Essential facts of the monitoring of the sand extraction and its impact on the Flemish banks on the Belgian continental shelf from 2003 to 2012.

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Abstract

The monitoring of sand extraction on the Flemish sandbanks of the Belgian continental shelf is based on multiple types of data: statistics derived from the extraction registers, data from the Electronic Monitoring System (EMS = "black-boxes") on board the dredging vessels (complete records are available since 2003), and regular bathymetric surveys with the multibeam echosounders (MBES) EM1002 and EM3002D (installed on the R/V Belgica) across the sandbanks along parallel lines and on specific areas. The analysis of the various types of data provides a 4D (space and time) view of the evolution of the extraction and admits robust and pragmatic conclusions about the real impact of the sand extraction on the marine environment. From 2003 to 2012, the global bathymetric evolution, based on MBES EM1002 and EM3002D measurements along lines across the control zones, confirms the straightforward relation between the extraction and the bathymetrical evolution. On a larger scale, virtually all of the bathymetric variation can be explained by the extraction itself. In areas without any extraction, no significant trend of the bathymetry is observed.

1. INTRODUCTION

According to the Belgian law of 13 January 1969 (Article 3, § 2, 3) which states that "the exploration and exploitation are subject to an ongoing review of the influence of the activities concerned on the movement of sediments and the marine environment ", the Continental Shelf Service conducts a regular monitoring of the sand extraction on the Belgian Continental Shelf since November 1999.

This monitoring is based on different types of data: statistics derived from the extraction registers, data from the Electronic Monitoring System (EMS = "black-boxes") onboard the dredging vessels, and regular bathymetric surveys with the multibeam echosounders (MBES) EM1002 and EM3002D (installed on the R/V Belgica) on monitoring areas and across the sandbanks along the old DECCA lines. The analysis and combination of these different types of data provide a 4D (space and time) view of the evolution of the extraction and allow the assessment of its environmental impact.

The impact of the extraction on the seafloor is studied on two different levels. First, a number of reference areas are surveyed several times each year. The delimitation of these monitoring areas is based on the constant monitoring of the extraction activities with the EMS: they coincide with the most extracted areas. These monitoring zones are studied in detail, with resulting grids of 1x1 m, and provide a good idea of the local impact of the most intense extraction on the seafloor.

Based on this local approach on the most dredged areas, a first internal report summarizes the data acquired from 1999 to 2001 on the impact of

extraction on the Kwintebank (Degrendele et al., 2002). Later, many issues relating to the impact of dredging on the marine environment have been widely discussed in the context of multidisciplinary scientific projects: the international project EUMARSAND (01/11/2002-31/01/2006) funded by the EU and the national projects MAREBASSE (01/02/2002-30/04/2006), SPEEK (15/12/2003-30/04/2006) and QUEST4D (01/01/2007-31/01/2011) funded by the Belgian Science Policy (BELSPO).

From the perspective of sustainable management of the sandbanks, lessons from the European project EUMARSAND and the resulting recommendations (Van Lancker et al., 2010) are of prime importance. Sedimentological and morphological analysis based on data acquired from 1999 to 2005 (before and after extraction) shows the stability of the depression of the Kwintebank after cessation of dredging on February 15, 2003. MBES data demonstrates that regarding the bathymetry and the geomorphology, the extraction has a local non-cumulative impact and that potential recovery is nonexistent (Bellec et al., 2010, Degrendele et al., 2010). The project EUMARSAND also demonstrates that at decadal scale, the sand of the Kwintebank should be considered as a non-renewable resource and that extraction has a local non-cumulative impact.

In addition to this local approach by monitoring restricted areas, the regular surveying of a large number of straight parallel lines along the "DECCA" (old positioning radio system lines) across the sandbanks and the channels in the extraction areas provides us with valuable information on the global evolution of the bathymetry of the sandbanks and the channels and allows a comparison between extracted and non-extracted areas.

