Report MITIC/01-2009

The present report was developed in the aim of Luis Quaresma PhD work, in the domain of Physical Oceanography, taking place at SHOM (French *Service Hydrographique et Océanographique de la Marine*), followed by UBO (French *Université de Bretagne Occidentale*) and HIDROGRÁFICO (Portuguese *Instituto Hidrográfico*) and co-supported by HIDROGRÁFICO and FCT (Portuguese *Fundação para a Ciência e Tecnologia*).

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A2. WIBM2009_msl_MAY15.xyz (1' resolution) - mean sea-level reference version

A3. ETOPO-1 DTM (1' resolution)

A2. BATMANE DTM (1' resolution)

A3. GASCM DTM (1' resolution)

A4. IFREMER DTM (0,5' resolution)

A5. IH-PTMARGIN_05min.xyz (0,5' resolution)

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INSTITUTO HIDROGRÁFICO

DIRECÇÃO TÉCNICA

DIVISÃO DE OCEANOGRAFIA

PROJECTO OC MITIC/09

REL. PT OC 01/09

WIBM 2009

WEST IBERIAN BATHYMETRY MODEL

The present document covers the generation proceedings of the West-Iberian bathymetry digital terrain model (DTM), to be used in the numerical modelling of the internal tide, over the Portuguese and Galiza continental slope and margin.

The existing West-Iberia DTM, previously used by SHOM (in "Maquette Sud"), evidence bathymetry inaccuracies and miss topographic details, which are important in the study of the internal tide generation and propagation. This fact becomes critical along the West-Iberia continental margin, where topographic accidents and complex coastline coexist in a shallow-water region. To overcome this problem, the present work proposes a new DTM of the West-Iberia domain build by the assembling of new datasets.

Some conditions were taken in account to help the construction of the present model:

- **Domain Limits**. The model should represent the main bathymetric features present in the study area, as well as near topographic accidents that can generate impacts over the regional circulation. To gather all of these, and keep the frontier region free of complex topography, the following domain was chosen:

    - Latitude: from **32.0ºN** to **46.0ºN**
    - Longitude: from **16.0ºW** to **1.0ºW**

- **Database**. The bathymetric information was collected from different databases, as well as from other accessible datasets, like coastal nautical charts:

    - **ETOPO-1**
    - **BATMANE-2000**
    - **GASCM-2004**
    - **IFREMER** (analysed but not used)
    - **IH-PTMARGIN**
    - **Galiza nautical Charts**

- **Resolution**. The several data sources have different resolutions. The adopted one is a compromise between the resolutions of the used datasets, the detail needed and the numerical modelling cost: **1' (minute).**

- **Projection**. The adopted projection is the **Uniform**, easy to be re-projected in a different system (when needed).

- **References.** The chosen geographical reference was the WGS-84, and the vertical reference the zero hydrographic.

- **Products**. The present work aims the generation of a new West-Iberian Bathymetry model (in an accessible xyz ASCII format). A second version of this model is made available with a mean sea-level vertical reference.

1. AVAILABLE BATHYMETRY DATABASES

Different databases were made available for the present work, in the core of a scientific protocol signed by HIDROGRÁFICO and SHOM. They were complemented by freeware bathymetry data and nautical charts interpretation and vectorization:

1.1. ETOPO-1 (NOAA-NGDC, Global Relief Model). This is an 1 arc-minute global relief model of the Earth's surface, that integrates both land topography and ocean bathymetry, covering between -90° to +90° in latitude and -180° to +180° in longitude. It was built from numerous global and regional data sets and results as an improvement to the ETOPO2v2 Global Relief Model. The best available regional and global digital data sets were obtained by NGDC (NOAA, National Geophysical Data Center) and shifted to common horizontal and vertical datum: World Geodetic System 1984 (WGS84) and mean sea level (MSL).

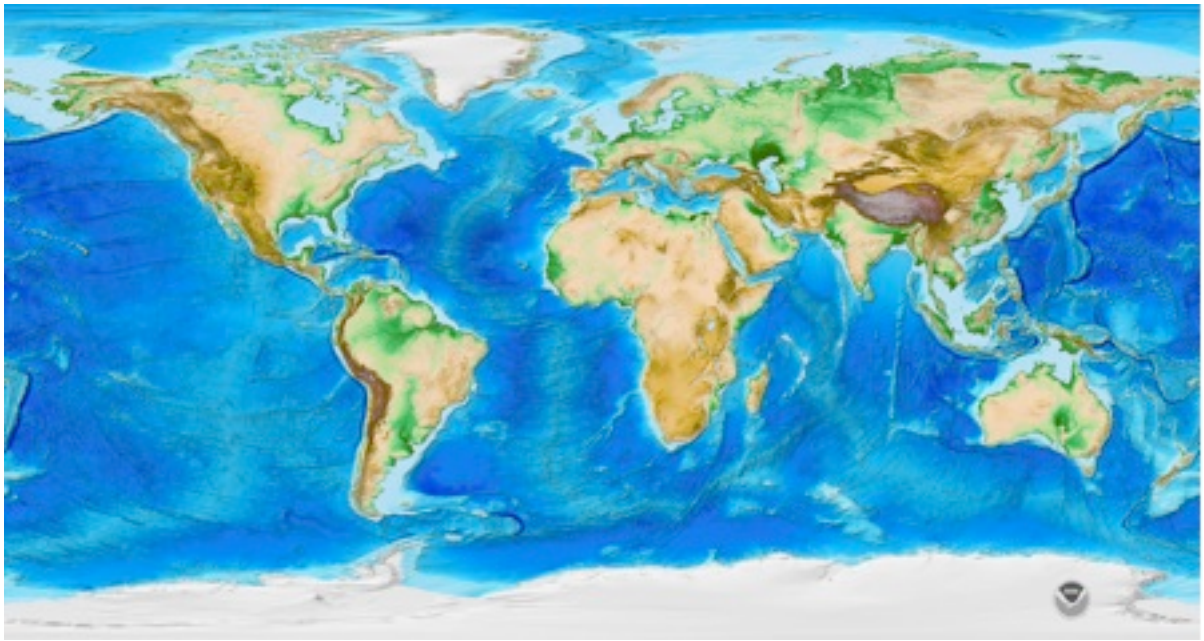


Fig.1 NOAA-NGDC Global Relief Model

1.2. BATMANE-2000 (SHOM, *Bathymétrie de l'Atlantique Nord-est*). Build in 2000, this model congregates all the available (until 1999) bathymetry information from the French database, hold by SHOM. The missing coverage was complemented by GEBCO data:

- Resolution: 1'
- West-Iberia sub-domain: 30ºN-55ºN / 20ºW-0ºW
- Source: numerical information (1999 SHOM database)
- Reference: WGS-84 (zero hydrographic)

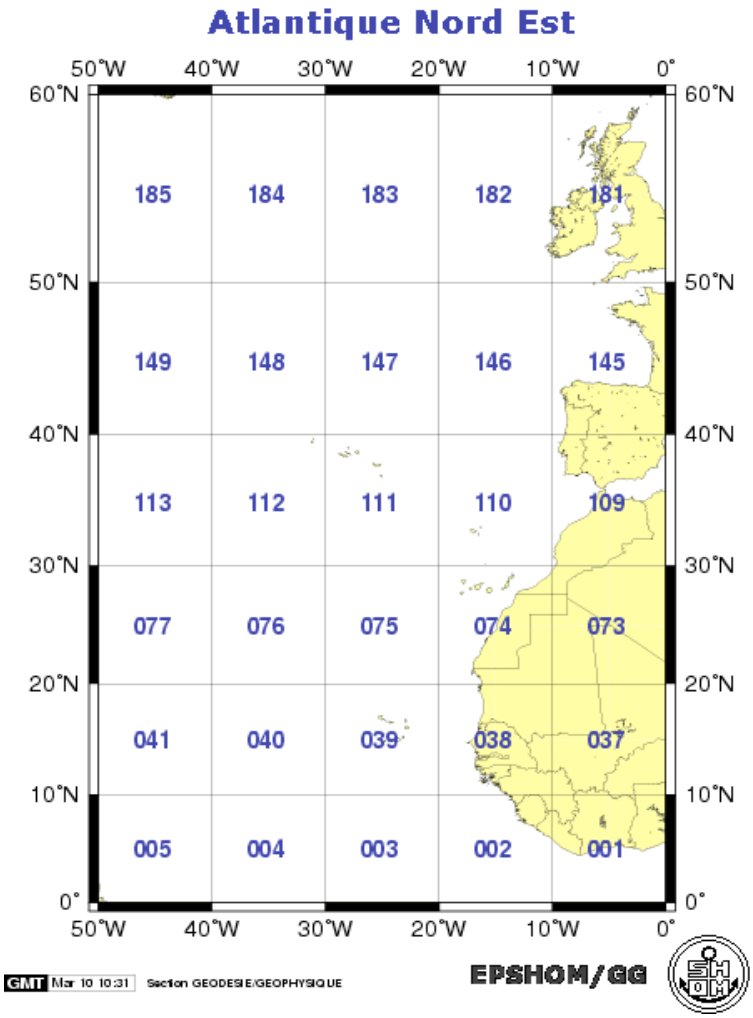


Fig.2 Global BATMANE-2000 DTM domain. In the present work sub-domains 146,145,110 and 109 were analysed and used.

1.3.GASCM-2004 (SHOM, *bathymétrie de la maquette operational MANCHE-GASCOGNE*). Bathymetric model of the "Gascogne" golf and "Manche" channel, build by SHOM to be used in an operational regional circulation model. It is based on BATMANE-2000 and includes data from nautical charts to improve information near the Northern-Spanish coast and at the "Manche" channel (CORRÉARD 2004):

- Resolution: 1'
- Domain: 42ºN-52ºN / 16ºW-0ºW
- Source: numerical information (from BATMANE-2000) and nautical chart vectorization
- Reference: WGS-84 (zero hydrographic)

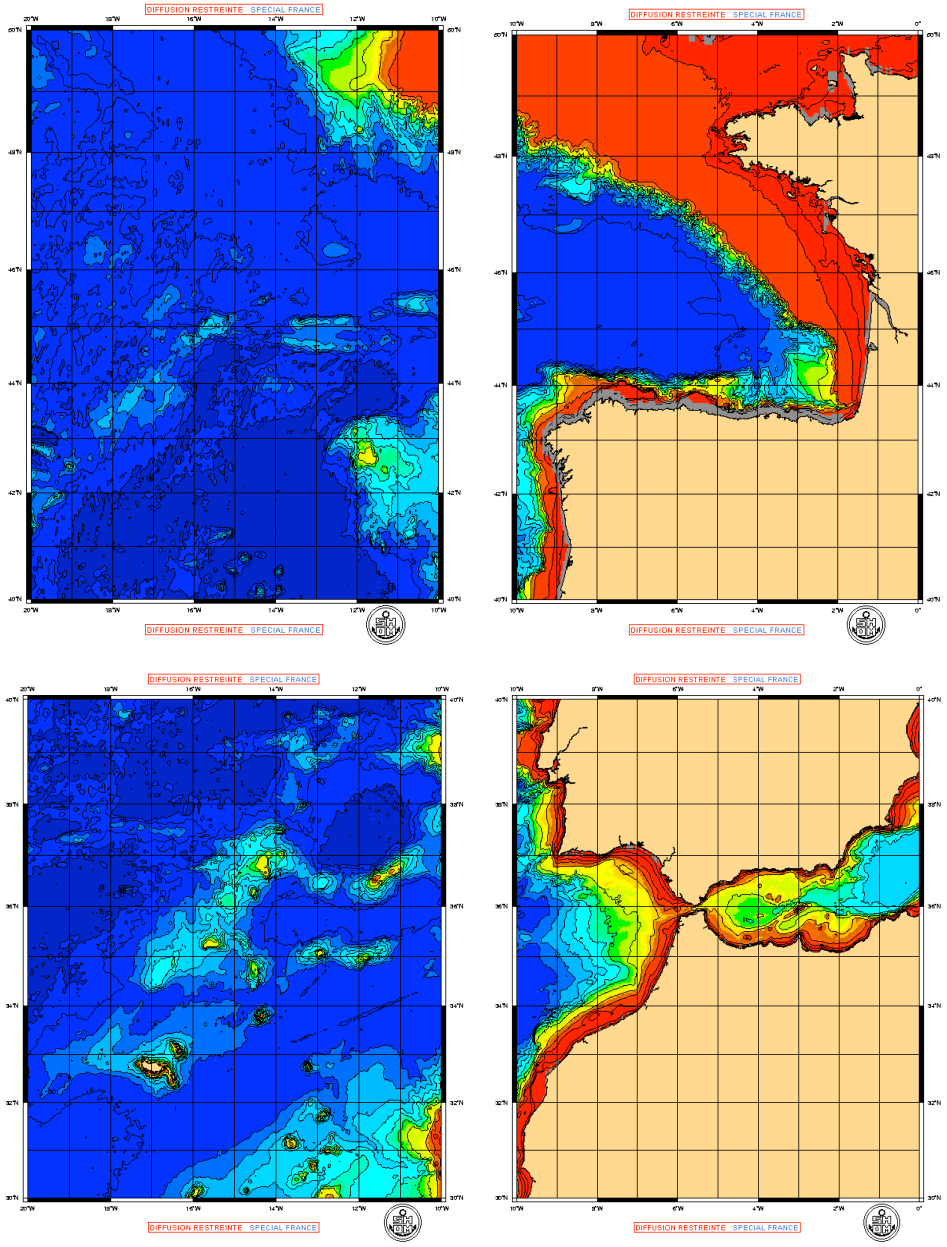


Fig.3 BATMANE-2000 DTM sub-domains 146, 145, 110 and 109.

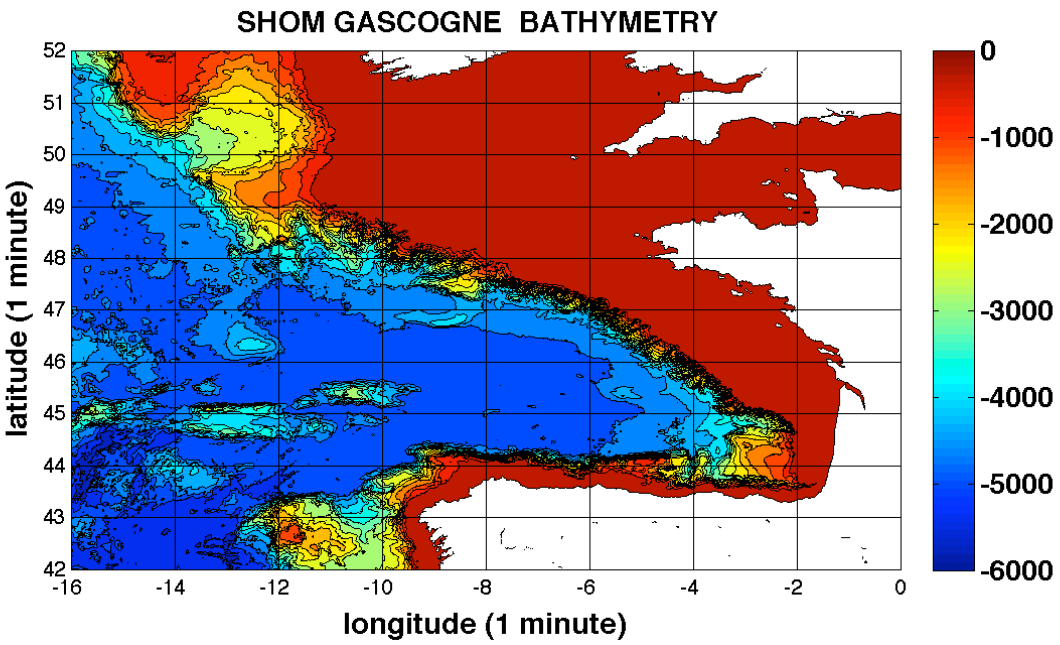


Fig.4 GASCM-2004 DTM domain.

1.4.IFREMER (*North-East Atlantic bathymetry*). This DTM is a compilation of several french bathymetric data (including SHOM's database and other datasets collected by Ifremer) produced by Sibuet et al. (2004):

- Resolution: 0.5'
- Domain: 32ºN-50ºN / 30ºW-3ºE
- Source: numerous datasets
- Reference: WGS-84 (zero hydrographic)

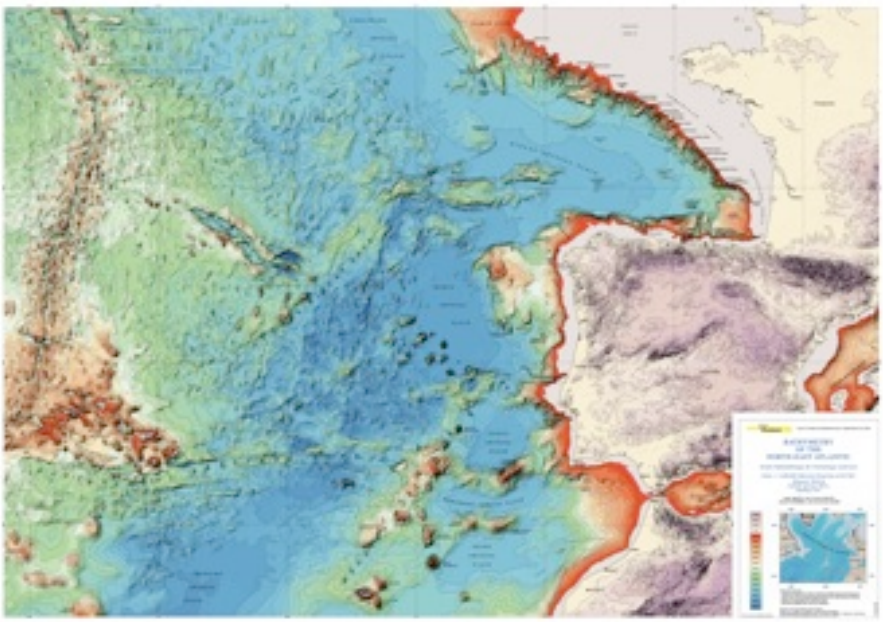


Fig.5 IFREMER DTM domain

1.5.IH-PTMARGIN (HIDROGRÁFICO, *Portuguese continental margin bathymetry*). Collection of Portuguese hydrographic data, measured by HIDROGRÁFICO until present. It's a high-resolution bathymetry dataset of the Portuguese continental slope and margin (compiled in 2008 aiming the present work):

- Resolution: 0.5'
- Domain: 36ºN-41.9ºN / 10.25ºW-7.3ºW (not fully covered)
- Source: numerical information (2008 IH database)
- Reference: WGS-84 (zero hydrographic)

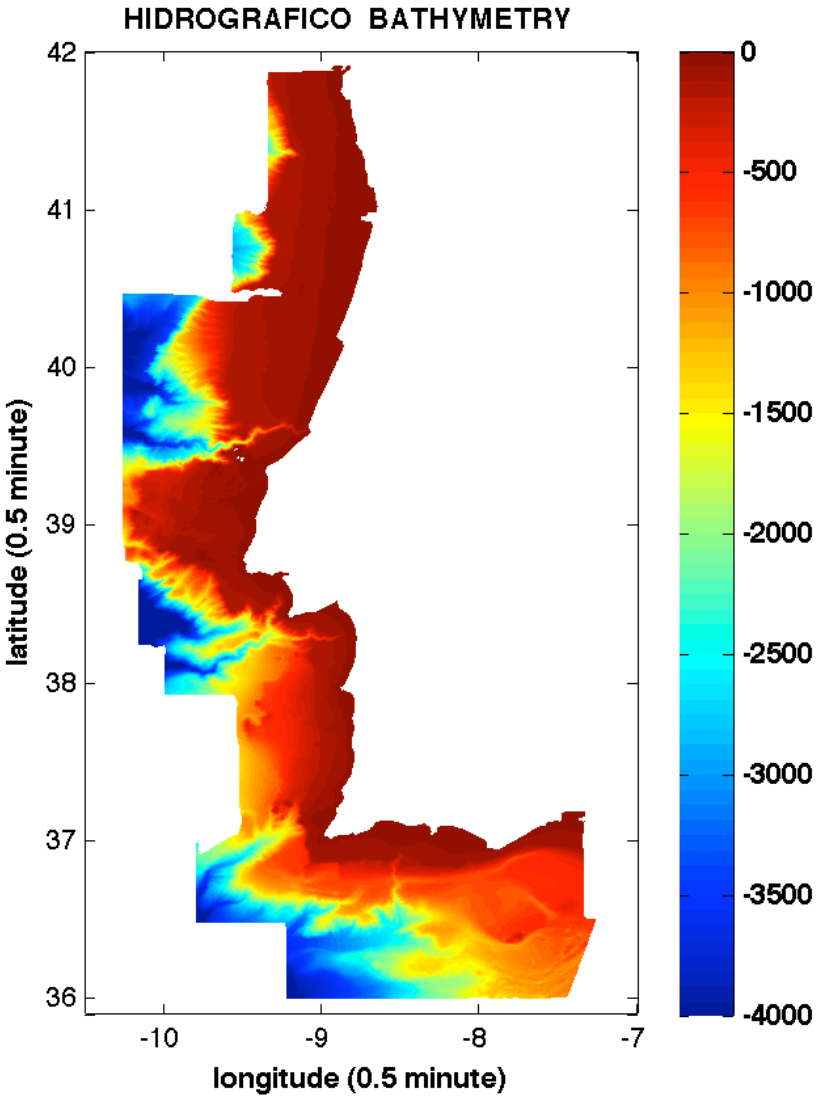


Fig.6 IH-PTMARGIN dataset domain.
Note that the covered area is not uniform.

2. METADATA INFORMATION

For a correct usage of the different databases it is important to look at the origin of the sounding information. This is part of the metadata associated with each model:

2.1 ETOPO-1 (NOAA-NGDC, Global Relief Model). The Bathymetric datasets used in the compilation of ETOPO1 were obtained from the Japan Oceanographic Data Center (JODC), NGDC, the Caspian Environment Programme (CEP), and the Mediterranean Science Commission (CIESM). The CIESM has produced a morpho-bathymetric map of the Mediterranean Sea (Fig. 7), derived from multibeam swath sonar surveys (*Medimap Group et al.*, 2005). Benoit Louibrieu, Ifremer, has provided to the generation of this DTM a 1-km grid of the Mediterranean Sea.

