Analysis of Bathymetric Datasets Quality : A Margin Case Study

- Introduction
- Datasets description
- Data cross validation: results
- Conclusions

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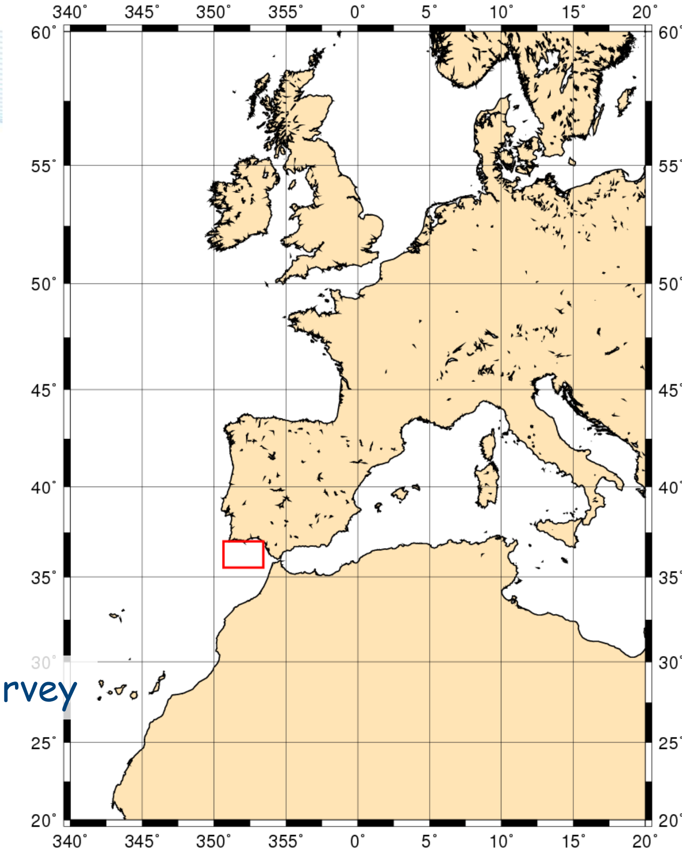
Purpose of this study



Comparison of bathymetric datasets with high quality discrepancy

- Single beam datasets
- MBES datasets acquired in { vessel transits / scientific or hydrographic survey }
- Global DTM { ETOPO1/GEBCO / V11.1 model of Smith & Sandwell }

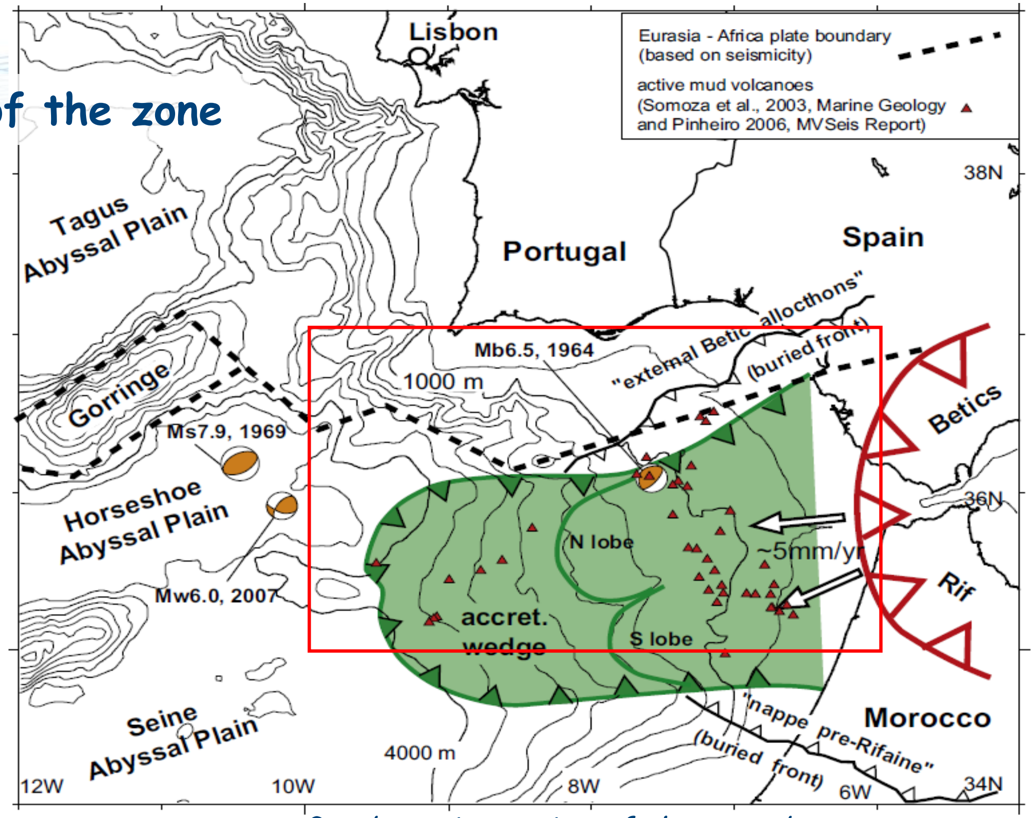
This studied area is **complex**:

- MOW Mediterranean Outflow Water
- Bathymetric rugosity
- Geo dynamically

Description of the zone

This geodynamical and geological area is **well-known**. The studied area is

- located off the straight of Gibraltar
- a complex boundaries between the Africa and Eurasian plates.



*Geodynamic setting of the area **

"Tectonic shortening and gravitational spreading in the Gulf of Cadiz accretionary wedge: Observations from multi-beam bathymetry and seismic profiling", Marc-André Gutscher et Al., Marine and Petroleum Geology 26 (2009) 647–659

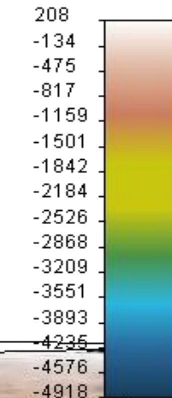
The region corresponds to an accretionary wedge related with the subduction of the oceanic lithosphere eastward the Befic-rif Alboran sea.

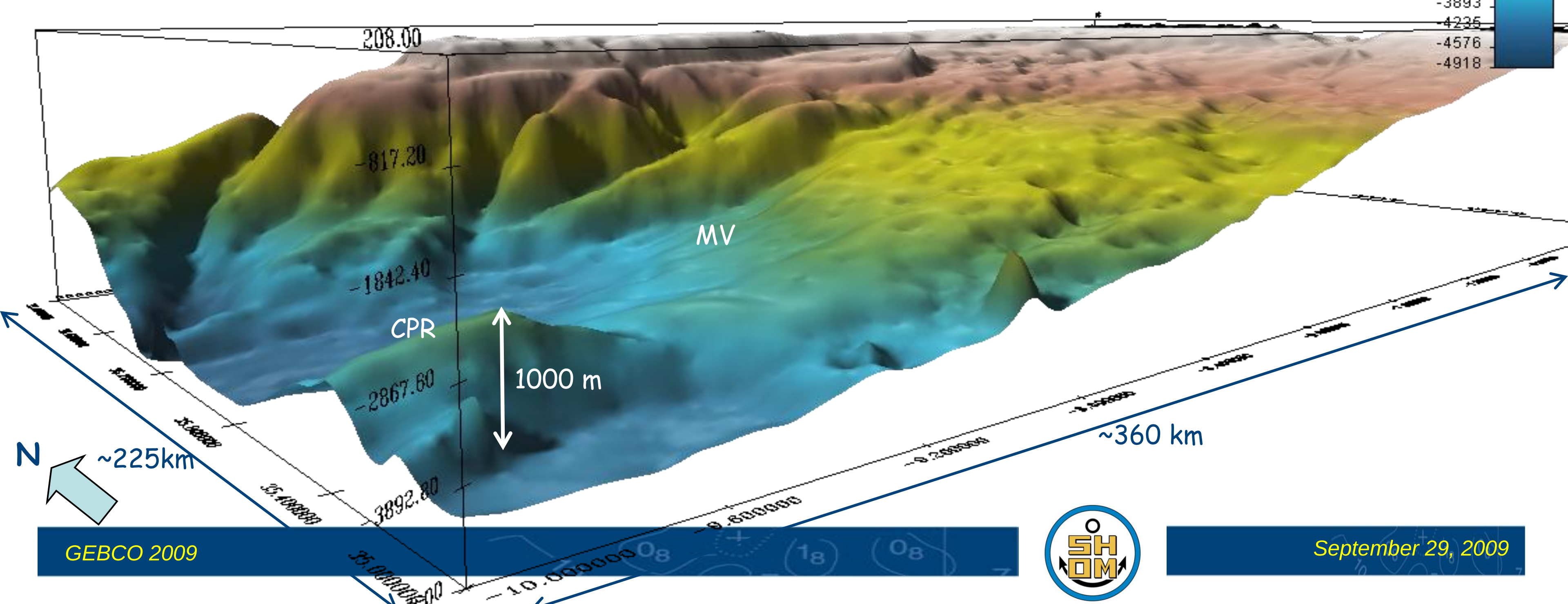
A west movement of the tectonic block (5mm/yr) is moreover observed from GPS data.

