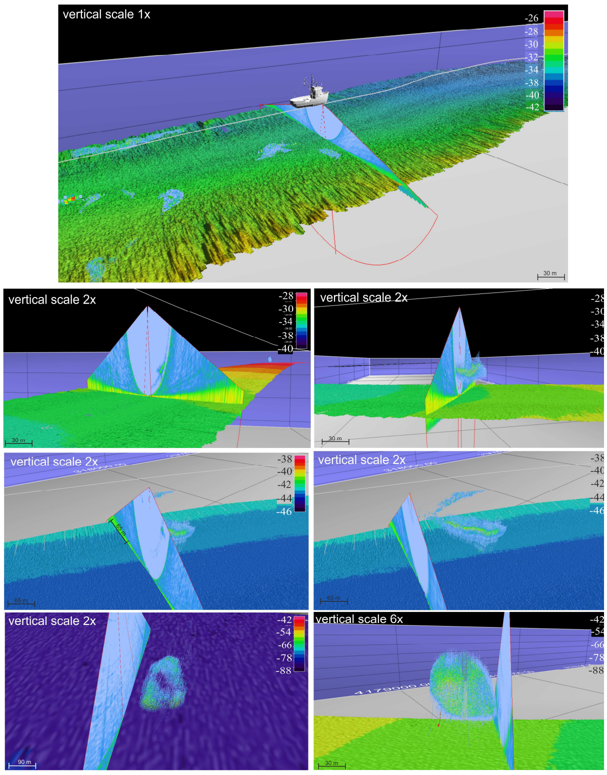

Fig. 6. Schools of fish identified with water column backscatter of the Simrad EM3002D

IV. CONCLUSIONS

Multibeam sonar systems are currently useful instruments for the characterization of the seabed, as they provide co-located bathymetry and backscatter data. In particular, in this paper we wanted to emphasize how the acquisition and the processing methodologies affect the final output. The most important thing is a good acquisition, from a proper installation (i.e. few vibration in the pole) to careful calibration, but above all to a correct use of the acquisition parameters such as power, pulse length and gain. So, the mosaic resulting must be at least noisy possible for a good seabed map. This is especially true in the use of automatic image classification, which provide objective and quantitative results.

The application to WCI data allowed us to visualize and isolate high-resolution 3-D fish schools, attempting a first study on fish schools' shapes. It was also possible to identify the species of fishes (in our case, anchovies and sardines) through trawl catches. In conclusion, the methods applied in this case study has produced interesting and novel results and 3-D shapes of fish schools with high resolution, because we used an instrument created for hydrographic survey, with over 200 number of beam and with 0.5° beam angle across track. The management of these data still is not simple, but the progresses that can be obtained with these instruments in both fishery and scientific research, which can have a great importance for fish stock management. Finally, such comments on the WCI, can be considered even in other scientific fields, e.g. detection of gas plumes, estimation of suspended sediments and improvement of wrecks least-depth determination.

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