Analysis of Bathymetric Datasets Quality : A Margin Case Study

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Abstract : *In this study, we compare various bathymetric datasets with inhomogeneous quality which can be used to model the sub marine relief. Accurate bathymetric datasets as Multi beam echo Sounder data are analysed in two acquisition contexts: vessel's transit and scientific or hydrographic surveys. The chosen area is the south of the Iberian margin (near the Gulf of Cadiz) where a strong current takes place: the Mediterranean Outflow Water (MOW) which can modify the water column structure and then the acoustic wave propagation of the sounders. The data are qualified and cross-validated. We compare the measurement data points and the resulting MBES models with global models (ETOPO1/GEBCO and the V11.1 model of Smith and Sandwell). The contribution of each data type is analysed in term of applications (shelf study, hydrographical needs and applications etc..).*

In this study, we compare different bathymetric datasets with high quality discrepancy:

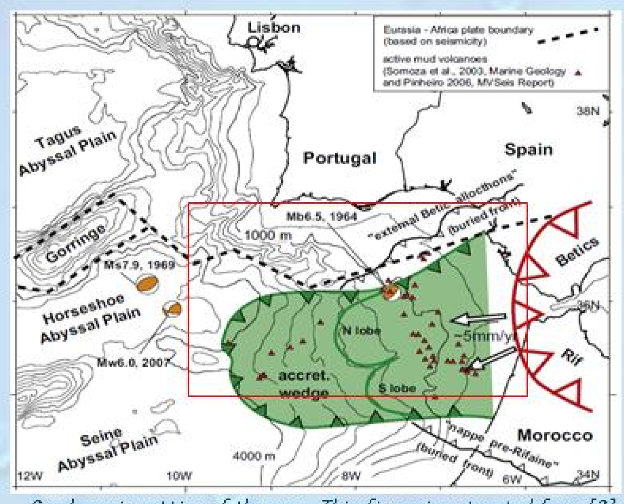
- single beam and multibeam soundings acquired during transit lines
- multibeam soundings collected during two scientific surveys
- two global models: ETOPO1/GEBCO, v11.1 model of Smith and Sandwell.

The data were selected among a subset of existing bathymetric data on this zone [2].

This data quality analysis is the preliminary stage of a data fusion problematic. Currently, SHOM service works, within the ENVGEO framework, on fusion techniques of gridded and in-situ Bathymetric datasets, in a manner that accounts for data uncertainty. Moreover, data uncertainties knowledge acts as constraints on DTM interpretation in terms of hydro dynamical, morphological and geological aspects.

This oceanographically complex area located off the strait of Gibraltar is under the influence of a strong current: the Mediterranean Outflow Water (MOW) [1]. This current which is at the origin of the giant Contourite Depositional System and the earthquake activity explain the complexity of its seabed. Both features arouse scientific interest.

Gulf of Cadiz: Studied area



Geodynamic setting of the area. This figure is extracted from [2]

A complex geodynamical area:

This geodynamical and geological area is **well-known**. The studied area is located off the straits of Gibraltar, lying astride a complex boundaries between the Africa and Eurasian plates

The region corresponds to an accretionary wedge related to the subduction of the oceanic lithosphere eastward the Befic-rif Alboran sea.

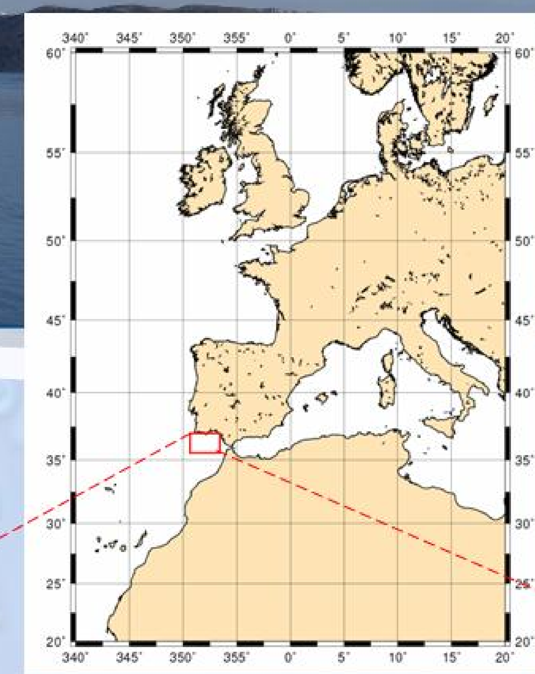
A west movement of the tectonic block (5mm/yr) is moreover observed from GPS data.