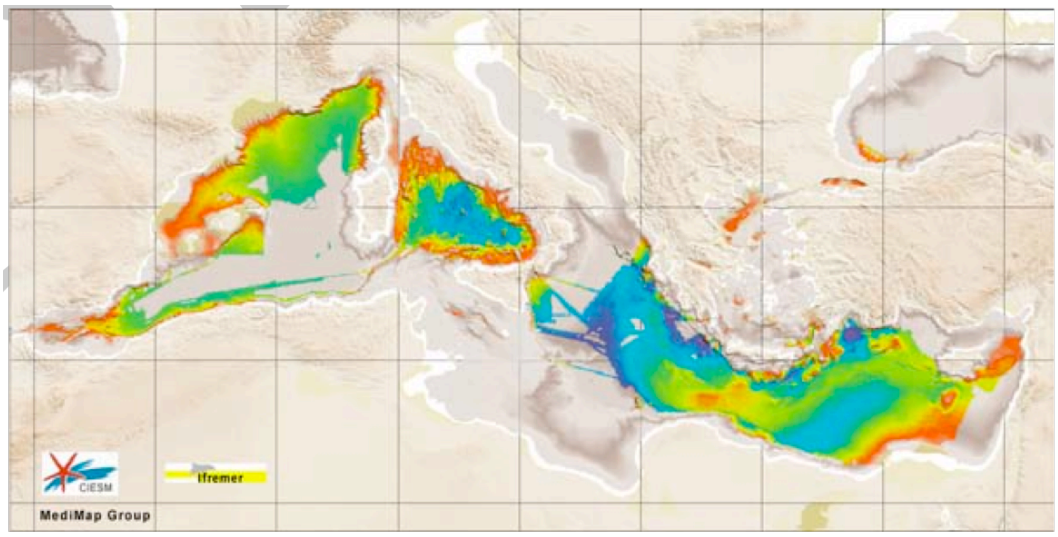


Fig.7 MEDIMAP morpho-bathymetric map of the Mediterranean Sea derived from multibeam swath sonar surveys.

NGDC created bathymetric pre-surfaces in order to interpolate bathymetric data into coastal regions, poorly represented in the global datasets. A global bathymetric pre-surface (excluding south of 60°S) was created using the Measured and Estimated Seafloor Topography data (between -500 m and 0 m), derived from satellite altimetry (Geosat and ERS-1) and shipboard depth soundings. This data was gridded at 2 arc-minute cell size using *GMT*'s 'surface' tool.

2.2 BATMANE-2000 (*bathymétrie de l'atlantique nord-est*). This DTM was build from data obtained by distinct hydrographic systems (multi-beam and single-beam), bringing different resolutions to the SHOM database. GEBCO information was assembled in areas not covered by SHOM, and a Sandwell interpolation scheme was used along coastal regions (where data is missing). At the origin this database has different node densities (2', 1' and 0,2'), according to the employed hydrographic systems. This imposes irregular quality flags to the 1' BATMANE DTM, made available. The quality parameter is classified by colours and is based on the cloud density of the hydrographic data source:

[Classified information]

Fig.8 BATMANE sub-domains 146, 145, 110 and 109 data quality flags (in SHOM GUIDE METOC 2007):

- **Green.** Existing sufficient measurements to characterize very well the region
- **Blue.** Existing sufficient measurements to well characterize the region
- **Yellow.** Existing sufficient measurements to characterize the region
- **Red.** Not to many measurements to characterize the region

2.3 GASCM-2004 (*bathymétrie de la maquette operational GASCOGNE*). Build to be used in the SHOM's operational circulation model of the West coast of France, it's based on BATMANE-2000 and includes Spanish nautical charts information (as well as other sources from the north region of its domain). The charts information tried to improve the DTM quality over the Spanish north coast, where BATMANE hydrographic data source density is poor (see Fig.8). The data quality information and the GASCM building technique is part of MARCHE EPSHOM/HOCER report nº02.87.071 (July 2004).

2.4 IFREMER (*Noth-East Atlantic bathymetry*). This DTM assemble numerous data, with different origins and resolutions. To homogenise these sets a strong filter was applied, losing therefore important topographic details. Even filtered, it is important to notice that this DTM congregates a large amount of information, allowing a good representation of the Northeast Atlantic bathymetry.

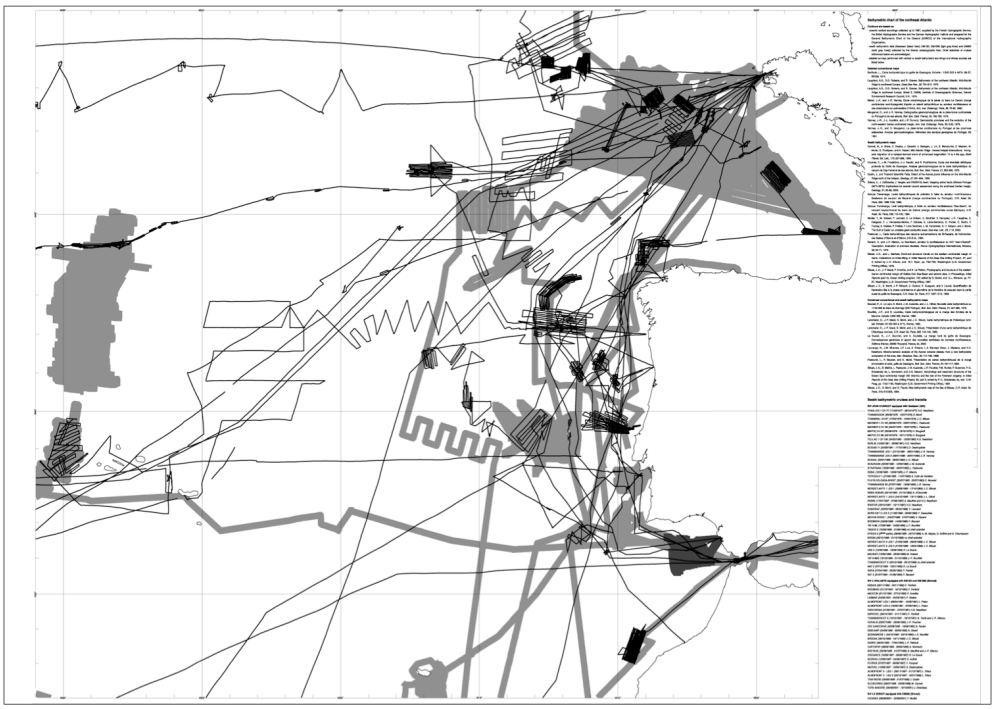


Fig.9 IFREMER measurements footprints (bold line=multi-beam data; line=single-beam data)

2.5 IH-PTMARGIN (*Portuguese continental margin bathymetry*). The aim of this Portuguese dataset was to gather all the available high-resolution data present at HIDROGRÁFICO database covering the Portuguese continental margin (obtained also by distinct hydrographic systems as multi-beam and single-beam). The original measurements have higher resolution than the final dataset. No extrapolation was made, keeping therefore an uncompleted coverage of the domain.

3. GALIZA CHARTS VECTORIZATION

The previous data quality interpretation reveals that the Northwest coastal region of Spain is poorly represented in all the available databases. This fact is mainly due to absent sounding information along this margin. To overcome the problem, in a critical region like the cape of "Finisterra" and the Galiza "Rías", two Spanish nautical charts were vectorized (aiming the construction of a local DTM).

3.1 INT1890-41B. "*Oceano Atlantico Norte – Costa Noroeste de España (de Las Islas Sisargas a la desembocadura del Rio Miño)*":

- Scale: 1/200 000.
- Reference: WGS-84 (zero hydrographic).
- Vectorization: Coastline; Isobaths 10m, 20m, 30m, 50m, 100m, 200m, 500m ; Complete soundings information from coastline to isobaths 500m.

3.2 INT1808-41A. *"Oceano Atlantico Norte – Costa Noroeste de España (de Las Estaca de Bares al Cabo Finisterre)":*

- Scale: 1/200 000.
- Reference: WGS-84 (zero hydrographic).
- Vectorization: Coastline; Isobaths 10m, 20m, 30m, 50m, 100m, 200m, 500m; Complementary soundings information from coastline to isobaths 500m.

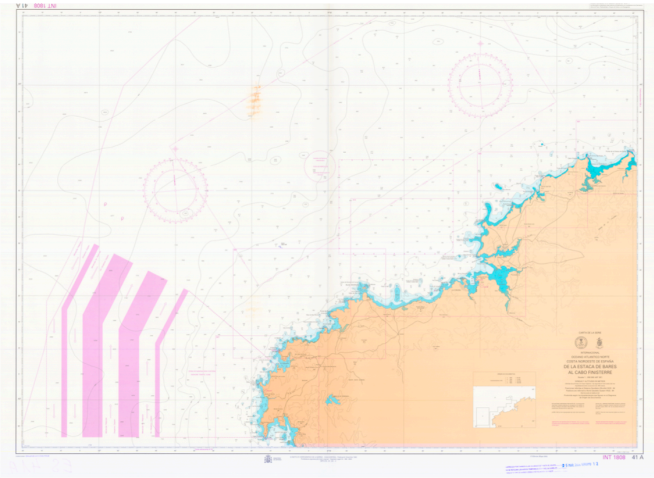


Fig.10 a) INT1808-41A chart

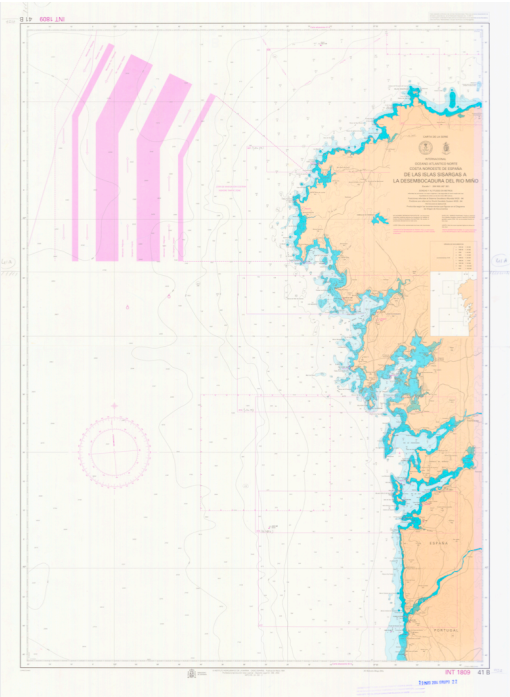


Fig.10 b) INT1890-41B chart

The vectorization was carryout with ARCVIEW 3.2 software, and began by the geo-referenciation of both INT1890-41B and INT1808-41 images (in .tiff format). The image raster information was transformed to vector and then exported to MATLAB. This last software compiled all the vectorized data and a Digital Terrain Model (with 0.2' resolution) was produced by 2D interpolation, using a cubic function based on a Delaunay triangulation (griddata.m).

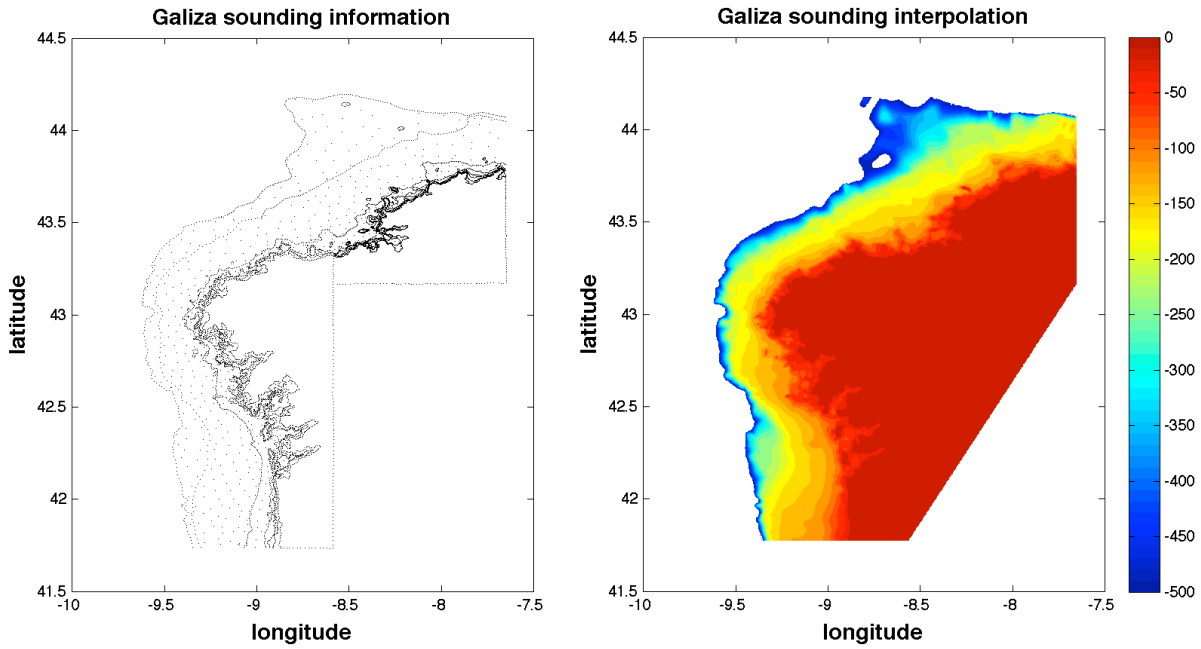


Fig.11 Galiza charts vectorization and interpolation

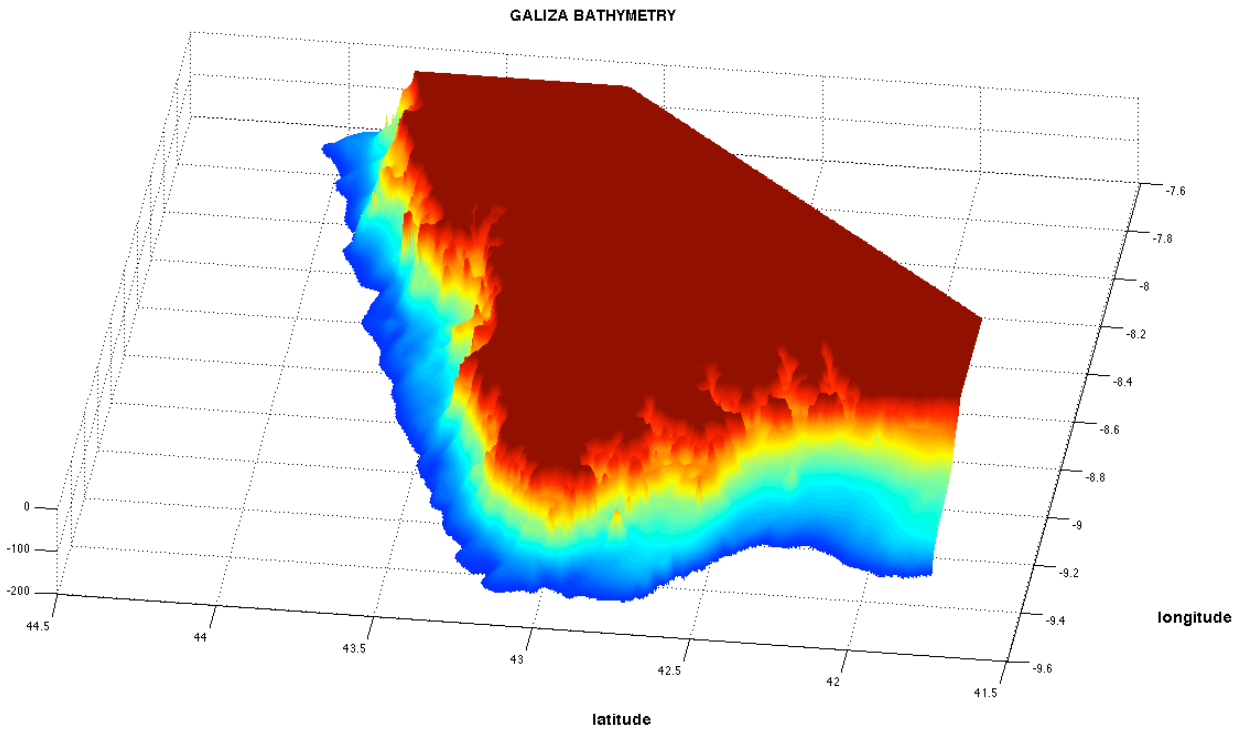


Fig.12 3D Representation of the produced Galiza Charts information DTM (0-200m depth)

4. BATHYMETRY ANALYSIS

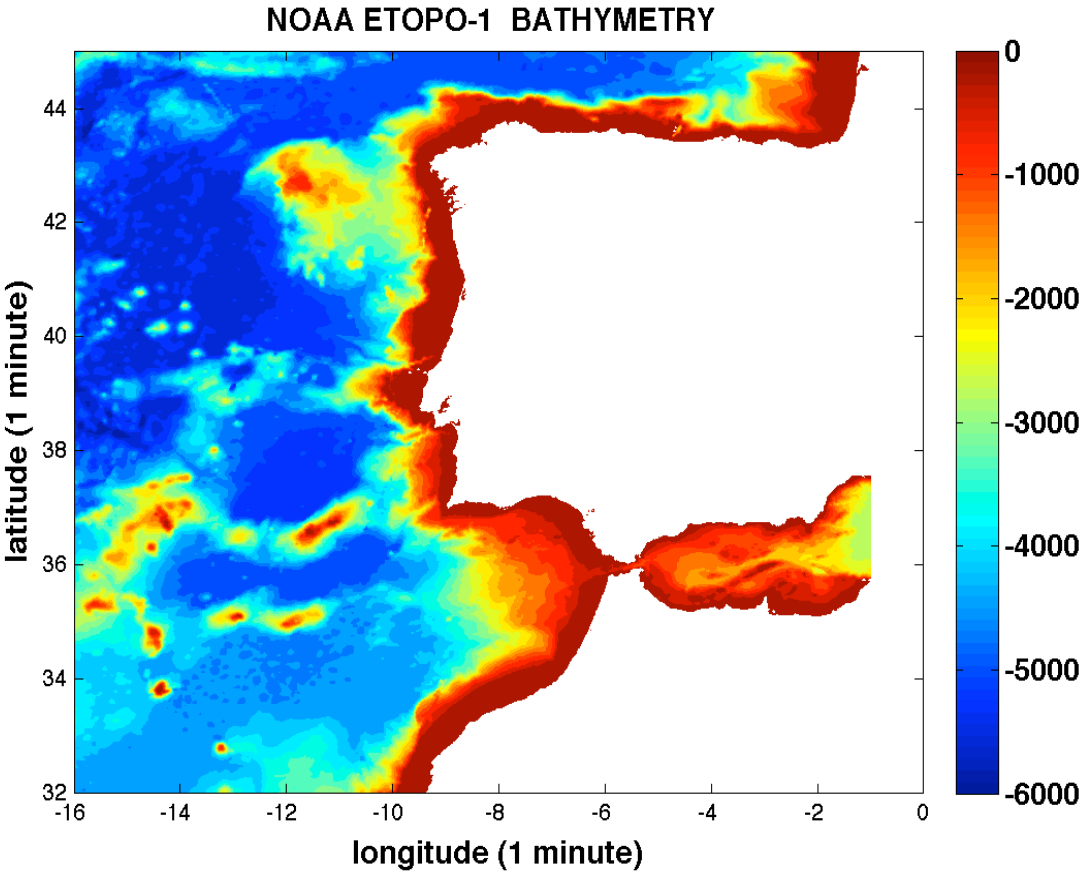
The differences in resolution, data quality and domain limits impose a multiple use of the available datasets, in order to build a new regional DTM that can better represent the study area.

4.1. The main DTM support

This work started by the choice of the best complete regional dataset (to be used as the main support for the new DTM). Three different databases where analysed by the evaluation of the Shallow-water region (0-200m depth, Fig.13, 14 and 15 .b) and the Slope region (200-3000m depth, Fig.13, 14 and 15 .a) bathymetry contour:

1. NOAA's ETOPO-1. This dataset results from multiple information sources, including satellite altimetry that estimates quite well the shallow water bathymetry (where data is missing on every available datasets). However, this DTM shows many topographic errors over the Iberian continental slope and shelf. Nevertheless, the entire Mediterranean region seems to be well represented, where significant bathymetry details coexist with coherent continental margin topography estimation. See Fig.13
2. SHOM's BATMANE-2000. This is a very good dataset that compiles most of the French database in a 1' resolution DTM. An important coverage of the West-Iberian deep region allows this DTM to represent with detail the most important topographic features present here. Yet, some errors where found along the study area, especially over the Portuguese and Galiza continental margin. See Fig.14
3. IFREMER's *Noth-East Atlantic bathymetry*. Besides the good data source quality and the large area covered by Ifremer measurements, this dataset seems to be too filtered. Meaning the lost of bathymetry detail (evident on the Cadis Golf deep region and along all the continental margins, present in the domain). See Fig.15

The previous analysis was performed by checking the details in the tree DTM's and by comparing them with each other and with all the other local datasets (made available for this work). The chosen DTM was the BATMANE-2000 since this evidence more information than the others, as well as less errors. Nevertheless, these are significant errors that where corrected by the use of other datasets, as will be present next (see chapter 5).