This contribution aims to provide a summary of this large scale approach with data acquired between 2003 and 2012. Since 2003, EMS is operational on all vessels operating on the Belgian waters and the resulting database allows an accurate evaluation and mapping of the extracted volumes for any area and time period. From 2008 to 2012, 5 sets of "DECCA" lines across the Flemish banks and their adjacent channels have been recorded with the high resolution EM1002 and EM3002D MBES.

To quantitatively evaluate the impact of the extraction on the bathymetry on a large spatial and temporal scale, these five annual MBES surveys along DECCA lines are correlated with the extracted volumes based on EMS - black boxes data. This approach allows an extension of our spatial and temporal point of view and leads to more robust and pragmatic conclusions on the impact of the sand extraction on the marine environment.

2. EMS DATA

The EMS is a fundamental tool for the control of the extraction because it assesses the extracted volume for any area and for any time interval.

The operating principle of the EMS is summarized in the following paragraphs and in figure 1. The EMS automatically records the following parameters: identification of vessel, code of concessionary, date, time, geographical position, speed, status of dredging pump(s) and dredging activity. All necessary sensors are installed to enable the recordings of the parameters above-mentioned. The acquisition rate depends on the ships' activity with additional records during anomalies of the EMS. The EMS is designed to record the sand and gravel extraction activities on the Belgian part of the North Sea: (1) to verify if the trailing suction hopper dredgers are extracting in the designated areas and (2) to verify the average speed of the ships while dredging. Part of the data processing also involves retrieving metadata fields of the dredging operation, such as date, start time, stop time, concession code, average speed, geographical position recognition and distance calculations of tracks inside or outside the designated areas.

As the EMS is not equipped with sensors to record the load of dredged materials in real-time, a method is developed to estimate the extracted volume of a trailing suction hopper dredger within a certain timeframe. This method is based on the following assumptions:

- The extracted volume (m³) per second is constant, and is based on the known fixed loading capacity of a ship and the duration (in seconds) of the dredging operations.

- The ship is completely empty when the dredging activity starts.
- The ship is completely loaded when the dredging activity ends.

Based on these assumptions and on the calculated time difference between consecutive data points, the extracted volume (m³) is computed for each EMS record. The EMS database can then be used to evaluate the extracted volumes within any timeframe and within any area.

The reliability of the estimation of the extracted volumes from EMS data can be evaluated by comparing the total annual volume calculated from EMS data with the total annual volume independently calculated from the extraction registers. These registers are the extraction quantities that are declared by the extraction vessels. A mean deviation of 3% is observed between the two data sets. This low deviation confirms the validity of the assumptions used as basis for calculating the extracted volumes from EMS data.

3. MBES DATA

Since 2008, one MBES survey has been performed in spring each year along DECCA lines across the Flemish banks in zone 2 (Kwintebank, Buiten Ratel and Oostdyck). Table 1 provides the codes, dates and MBES types of the surveys used in this contribution:

Survey	Date	MBES
C0810	21-25 April 2008	EM1002
C0911	15-17 April 2009	EM3002D
C1011	26-30 April 2010	EM3002D
C1115	16-20 May 2011	EM3002D
C1213	07-11 May 2011	EM3002D

Table 1: table of surveys, dates and MBES types

These measurements are repeated each year around the same period in order to evaluate the global evolution of the sandbanks. More specifically, the impact of the extraction (e.g. Buiten Ratel) or even the possible recovery (e.g. Kwintebank) can be studied on a larger scale using these data.

All data were acquired onboard the R/V Belgica with the EM1002 (2008) and EM3002D (2009-2012) MBES. The quality of the measurements has been evaluated in relation to the reigning hydrographical norm (IHO standards for hydrographic surveys, 5th Edition, 2008, Special Publication N°44). Both vertically and horizontally the EM1002 and EM3002D measurements are within the scope of the confidence interval of the Special Order standard from IHO.