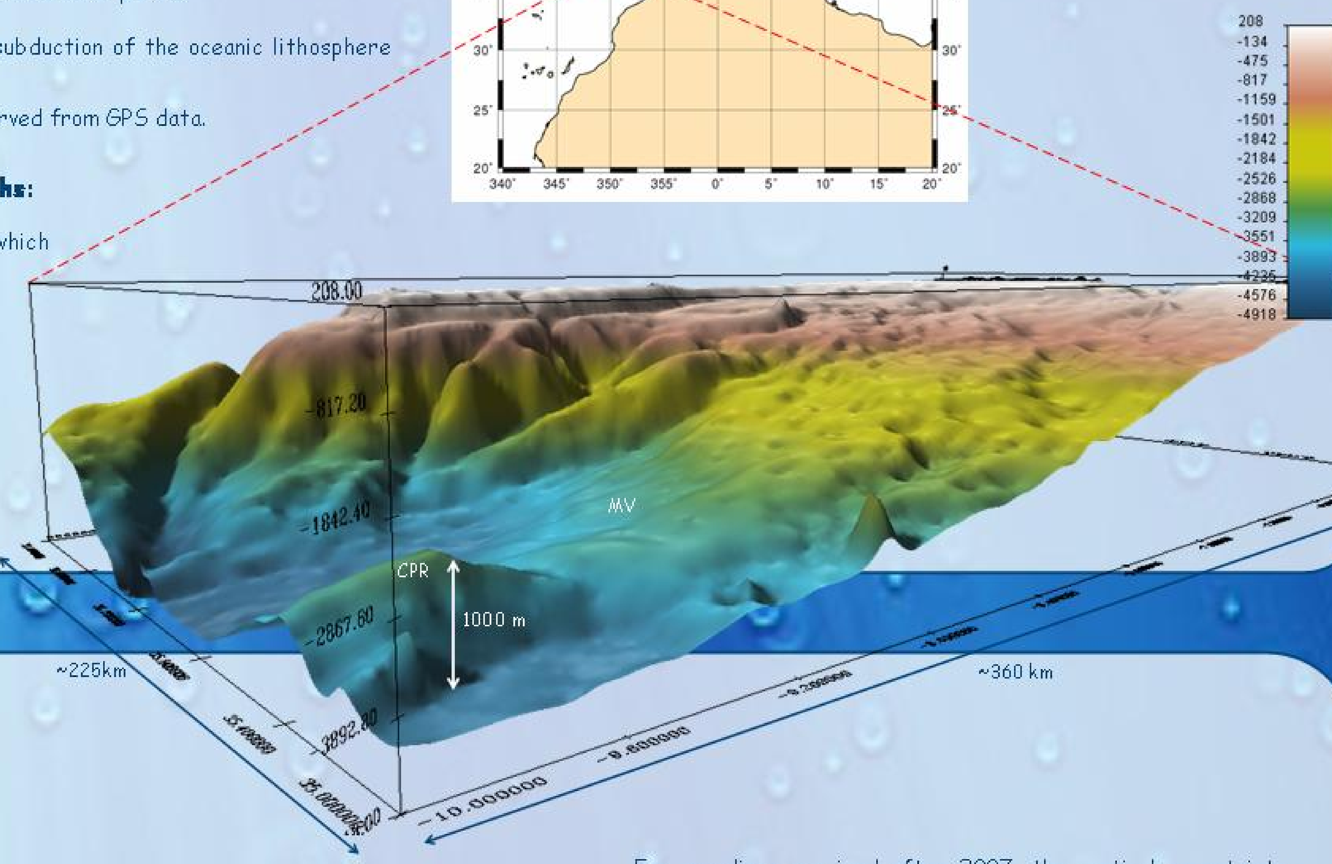
Our seafloor map highlights structures of various lengths:

The **Coral Patch Ridge** (CPR) an ESE trending basement high which indents the high rugosity sedimentary slope

The **hummocky slope** gently dips to the west with slope values ranging from 0.8° to 1.2°/ This wedge depicts sub kilometric wavelength structures with typical vertical drop of 200 m.

A **mud volcano** (MV) has been studied by Gutscher and al. [2]. This structure, located at N 35°30 and W 9°, is about 450 m thick and has a width of about 2.5 km