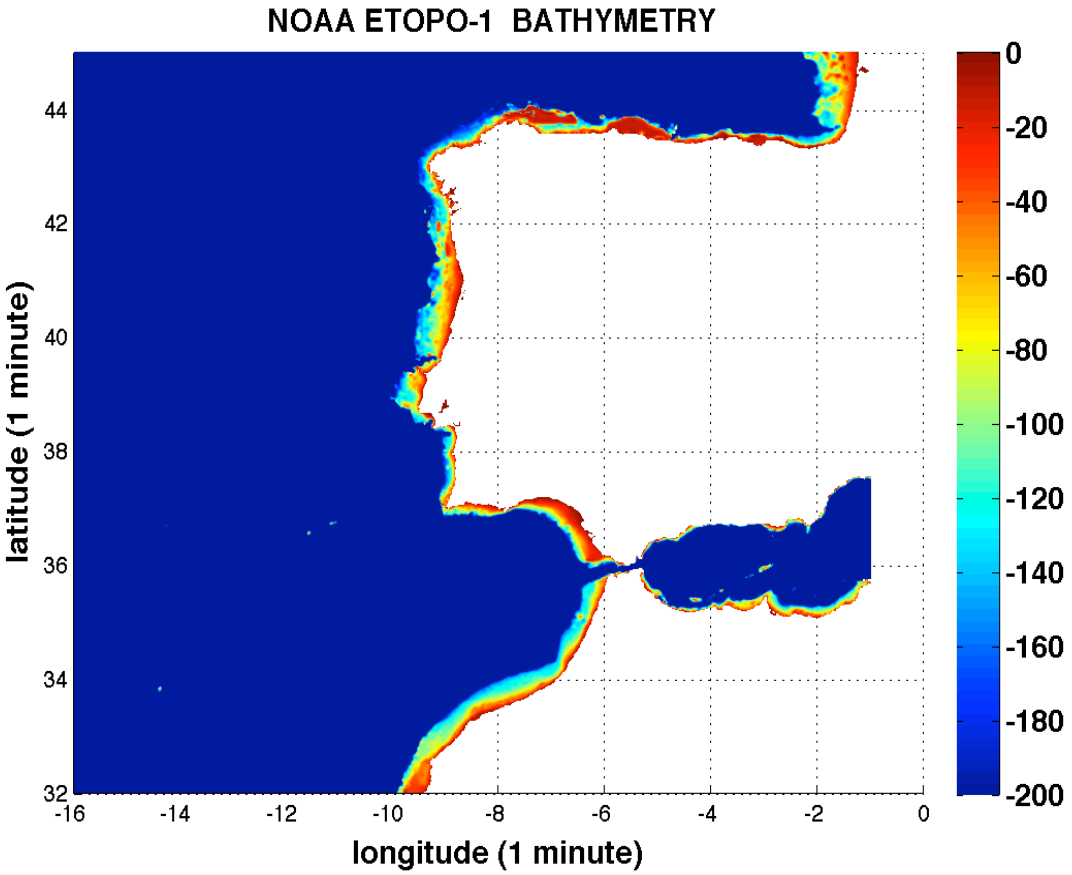
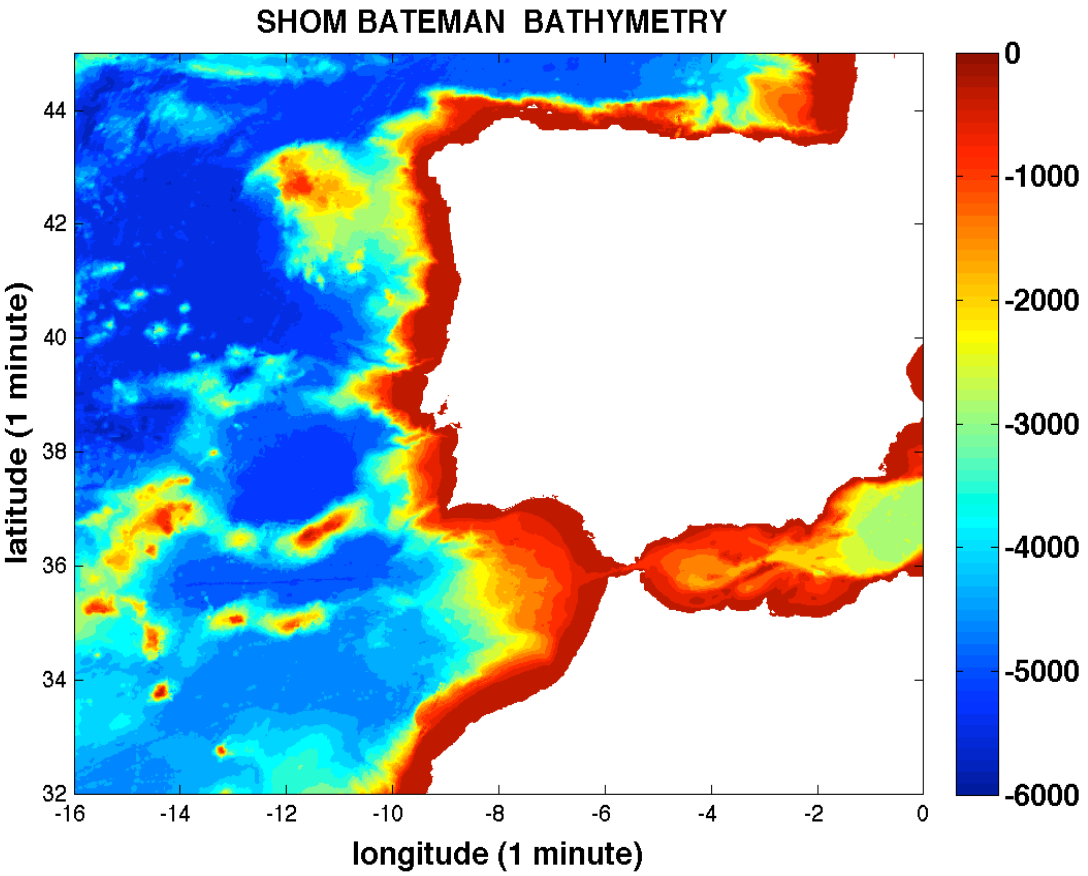


Fig.13 ETOPO-1 DTM representation, focusing: a) the slope, b) continental shelf



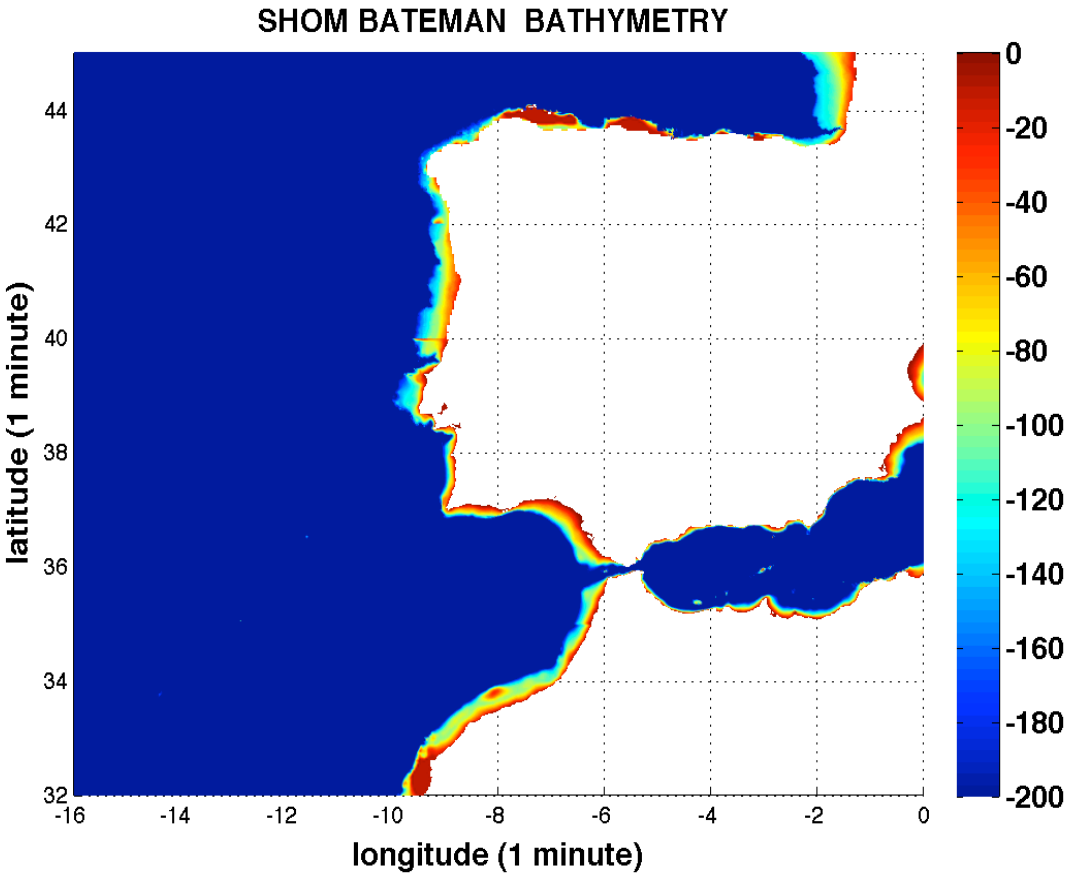


Fig.14 BATMANE DTM representation, focusing: a) the slope, b) continental shelf

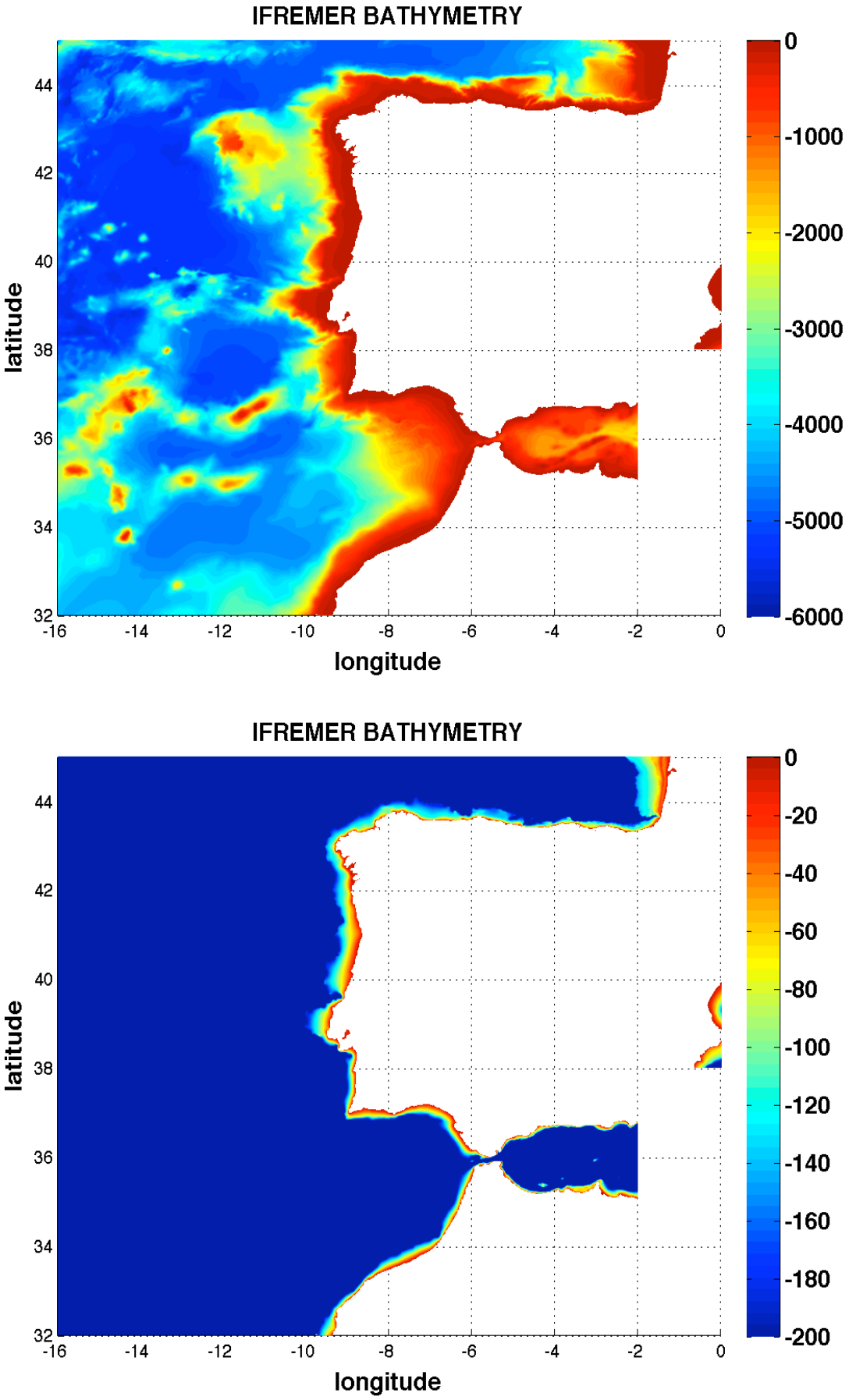


Fig.15 IFREMER DTM representation, focusing: a) the slope, b) continental shelf

The correction made to BATMANE DTM where based on the data quality interpretation (presented in chapter 2) and on the observation of topographic details shown by each dataset, over some bathymetry features:

- **South Gascogne continental slope and margin,**
- **Galiza coastal margin,**
- **Galiza bank,**
- **Torre sea-mounts,**
- **Portuguese continental margin (Nazaré submarine canyon),**
- **Gibraltar strait,**
- **Morocco's Western margin**

4.2. South GASCOGNE continental slope and margin

This region is part of the GASCM (an improved dataset from BATMANE-2000), IFREMER and ETOPO-1 DTM domains. Both GASCM an IFREMER are based on BATMANE, having GASCM incorporated detailed information from Galiza nautical charts and IFREMER filtered the original data source. ETOPO-1 evidence too many problems on this region (Fig13.a) enabling its use. The images below show that the GASCM conserves additional detailed features and evidence further coherent bathymetric information that IFREMER's DTM.

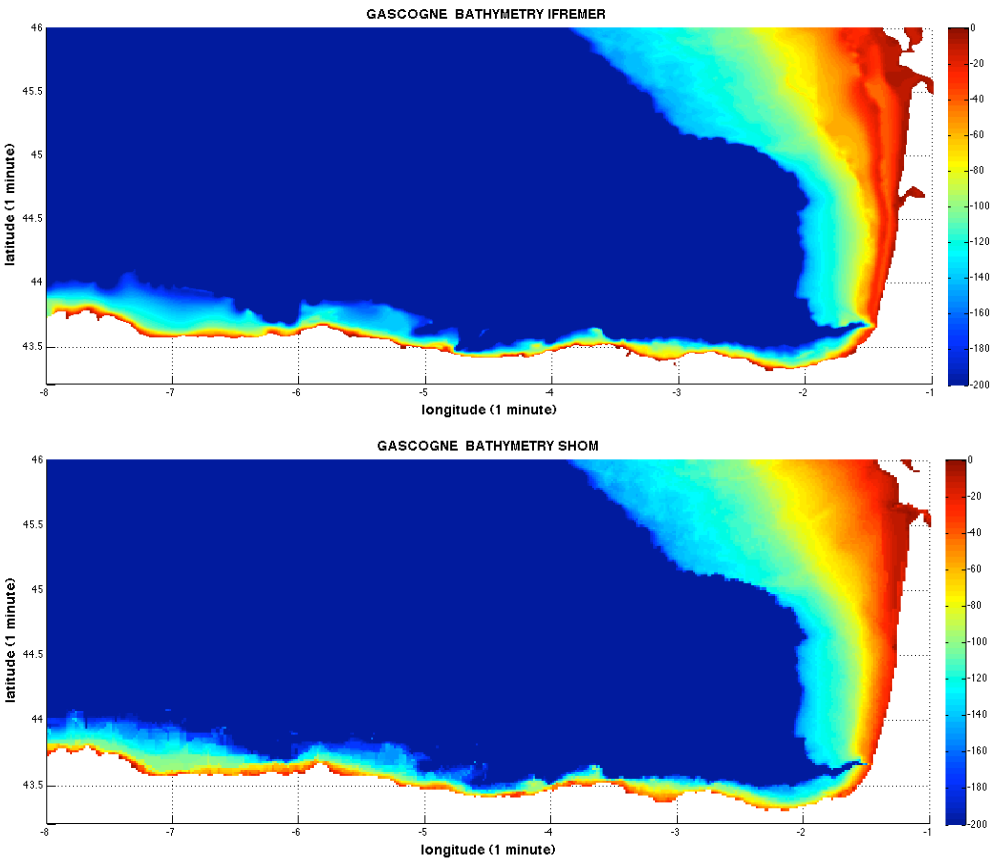


Fig.16 South Gascogne continental platform represented by IFREMER and GASCM DTM. Notice that along the French coast IFREMER shows a false submerse dune).

The slope region of the "Gascogne" golf is also better represented by GASCM, since IFREMER seems to lose bathymetry details by strong data filtering. For these the GASCM DTM was adopted to correct BATMENE over this region.

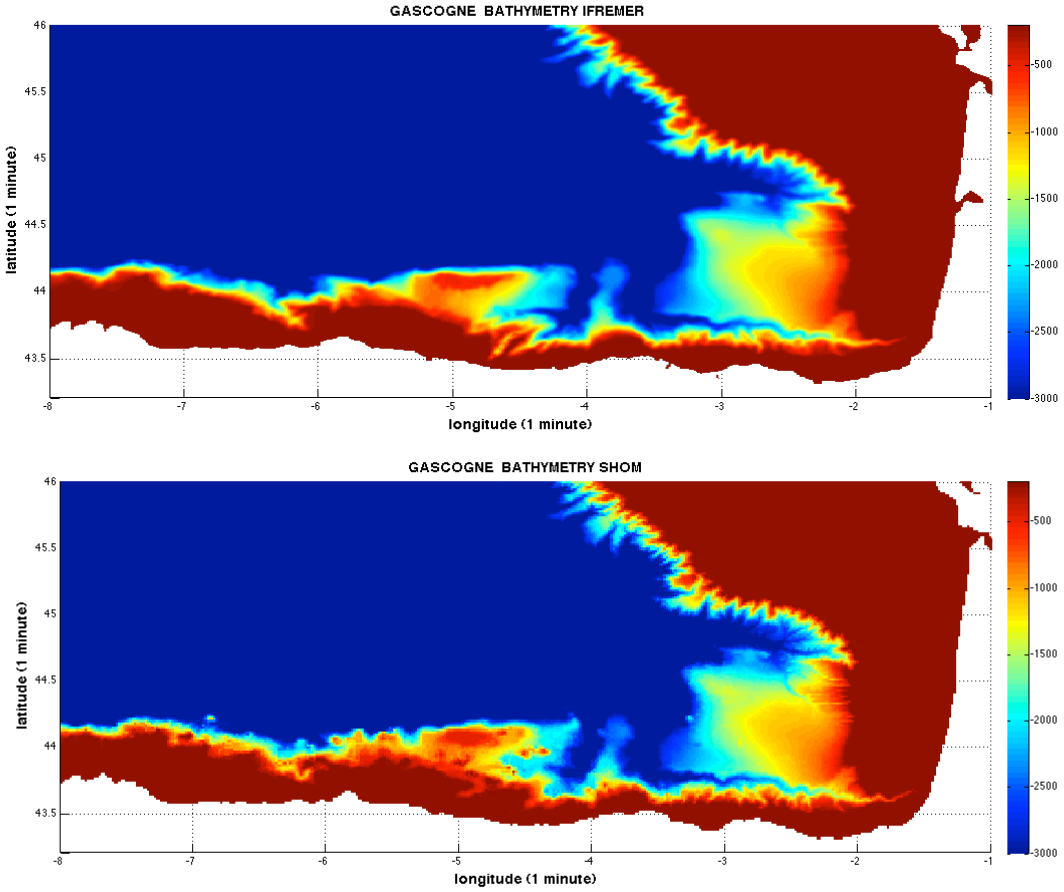


Fig.17 South Gascogne continental slope represented by IFREMER and GASCM DTM.

4.3. GALIZA coastal margin

All the available databases give the impression to represent roughly the Galiza coastal region, due to absent sounding information (especially near the coast and inside the Galiza "Rías"). The following images show that the nautical chart correction made in GASCM didn't reach this shallow water region, and that the IFREMER data erased the complex bathymetry over the cape of "Finisterre" area (Fig.18). On other hand, the vectorization and interpolation of data from local Galiza nautical charts (see chapter 3) seems to adequately represent the topographic details, along this continental margin. For these the Galiza Nautical Charts DTM was adopted to correct BATMENE over this region, within the 0-390m isobaths.