After the processing of the data (position, tide and draught correction, data cleaning) the soundings are modeled. The resulting grids are subtracted from the reference model based on MBES surveys from 2003, showing the bathymetrical evolution since 2003 (Figure 2). A positive difference corresponds with an increase in amount of sediment while a negative difference indicates a decrease.

Compared to the singlebeam echosounder that provides a simple set of bathymetric values along the navigation line, the great advantage of the MBES is the acquisition of a corridor of variable width (function of the depth) with a high density of soundings. Under normal survey conditions the EM3002D, with its 508 beams distributed over an opening angle of 140° and with its ping rate up to 15 Hz, has an average density of 3-4 soundings/m². The high sampling rate combined with a precise real-time correction for heave, roll and pitch gives the data from the EM3002D an unbeatable advantage in statistical credibility and accuracy. For this reason, the bathymetric models of the corridors recorded along the DECCA lines with the EM3002D allow us to assess with a high reliability and precision the bathymetric variation with a reference model.

4. EMS -MBES CORRELATION

The full dataset will enable a joint assessment of the bathymetric variations and volumes of sand extracted during a period of ten years across the the Flemish sandbanks. To quantitatively evaluate the impact of the extraction on the bathymetry on this large spatial and temporal scale, MBES datasets surveyed along DECCA lines results are correlated with the extracted volumes computed from the EMSdata.

This assessment is based on the two following independent datasets (Figure 3 A, B and C):

- For each survey the data are merged to produce a single grid of 5x5 m resolution covering zone 2 of the Flemish banks; each grid represents the bathymetric variation along the DECCA lines between the date of the survey and 2003, date of the reference grid.

- For each survey a grid (100x100 m resolution) of the extracted volumes in zone 2 is estimated from EMS data (black boxes). For each grid cell, the total extracted volume is computed for the same time interval as the bathymetric data.

Using the extracted volume grid, masks are created for successive extracted volume intervals. For each mask, the statistics of all the grid cells included inside the mask are computed for both the extracted volume grid and the DECCA difference grid. Using the extracted volume statistics computed for each mask, an estimation of the mean bathymetric difference due to the extraction is obtained by dividing the mean extracted volume (in m³) with the surface of the mask (in m²). This value represents the theoretical bathymetric (ΔZ component) difference caused by the extraction.

For each survey, the predicted bathymetric differences caused by the extraction activities are compared with the bathymetric differences measured with the EM3002D along the DECCA lines. Tables 2 and 3 and figure 4 summarize the results.

A very high linear correlation is observed between the bathymetric differences measured with the MBES and the bathymetric differences caused by the extraction. It must be underlined that for the whole area where the mean extracted volume is null (no extraction), the bathymetric difference is practically equal to zero (mean value of the 5 surveys = -0.03 m). A slight error on the draft measurement of the ship is sufficient to explain variation as low. Finally, a simple linear regression (weighted by the number of observations and without constant) Y=X allows to summarize the relationship between the extraction and the bathymetric variation observed on the Flemish sandbanks and their adjacent swales with a high statistical level of significance (see table 3 and figure 4 for the detailed statistics).

5. CONCLUSIONS

On the Flemish sandbanks and within a period of 10 years, on a mean point of view, a simple linear relationship is observed between the bathymetric differences measured with the MBES and the bathymetric differences caused by the extraction. At the time scale considered, our results show that the extraction can explain most of the measured bathymetric variations and demonstrate also the natural stability of the Flemish sandbanks.

6. ACKNOWLEDGMENT

3. REFERENCES

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Degrendele, K., Roche, M., Schotte, P., Van Lancker, V.R.M. & Bellec, V., 2010. Morphological evolution of the Kwinte Bank central depression before and after the cessation of aggregate extraction. Journal of coastal research, SI, 51: 77-86.