Morphological behaviour of the studied area

Our seafloor map highlights:

- 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 getting 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. This structure, located at N 35°30 and W 9°, is about 450 m thick and has a width of about 2.5 km





Main goals of this quality estimation study

Data **fusion** framework

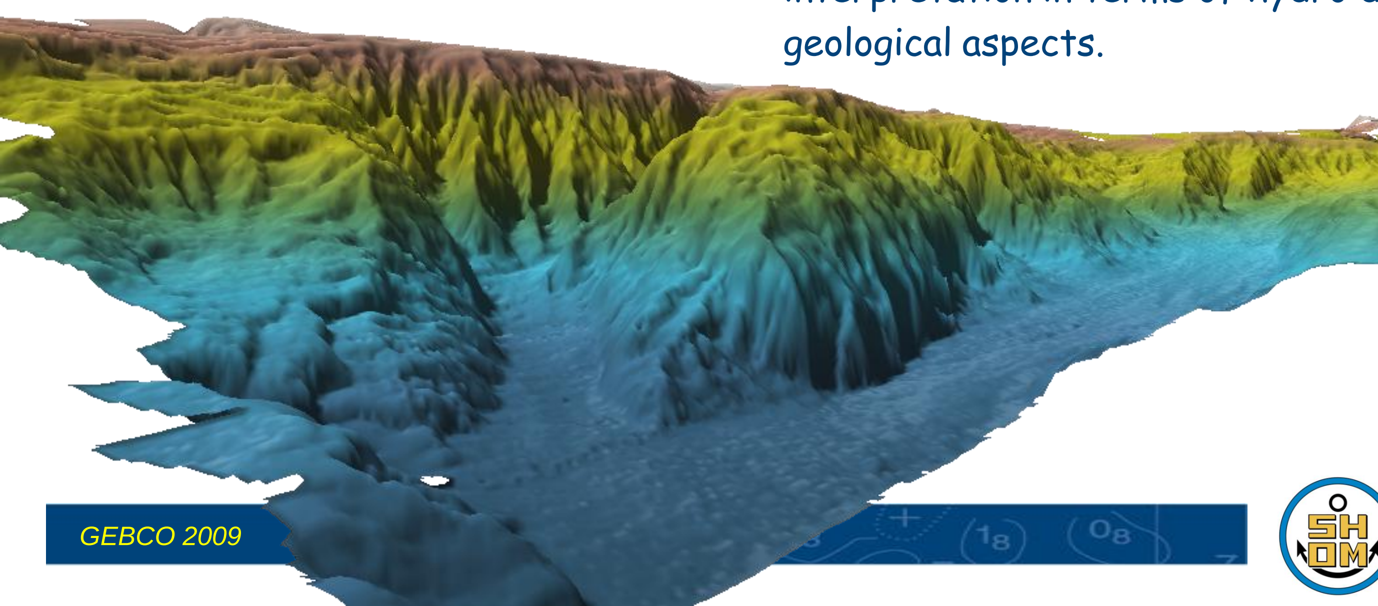
Various data sources of different quality for bathymetric DTM production

Within the ENVGEO context, SHOM is currently working on fusion techniques of gridded and in-situ Bathymetric datasets

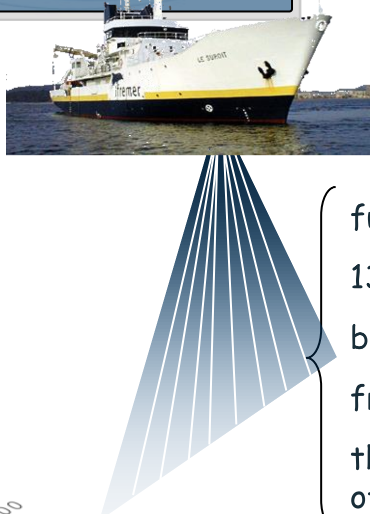
This study is this first stage

Improvements of DTM analysis and interpretation

Data uncertainties knowledge acts as constraints on DTM interpretation in terms of hydro dynamical, morphological and geological aspects.



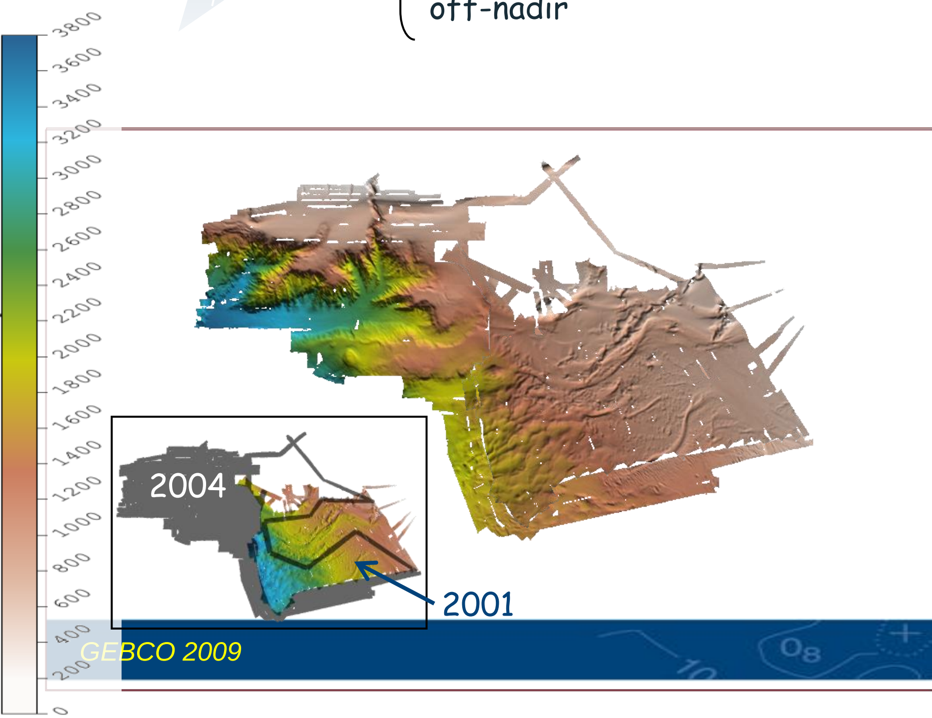
MBES DATA acquired during the two scientific surveys



SIMRAD EM300 sensor installed onboard the N/O Suroît

(Raw data are courtesy of IFREMER/SISMER)

- full swath mapping with depth ranges between 10 m and 5000m
- 135 beams per ping
- beamwidths as narrow as 1°x2°
- frequency is 30-34 kHz
- the system accuracy is 0.2% of water depth at nadir, and 0.5% of water depth between 60° and 70° off-nadir



