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Long-term calibration analysis of scientific echosounders used in research vessels

Córdoba-Sellés, Pilar[1]
Instituto Español de Oceanografía, Centro Oceanográfico de Baleares
Muelle de Poniente s/n. 07015 Palma de Mallorca (Spain)

Iglesias-Marroig, Magdalena
Instituto Español de Oceanografía, Centro Oceanográfico de Baleares
Muelle de Poniente s/n. 07015 Palma de Mallorca (Spain)

Ventero-Martín, Ana
Instituto Español de Oceanografía, Centro Oceanográfico de Baleares
Muelle de Poniente s/n. 07015 Palma de Mallorca (Spain)

Nava-Baro, Enrique[2]
Universidad de Málaga. ETSI Telecomunicación
Campus de Teatinos, 29071 Màlaga (Spain)

ABSTRACT

The use of scientific multifrequency echosounders like SIMRAD EK60 in resource-assessment surveys of small pelagic fish like sardine or anchovy, has been employed by the Spanish Institute of Oceanography (IEO) for more than thirty years. The quantitative use of its data for biomass estimations, makes necessary that accurate echosounder calibrations are done at the beginning of the acoustics surveys.

Echosounder stability over time, is fundamental to guarantee the consistency of the annual results and to ensure their comparability.

This paper shows a long-term comparison study of the calibrations of SIMRAD EK60 echosounders that were installed in different Research Vessels (R/V), carried out in different locations and in different seasons. A study of calibration results was carried out by three different methods; the first of them, using a specific echosounder software tool, the second using an ad-hoc design optimization algorithm over previous software selecting and filtering data and finally, using an algorithm recommend by ICES, doing an optimization of raw data.

Keywords: long-term, calibration, echosounder
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[1] pilar.cordoba@ieo.es
[2] en@uma.es

1. INTRODUCTION

Sustainable management of fishery resources is one of the important challenges that humanity must confront. Annually, all research institutes involved in fishery management carry out surveys for fish stock assessment. In the case of small pelagic fish species like sardine (*Sardina pilchardus*), anchovy (*Engraulis encrasicolus*) or Atlantic mackerel (*Scomber scombrus*) or zooplankton species, the use of scientific echosounders is the standardised methodology to estimate their abundance and distribution, by the same token, it is the method used to characterize all their habitats [1]. The advantage of the acoustics methods is their non-invasive character, which reduce the amount of fishing number of catches, as selective fishing is only necessary selective fish to identify the species and their length distributions.

The design of the surveys, along systematic parallel transects, systematic zig-zag or random design, allows the covering of the whole continental shelf, from the area of study.

Obtaining quantitative results from acoustics signals, made necessary to do frequently accurate calibrations of echosounders, specially before the start of any stock estimate surveys [2].

The standard method for calibration of fishery-research echosounders is known as the Sphere method[1][2]. This uses metal spheres with a known target strength (TS), a measure of the size of the echo[3] that produces this target, like a reference to determine the transducer gain, that is defined as the intensity ratio observed at a distant point, comparing the real transducer with an idealized lossless omnidirectional transducer[2]. This parameter can be used to measure the long-time stability of transducers[1].

Nowadays, the reference spheres widely used to calibrate scientific echosounders are made from tungsten carbide (WC) with 6% Co added as a binder and from electrical-grade copper (Cu), both materials are excellent for precision calibration spheres[4] and their TS are comparable with the living organisms to be observed[2]. The 38.1 mm WC sphere presents the advantage that it can be used for the range of transducers frequencies from 38 to 200 kHz, on the other hand, Cu spheres present an specific diameter for any frequency, 63, 60, 32, 23 and 13.7 mm to 18, 38, 70, 120 and 200 kHz, respectively.

2. MATERIALS AND METHODS

2.1 Acoustic sampling

In this paper, all available results of the calibration being analysed are from echosounders SIMRAD EK60 equipped with 5 split-beam transducers (nominal frequencies 18, 38, 70, 120 and 200 kHz) which are installed in four R/V used for the IEO in its annual biomass estimation surveys with acoustics methods.