Van Lancker, V.R.M., Bonne, W., Garel, E., Degrendele, K., Roche, M., Van den Eynde, D., Bellec, V., Brière, C., Collins, M.B. & Velegrakis, A.F., 2010. Recommendations for the sustainable exploitation of tidal sandbanks. SI, 51: 151-164.
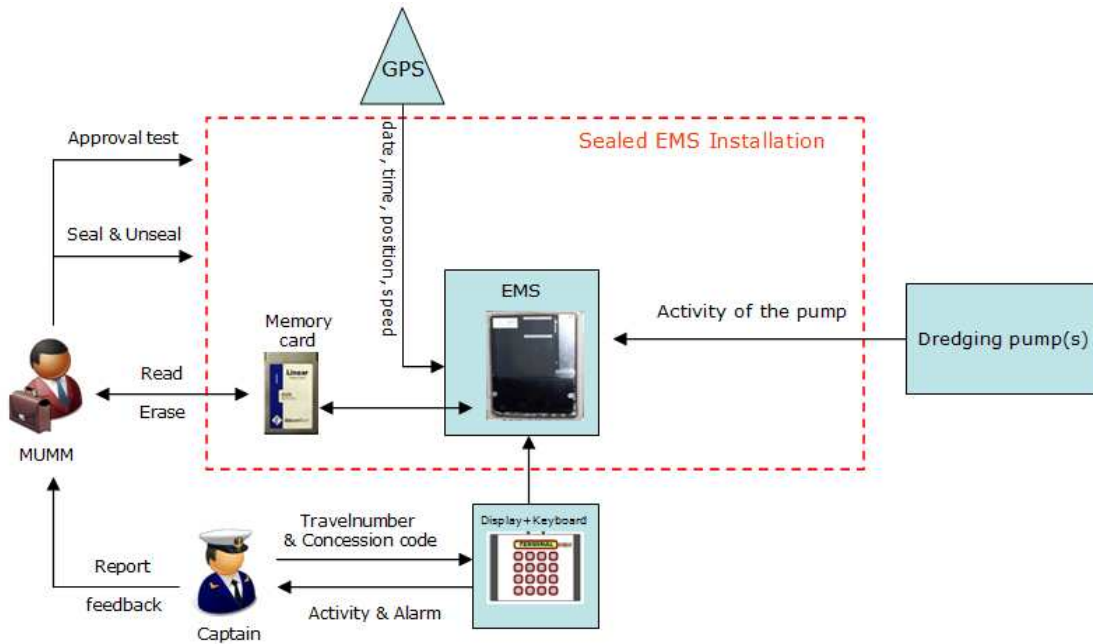
Figure 1: Electronic Monitoring Systems (EMS = "black-boxes").