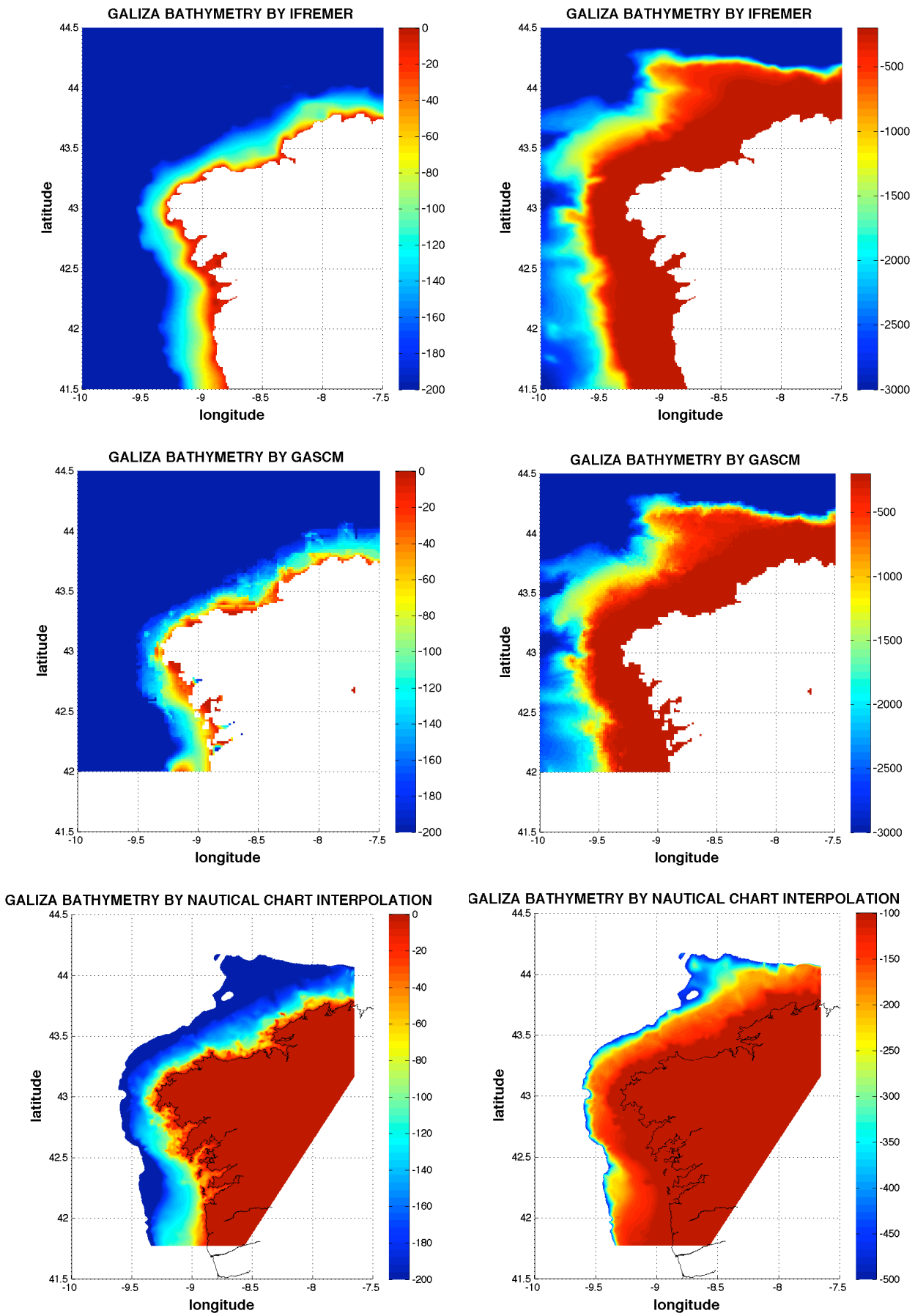


Fig.18 Different bathymetry sources at Galiza coastal margin. It is possible to see that IFREMER is too filtered, GASCM show false topographic features near the coast and inside the Galiza "Rías"(ex. 42ºN) and that the Galiza-Charts DTM reproduces important details at shallow water regions.

4.4. GALIZA bank

Galiza bank is an important topographic feature nearby the West-Iberia continental margin. It develops from 41ºN to 43.5ºN, meaning that GASCM (south limited at 42ºN) cannot represent the entire structure. However, if coupled with the original BATMANE data, this database is superior in detail than the IFREMER DTM. The two images below show how well this junction works (away from the coastal region).

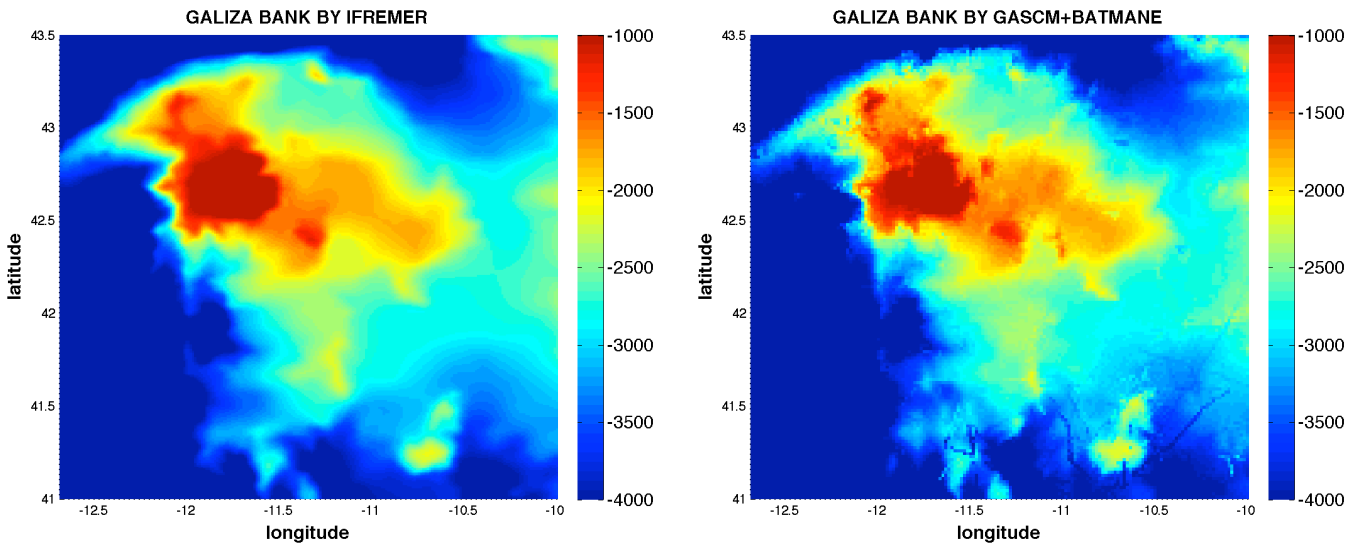
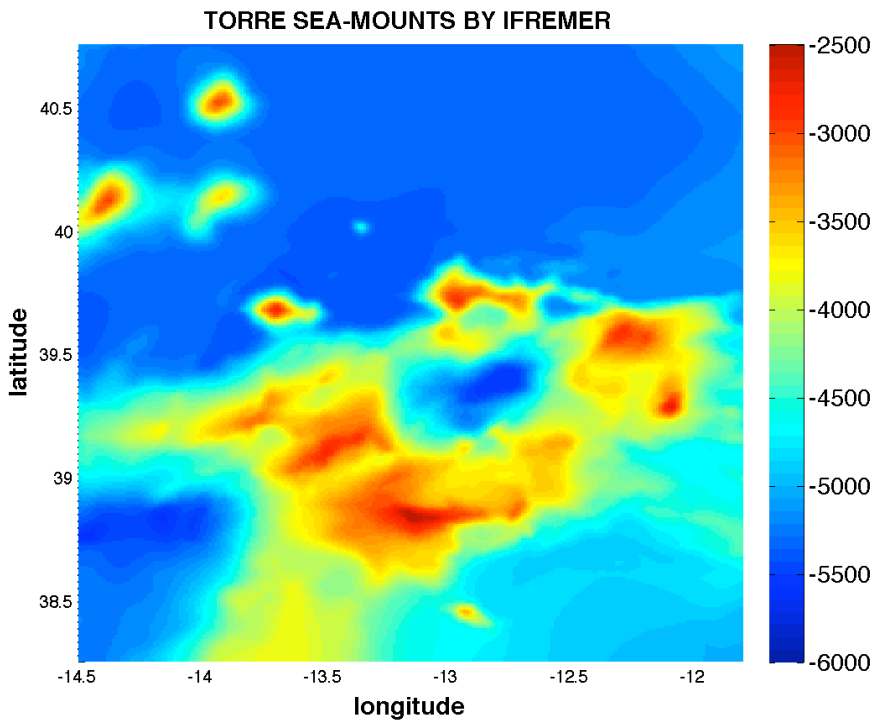


Fig.19 Galiza bank represented by both IFREMER and GASCM/BATMANE composite. Note that the junction of these two databases it's performed at 42ºN.

4.5. TORRE seamounts

The Torre seamounts are interesting topographic accidents located westerly from the Iberian margin. By its complexity, they become a great data quality proxy to test both IFREMER and BATMANE datasets.

The metadata information (presented at chapter 2) illustrate that IFREMER has higher density measurements cover that BATMANE. But a closer look at each DTM evidences a superior detail representation from BATMANE (see Fig.20). Similar analyses were made to other seamounts, present on the southwest region of WIBM domain, with the same results. For this reason the BATMANE dataset is the choice for all southwest sub-domain of WIBM.



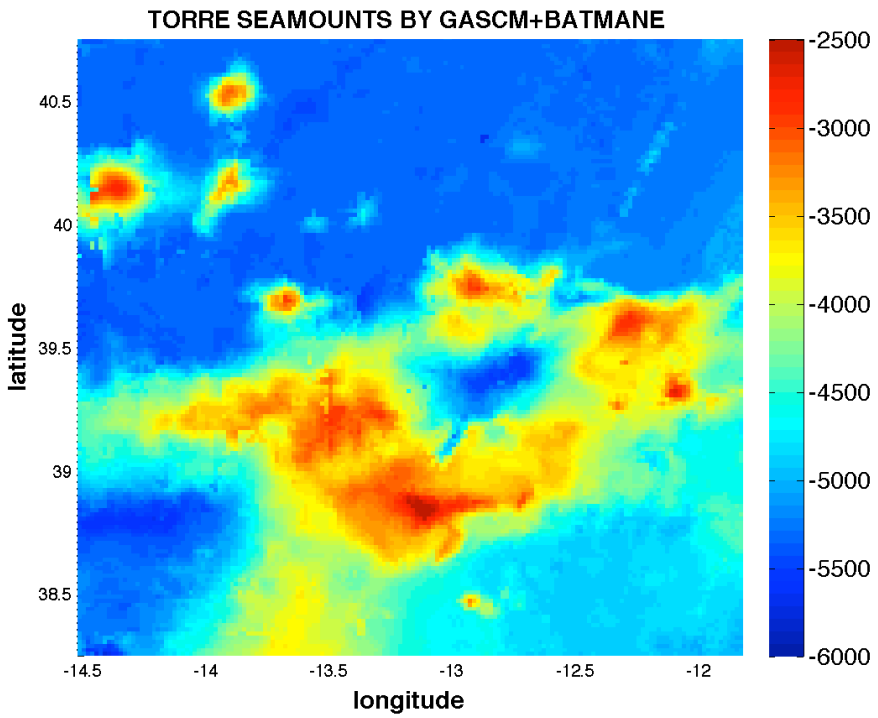


Fig.20 TORRE seamount represented by both IFREMER and GASCM DTM.

4.6. Portuguese continental margin

The Portuguese continental slope and platform is the centre of the WIBM domain. It's here where the numerical model will focus the study of the internal tide and regional circulation. For that, it is important to include in the WIBM DTM higher quality bathymetry information at this area. Aiming it, IH has gather their last hydrographic records in a 0,5' resolution model to be assembled in WIBM (see Fig.6). This step brought an unquestionable quality upgrade to the present bathymetry model.

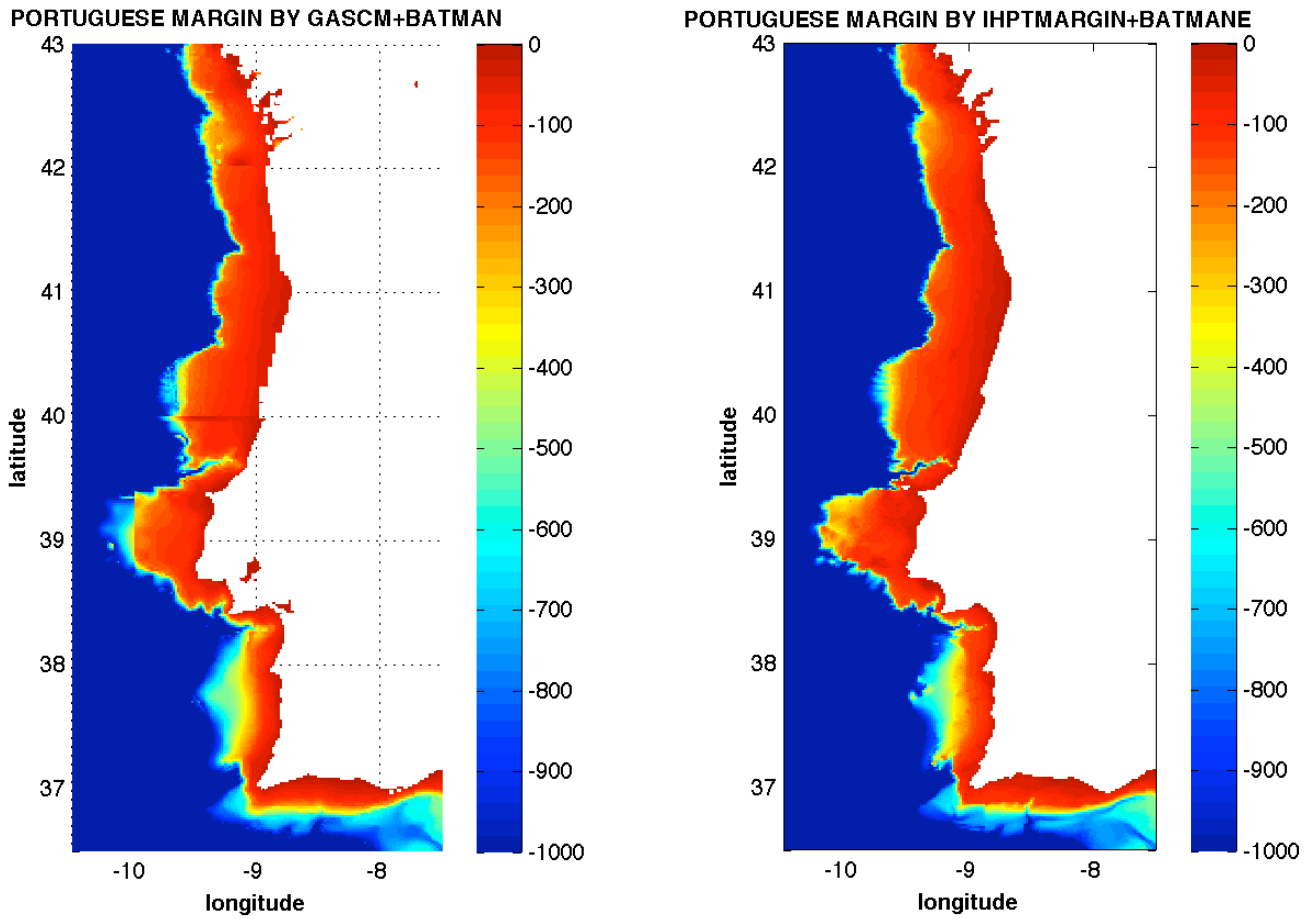


Fig.21 Portuguese Margin represented by both BATMANE (plus GASCM) and IH-PTMARGIN (plus BATMANE).

ETOPO-1 evidence too many problems on this region (Fig13) enabling its usage. IFERMER DTM represents well the Portuguese bathymetry, but was putted apart since its high level filtering data erase important details, along this region (see Fig.15). To evidence the difference between the BATMANE and IH-PTMARGIN, a zoom is made to the Nazaré Submarine Canyon region, where BATMANE shows several problems and misses details along the canyon axis (see Fig.22). Note however the similarity over the surrounding continental slope information (deeper than 2000m). This statement is verified along the Portuguese margin, allowing the assembling of the

IH-PTMARGIN into the BATMANE DTM (discussed in the next chapter). In fact, at its origin the BATMANE DTM incorporated also information from the IH database.

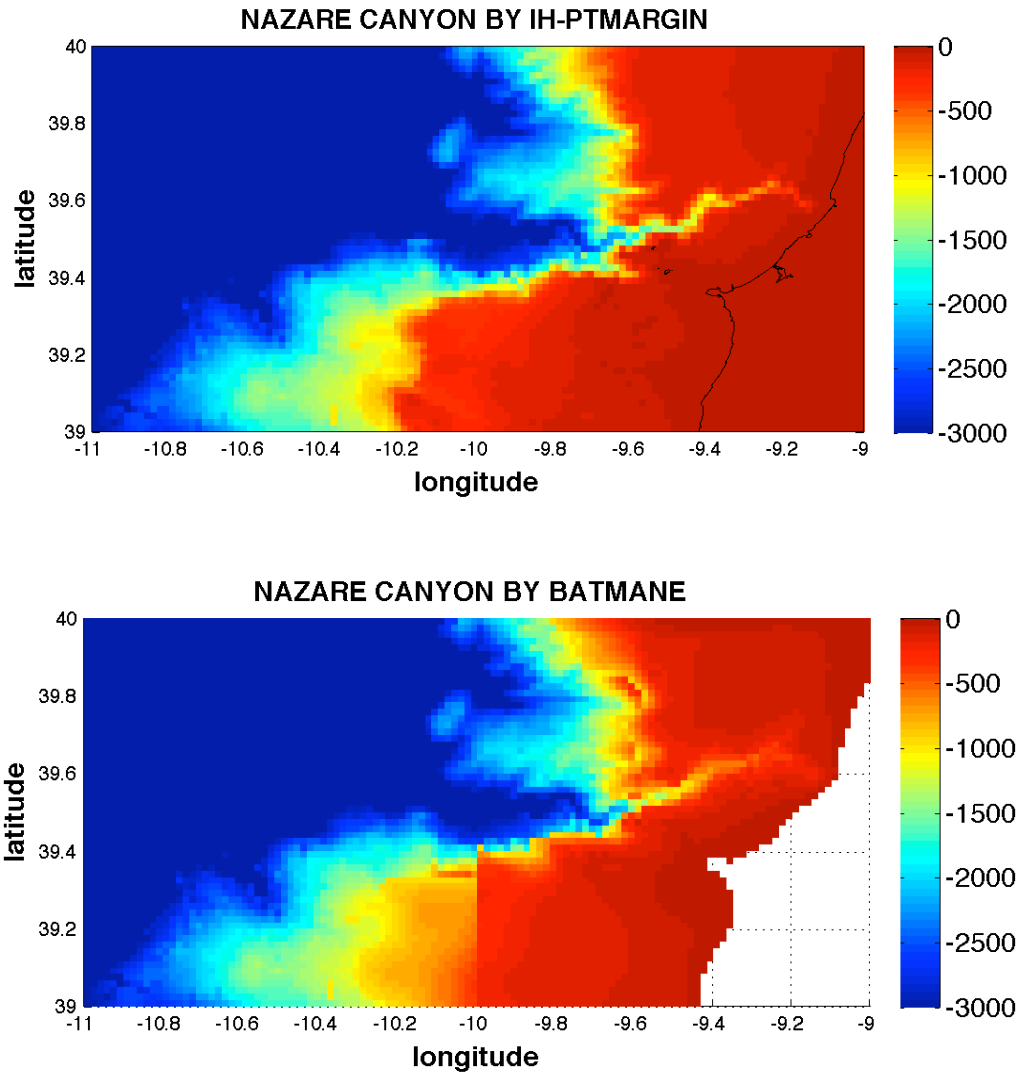


Fig.22 Portuguese Margin (Nazaré canyon region) represented by both BATMANE and IH-PTMARGIN DTMs.

4.7. GIBRALTAR strait

The Gibraltar strait is an important oceanographic feature, where the Mediterranean-water-outflow enters within the West-Iberian domain. To modelling this process it is important to have the strait topography well represented in the WIBM. This region (as well as the surrounding Cadiz and Alborrean sea) is represented in ETOPO-1, IFREMER and BATMANE DTMs. The three databases report low-density measurement converged. Although, the ETOPO-1 was adopted to correct BATMANE, since it shows better topographic details along the strait, as well as over the Cadiz Golf. Notice also, that ETOPO-1 represents quite well the marginal regions of the Mediterranean, differently from the Portuguese and Galiza continental margin.

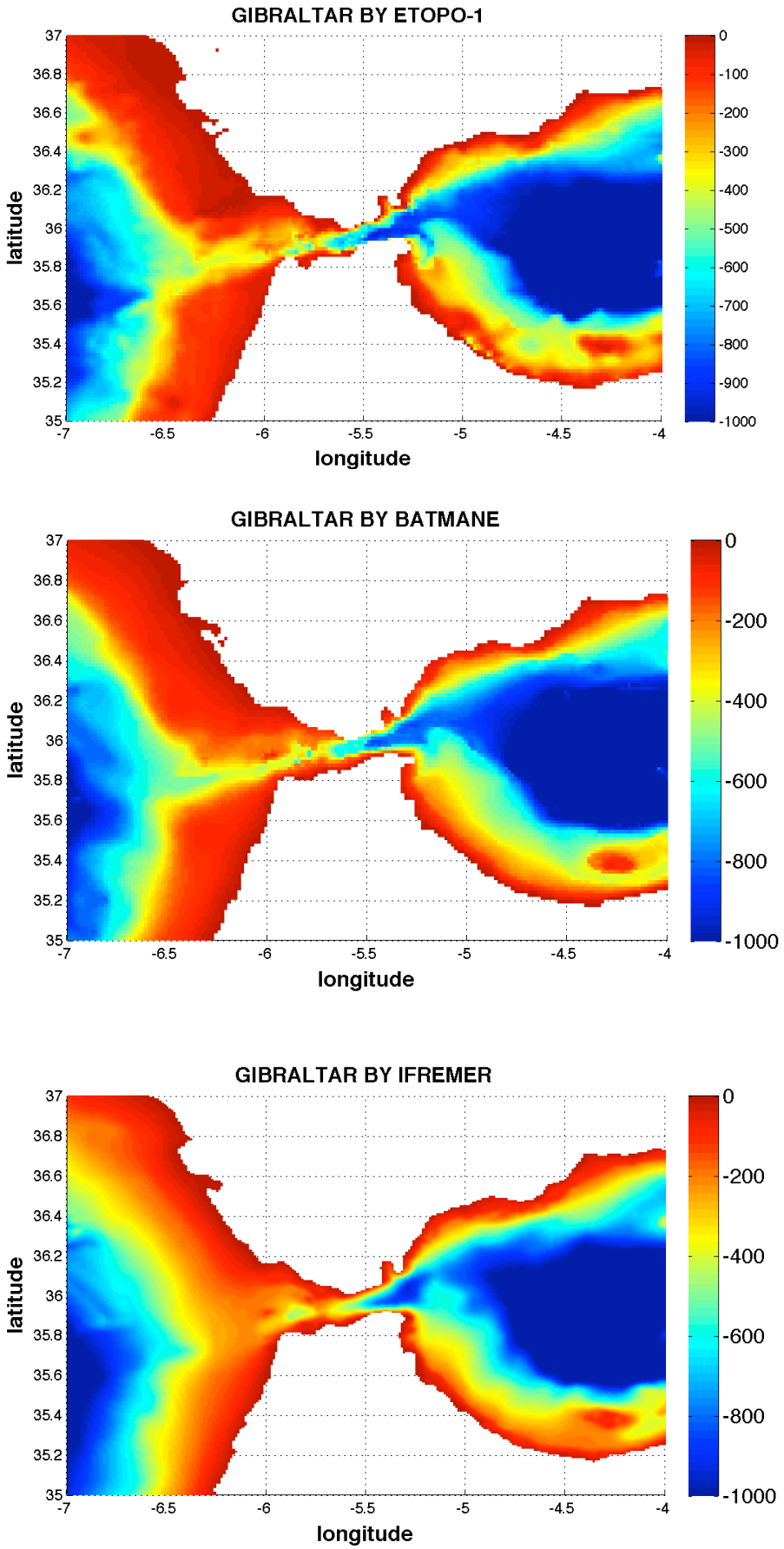


Fig.23 Gibraltar strait represented by ETOPO-1, IFREMER and BATMANE DTMs.