Control of the system's internal consistency (patch test) before the survey

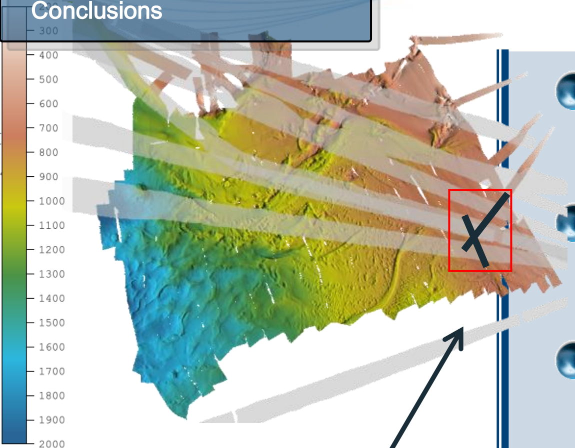
Due to the complexity of the water mass in this area, velocity profiles were regularly acquired

Lines were planned to *a posteriori* estimate the data's uncertainty

MBES surveys: Quality control

Procedure's steps

- Systematic error detection
  - Filter of the outerbeams due to sound velocity errors
- Outliers Detection
  - Automatic detection algorithm applied : ESA, manual control of its results
- Control quality report
  - Internal consistency checks, comparison with available bathymetric data

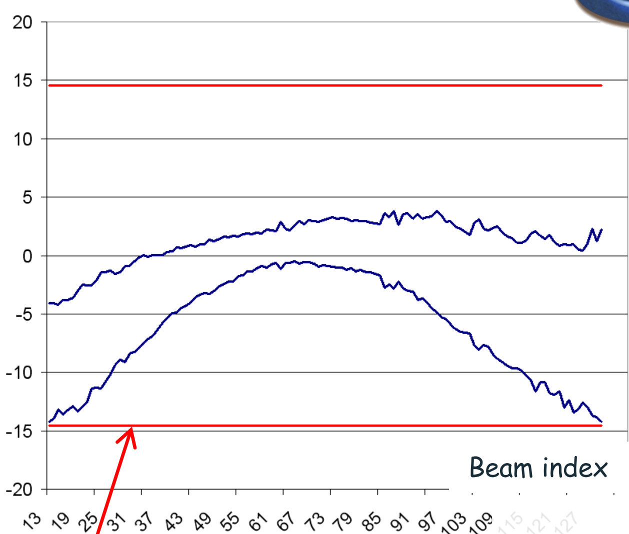


Consistency checks localization

Results

- Approximately 10%-12% of soundings were invalidated during the cleaning process
- Consistency checks at several water depth, on flat sea bottom, allow quantifying the vertical uncertainty ….

0.11% vertical uncertainty estimated on nadir
0.4% " " " on outer beams



S44 (IHO, 2008) **order 2** depth uncertainty threshold 95% confidence interval

$$\sigma_{95\%} = \sqrt{a^2 + (bz)^2} \qquad a = 1m \qquad b = 2.3\%$$

Bathymetric DATA acquired during ship's transits

Archive bathymetric data represents less than 2 millions of soundings

Data were acquired between 1954 and 2008

Single beam echo sounder (SBES) used before 2000

98% of this dataset comes from one survey line using a Raytheon 12kHz depth recorder installed onboard "D'*Entrecasteaux*" (SHOM). This sensor has a 32° beam width. Data were collected in 1999 using GPS navigation system.

Multibeam echo sounder data from 2000 to 2008

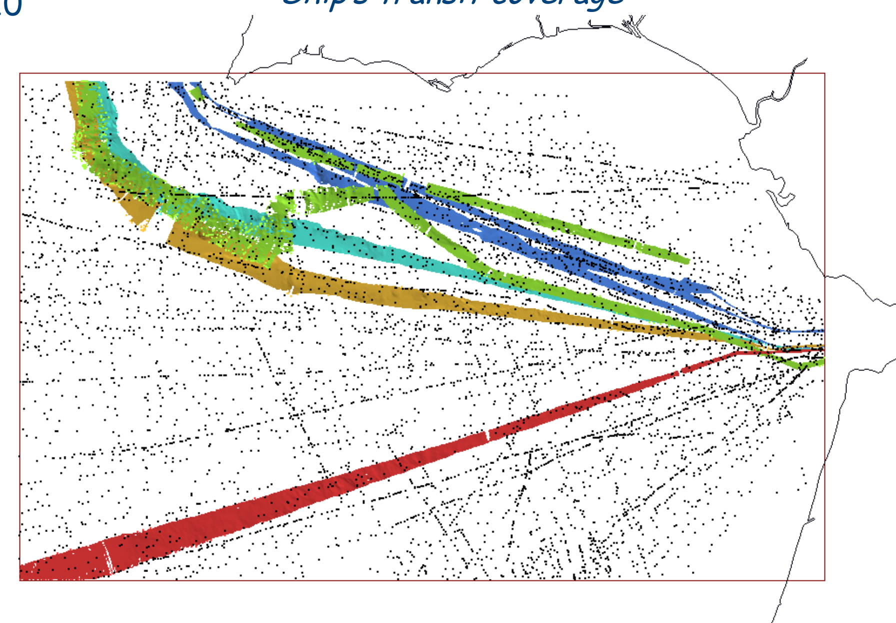
98% of the archive bathymetric data were acquired using MBES systems : mainly the SIMRAD EM1002 and EM120 installed onboard "*Beautemps Beaupré*" (SHOM)

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 beam geometry can generate up to a 150° swath

The other system (a SIMRAD EM120) operates at 12 kHz to map depths from 500 to 11000 meters.

Both systems surpass the IHO standards:
0.2% vertical uncertainty for the EM120 nadir beams and ~0.3% for the EM1002

Ship's transit coverage



Bathymetric data transit surveys: Quality control

Bathymetric dataset acquired during each transit track were separately controlled before their storage in the database.

Survey report's conclusions:

SBES data:

The ship's localization is better than 10m, being punctually degraded to 100m depending on the GPS acquisition mode

Sounding's vertical accuracy is better than 1% of the water depth

MBES data:

Before 2007: Transit datasets fall within the last order precision given in order-4: meaning that the area was not completely insonified in the hydrographically term as defined by the S44 standard. This data does not belong to one of the 3 S44-orders.

2008: The vertical uncertainty was deduced from previous MBES performances tests as no cross lines were carried out. Bathymetric data falls 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

Global bathymetric grids features

Several global relief model of the Earth's surface exist.

These grids differs in:
- resolution
- data sources
- building process

Two global models were selected

- **ETOPO 1 grid (Amante and Eakins 2009):** http://www.ngdc.noaa.gov/mgg/global/global.htm

  is a 1-minute global relief grid of the Earth's surface (on the oceans the model is derived from altimetry and ocean soundings – no precision on the version used and on the building process)

  ETOPO 1 model of our studied area is included in the GEBCO estimated seafloor bathymetry.

- **Smith and Sandwell model v11.1 (2009):** http://topex.ucsd.edu/marine_topo/mar_topo.htm

  This 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.