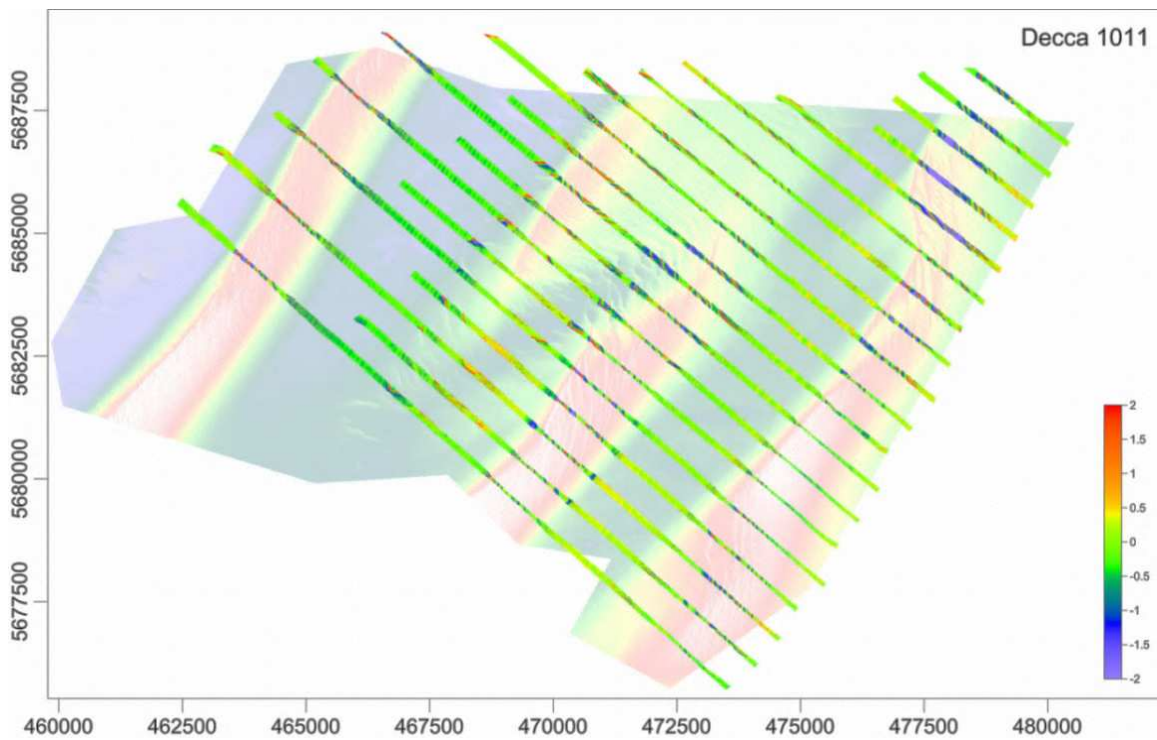Figure 2. Overview of the MBES survey along the DECCA lines in zone 2, obtained during the Belgica 2010/11 campaign, showing the difference (scale bar in meters) with the reference model obtained in 2003 (background image). Orange to red colors indicate an increase in sediment while blue to purple colors indicate a decrease in amount of sediment. Green represents stable areas. Map coordinates are UTM zone 31N and in meter.