The times series span from 2005 to 2018 (Table 1). PELACUS survey covers the North Atlantic and Bay of Biscay region, from the north of Portugal to the French border, this survey is carried out in spring, during March and April. MEDIAS surveys cover the Spanish Mediterranean Sea during June and July, this area was covered from 2009 to 2013 in the ECOMED survey that was carried out in winter, November and December, and finally ECOCADIZ-Reclutas survey covered the Cadiz Golf and the South of Portugal during October.

Table 1. Stocks estimation surveys with acoustics methods included in this study

Survey	Year	R/V
PELACUS	2005-2014	Thalassa
	2014-2018	Miguel Oliver
MEDIAS	2009-2013	Cornide de Saavedra
	2014-2018	Miguel Oliver
ECOCADIZ-Reclutas	2013-2017	Ramon Margalef
ECOMED	2007-2009	Cornide de Saavedra

The main characteristics of the research vessels are presented in Table 2. The R/V Ramon Margalef (RM), has located the acoustics transducers in a drop keel and has two propellers, Thalassa (T), Miguel Oliver (MO) and Cornide de Saavedra (C) have only one propeller. With the exception of C, all three were built according to the underwater noise limits proposals published in 1995 for the International Council for the Exploration of the Sea (ICES)[5].

Table 2. Research Vessels characteristics. Built according to the ICES noise specifications except Cornide de Saavedra.

R/V	Length (m)	Beam (m)	Draught (m)	Power (CV)	V_{max} (kn)	Shafts
Thalassa	73.7	14.9	6.1	1x2900	14.7	1
Miguel Oliver	70.0	14.4	5.5	2x1359	14.0	1
Cornide de Saavedra	66.7	11.25	4.6	1500+750	14.0	1
Ramon Margalef	46.7	10.5	4.2	2x1223	13.0	2

All scientific echosounders that are used to do the present study, are SIMRAD EK60 and their main characteristics are summarized in Table 3. All R/V possess transducers of 18, 38, 70, 120 and 200 kHz, the transducers installed are respectively, SIMRAD ES18-11, ES38B, ES70-7C, ES120-7C and ES200-7C, the R/V RM and T possess, in adition, the ES333-7C transducer, that are not included in this study because the time-series is too short to include in this paper.

Table3. Main characteristics from transducers of scientific echosounders SIMRAD EK60 allocated in the R/V.

Transducer	Type	Material	Directivity (dB)	$10\log\psi$ (dB)	Beamwidth (deg)	Electro-acoustic efficiency
ES18-11	Split-beam	Ceramic	25±1	-17±1	11±2	0.75
ES38B	Split-beam	Ceramic	28±1	-20.5±1	7±1	0.50
ES70-7C	Split-beam	Composite	28±1	-21±1	7±1	0.75
ES120-7C	Split-beam	Composite	28±1	-21±1	7±1	0.75
ES200-7C	Split-beam	Composite	28±1	-20.5±1	7±1	0.75

The procedure followed to make all the calibrations analyzed in this paper was a standardised protocol established by the Fisheries Acoustics Lab of the Balearic Oceanographic Centre, that is based in the methodology described by Foote et al[6], recommended by the manufacturer [7], and included in the ICES recommendation[1].

One of the most important requirements to obtain precise results of the calibration is to carry it out in a homogeneous and stable medium, for that reason, R/V were located in quiet areas, without large differences in tidal height or strong tidal current, far away from areas near river mouths or with heavy traffic, and it is very important that the selected area will present little or no fish presence.

To avoid the erratic movement of the reference sphere that could produce an increase of the uncertainty results, the vessel must be anchored. By means of three winches allocated on the deck, the reference sphere is situated below the transducer face with three monofilament nylon lines or Dyneema® lines. These lines allow moving the reference sphere covering all the beam width. Figure 1 shows a projection of the R/V MO with the layout of the spheres and the weight, that is added to keep the system stable.