4.8. Morocco's Western margin

The last analysed topographic feature was the North-western African margin, where BATMANE shows some topographic anomalies along the Shallow-water region, differently from ETOPO-1 DTM. For this, the original WIBM was also corrected by ETOPO-1 over this site.

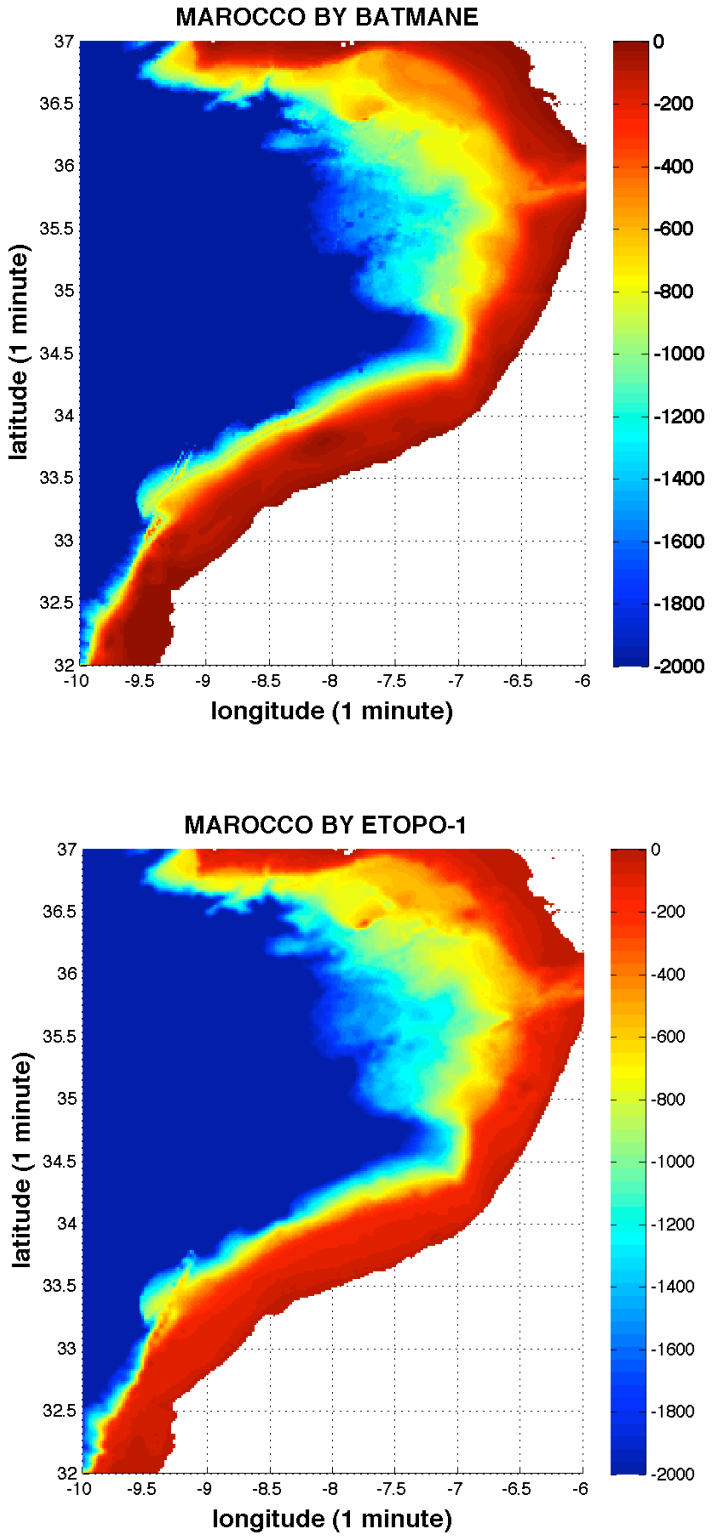


Fig.24 Morocco margin represented by ETOPO-1 and BATMANE DTM's.

5. THE MEAN SEA-LEVEL

Even if the adopted vertical reference was the zero hydrographic, a mean sea-level model was made available to the present work. This mean sea-level solution comes from a French model called MARMONDE (developed by Bernard Simon), and results from a spatial fitting between multiple tide gauges data and satellite altimetry (see Fig.25).

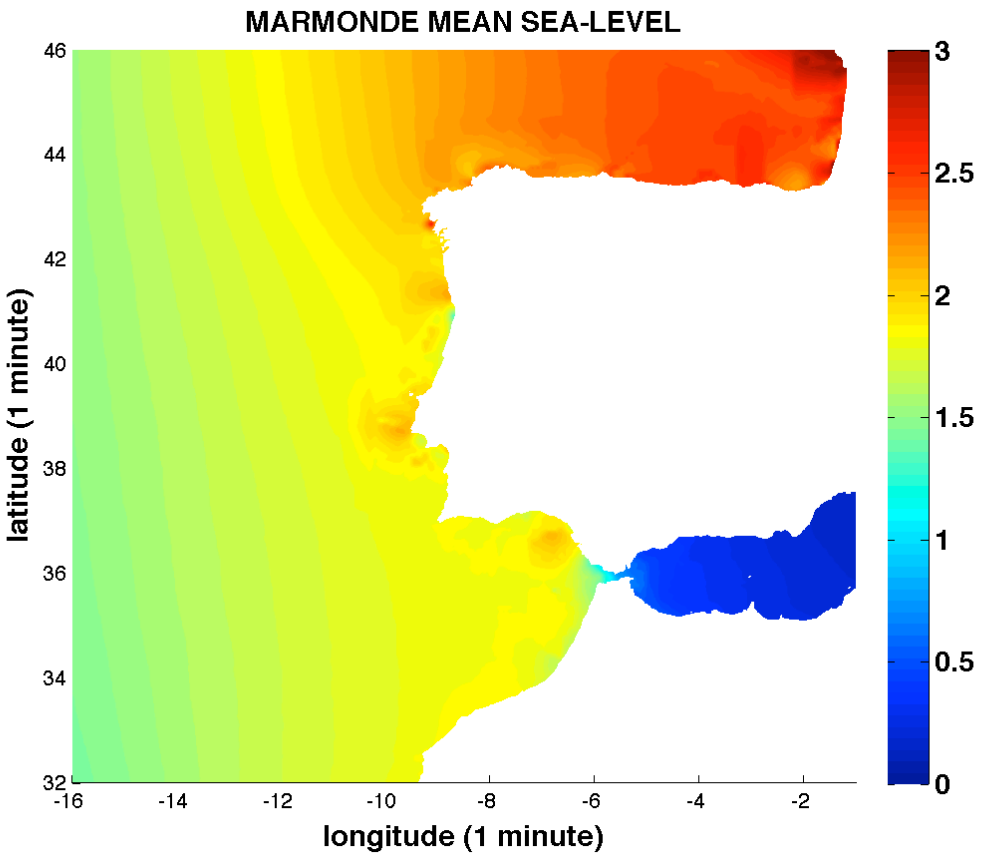


Fig.25 Bernard Simon mean sea-level solution (meters above the zero hydrographic), at WIBM region (model MARMONDE).

This dataset allowed a possible reduction of the vertical reference of ETOPO-1 to the to zero hydrographic (adopt in this work), as well as the conversion of de WIBM-2009 model (build in the next Chapter) into a second version, where the its vertical reference becomes the mean sea-level (WIBM_msl-2009). This new DTM, was produced by adding the present solution (Fig.25) to the WIBM DTM (zero hydrographic referenced), and is part of an attached data directory to the present document.

6. BUILDING WIBM COASTLINE

After gathering the several databases it is necessary to add a coastline to the bathymetry model. This process help to cover the land areas, as well as put in evidence the missing information between data and the coast (at very shallow water regions, were the available databases don't reach). The coastline source is the NOAA Shoreline Database. This is a high-resolution satellite-derived data generated by the US National Geospatial-Intelligence Agency (NGA):

Scale(s): 1:75,000 and smaller

Coverage: Worldwide, from about 60-degrees South latitude to 80-degrees North latitude.

Spatial Reference: Geographic coordinate system; Horizontal Datum – World Geodetic System (WGS 84)

Tidal Datum: High water line

Data Format: ESRI shapefiles that can be downloaded from internet by region.

Accuracy: Approximately 50 meters

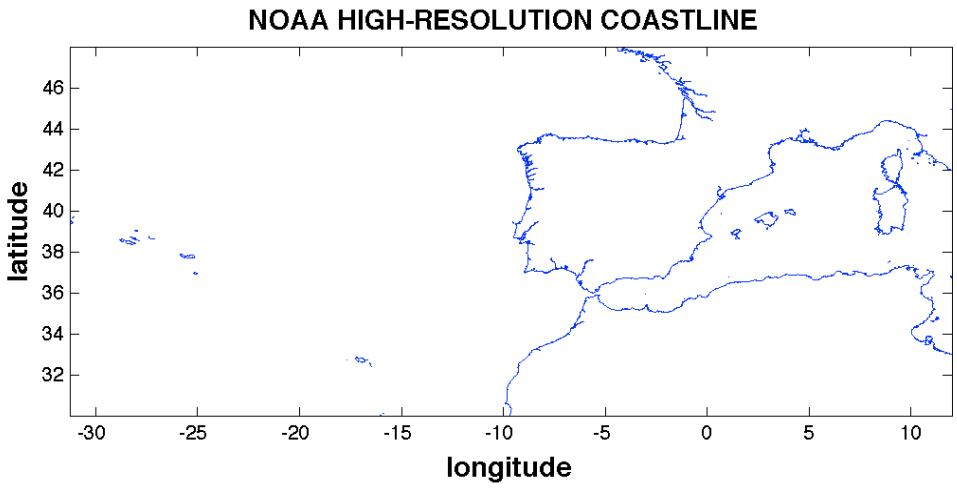


Fig.26 Region nº8 from NOAA Shoreline Database

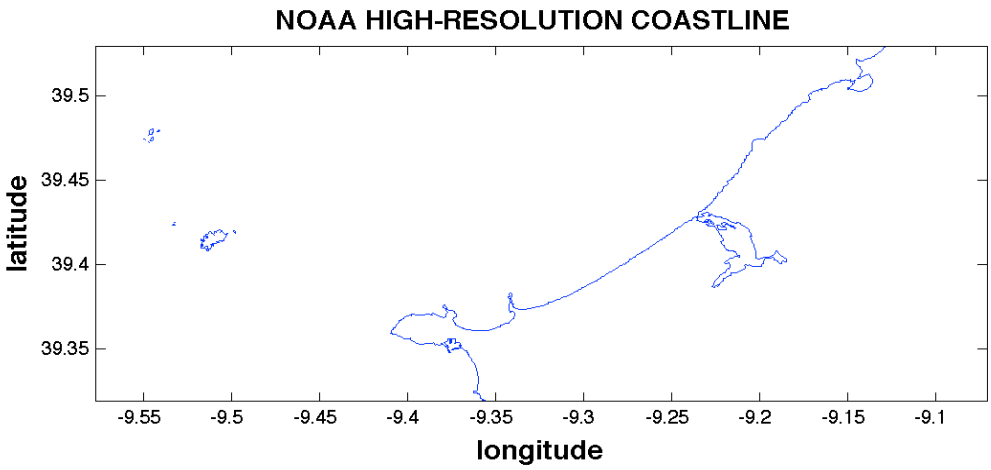


Fig.27 The accurate coastline is sufficient enough to represent all the small islands, rivers and estuaries along the Portuguese and Galiza coast. The figure shows cape of "Peniche" , the "berlengas" Islands, "São Martinho" bay and "Óbidos " estuary.

The original shapefile ('NGA_GlobalShoreline_cd8.shp') was converted to a lat/lon vector, delimited to the model domain. This vector was then transformed to raster by matlab vect2mtx.m function. By using the encodem.m function we defined 3 distinct regions (ocean, coast and land):

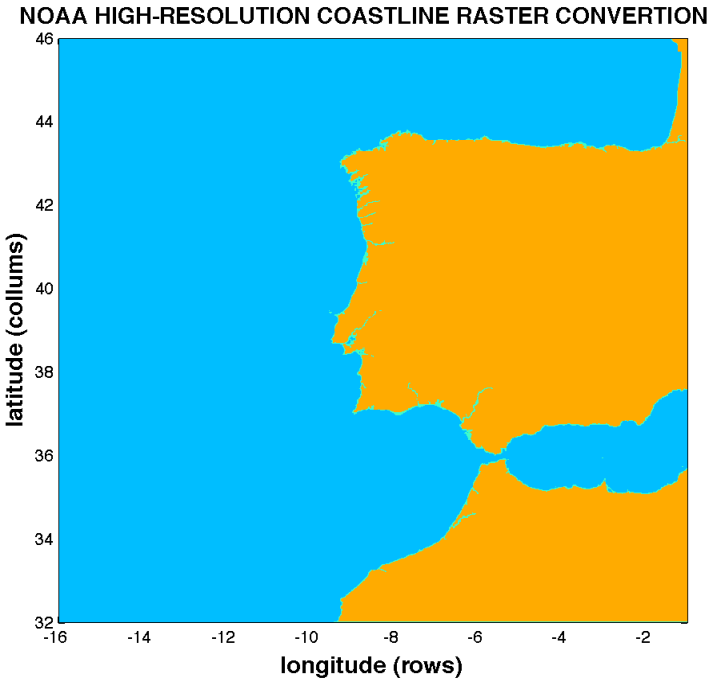


Fig.28 The original shapefile NGA_GlobalShoreline_cd8.shp converted to raster, with 3 level classifications.

To verify the conversion performance the raster was intercept by the original lat/lon vector and a zoom analysis was then made over complex coastline regions (Fig.29).

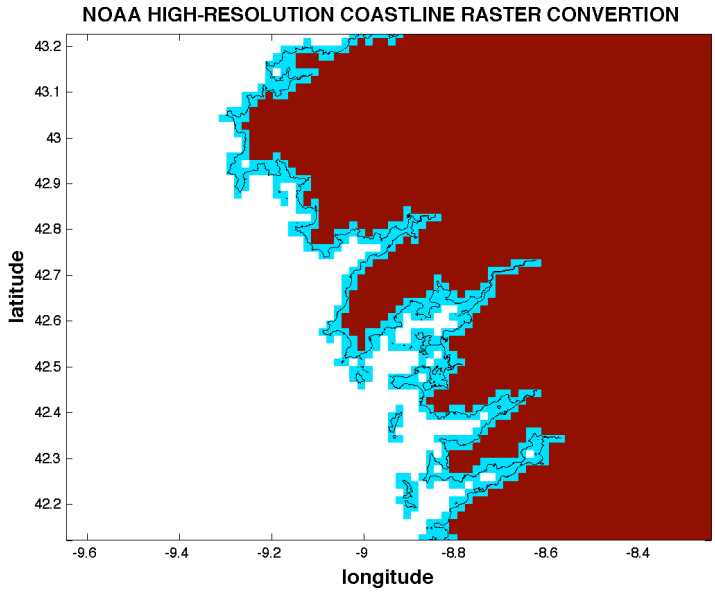
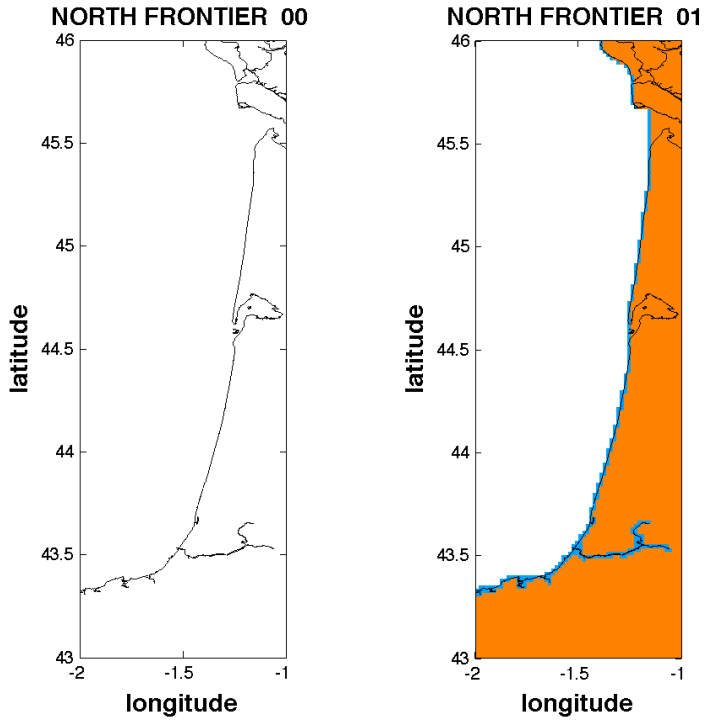


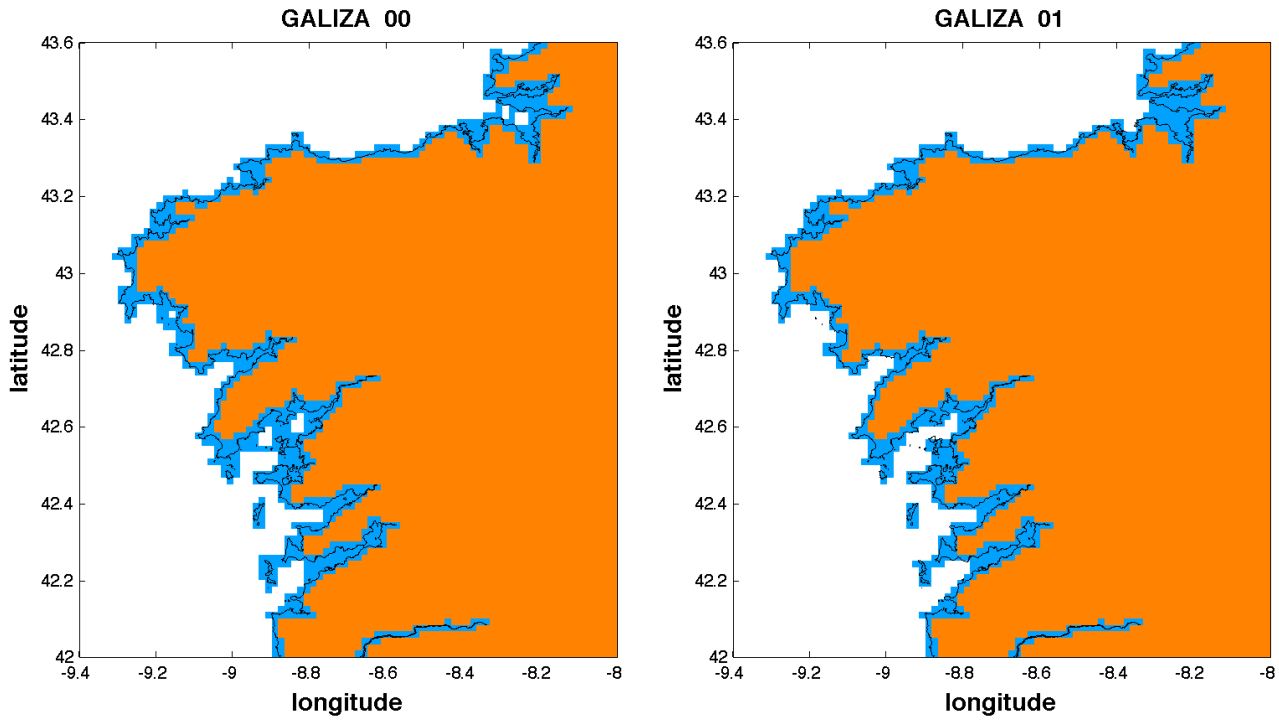
Fig.29 Coastline Raster visualization with the 3 level classification (ocean=white; costline=blue; land=red)

By the observation of the previous results some corrections were made to prevent numerical problems and to approximate the coastline to better represent the domain within the WIBM DTM resolution (1'):

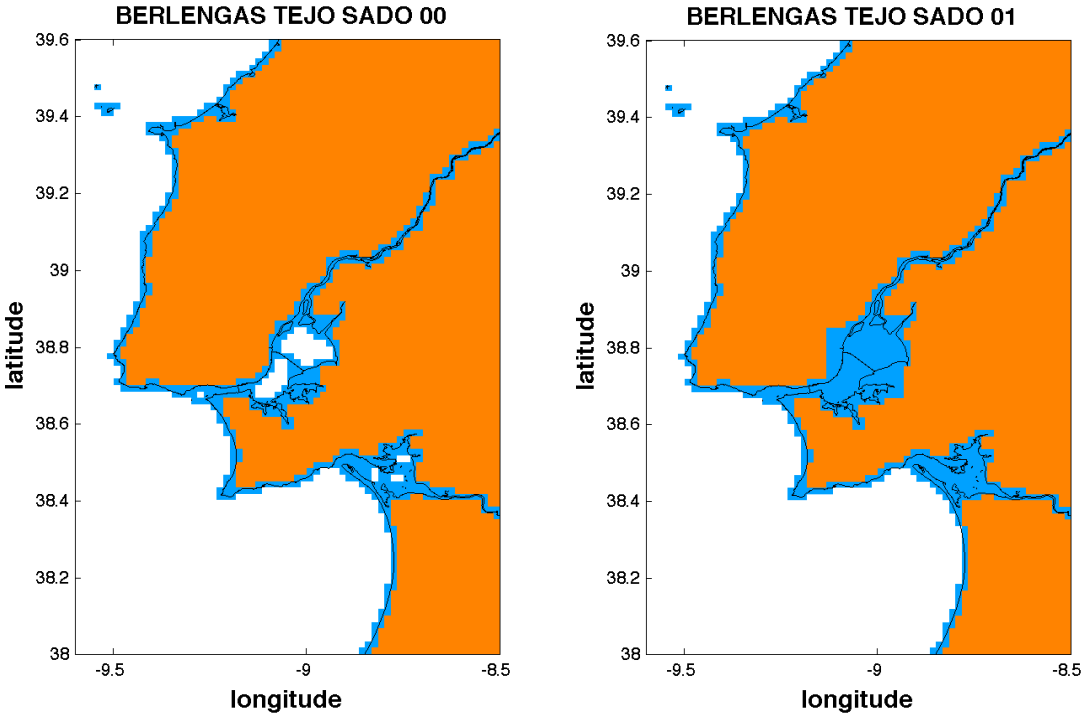
6.1 **North zone.** Close the Gironde and Arcachon rivers (Fig.30).