MBES comparisons: transits soundings vs survey's DTM

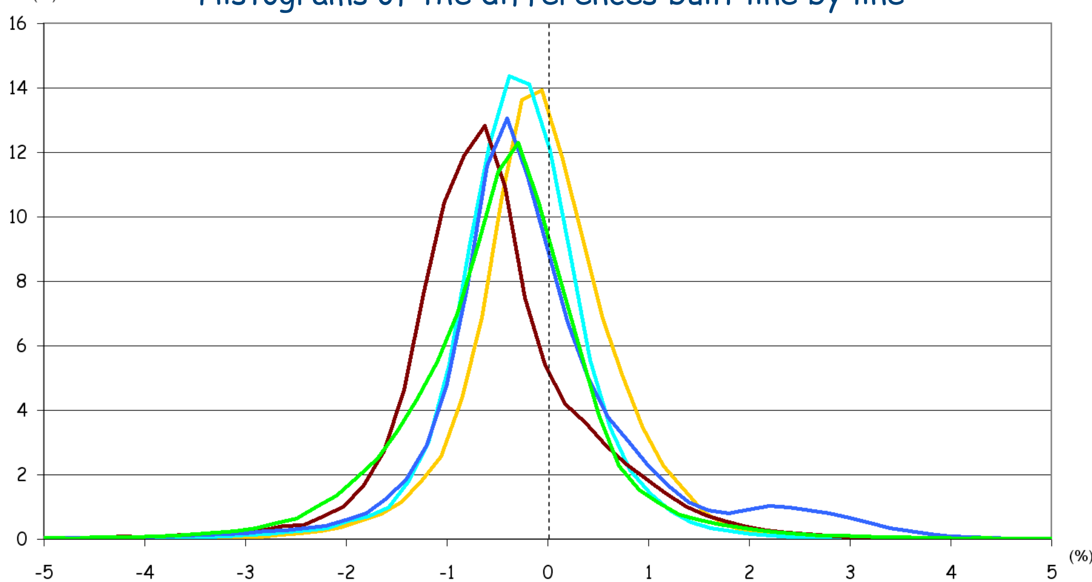
Transit soundings gathered by acquisition lines

Differences measured between transit soundings and survey DTM

Global statistics

Differences mapping

Histograms of the differences built line by line

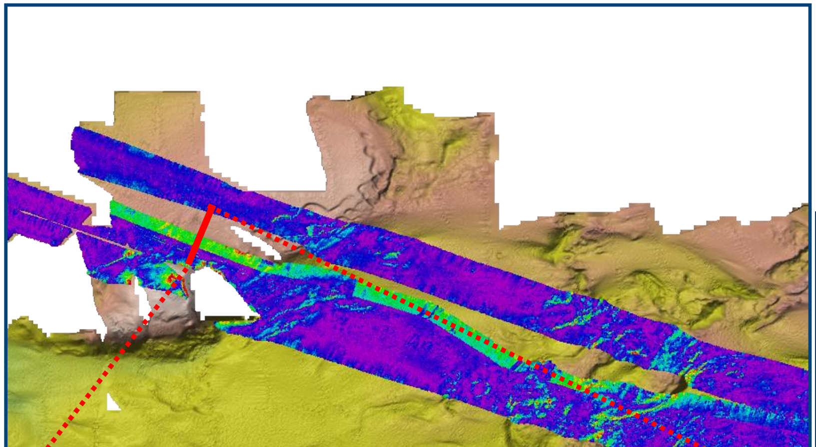


- Average differences are less than 0.5% of the water depth
- The width of the histogram mode depends to the transit line observed
- The histograms described long-tailed distributions, with a nearly bi-modal one
- Maximum values can punctually exceed 25% of water depth

MBES comparisons: transits soundings vs survey's DTM

Attention was paid on aggregates of high difference values

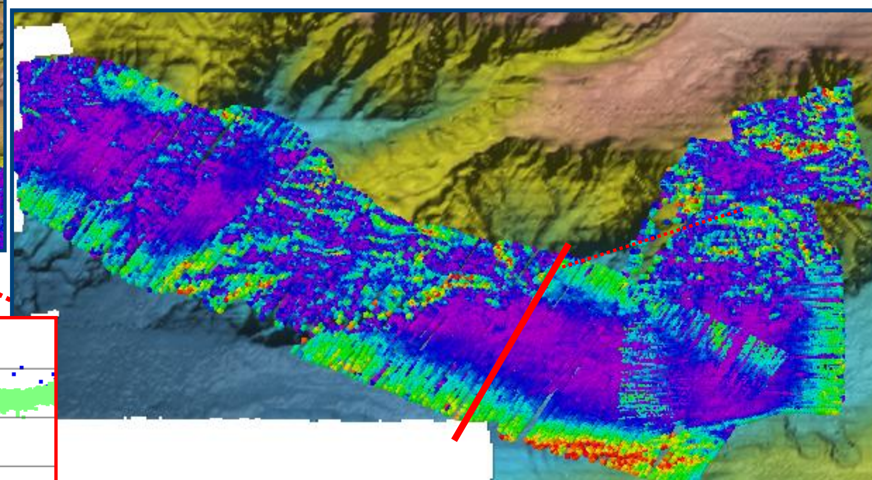
Two types of aggregate depending of their shape:

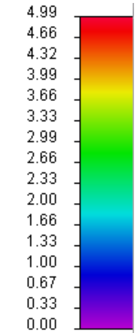


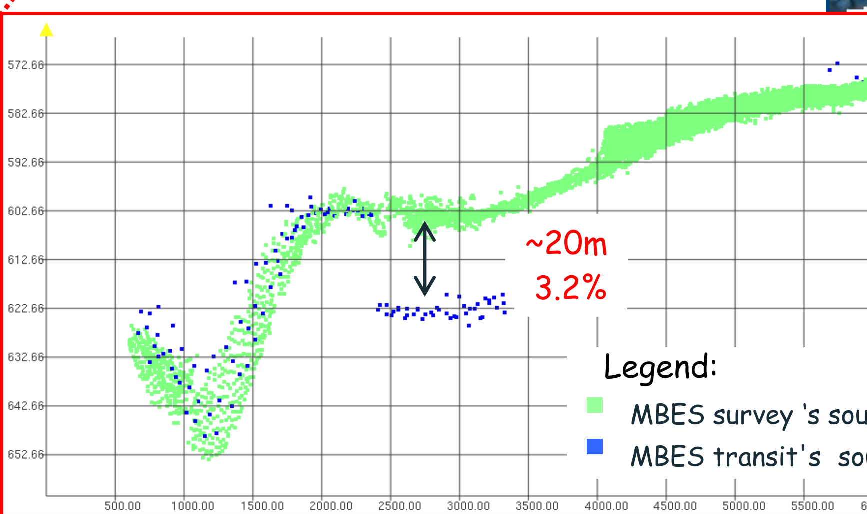
Comparisons restricted on one transit swath

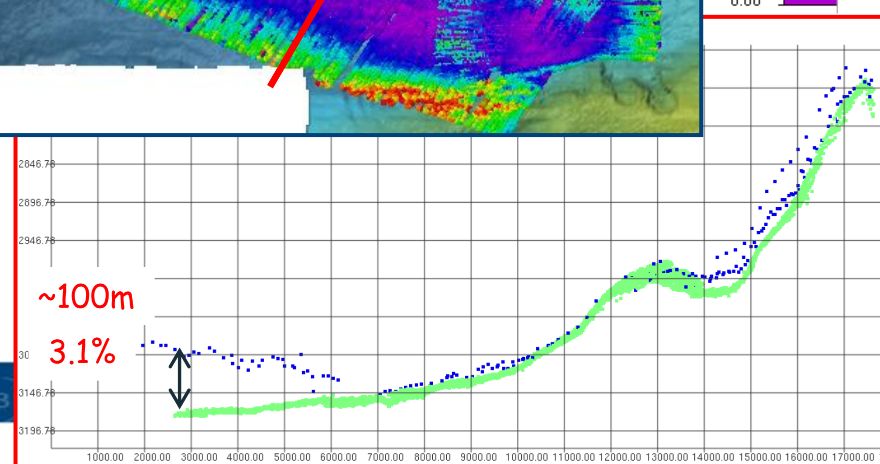
- Those correlated with the swath depict artifacts

  Dysfunction of a subset of external beams, sound velocity errors ..