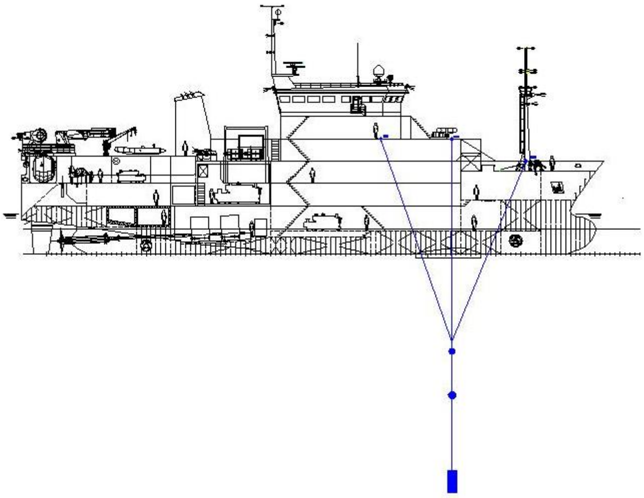


Figure 1. Diagram of the placement of the reference sphere inside the acoustic axis of the transducers in the R/V Miguel Oliver

The reference target must be placed at a sufficient depth to avoid the near field, that distance may be estimated by Equation 1:

$$R_{opt} = \frac{2\, d^2 f_0}{c}$$

where d is the greatest width of the transducer face, f_0 is the transducer frequency and c is the sound speed in water.

The acoustic transducer emits and receives acoustics signals with a dependent power of the incident angle, according to its directivity pattern $D(\theta, \varphi)$, Equation 2;

$$D(\theta, \varphi) = 2 \left| \frac{J_1(ka\ \sin\theta)}{ka\ \sin\theta} \right|$$

where (θ, φ) are spherical coordinates, J_1 is the Bessel function of first order, k is the wave number and a is the open radius.

Transducer gain is related to the directivity according to Equation 3

$$G(\alpha, \beta) = \eta D(\alpha, \beta)$$

Using this concept, we can express the power of backscattering echo of a small target, received in a transducer like Equation 4:

$$P_T(W) = \; P_t G \frac{10^{-\alpha r}}{4\pi r^2} \sigma \frac{10^{-\alpha r}}{4\pi r^2} \frac{\lambda^2}{4\pi} G$$

where P_t is power that the transducer emits, G is the transducer gain, α is the medium attenuation, and σ is the backscattering area of the target.

The parameter that characterizes the target is σ, and it could be expressed according Equation 5 like

$$\sigma(dB) = 5 \log P_T + 40 \log r + 20\alpha r - 10 log \frac{P_t G^2 \lambda^2}{64\pi^3}$$

But to refer to a target, the target strength (TS) parameter is widely used, to correlate to the linear expression of σ.

The target strength value of the reference sphere is widely dependent of the sound speed, for that reason, before starting the calibration, a CTD (conductivity, temperature and depth) profile was made to determinate the temperature and salinity of the whole water column in the calibration location. The reference spheres used were the indicated ones by the manufacturer and in all the cases the maintenance procedure was followed.

With the reference sphere located in the centre of the transducer beam, helping with the winch lines, the sphere covers the entire traducer beam with the objective of having a complete and homogeneous coverage of this with the sufficient experimental points to obtain calibration parameters and model fitting to find out the transducer directivity.

In all the case studies in this paper, the SIMRAD ER60 software tool Calibration.exe tool was used to make, save and analyze the experimental procedure. All .raw files generated by the echosounder, as well as, .txt files produced by Calibration.exe tool, were saved to post-processing analysis.

2.2 Post-processing analysis

The long-term calibration data were analyzed with three different methods:

1. Using the SIMRAD ER60 software tool. This program analyzes raw files and gives a txt file with the calibration parameters from the transducer. Also gives the fitting yo the experimental results to two theoretical beam models: polynomial beam model, that is not specified, and the beam model, that follows Equation 6:

$$G(\alpha,\beta) = G_0 + \left(\frac{\alpha - \alpha_0}{B_\alpha}\right)^2 + \left(\frac{\beta - \beta_0}{B_\beta}\right)^2 + 0.18\left(\frac{\alpha - \alpha_0}{B_\alpha}\right)^2 \left(\frac{\beta - \beta_0}{B_\beta}\right)^2$$

2. Using the txt file obtained from the method 1, which contains all the TS data from the experimental points, adjust these data to a model with a Levenberg-Marquardt optimization algorithm, and employ a selection for proximity to the centre transducer axis algorithm.