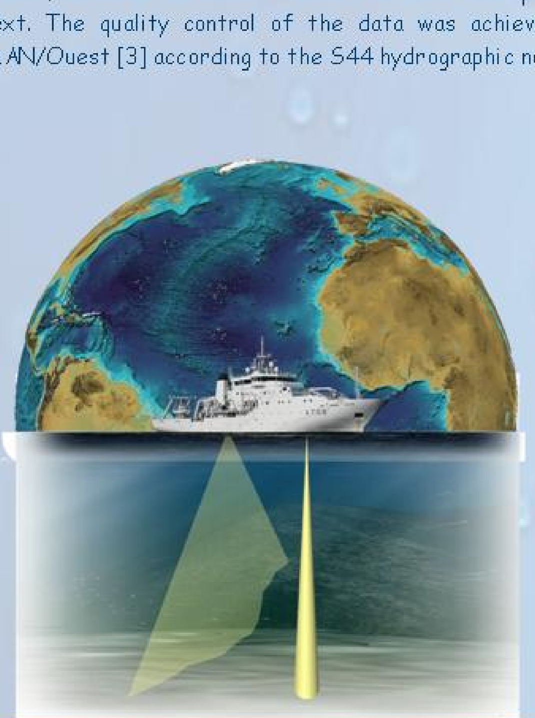




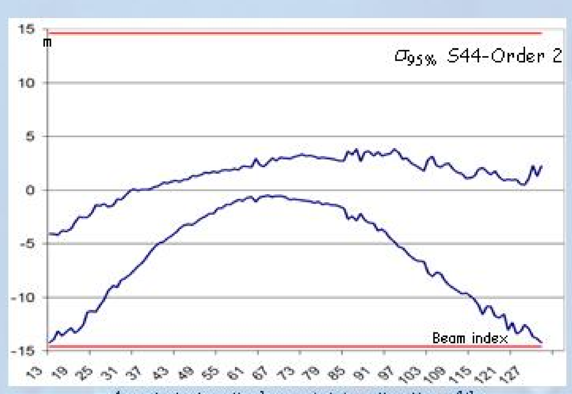
Datasets description

The multibeam raw datasets acquired during the two scientific cruises - CADISAR1 and CADISAR2 were provided by SISMER. These two bathymetric datasets were acquired in 2001 and 2004 using a SIMRAD EM300 multibeam echosounder installed onboard the R/V *Le Suroît*. This 30 kHz system is capable of full swath mapping in depth ranges up to 5000m. It runs with up to +/- 75° angular swath with 135 beams per ping, with beamwidths as narrow as 1°x2° depending on water depth. Its accuracy is 0.2% of water depth at nadir, and 0.5% of water depth between 60° and 70° off-nadir.

These two multibeam datasets were processed using the IFREMER/Caraibes software within the ENVGEO project context. The quality control of the data was achieved by ALTRAN/Ouest [3] according to the S44 hydrographic norm

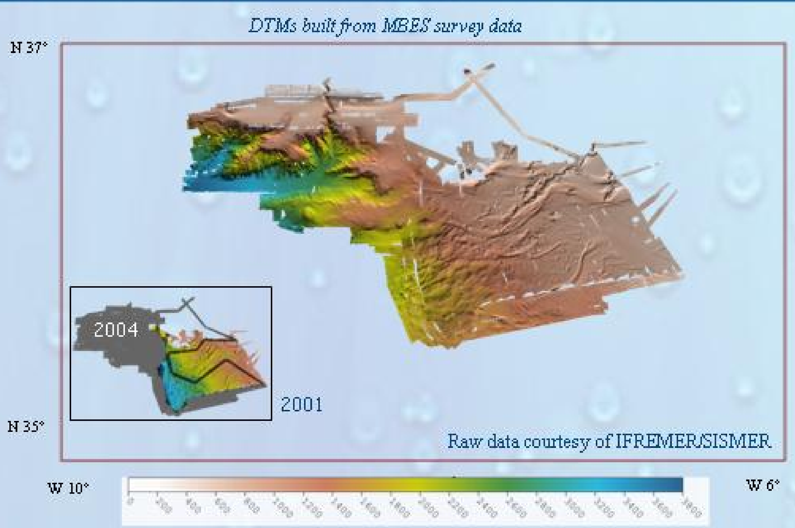


The validation process has invalidated 9.8% of 31.4 millions of soundings acquired on the east side (*resp.* 12.8% of the 30 millions soundings on the west side). These high rates of invalidated soundings are explained by the complexity of the water mass in this area, that leads to filter the outerbeams. Despites these sound velocity artifacts, internal consistency checks on track's intersections show that the resulting MBES dataset falls within the S44-Order 2 [4]. The figure below represents the vertical uncertainty estimated across the swath. The vertical uncertainty was locally estimated at 0.11% of water depth on nadir and 0.4% on external beams.