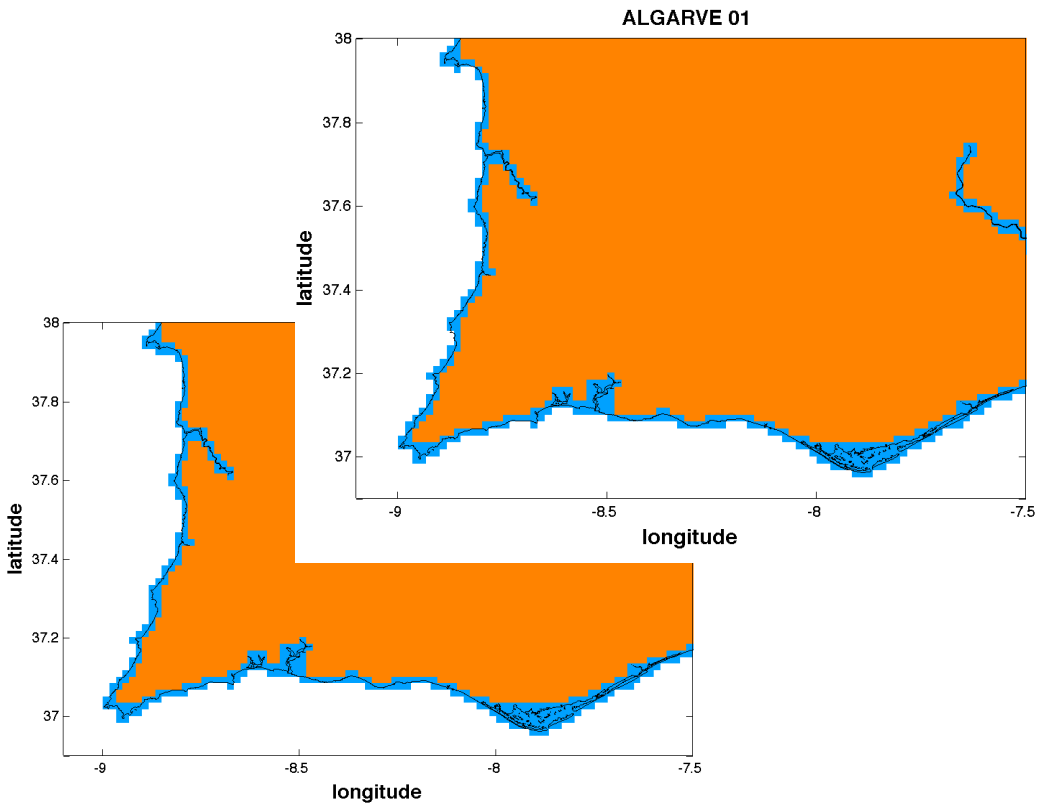
6.2 **Galiza "Rías".** Erase the small islands and repair the coastline inside the "Rías". This was performed with the help of Galiza nautical charts interpretation (Fig.31).



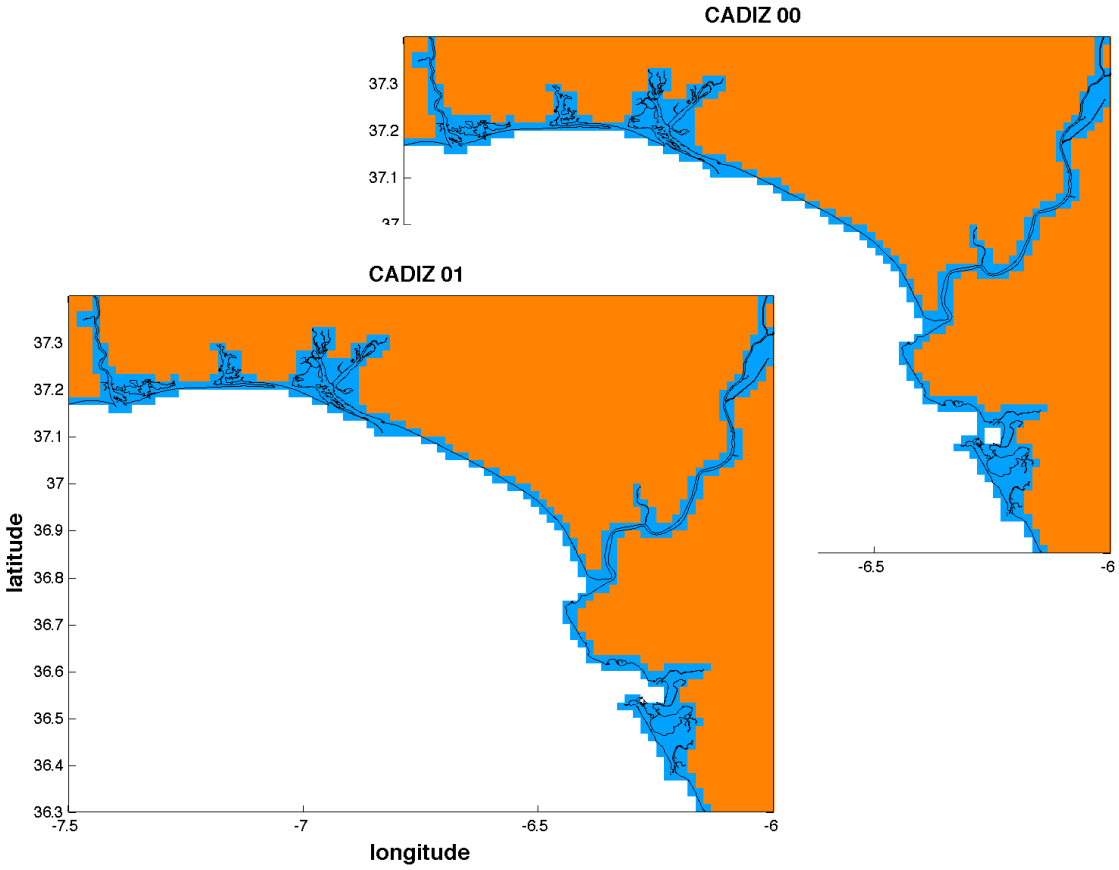
6.3 **Berlengas Island, Tejo and Sado rivers**. Both rivers were closed and berlengas island mesh was kept by analysis of Portuguese nautical chart (this area corresponds to all the island surroundings with less than 10m depth). (Fig.32).



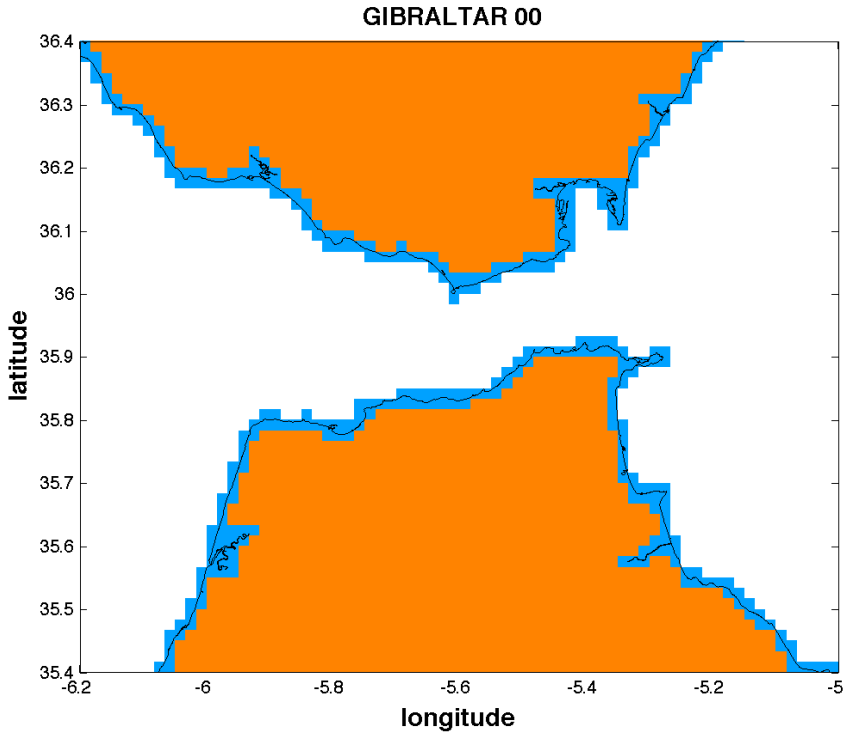
6.4 **Algarve.** Some small adjustments were made on Cape of "Sines" and Cape of "Sagres". On other hand it is possible to see that the algorithm turned well at the "Ria Formosa" Delta (Fig.33).



6.5 **Cadiz**. A small adjustment was made inside the port (Fig.34).



6.6 **Gibraltar**. Nothing was changed (Fig.35).



6.7 **Melilla (Morocco).** The estuary was covered and the Cape of "Melilla" finalized. The islands were kept (Alboran).

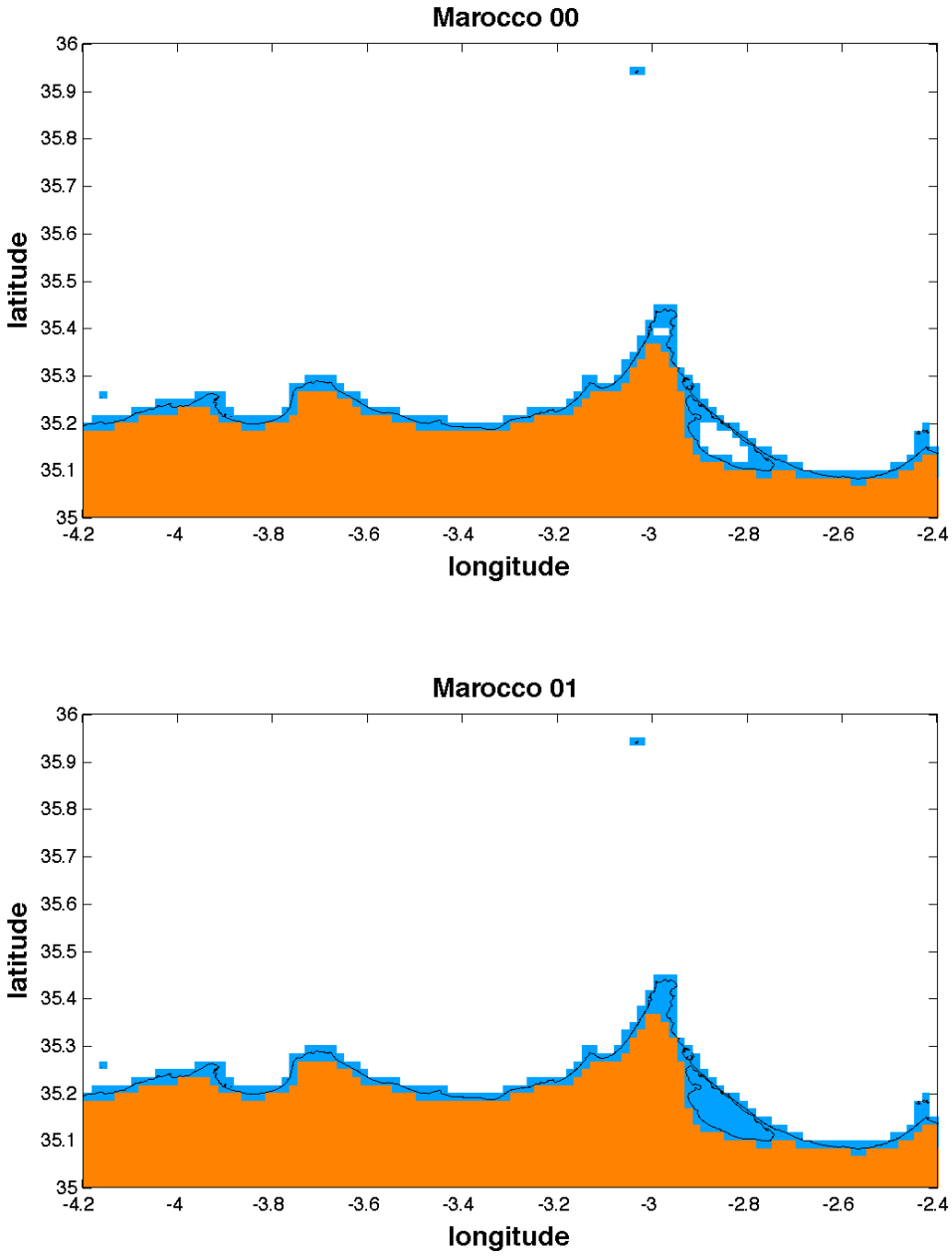


Fig.36 North coast of Morocco. a) Coastline raster before corrections; b) Coastline raster after corrections

7. BUILDING WIBM BATHYMETRY

The construction of WIBM DTM tried to take advantage of the best data available, within different information sources: **ETOPO-1, GASCM-2004, BATMANE-2000, IH-PTMARGIN** and **Galiza Nautical Charts DTM**. The spatial limits definition of each collected data were adjusted to minimize junction steps. This processes was performed in several attempts and controlled by visualization of the residual differences along each boundary connection. The following list show the sequence performed along the WIBM construction, as well as the adopted limits:

- **BATMANE-2000** (32N-42N / 16W-1W). **Chosen as the main DTM support**

- **GASCM-2004** (42N-46N / 16W-1W). Chosen to correct all the north part of the domain (including the all the French and Spanish continental slope and platform).

- **ETOPO-1** (32N-38N / 7.5W-1W). Chosen to correct both Mediterranean Sea and Cadiz Golf (including the Gibraltar Strait). Note that, to use this dataset a vertical reference reduction was performed to convert its mean sea-level reference to zero hydrographic (by using the MARMONDE mean sea-level solution).

- **ETOPO-1** (Existing data from 0-2000m isobaths, inside the domain 32N-36N / 11W-1W). Chosen to correct the Morocco's continental margin (slope and platform).

- **IH-PTMARGIN** (Existing data inside the domain 41.8N-44.2N / 9.6W-7.7N). Chosen to correct the Portuguese continental margin (slope and platform).

- **Galiza nautical charts** (Existing data from 0-390m isobaths, inside the domain 41.8N-44.2N / 9.6W-7.7N). Chosen to correct the Galiza continental platform.

- **NOAA's high-resolution coastline**. Chosen to correct the coastline limits.

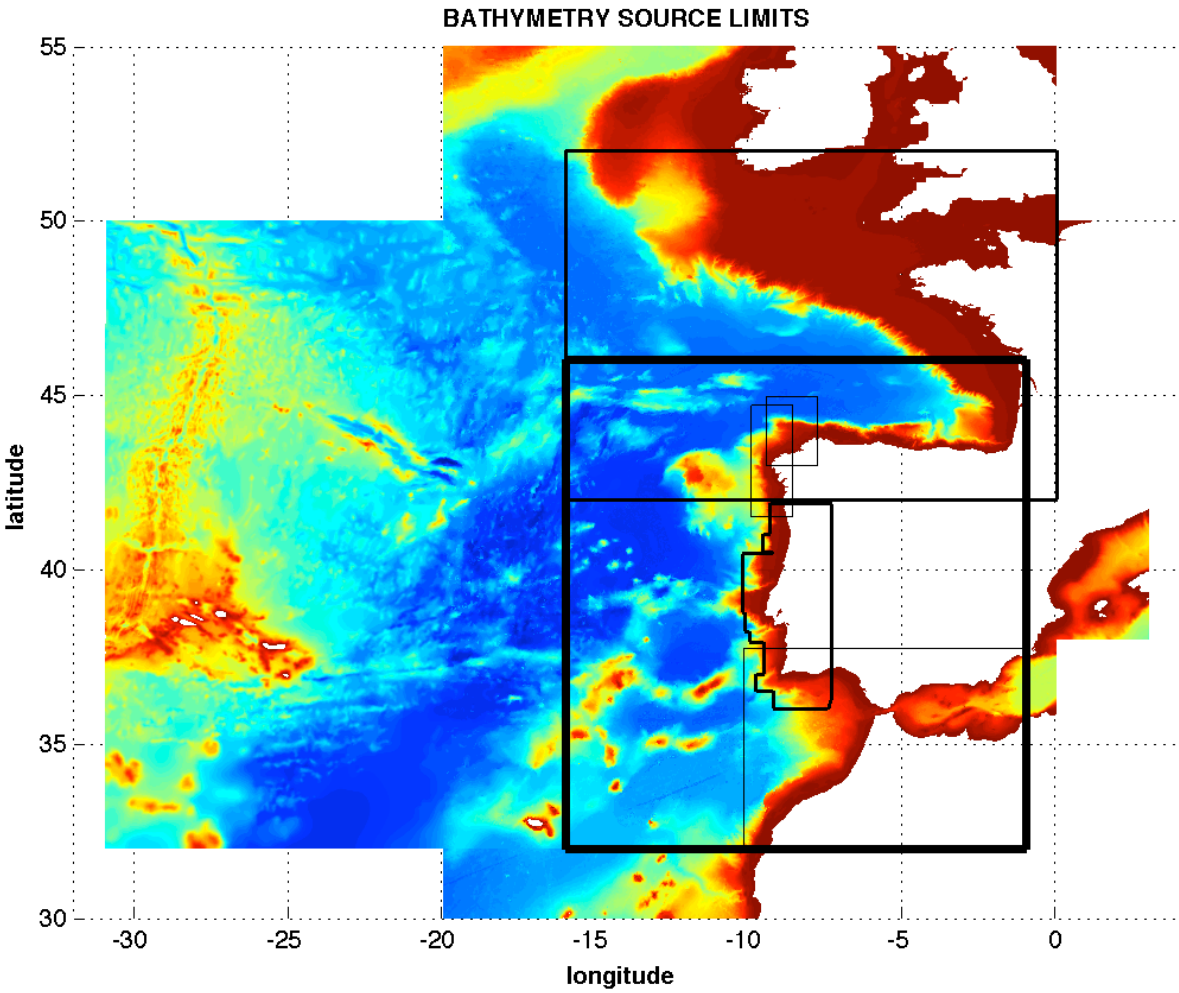


Fig.37 Available bathymetric information. The Bolded Square limits the WIBM domain and the other areas show the limits of the different used information sources (see chapter 1 and 5).

7.1 STEP 1: WIBM1 = GASCM CONCATENATION INTO BATMANE

The BATMANE-2000 DTM was adopted as the main DTM support to build WIBM-2009. The first correction performed was the replacement of the North part of the domain by GASCM-2004 (since this model it's it self a correction to BATMANE's DTM). The chosen boundary between of these two sub-domains of BATMANE and GASCM DTMs (Fig.20.a) corresponds to the south limit of GASCM (42ºN). The frontier cuts the west-Iberia margin in a region more a less homogeneous (not slicing any complex bathymetric feature). These DTMs have the same origin, vertical reference, resolution and projection (WGS-84) allowing a direct junction.

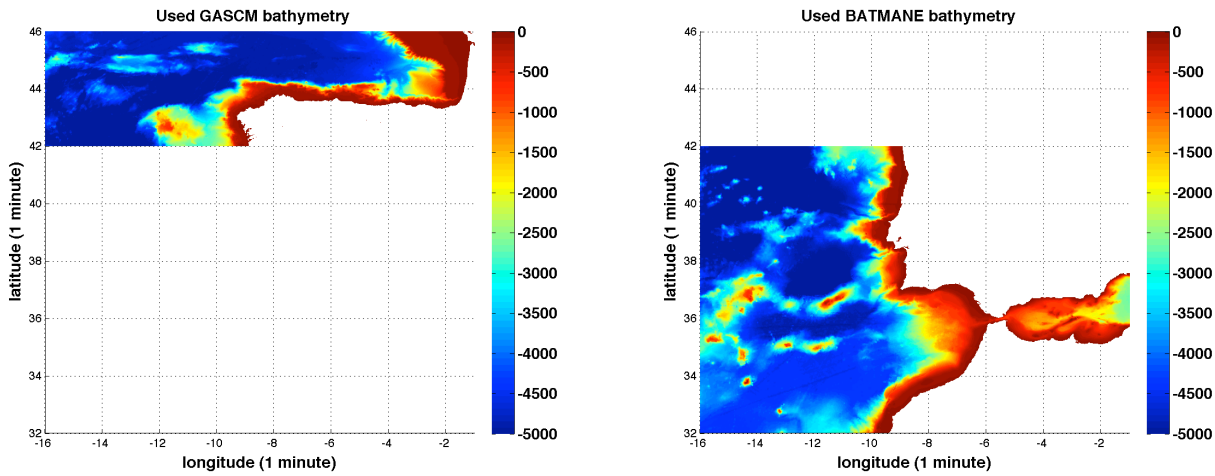


Fig.38 STEP 1: Used GASCM and BATMANE sub-domain in the WIBM construction.