3. Doing an optimization from raw calibration data using the Matlab script (R2017b Mathworks) ExCal[1]. This is the most flexible strategy,

because it allows to increase the number of experimental recorded data that are used to calculate the calibration parameters.

3. RESULTS

The results of the Thalassa echosounder calibrations carried out before starting the PELACUS survey were shown in Figure 2, we can see the results obtained with the SIMRAD software tool Calibration.exe, we can appreciate the stability of the results over time. Lower frequencies show maximum variation around 0.2-0.3 dB, higher frequencies show higher variations, around 1.08-1.72. These results indicate the high stability of the echosounder over years.

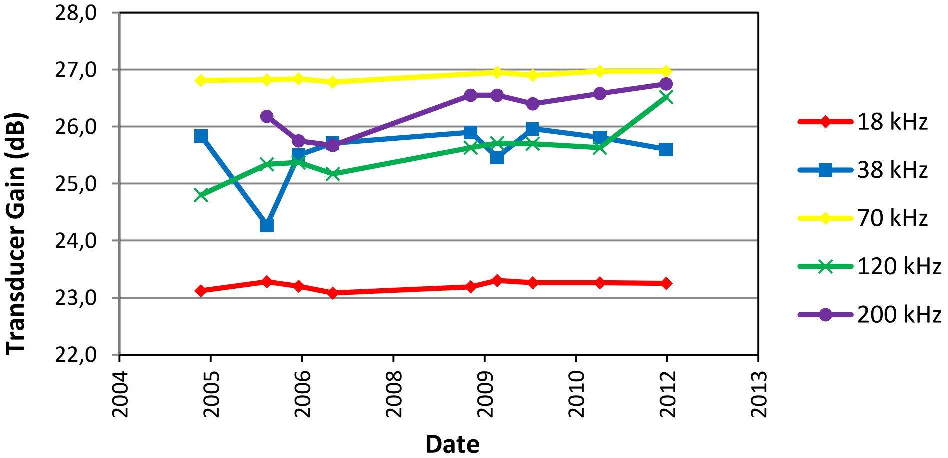


Figure 2. Time series of echosounder gain results for R/V Thalassa. The data correspond to the PELACUS survey (2005-2012)

The comparison of the results for the 38 kHz transducer gain obtained from the three methods analysed are shown in Figure 3:

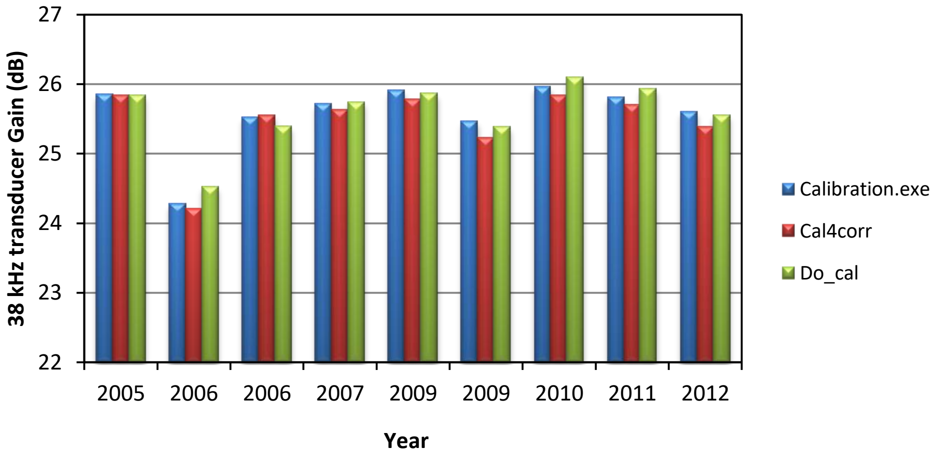


Figure 3. Time series of 38 kHz transducer gain results for R/V Thalassa. The data correspond to the PELACUS survey (2005-2012)

Table 4 shows the comparison of the results for the transducer gain obtained from the three methodologies, we can see that the results are very similar in all the cases, these results indicate the robustness and reliability of the manufacturer tool.