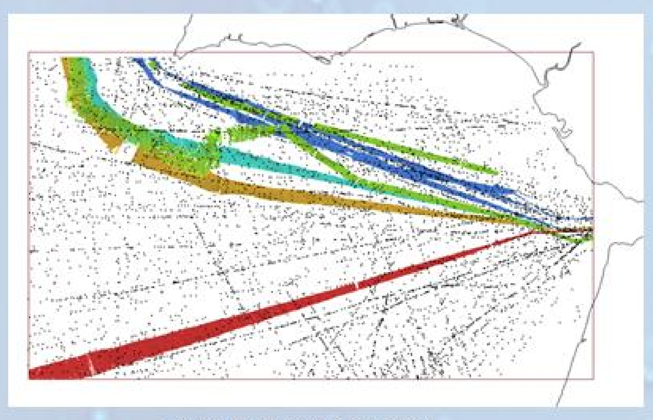
A posteriori vertical uncertainty estimation of the MBES survey data at 630m of water depth.

DTMs built from MBES survey data



Raw data courtesy of IFREMER/SISMER

Our study area lies off the Southwest coast of Iberia. Besides of its morphological and environmental behaviours, this area presents the advantage of being close to the strait of Gibraltar. Number of ships and particularly hydrographic vessels pass across it, when sailing back to their port of registry in the Atlantic ocean. In addition to the two multibeam survey datasets, other conventional bathymetric data was collected between 1954 and 2008 using both single and multibeam systems.


Archive bathymetric data coverage

Compared to the tens millions of soundings acquired during the two surveys, **the archive bathymetric data** represents less than 2 millions of soundings. This dataset is composed of two types of measurements: single beam (SBES) data acquired before 2000 and multibeam (MBES) data.

98% of the **SBES dataset** comes from one survey line. These soundings were acquired using a 12kHz Raytheon depth recorder installed onboard "D'*Entrecasteaux*" (SHOM). The seafloor was mapped with a 32° beam width using GPS navigation system.
The ship's localization is best than 10m, being punctually degraded to 100m depending on the GPS acquisition mode. Sounding's vertical accuracy is estimated to be better than 1% of the water depth.

98% the archive data were mainly acquired using the **MBES** systems installed onboard "*Beautemps beaupré*" (SHOM). This ship is equipped with two separate multibeam mapping systems, one for shallow water (95kHz Simrad EM1002) and one for deep water (12 kHz Simrad EM120). The EM1002 system operates from shoreline to 1000 metres. It forms 111 receive beams with a spacing of 2° distributed across track and 2° wide along track. The other system, namely the SIMRAD EM120 operates at 12 kHz to map depths from 500 to 11000 meters. The beam geometry of these systems can generate up to a 150° swath that can cover as much as 7.4 times the water depth. Both systems surpass the IHO standards: a 0.2% vertical uncertainty for the EM120 nadir beams and ~0.3% for the EM1002 nadir beams.

Survey report's conclusions show that before 2007, the MBES transit datasets fell within the last order precision given in order-4: which means that the area was not completely insonified in the hydrographically term as defined by the S44 standard.

For soundings acquired after 2007, the vertical uncertainty was deduced from previous MBES performances tests as no cross lines were carried out. The bathymetric data fall within the S44-order 3.
Due to the huge amount of MBES data, a subset of soundings is stored in the data base. The selection process is based on a "shoal-biased" approach to preserve navigation dangers.

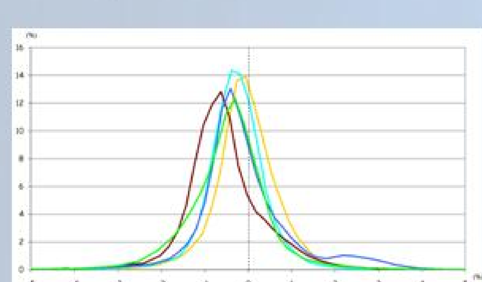
Several **global relief models** of the Earth's surface exist. These grids are build in different manners amongst which their resolution, data sources and building process. The diversity of global models demonstrates the constant effort for providing the "marine" community with fine and accurate bathymetric grids. In counterpart, the coexistence of global grids obscure decision making user process, as no objective and precise criteria are available for choosing one of them.

Two among the - at least - six global digital bathymetric grids available were selected, the ETOPO 1 [6] and the V11.1 Smith and Sandwell model [7].

The ETOPO1 is a 1-minute global relief grid of the Earth's surface. It is a product of NGDC. This model combines different global and regional datasets (on the oceans the model is derived from altimetry and ocean soundings - no precision on the version used and on the building process is given). ETOPO 1 model of our studied area is included in the GEBCO estimated seafloor bathymetry.
The Smith and Sandwell model is derived from satellite altimetry and marine bathymetric measurements. The transfer function between the satellite derived gravity signal and the bathymetry is used to model the relief of the oceans. For more details you can read the reference papers [8].