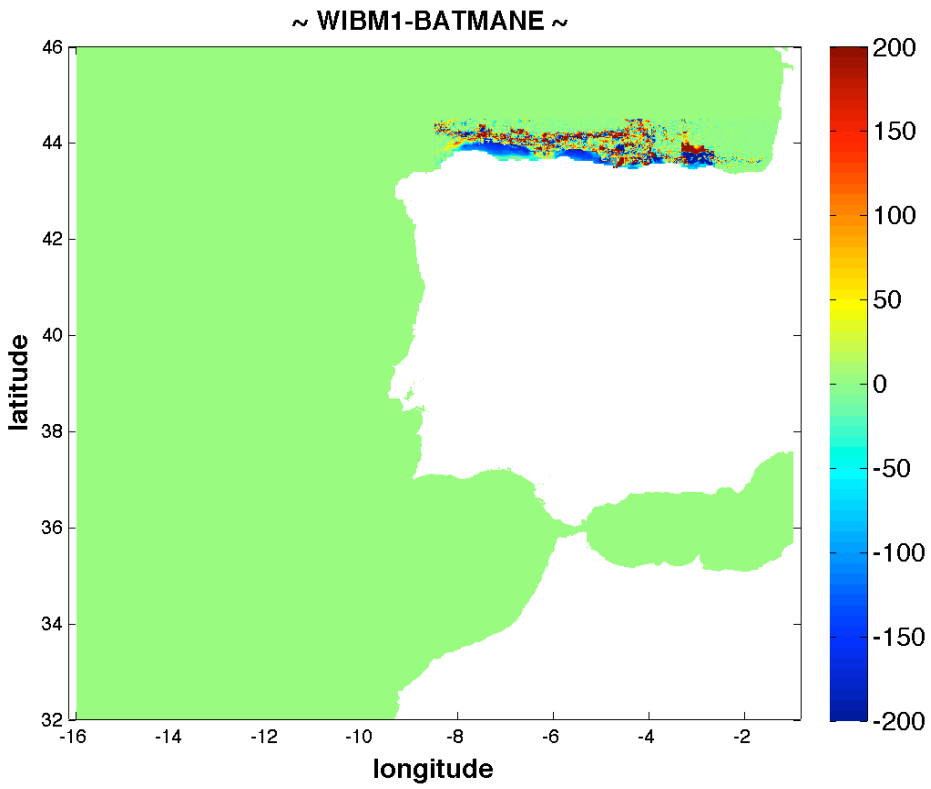


Fig.39 Control image of the Step1 transformation, showing the differences brought to the new DTM, from BATMANE-2000.

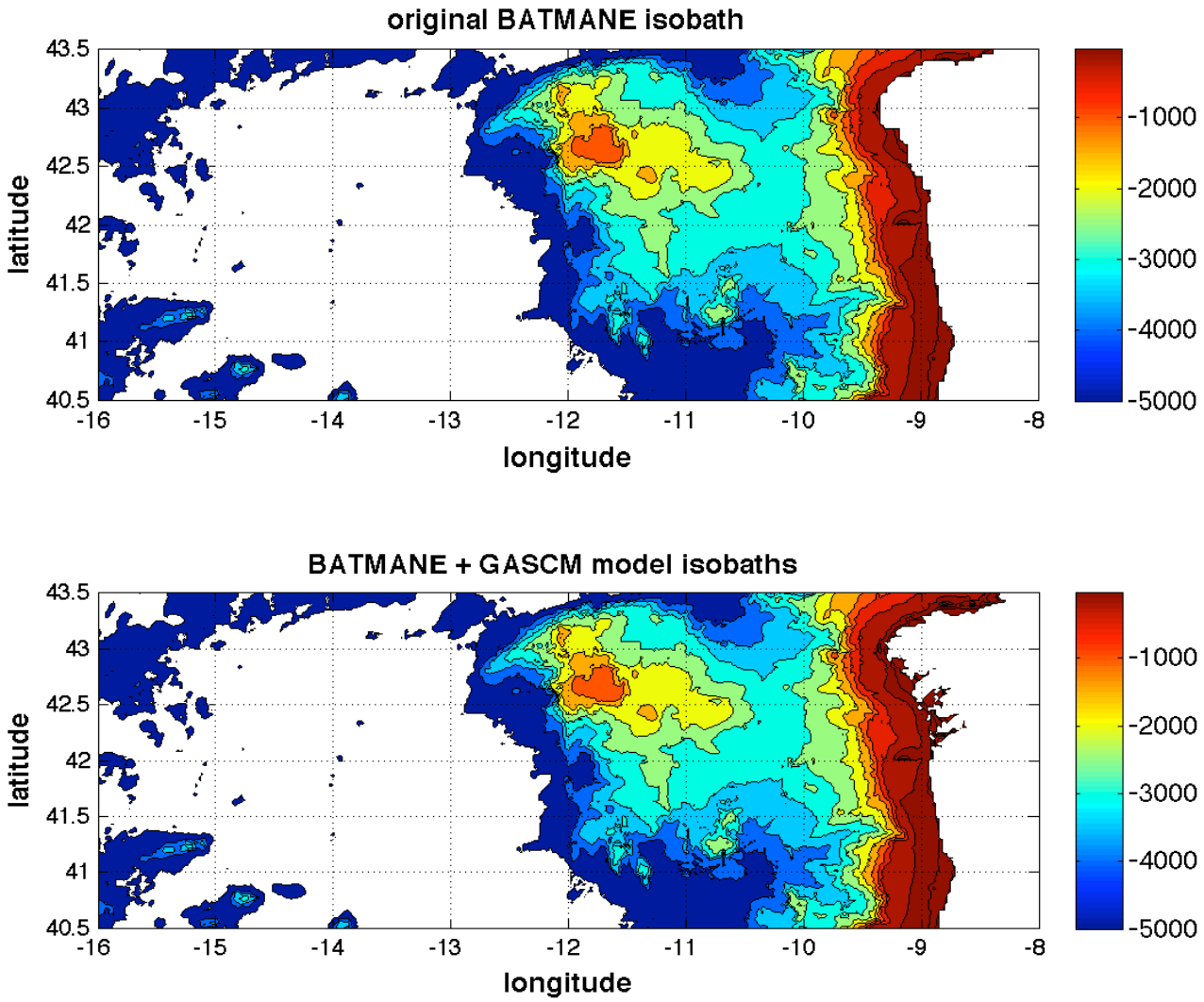


Fig.40 Since they have the same resolution and origin, the GASCM+BATMANE junction reproduce the original information contained in the BATMANE database, along the boundary region (42ºN). This fact is also visible at Fig.39

Notice that the same boundary reveals at the shelf (42ºN) unrealistic topography structures (Fig.20.b). This area will be corrected by both IH-PTMARGIN and Galiza-nautical-charts datasets (discussed next).

7.2 STEP2: WIBM2 = ETOPO1 CONCATENATION INTO WIBM1

The second step was the replacement of the Mediterranean region in the WIBM, created in step1, by ETOPO-1's DTM (already correct by MARMONDE, to arrive at the same vertical reference; see Chap.5). The chosen boundary (between these two sub-domains) was defined in order to gather the best information available from both DTM's and minimize junction steps (Fig.42). Another correction was performed to the Morocco's continental margin, replacing the 0-2000m isobaths band of the WIBM2 with the existing information from ETOPO1 (inside 32.0N-34.5N and 11.0W-6.0W, see Fig.13).

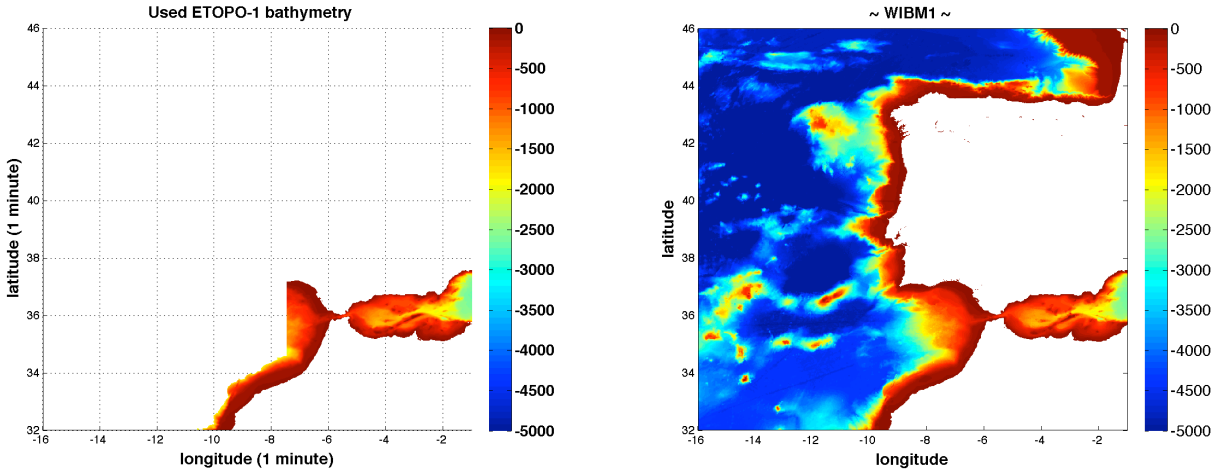


Fig.41 STEP 2: Concatenation of ETOPO-1 information into WIBM1.

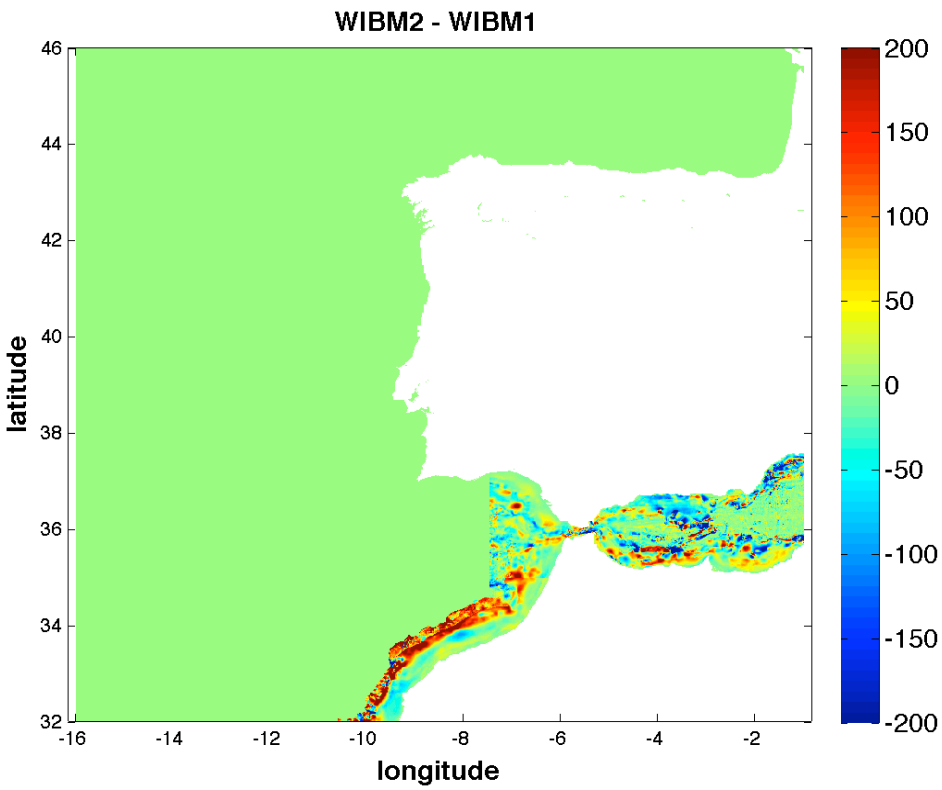


Fig.42 Control image of the Step2 transformation, showing the differences brought to the new DTM, from WIBM1. Topographic details changes can be see in Fig..43.

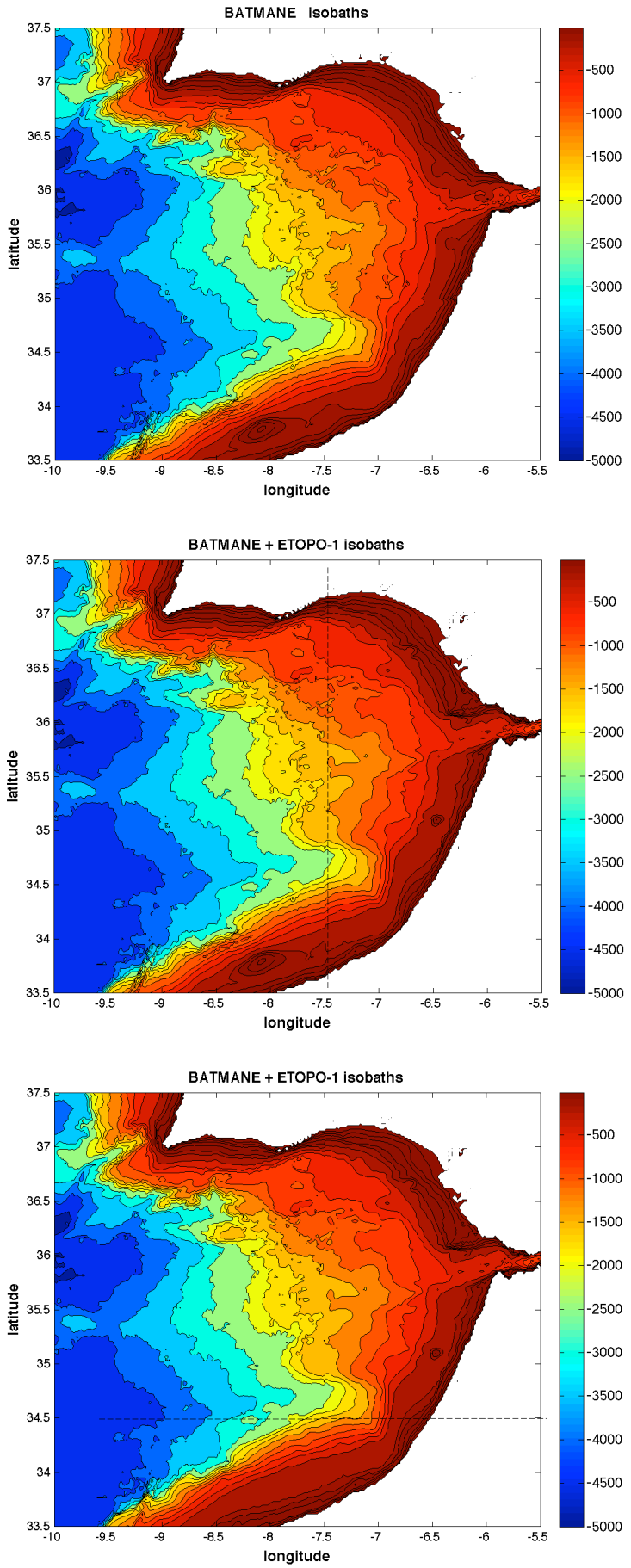


Fig.43 a) Original BATMANE bathymetry; b) A new WIBM DTM, where the Cadiz, Gibraltar and the Mediterranean bathy source comes from ETOPO-1. The line shows the junction limit. c) A new WIBM DTM, where the 0-2000m isobaths band over the Morocco's continental margin was replaced by ETOPO-1 data. In figure, the isobaths 2000m is represented by the yellow contour. The line shows the query limit.

7.3 STEP 3: WIBM3 = IH-PTMARGIN CONCATENATION INTO WIBM2

The original IH-PTMARGIN database has 0,5' resolution and its information covers a great part of the Portuguese continental margin. The BATMANE model has 1' resolution and integrates at its origin information from HIDROGRÁFICO database.

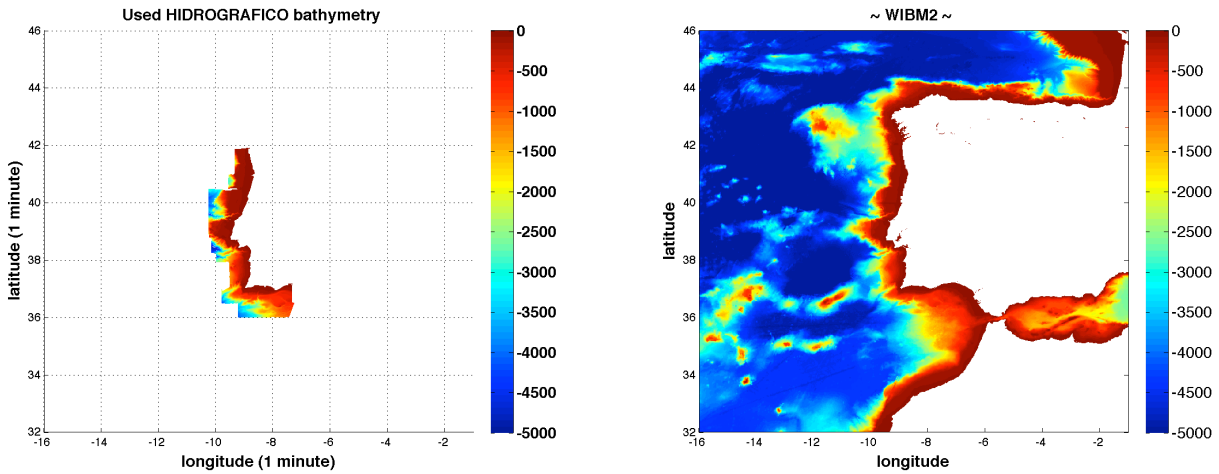


Fig.44 STEP 3: Concatenation of IH-PTMARGIN information into WIBM2.

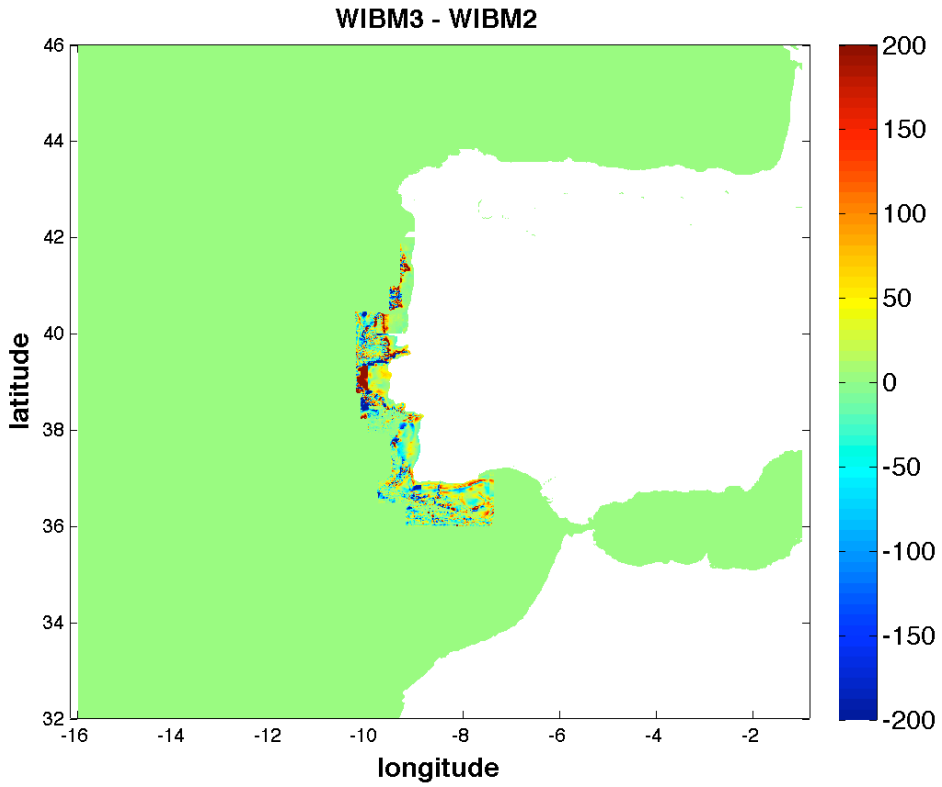


Fig.45 Control image of the Step3 transformation, showing the differences brought to the new DTM, from WIBM2. Topographic details changes can be see in Fig.46.

The quality analysis performed to both sources (see chapter 2) reveals that BATMANE has coherent data with IH-PTMARGIN, along the Portuguese slope. This fact allows the assembling of the Portuguese dataset (after re-sampled to 1' resolution) with the WIBM2 (mainly composed by BATMANE DTM at this region).

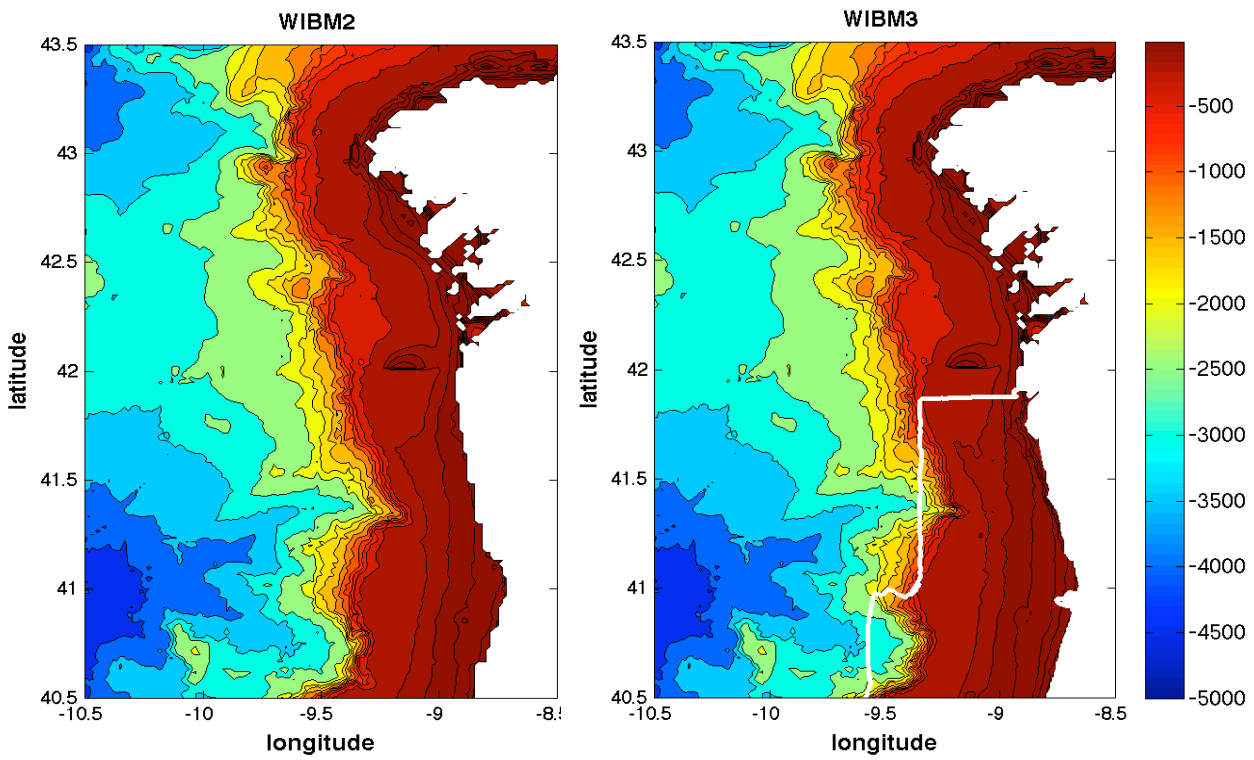


Fig.46 IH-PTMARGIN assembled to WIBM. The white line locates the limits between each model.