A

B

C
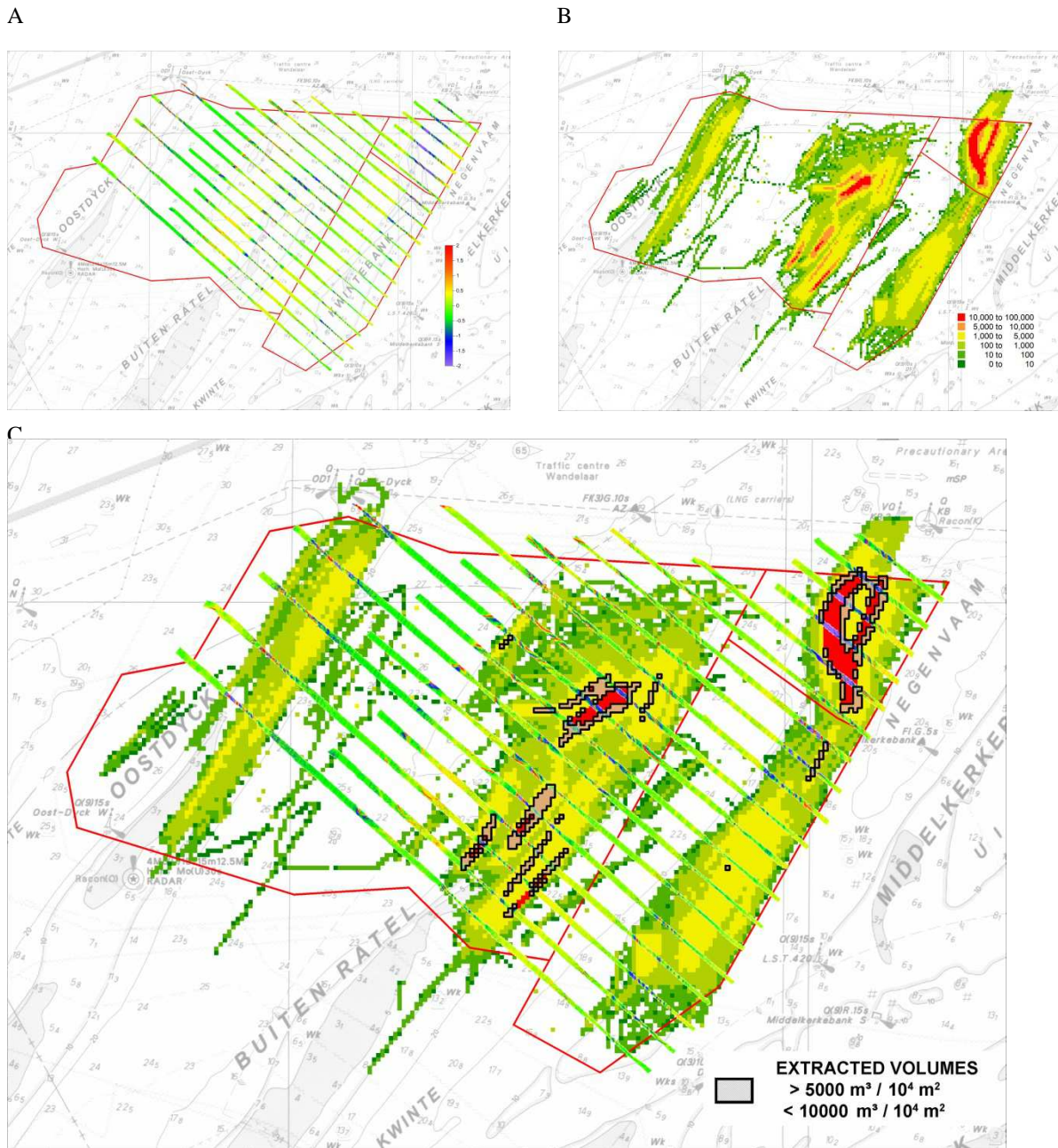
Figure 3 A, B and C: Analysis of the correlation between extracted volumes computed from the EMS data and bathymetric differences measured along the DECCA lines with the MBES; both datasets = same time interval.

A: Bathymetric difference measured with MBES along DECCA lines minus reference model 2003 (in m);

B: Extracted volume (m³/ha or m³/10⁴m²) from the EMS from 2003 to the MBES survey date;

C: Creation of a mask for a volumetric intervals (e.g. 5 10³ m³ < v < 10⁴m³); statistics of all grid cells inside the mask are computed for both layers A and B.