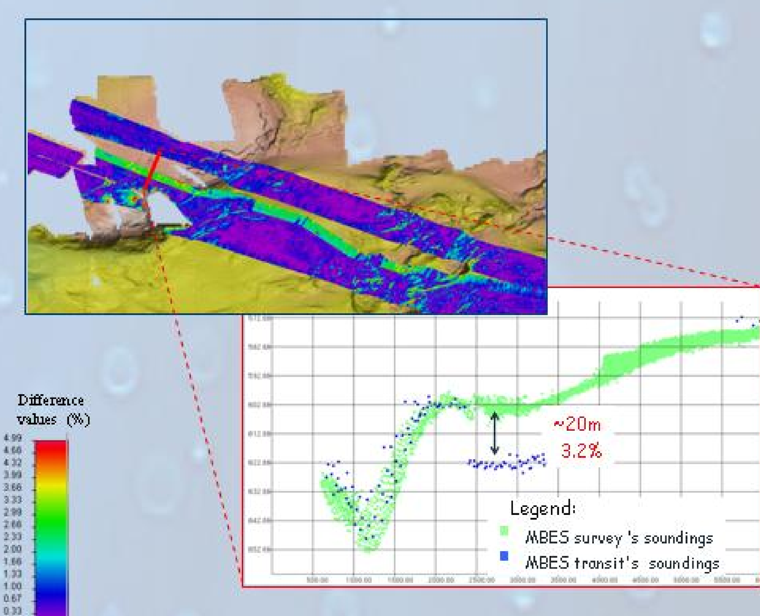
Data cross-validation

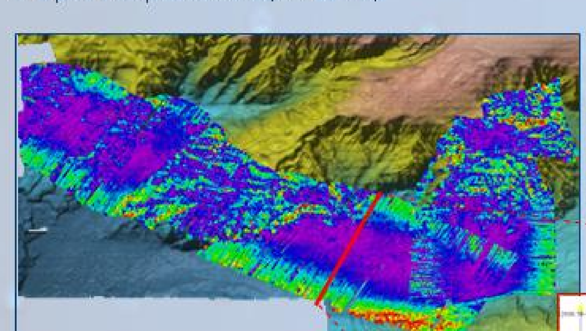
MBES: transit soundings versus survey DTM

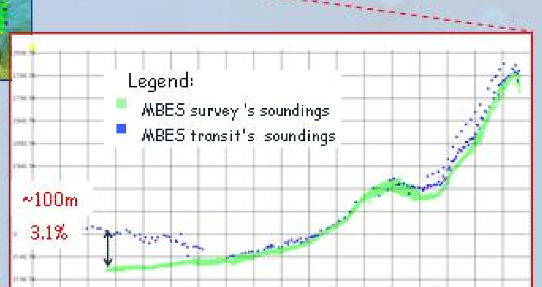

Histograms of the differences built line by line

MBES soundings acquired during each transit line were compared to MBES DTM. The results of this cross-validation were firstly analysed using global statistics. Whatever the transit line, the average difference is less than 0.5% of the water depth. As depicted by the figure on the left, the sampling distribution varies according to the line observed. In particular, the width of their mode and the length of their tails show that differences datasets are not normal populations. Moreover, higher differences can reach 25% of water depth.

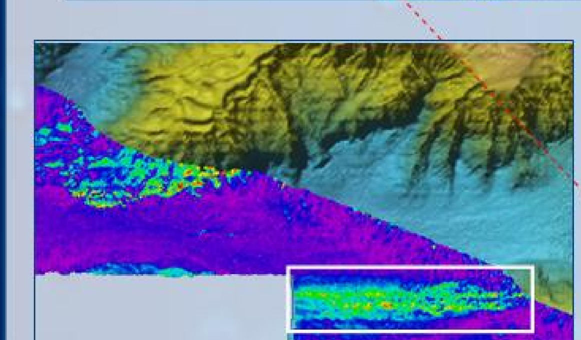
This global analysis was completed with local ones based on differences maps. Attention was paid on aggregates of high difference values. They are of two types depending on their shape which can be correlated with the swath tracks or the bathymetry rugosity. Aggregates correlated with the swath highlight artefacts in the datasets. As depicted by the figure on the left, differences maps show a dysfunction that punctually affects a subset of the EM120 external beams. As expected on this area, sound velocity artefacts are punctually observed (see below).