Table4. Time series of transducers gain results with three methods of analysis, M1 Calibration.exe, M2 Cal4corr, M3 Do_cal, for R/V Thalassa. The data corresponds to the PELACUS survey (2005-2012)

Year	18 kHz			38 kHz			70 kHz			120 kHz			200 kHz		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
2005	23,12	23,1	23,68	25,84	25,83	25,83	26,81	26,82	26,74	24,8	24,78	24,88			
2006	23,28	23,22	23,15	24,27	24,21	24,52	25,34	26,83	26,88	26,82	25,31	25,58	26,33	26,28	26,43
2006	23,2	23,24	23,03	25,52	25,55	25,39	26,84	26,76	27,34	25,37	25,4	25,48	25,75	25,76	25,57
2007	23,08	23,01	22,92	25,71	25,63	25,74	26,7	26,73	26,84	25,17	25,14	25,14	25,67	25,63	25,86
2009	23,19	23,06	23,26	25,9	25,78	25,86	26,95	26,86	26,95	25,63	25,62	25,57	26,55	26,65	26,88
2009	23,3	23,2	23,34	25,46	25,23	25,38	26,95	26,86	26,95	25,71	25,66	25,88	26,55	26,75	26,99
2010	23,26	23,21	23,33	25,96	25,83	26,09	26,9	26,83	26,98	25,7	25,69	26,13	26,4	26,4	26,77
2011	23,26	23,1	23,33	25,81	25,69	25,93	26,97	26,84	27,09	25,63	25,54	25,83	26,58	26,94	27,12
2012	23,25	23,16	23,25	25,6	25,38	25,55	26,97	26,88	26,91	26,52	26,48	26,66	26,75	26,91	26,83

We can see the same results in the analysis of the calibration data from the R/V Miguel Oliver, this vessel is normally calibrated twice per year, the first one in spring in the Vigo Estuary, and the second one in summer in the Bay of Palma. Like in the preceeding case, we can observe that the lower frequencies are really stable over time, while high frequencies present greater variability. 18 kHz frequency shows a maximum difference of 0.27 dB, and 200 kHz frequency shows 2.14 dB. The year over year variations for 18 kHz frequency is ±0.2 dB, ±0.4 dB for 38 kHz and ±0.2 dB for 70 kHz.

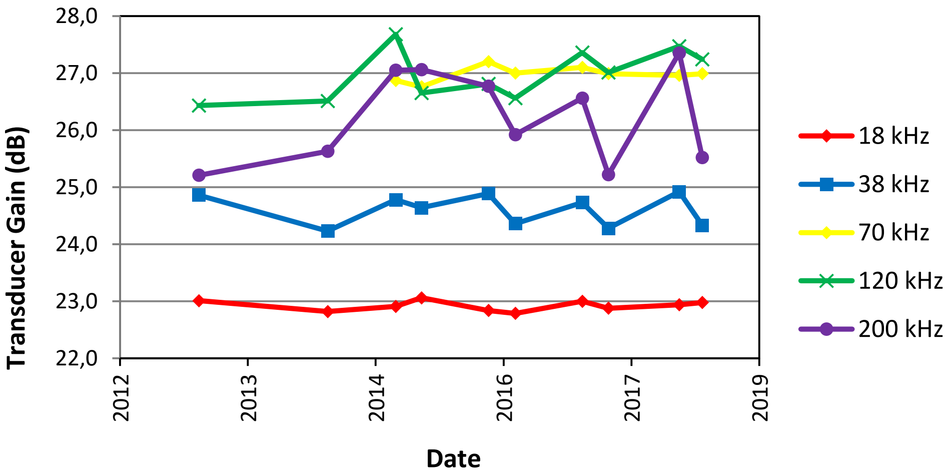


Figure 4. Time series of echosounder gain results for R/V Miguel Oliver. Data correspond to the PELACUS survey (2013-2018) and the MEDIAS survey (2014-2018).

In Figure 5 we can see the Sa correction results of the analysis with the three methodologies from the 38 kHz transducer from R/V Miguel Oliver. The results show that with method 3 we can obtain better sensible results, this method uses all the data registered, so the approach to the theoretical parameters is easier. This behaviour is similar for all the cases analyzed in this study.