CAMPAIGN	VOLUME INTERVALS (10³ m³/ha)	BATHYMETRIC DIFFERENCE DEDUCED FROM EMS			BATHYMETRIC DIFFERENCE BASED ON MBES MEASUREMENTS		
		mean	std	nb grid cells	mean	std	nb grid cells
C0810	0	0.00	0.00	16740	-0.13	0.41	613784
	>0 and ≤1	-0.02	0.02	6905	-0.13	0.65	415863
	>1 and ≤2	-0.14	0.03	748	-0.24	0.59	43122
	>2 and ≤3	-0.24	0.03	333	-0.31	0.53	21318
	>3 and ≤4	-0.35	0.03	187	-0.39	0.60	9888
	>4 and ≤5	-0.45	0.03	109	-0.61	0.69	8218
	>5 and ≤10	-0.68	0.14	186	-0.88	0.79	13323
	>10 and ≤15	-1.23	0.15	65	-1.31	0.86	3917
	>15 and ≤20	-1.72	0.14	44	-1.97	1.11	3440
	>20 and ≤25	-2.18	0.15	38	-2.66	1.22	3950
C0911	0	0.00	0.00	15768	0.04	0.39	730065
	>0 and ≤1	-0.02	0.02	7335	0.03	0.62	562207
	>1 and ≤2	-0.15	0.03	912	-0.10	0.62	74905
	>2 and ≤3	-0.24	0.03	534	-0.20	0.60	43640
	>3 and ≤4	-0.35	0.03	241	-0.24	0.68	21189
	>4 and ≤5	-0.44	0.03	133	-0.44	0.72	12528
	>5 and ≤10	-0.71	0.15	256	-0.67	0.83	25690
	>10 and ≤15	-1.22	0.15	70	-1.15	0.86	5832
	>15 and ≤20	-1.71	0.14	44	-1.97	1.21	4341
	>20 and ≤25	-2.18	0.15	38	-2.59	1.27	4898
C1011	0	0.00	0.00	15606	0.01	0.42	478146
	>0 and ≤1	-0.02	0.02	7225	0.00	0.64	398929
	>1 and ≤2	-0.14	0.03	978	-0.14	0.62	57576
	>2 and ≤3	-0.24	0.03	555	-0.22	0.56	32063
	>3 and ≤4	-0.34	0.03	284	-0.32	0.70	19013
	>4 and ≤5	-0.45	0.03	168	-0.40	0.80	14480
	>5 and ≤10	-0.70	0.14	318	-0.69	0.77	24003
	>10 and ≤15	-1.22	0.15	94	-1.06	0.87	6425
	>15 and ≤20	-1.72	0.15	59	-1.66	1.10	5186
	>20 and ≤25	-2.18	0.14	42	-2.59	1.30	4032
C1115	0	0.00	0.00	15547	-0.04	0.44	339484
	>0 and ≤1	-0.02	0.02	6734	-0.05	0.66	253207
	>1 and ≤2	-0.15	0.03	992	-0.18	0.65	37725
	>2 and ≤3	-0.25	0.03	606	-0.27	0.63	20526
	>3 and ≤4	-0.35	0.03	294	-0.34	0.68	11408
	>4 and ≤5	-0.45	0.03	186	-0.54	0.83	8810
	>5 and ≤10	-0.70	0.15	363	-0.76	0.83	17383
	>10 and ≤15	-1.21	0.14	142	-1.21	0.90	7621
	>15 and ≤20	-1.71	0.14	71	-2.09	1.27	3073
	>20 and ≤25	-2.21	0.15	57	-2.72	1.28	3880
	>25 and ≤30	-2.67	0.13	17	-1.62	1.23	460
C1213	0	0.00	0.00	15271	-0.03	0.45	308798
	>0 and ≤1	-0.02	0.02	6807	-0.04	0.66	255822
	>1 and ≤2	-0.15	0.03	918	-0.13	0.70	34954
	>2 and ≤3	-0.25	0.03	652	-0.29	0.66	24377
	>3 and ≤4	-0.35	0.03	390	-0.30	0.66	16603
	>4 and ≤5	-0.45	0.03	192	-0.46	0.83	8718
	>5 and ≤10	-0.70	0.14	394	-0.72	0.84	17948
	>10 and ≤15	-1.24	0.15	167	-1.04	0.84	8148
	>15 and ≤20	-1.70	0.13	99	-1.45	1.10	5212
	>20 and ≤25	-2.22	0.15	57	-2.23	1.29	3974
	>25 and ≤30	-2.68	0.12	28	-2.67	0.99	431
	>30	-3.64	0.47	38	-2.91	1.44	2042

Table 2: Correlation EMS - MBES measurements. Table of results per survey

	REGRESSION PARAMETERS			CORRELATION	
	Coefficient Y= a X	Standard Error	p-Value	Adjusted Squared Multiple R	Standard Error of Estimate
C0810	1.225	0.198	0.000	0.809	0.188
C0911	1.043	0.079	0.000	0.951	0.090
C1011	1.012	0.045	0.000	0.983	0.050
C1115	1.119	0.062	0.000	0.970	0.065
C1225	0.900	0.037	0.000	0.982	0.049
ALL DATA	1.035	0.041	0.000	0.925	0.103