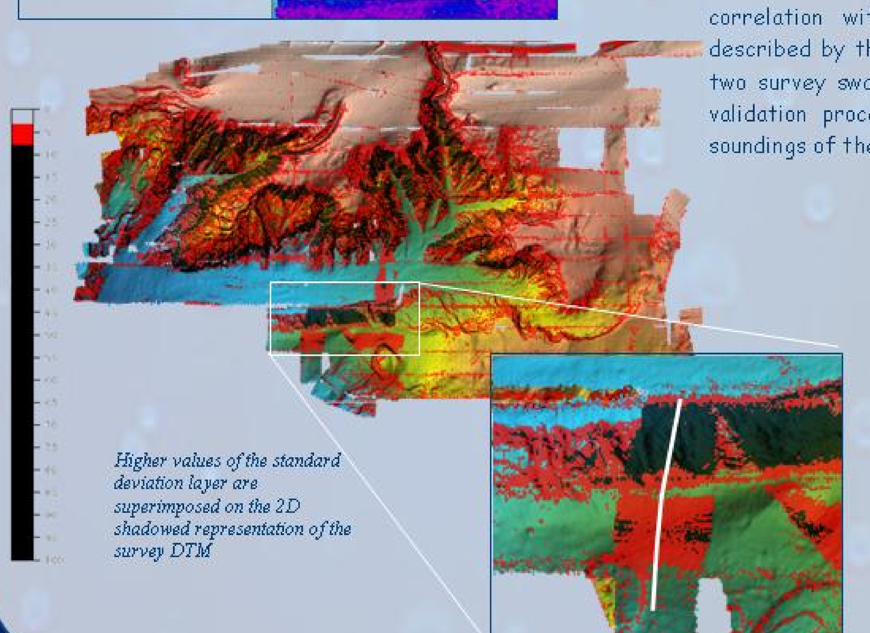


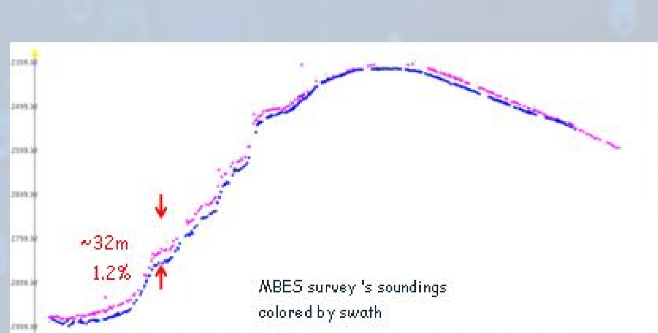
If other encountered aggregates are correlated with the bathymetry rugosity and may be mainly explained by the algorithm used to reduced the MBES dataset before its storage in database, one of them have retained our attention.



This aggregate is located on a high slope affecting only a limited part of it. Further investigations of the MBES surveys soundings datasets show it correlation with survey tracks crossovers. The bathymetric profile described by the soundings were colored by swath. The disparity between two survey swathes was already seen but not resolved within the survey validation process. The investigation can be continued as one of the soundings of the transit MBES fit one of the two swath soundings subsets.

Higher difference values highlight the presence of outliers in the MBES soundings datasets, which mainly affects the outerbeams of one transit line.


Higher values of the standard deviation layer are superimposed on the 2D shadowed representation of the survey DTM