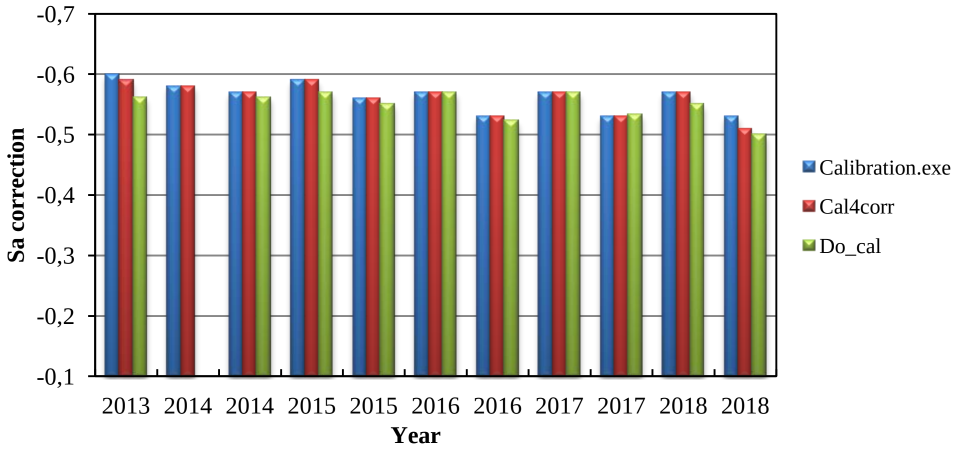


Figure 5. Time series of 38 kHz transducer Sa correction results for R/V Miguel Oliver. The data correspond to the PELACUS survey (2013-2018) and the MEDIAS survey (2014-2018).

Figure 6 and Figure 7 show the calibration gain results for 38 kHz and 18 kHz transducers of the R/V Coornide de Saavedra, like in all the cases analyzed, the gain results for the 18 kHz transducer is lower than the 38 kHz transducer. The results obtained for the three procedures are similar in all the cases with variations around 0.5 dB.

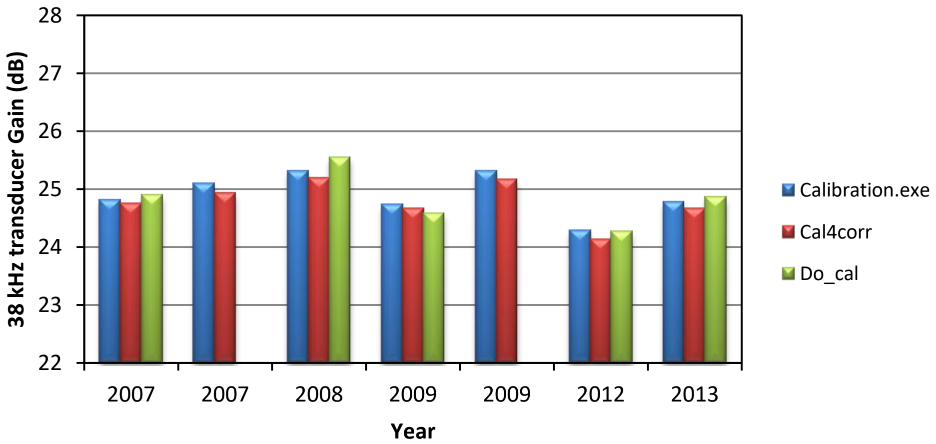


Figure 6. Time series of 38 kHz echosounder gain results for R/V Cornide de Saavedra. Data correspond to the ECOMED survey (2007-2009) and the MEDIAS survey (2009-2013).