Table 3: Results and statistics of weighted linear regressions without constant Y (MBES) = a X (EMS) Table of results per survey and for all the data together.
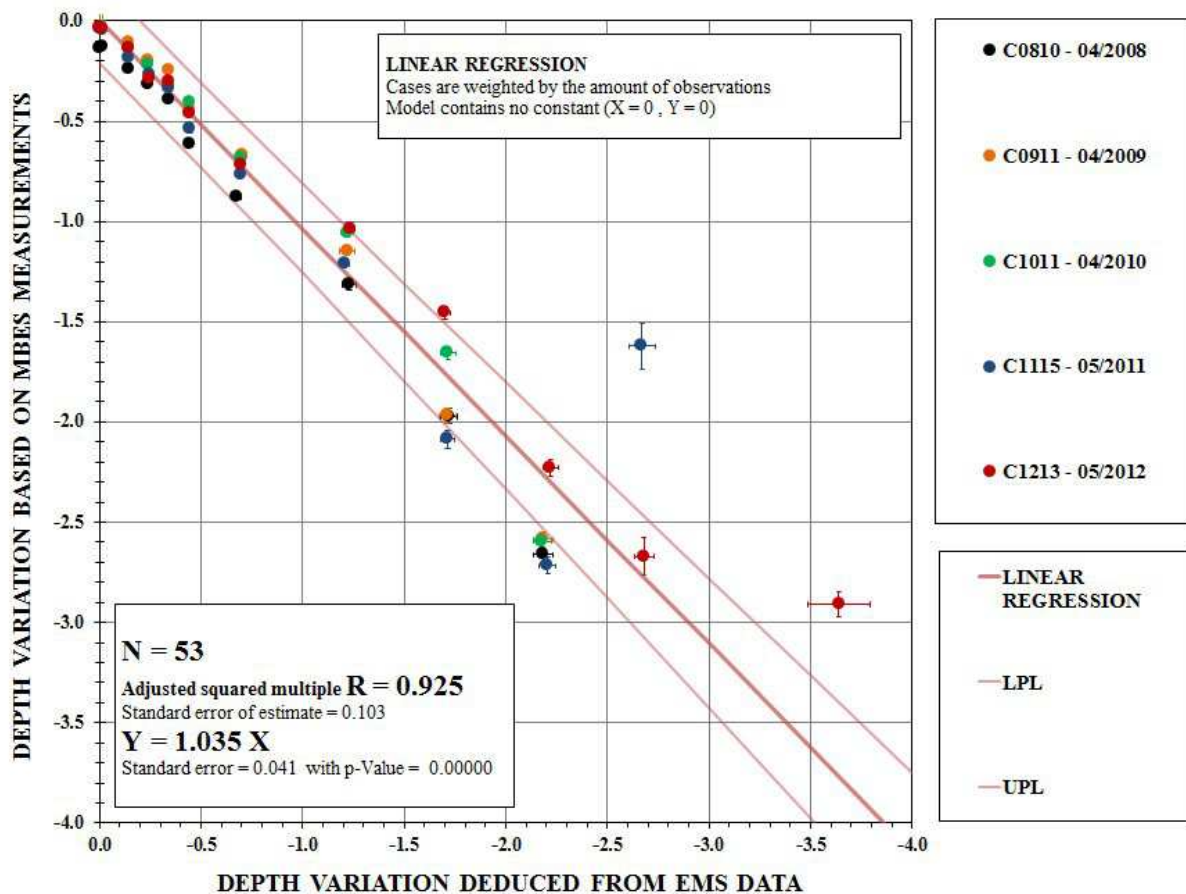

Figure 4: Plot of the bathymetric difference measured with the MBES *versus* the bathymetric difference deduced from EMS data; standard error of each measurement; weighted linear regression line without constant based on all the data together and related statistics.