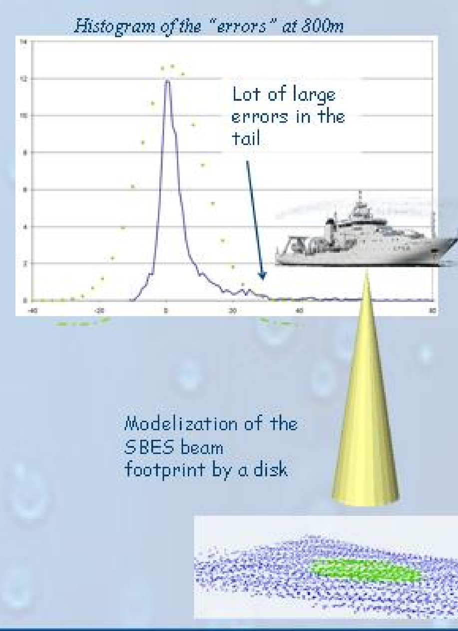


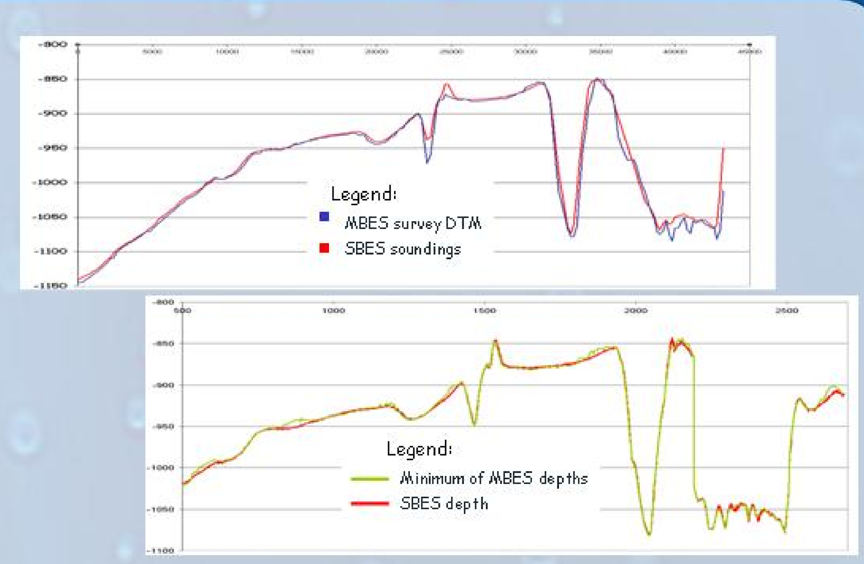
SBES transits versus MBES survey's DTM

The comparison between SBES measurements and MBES grids were extremely limited as SBES soundings are sparsely-distributed. The analysis was carried out only on SBES data acquired after 1999.

SBES soundings of that survey were acquired along two track lines that pass across MBES DTM. Differences between SBES soundings and MBES grid were computed. It appears that 5.9% of the errors exceed the maximum fixed by S44-order 2, which tolerates a maximum of 5%. As depths vary along the swath from 300 to 2000meters, empirical distributions of the "errors" were computed at different water depths. The results we obtain confirm those published by Marks and Smith in [9] : the "errors" do not follow a Gaussian distribution. Large errors contained in the tail of the distribution are located on areas of high slopes as depicted by the cross section built along the SBES swath. This observation can be explained by the 32 degree beam footprint of the single beam echo sounder. The measurements of a SBES were then simulated using the MBES soundings as reference.

Histogram of the "errors" at 800m

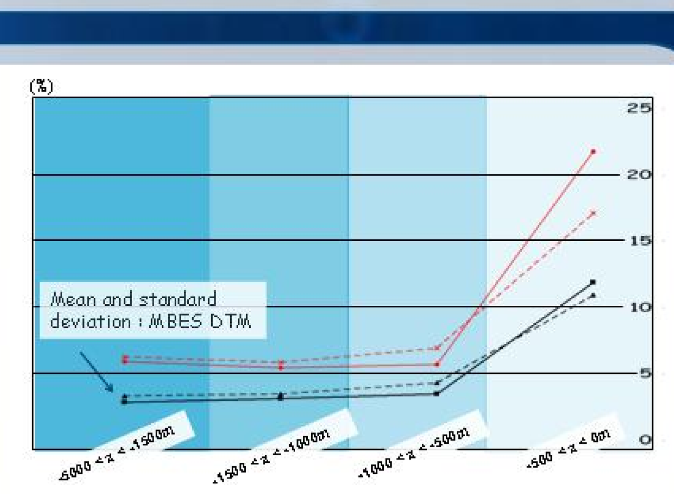




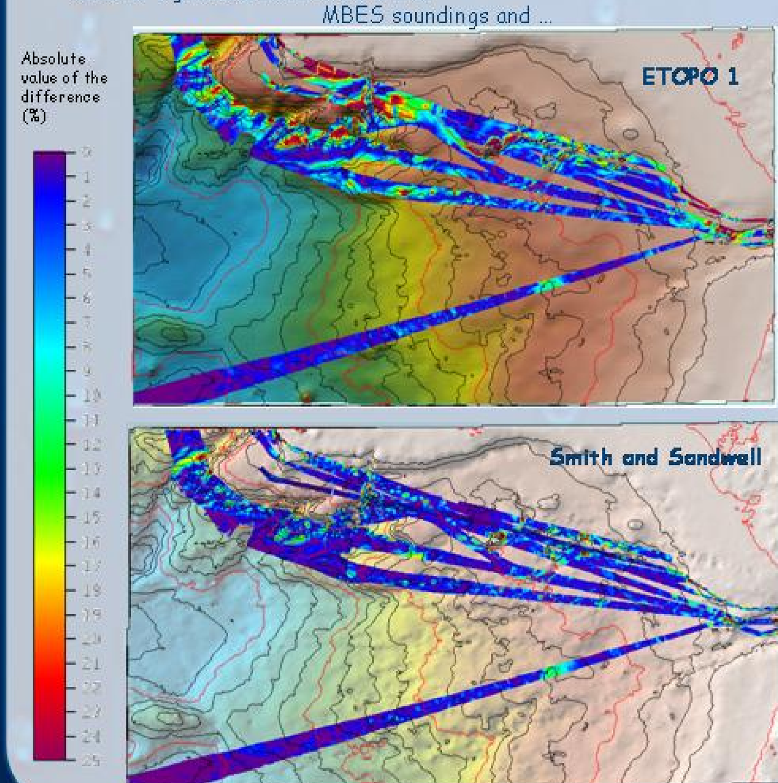
The beam footprint was modelized using a disk with a radius defined as a function of the depth. As attempted, the SBES soundings mainly vary according to the shoalest depth belonging to its footprint. As mentioned by Mark and smith in [9], the SBES uncertainty is also a function of the slope.