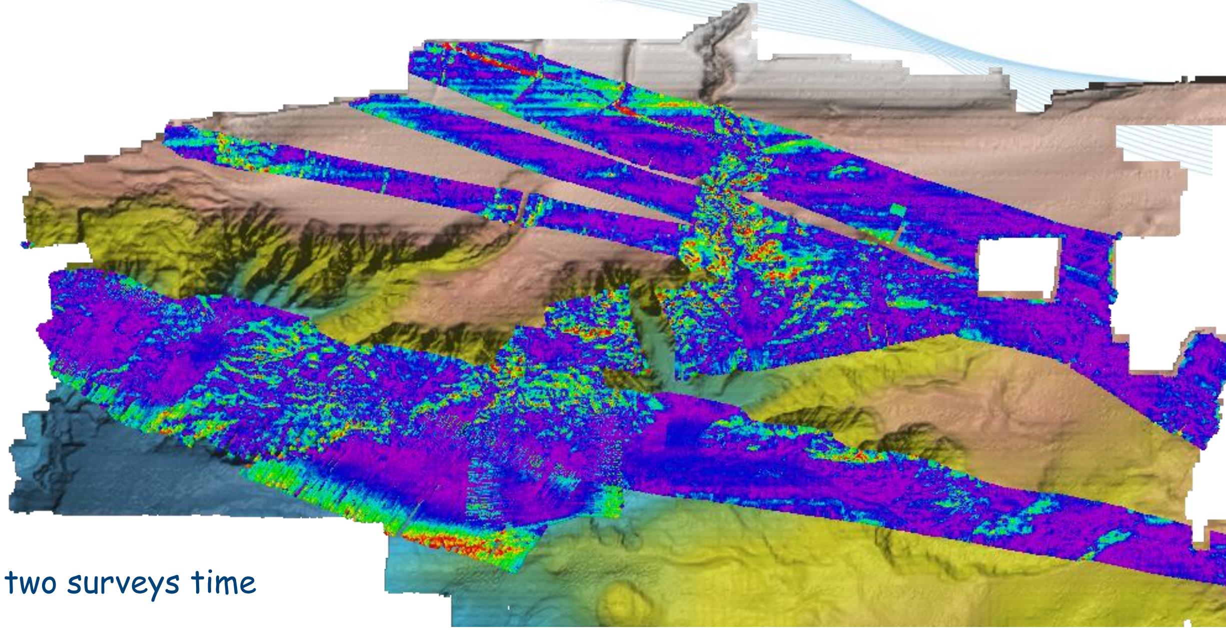




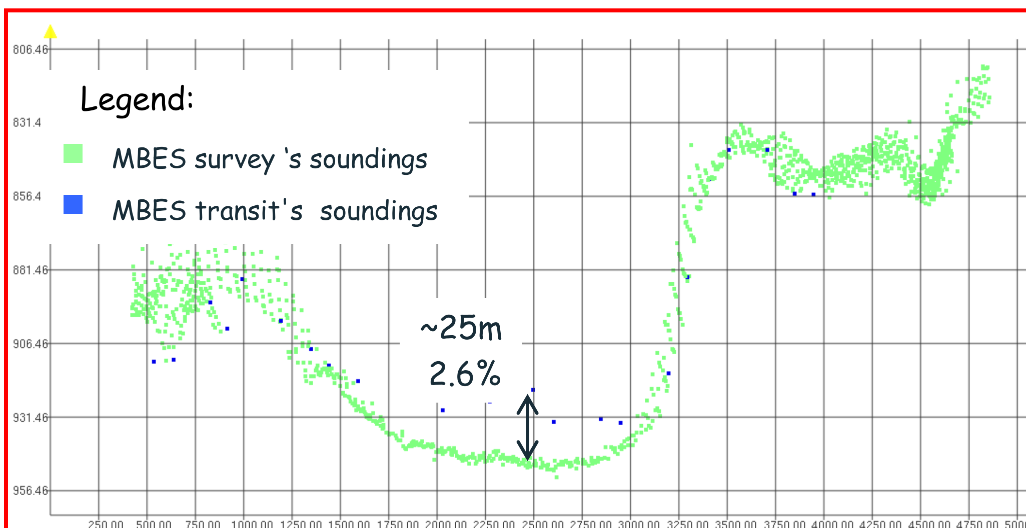




MBES comparisons: transits soundings vs survey's DTM

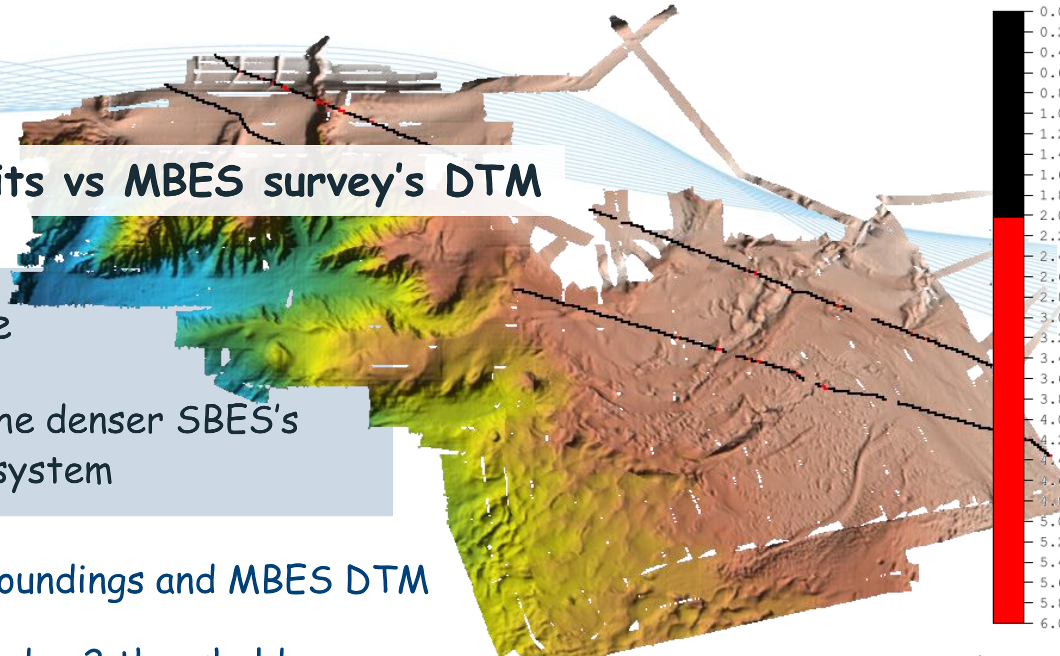


- Those correlated with the bathymetry rugosity, may be explained by:
  - The algorithm that selects the shoalest soundings to represent the seafloor in the database
  - Sediment evolution between the two surveys time



- Higher difference values are due to outliers in transit soundings datasets that affect outerbeams

SBES transits vs MBES survey's DTM



Absolute value of the difference (%)

SBES ship track coverage is sparse

The comparison was carried out on the denser SBES's track acquired using GPS navigation system

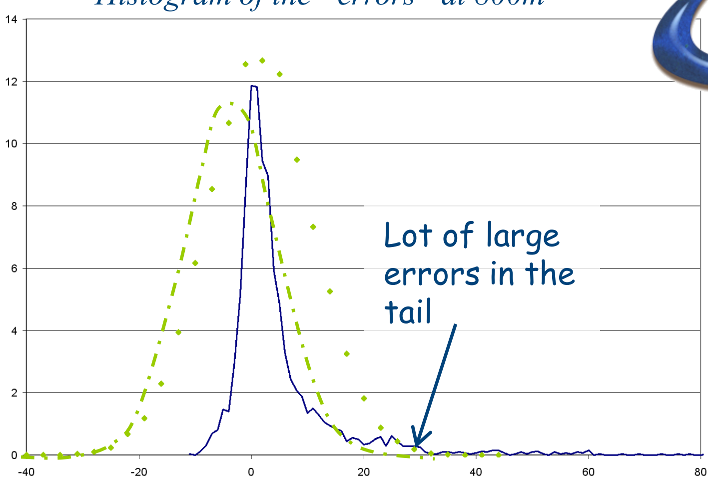
- Differences measured between SBES soundings and MBES DTM

  5.9% of the "errors" exceed the S44-order 2 threshold

- Depths along the swath vary between 300 to 2000 meters

  Classification of the "errors" according to the water depth

Histogram of the "errors" at 800m



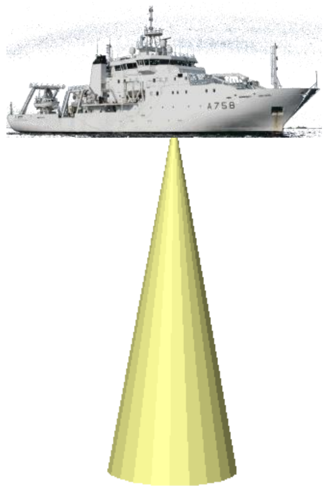
Empirical distribution differs from a Gaussian one –same result as the one published by Marks and Smith