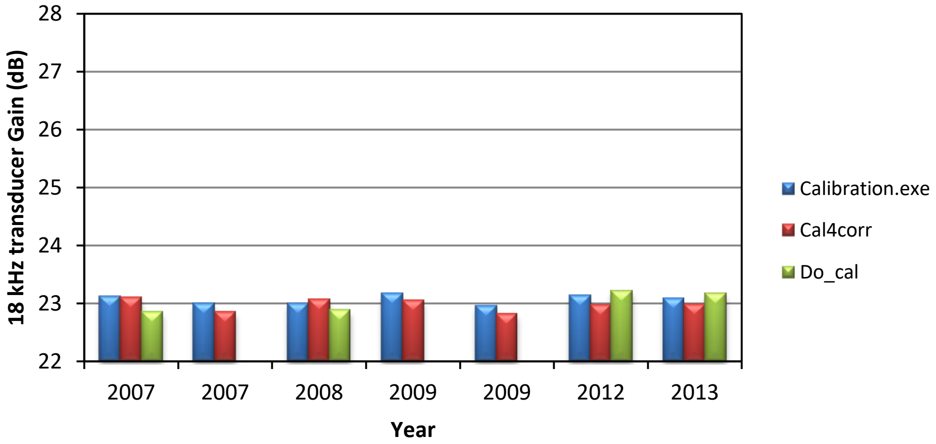
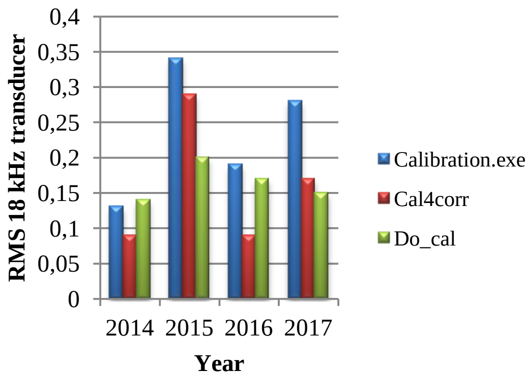


Figure 7. Time series of 18 kHz echosounder gain results for R/V Cornide de Saavedra. Data correspond to the ECOMED survey (2007-2009) and the MEDIAS survey (2009-2013).

Figure 8 shows the results of RMS data for the calibration data of the R/V Ramon Margalef, this vessel has the shortest time series that are analyzed, but the results are similar to the other cases. In all the cases, the biggest differences between the three methodologies used, are shown in the results of the RMS, we can observe in Figure 8 that in the majority of the cases the second and the third methods give better results, so this confirms the convenience of the use of optimization methods to obtain results that are more fitting to the theoretical beam model.

(a)



(b)

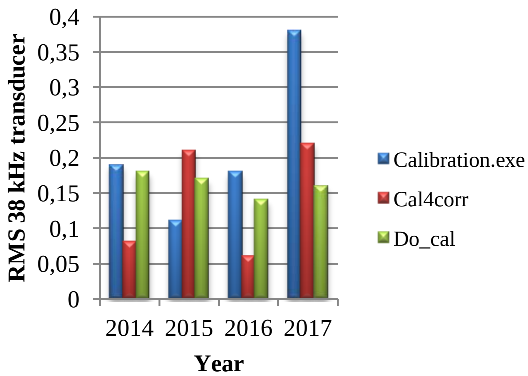


Figure 8. Time series of (a) 18 and (b) 38 kHz RMS results for R/V Ramon Margalef. Data correspond to the ECOCADIZ-Reclutas survey (2013-2017).

4. CONCLUSIONS

This paper shows an analysis of the time series results of the scientific SIMRAD EK60 echosounders calibrations installed in four research vessels used by the IEO in its small pelagic fish stocks assessment surveys with acoustics methods. These vessels have different characteristics and the calibrations have been carried out in different geographical areas and seasons. All the calibrations have been done using the same standardized protocol according to the recommendations from the manufacturer, to minimize the errors.

The data have been post-processed with three different methodologies, using the manufacturer software tool, using the same data but with an ad-hoc Matlab script to do a non linear optimization of all the calibration parameters, and finally using a non linear optimization with restrictions with the raw calibration data.

The transducers gain results show a good stability over the time, principally in the lower frequencies, ceramic transducers have maximum variations around 0.2-0.5 dB. The results for the higher composite transducers are bigger; in all the cases analyzed they are over 1 dB.

The results with the three methodologies show little variations in transducers gain and bandwidth, but big differences in the statistical parameters (RMS), this validates the use of optimization methods.

5. ACKNOWLEDGEMENTS

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