Global bathymetric DTM versus MBES data

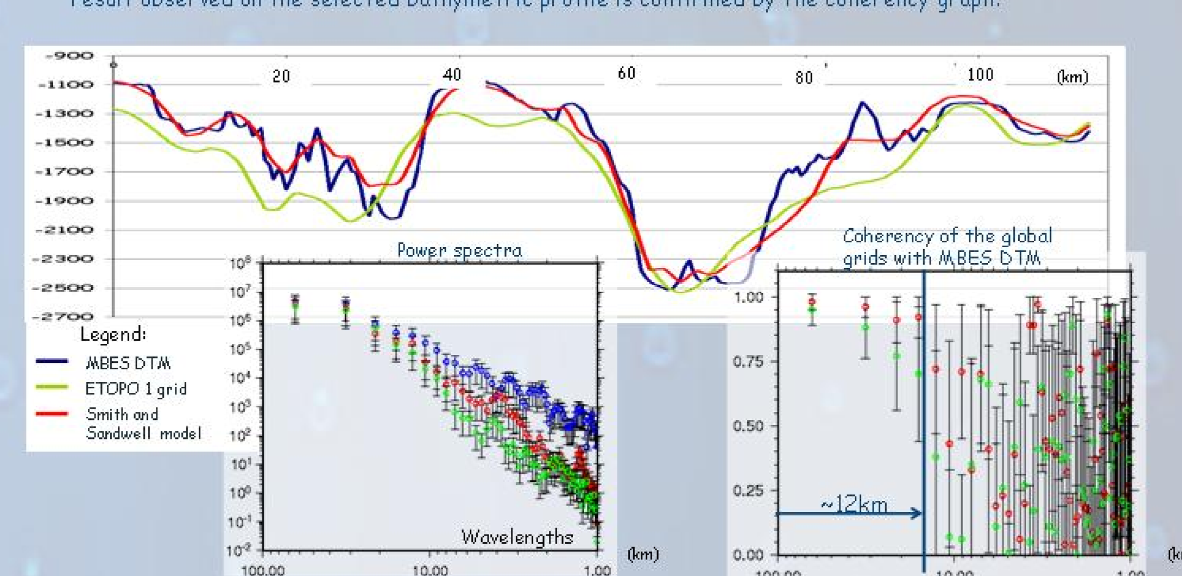
The differences were calculated between the global bathymetric grids and the two MBES datasets: MBES grids and MBES soundings. The conclusions are the same. The global statistics were computed according four classes of water depth:]-5000, -1500],]-1500, -1000],]-1000, -500],]-500, 0]. The maximum, minimum, mean and standard deviation values of the differences, for each MBES transit lines, show that the trend's feature of the two bathymetric models are similar. The higher differences are observed for water depth lower than 500m. Nevertheless, the Smith and Sandwell model gives better results than the ETOPO 1 grid even for water depth lower than 500m. Results obtained between global grids and MBES grids are the same. The differences maps point out that high values are gathered both on areas of high slopes and water depth lower than 500 meters. If the behaviours of the two differences maps are similar, once again, higher differences values are observed between the ETOPO 1 grid and the MBES DTM.



MBES soundings and ...



A bathymetric profile of 100km length allows comparing the three DTMs in terms of wavelengths. On the graphic depicting the signal energy for different wavelengths, we notice a slope break at 30 km for the ETOPO1 grid while the slope break of the Smith and Sandwell model occurs at approximately 10 km. This result observed on the selected bathymetric profile is confirmed by the coherency graph.



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Conclusions

Our quality analysis study shows that, even in a very complex area, the vertical uncertainties of MBES surveys qualified as S44-order 2 are clearly better than this standard (~2.3% z for our study). If MBES data collected during scientific surveys are very accurate, their coverage represents a few percent of the total area (less than 20%). That's the reason why, archive transit data have to be used to complete the bathymetric knowledge. As we have seen, validation process of such data is limited (S44-order 3 or 4 for MBES transits and worst for SBES soundings). If global bathymetric DTM are used, one has to keep in mind that they degrade rapidly with high rugosity area and in water depth lesser than 500m. DTM production within a fusion context needs a rigorous and complete data analysis process analogous to the one being done here. Our data quality analysis was done on bathymetric measurements and not model: implying that the storage of bathymetric data must preserve the spatial resolution of the sensor. In this framework, the fusion will be processed with respect to the expected application.