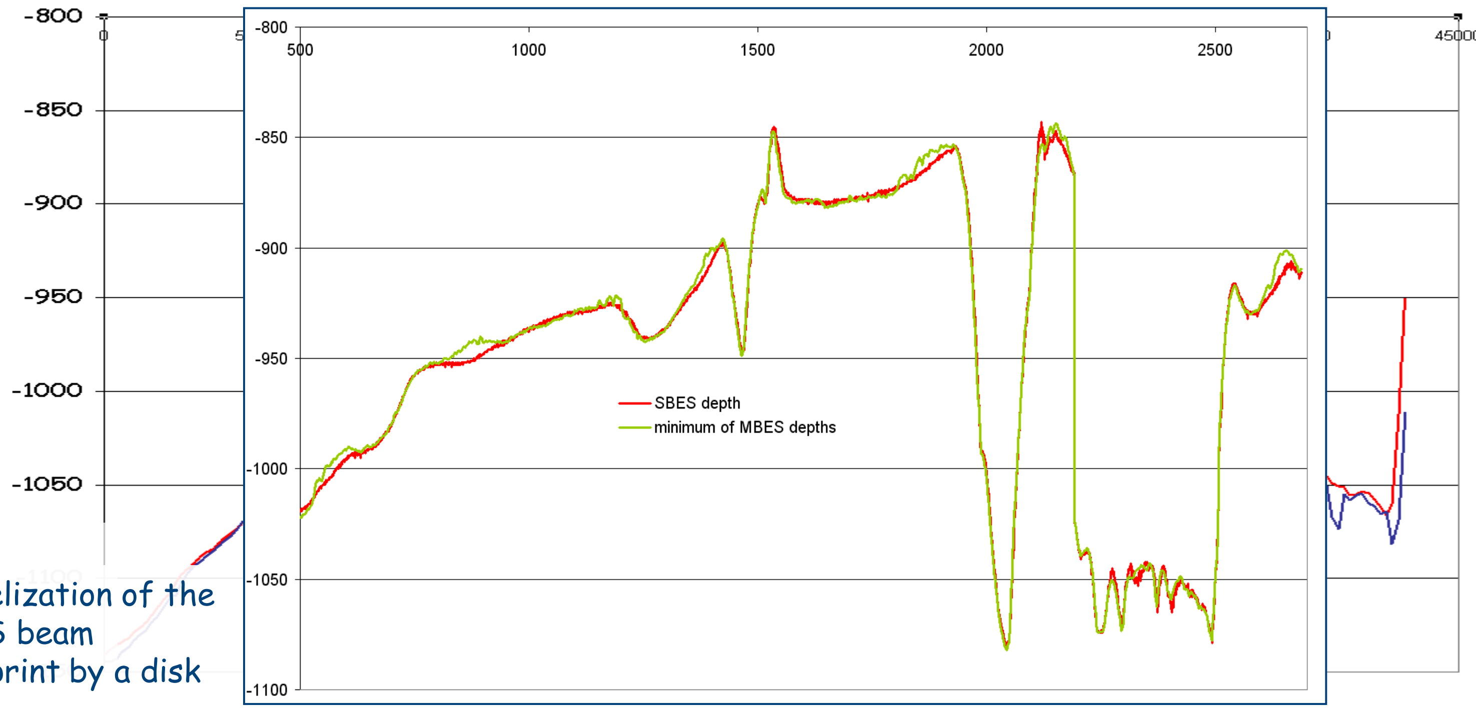
Large errors contained in the tail of the distribution are located on areas of high slopes

SBES transits vs MBES survey's DTM

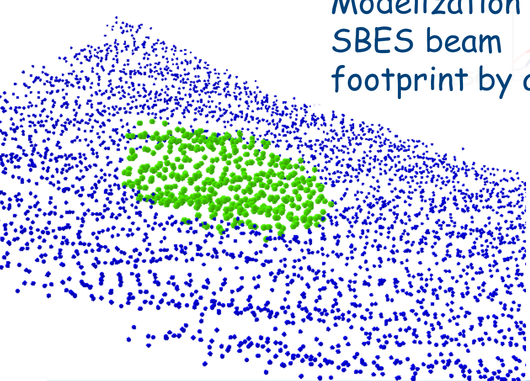
Bathymetric profile along the SBES swath

High error values comes from the 32° SBES beam footprint





Modelization of the SBES beam footprint by a disk



Legend:
- MBES survey DTM
- SBES soundings

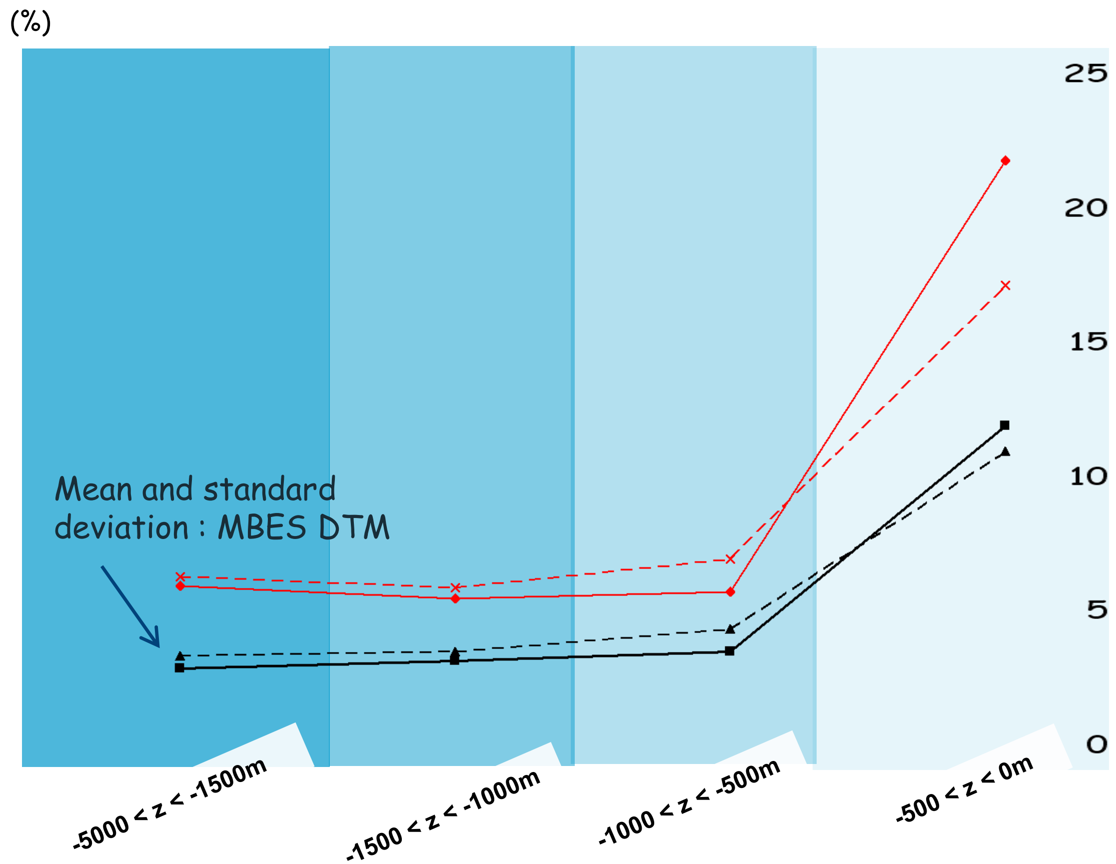
Simulation of SBES measurements from MBES soundings

"Errors" integrates the bathymetric slope

Global bathymetric DTM versus MBES data

Differences measured : { MBES transit soundings / MBES survey DTM } and { ETOPO1 grid / V11.1 Smith & Sandwell model }

Global statistics According four classes of water depth



{ ETOPO 1 / Smith & Sandwell model }

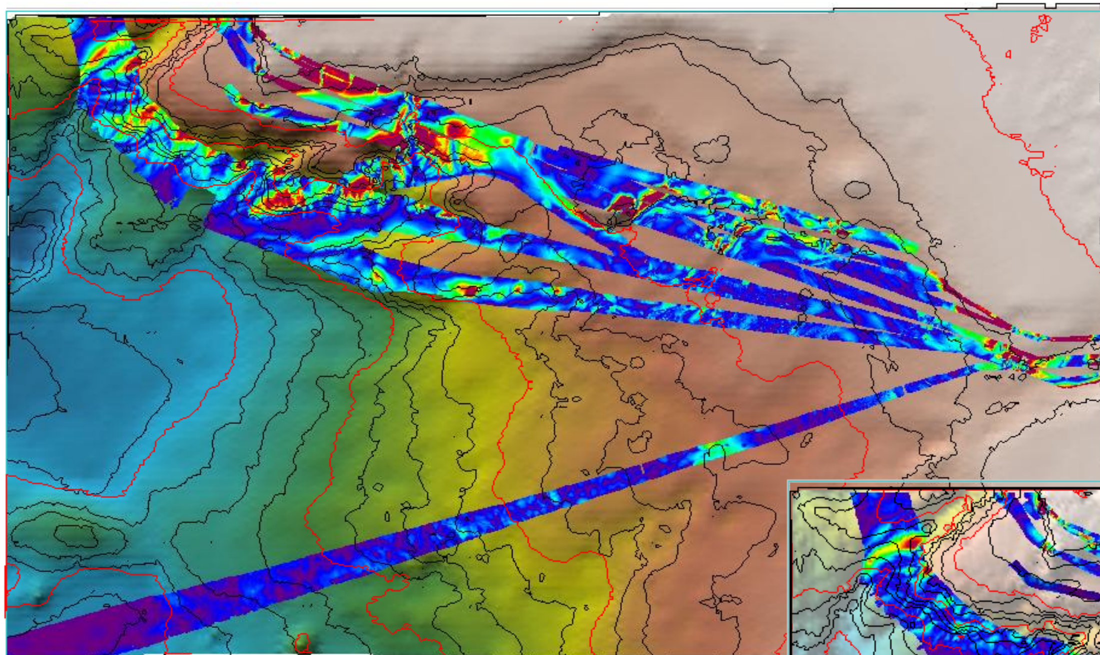
- Higher differences values for both global models occur in the for water depth less than 500m
- Global statistics show better coherence between MBES and S&S than between MBES and ETOPO1
- Comparisons between MBES soundings or MBES DTM and global DTM are similar

Global bathymetric DTM versus MBES data

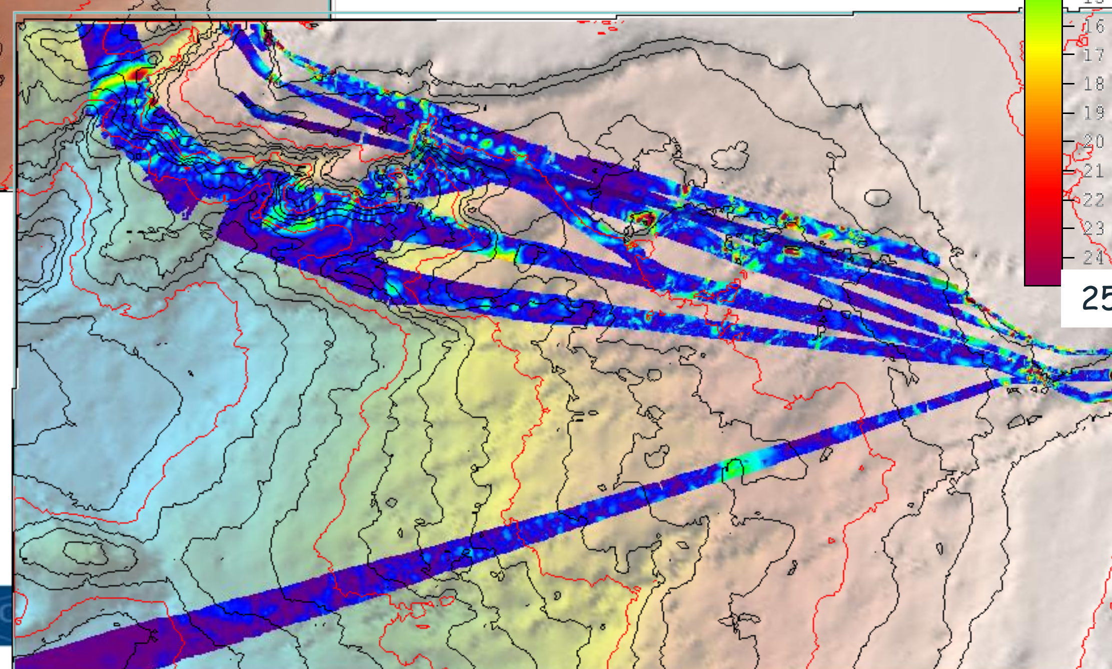
Differences mapping between

MBES soundings
And …

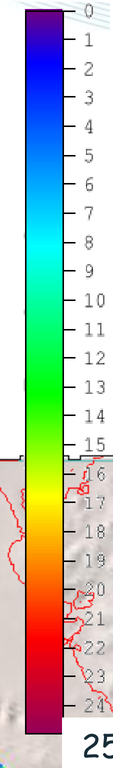
ETOPO 1



Smith and Sandwell



Absolute value of the difference (%)

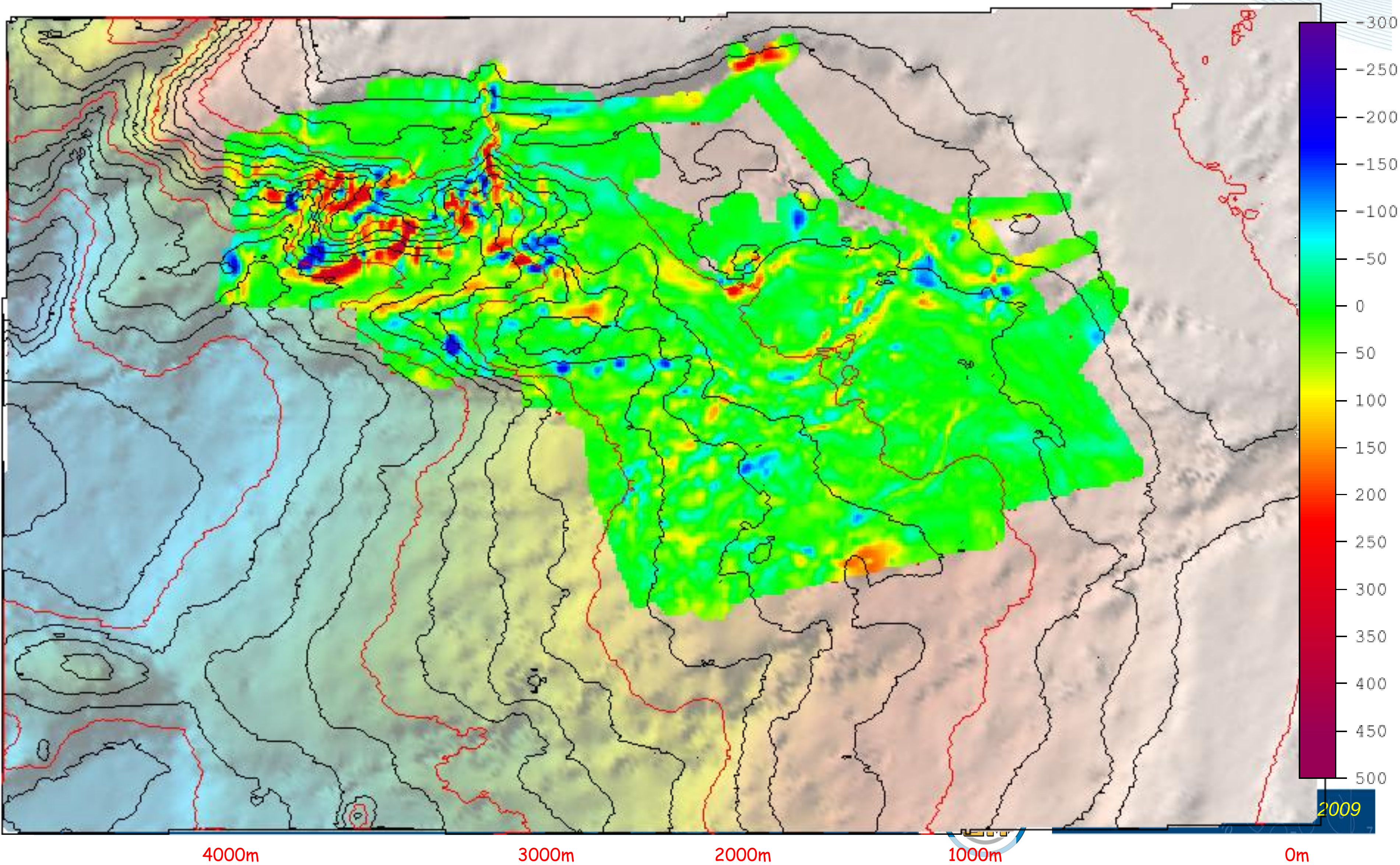


Higher difference values are localized on areas of:

- high slopes, rugosity
- Water depth lesser than 500m

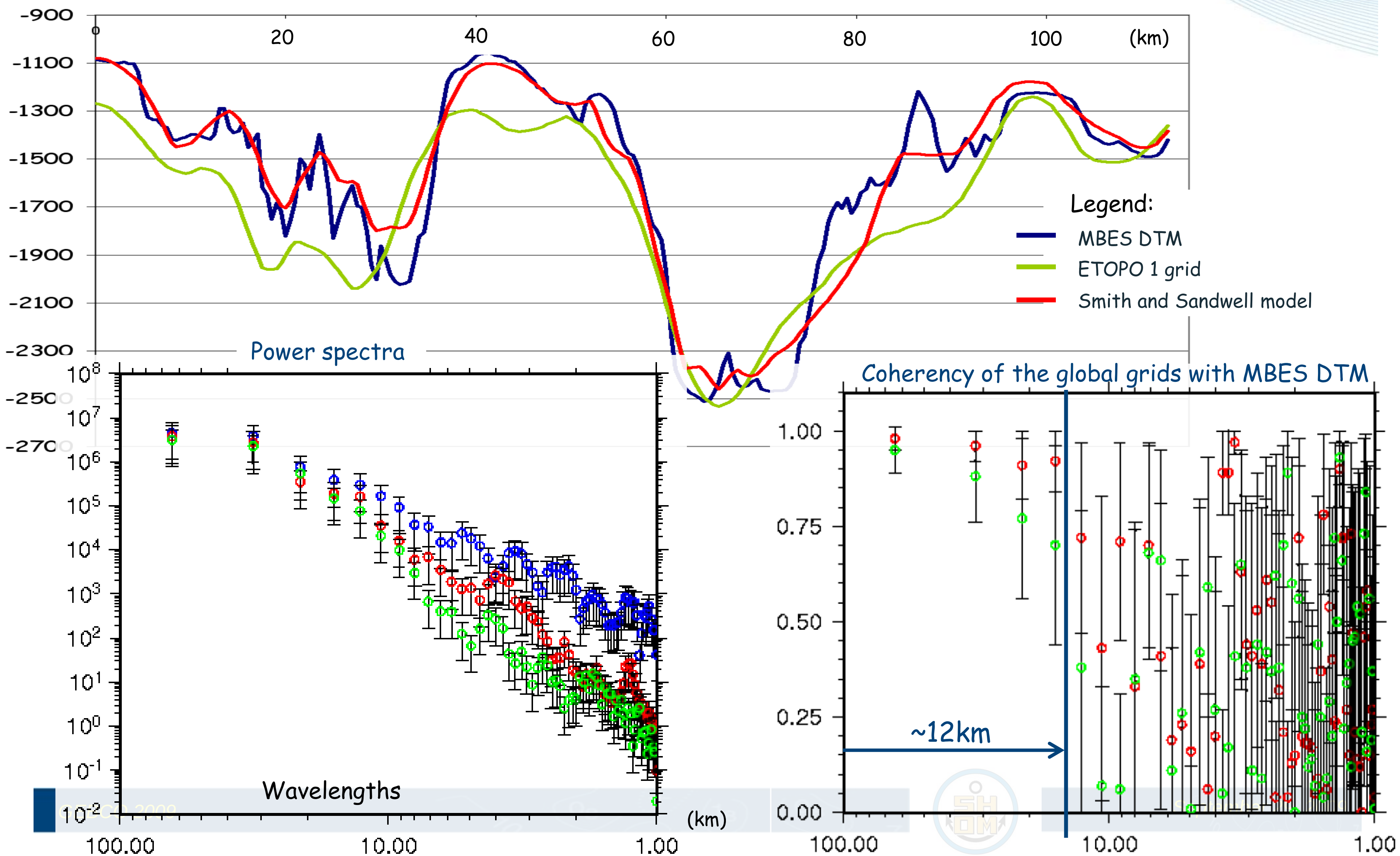
Global bathymetric DTM versus MBES data

Differences mapping between MBES DTM



Global bathymetric DTM versus MBES data

Coherence estimated along a bathymetric profile



Within the fusion framework

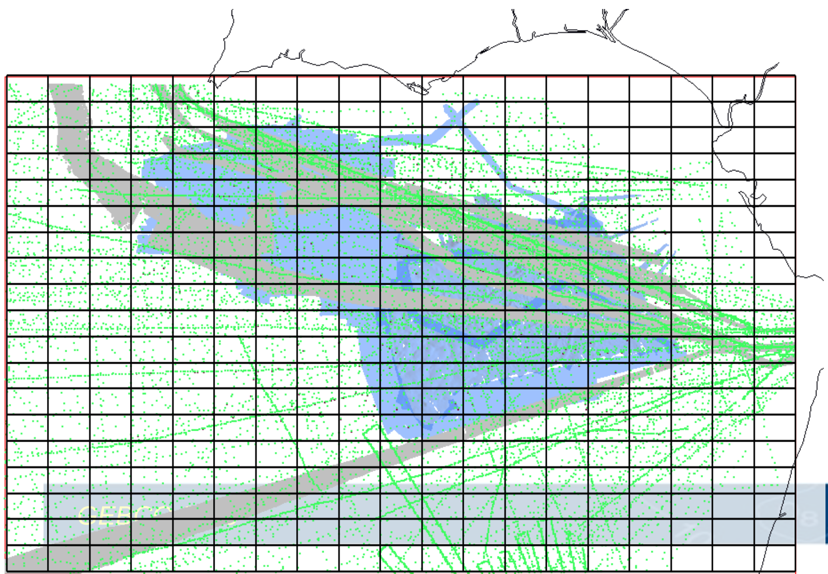
- Most of the time, vertical uncertainties of MBES surveys fall within the S44-order 2 are clearly better than the standards (~2.3% z for our study)

  MBES surveys are very accurate but represent a few percent of the coverage

  Archive transit data have to be used to complete the bathymetric knowledge

  Validation process of this data is limited (S44-order 3 or 4 for MBES transits and worst for SBES soundings)

  Global DTM degrades rapidly in high rugosity area and for water depth lesser than 500m



- Needs:

  A rigorous and complete data analysis process as we done

  Our analysis data was done on bathymetric measurements and not model: Which implies the storage of bathymetric data preserving the spatial resolution of the sensor

  The fusion must be done with respect to the expected applications