The integration was performed by a query that fond on WIBM2 DTM coexisting IH-PTMARGIN information, replacing it by this last dataset (on an "existing better data" scheme). Fig.48 shows how well this process results. Besides well integrated, some adjustments were performed to the chosen north and East frontier. The limits where changed at north to 41.85N and at southeast to 7.6W, minimizing small differences between the two datasets over the continental platform (Fig.46, Fig.47).

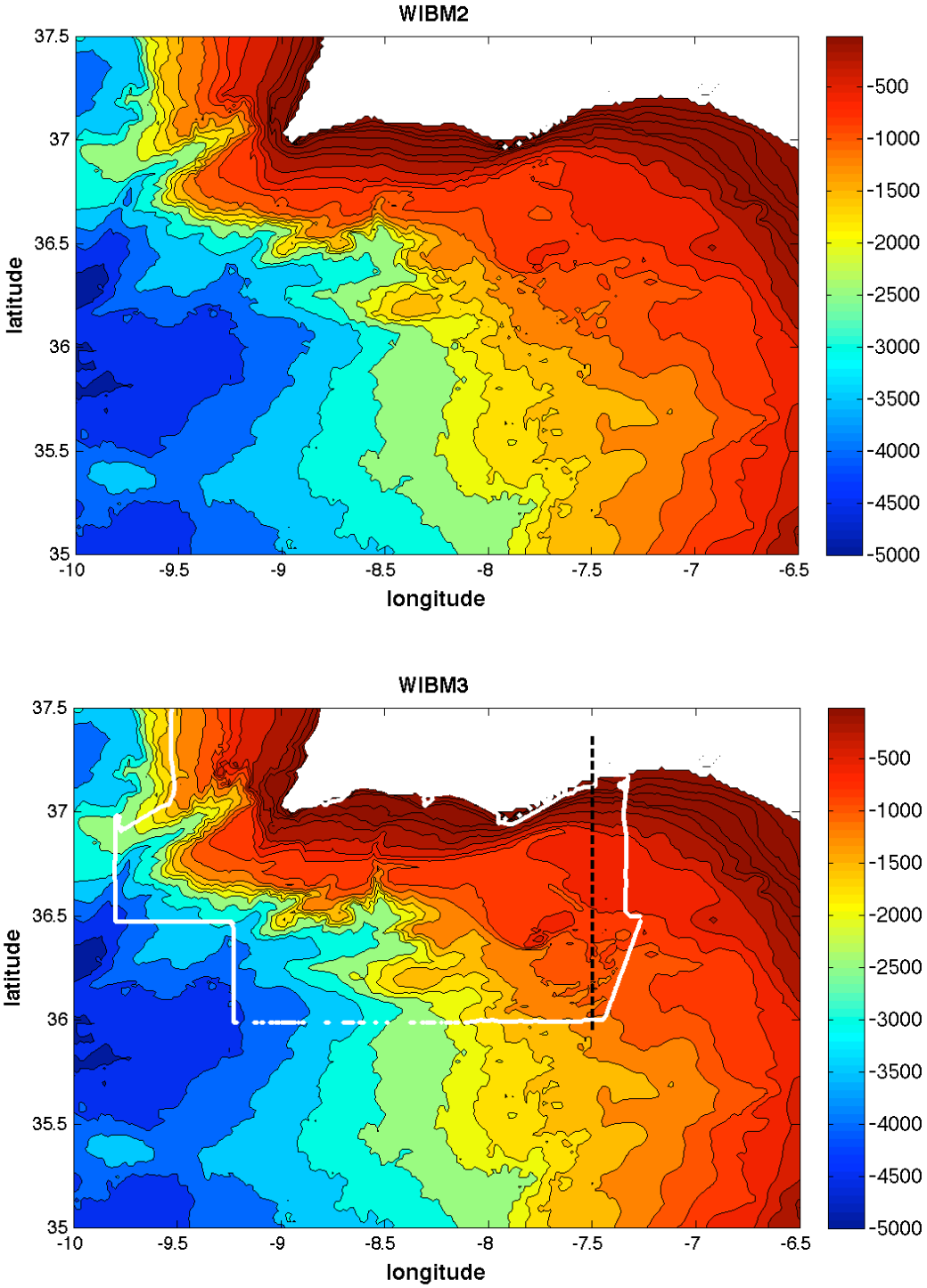


Fig.47 IH-PTMARGIN assembled to WIBM. The white line locates the limits between each model. The black line shows the Eastern limit chosen to minimise the junction step between the 2 models.

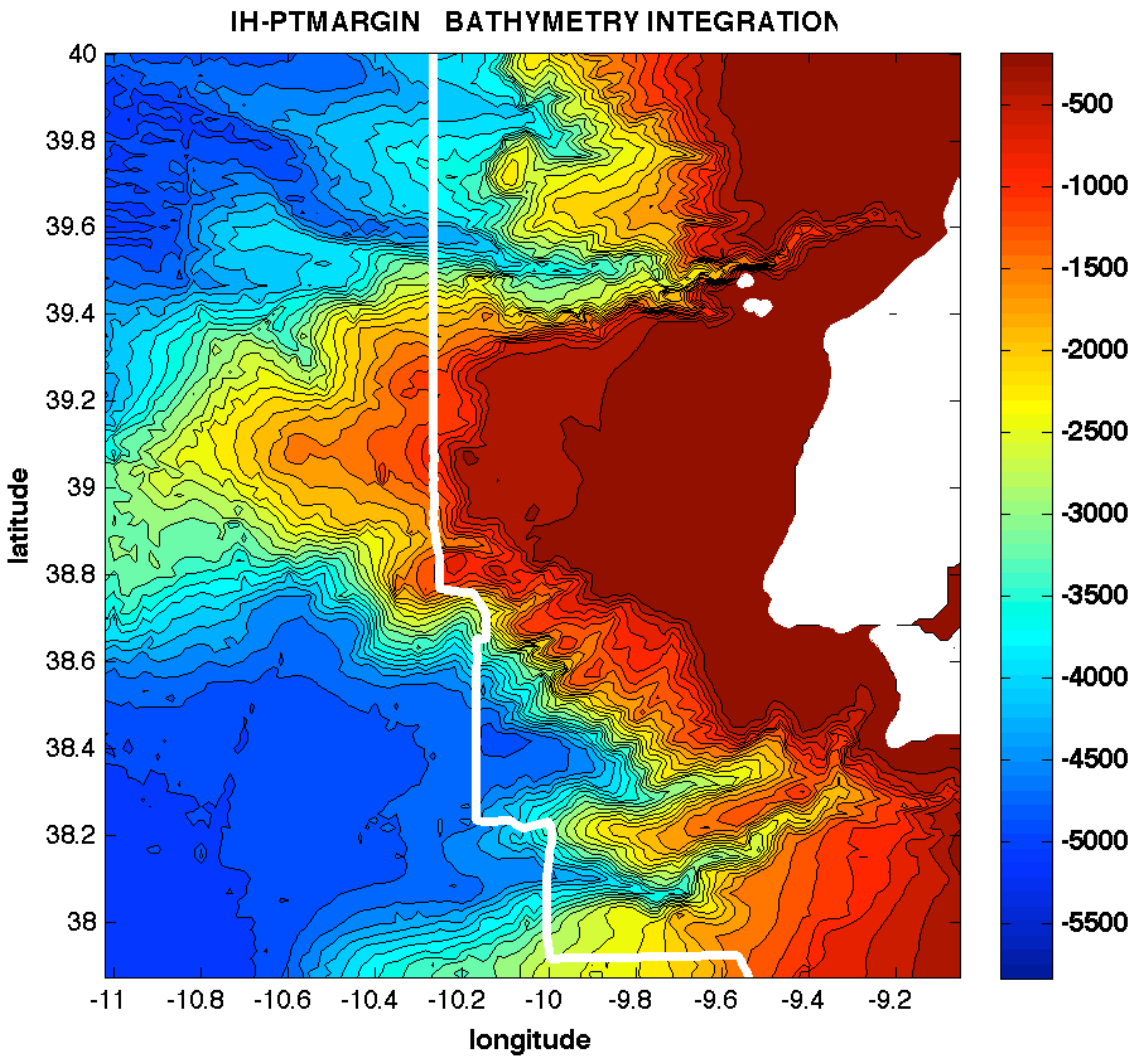


Fig.48 WIBM3 showing how well the IH_PTMARGIN was concatenated into the WIBM3 model. The white line represents the junction limits.

7.4 STEP 4: WIBM4 = GALIZA NAUTICAL CHART INFP CONCATENATION INTO WIBM3

Similar to the IH-PTMARGIN, the information obtained by the vectorization of the Galiza nautical charts was integrated to WIBM3 (BATMANE+GASCM+ETOPO1+IHPTMARGIN datasets).

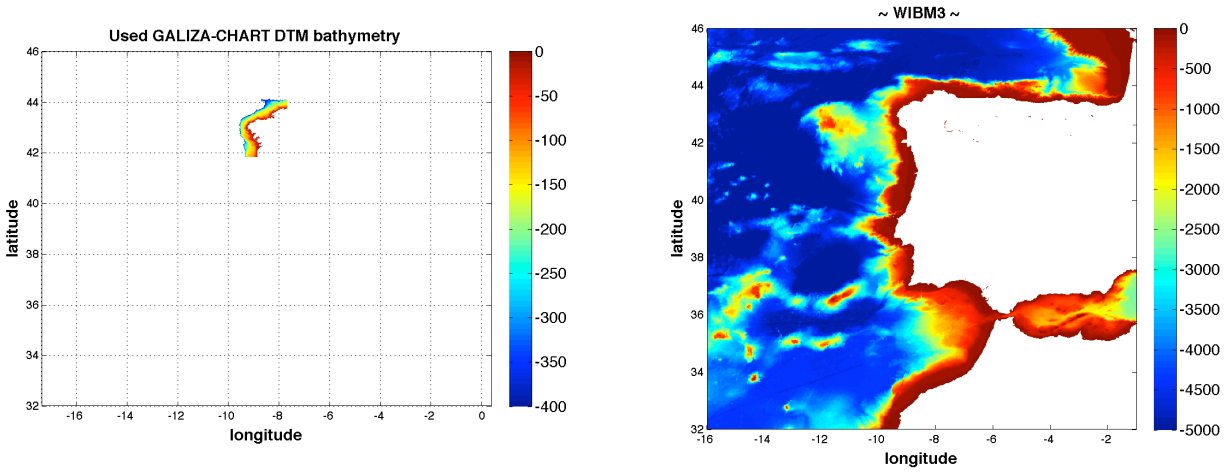


Fig.49 STEP 3: Concatenation of the GALIZA CHART information DTM into WIBM3.

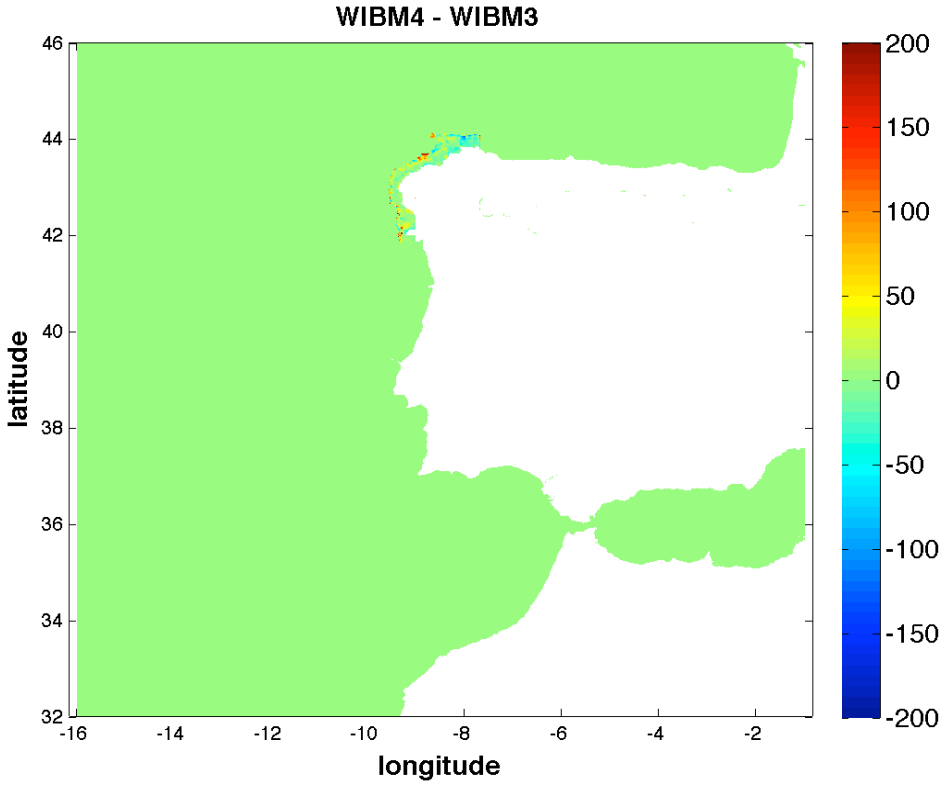


Fig.50 Control image of the Step4 transformation, showing the differences brought to the new DTM, from WIBM3. Topographic details changes can be see in Fig.52.

Instead of an "existing better data" assembling (as performed before), here the GALIZA CHART data was integrated by a query of depth level. Meaning, that inside of the sub-domain 41.8ºN-44.2ºN / 9.6ºW-7.7ºW, at depth between 0 and 390m, WIBM DTM adopted the 1´ information from the GALIZA CHART DTM.

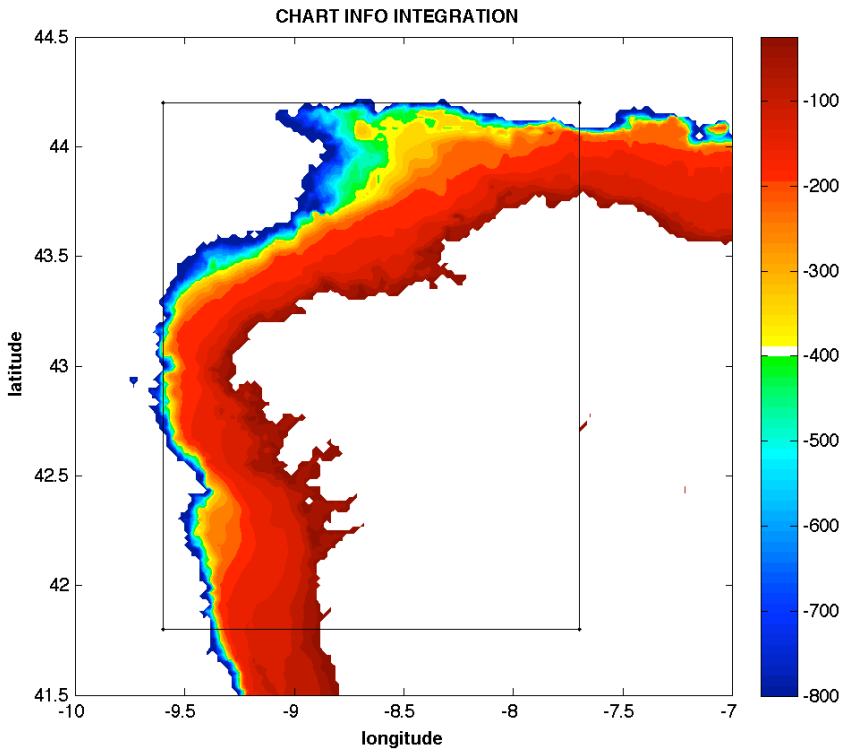
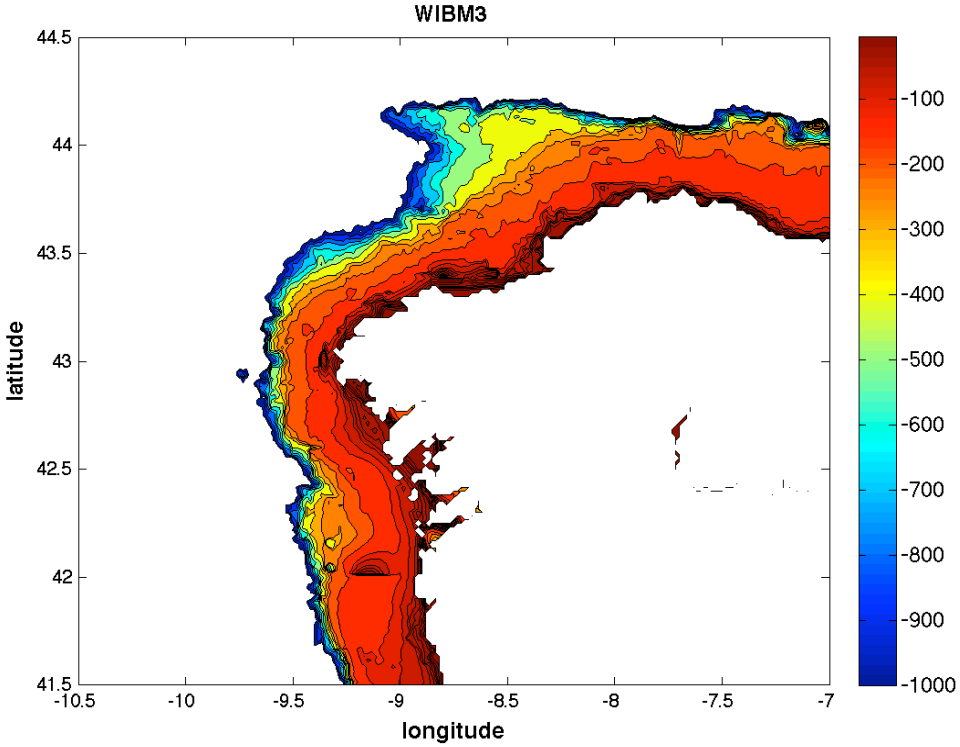


Fig. 51 Galiza charts data already assembled to WIBM. The square represents the domain changed and the 390m isobaths (depth limit) is located along the yellow-green contour boundary.

Note, that now both IH-PTMARGIN and GALIZA-NAUTICAL-CHART DTMs cover entirely the shelf region of WIBM, from 36ºN/7.6ºW to 42.2ºN/7.7ºW. The link of these two dataset it's performed at 41.8ºN (meaning that this dataset becomes linked directly with the IH-PTMARGIN data).



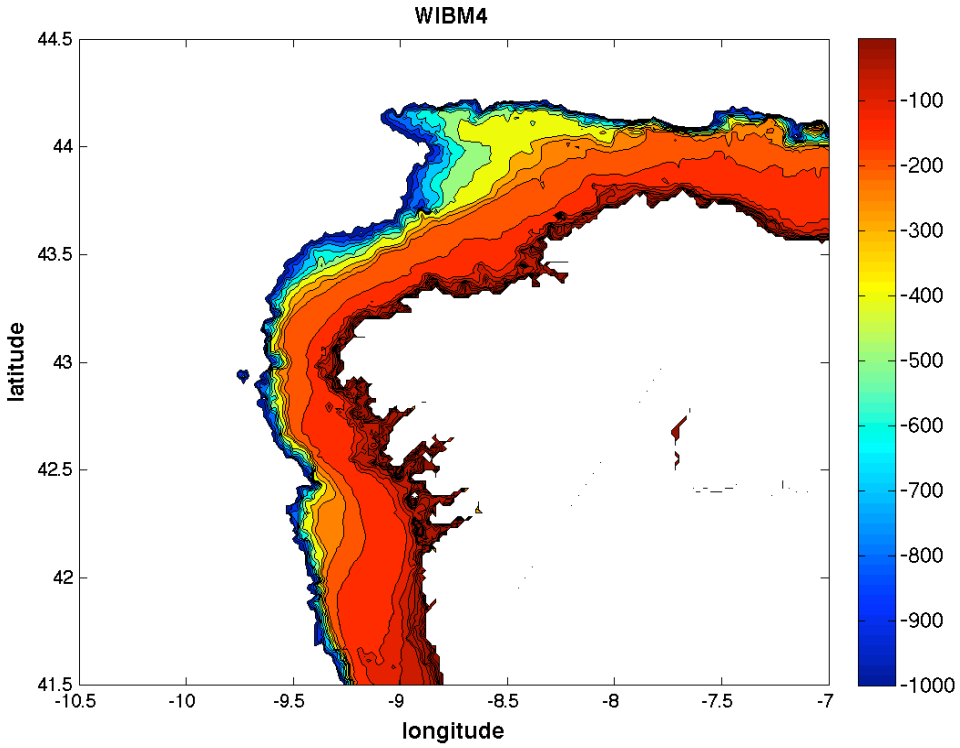


Fig.52 WIBM3 versus GALIZA-NAUTICAL-CHART DTM assembled to produce the WIBM4.

7.5 STEP 5: WIBM5 = COASTLINE INTERCEPTION AT WIBM4

The new coastline, developed from the NOAA Shoreline Database (Chapter 6), was integrated to WIBM DTM.

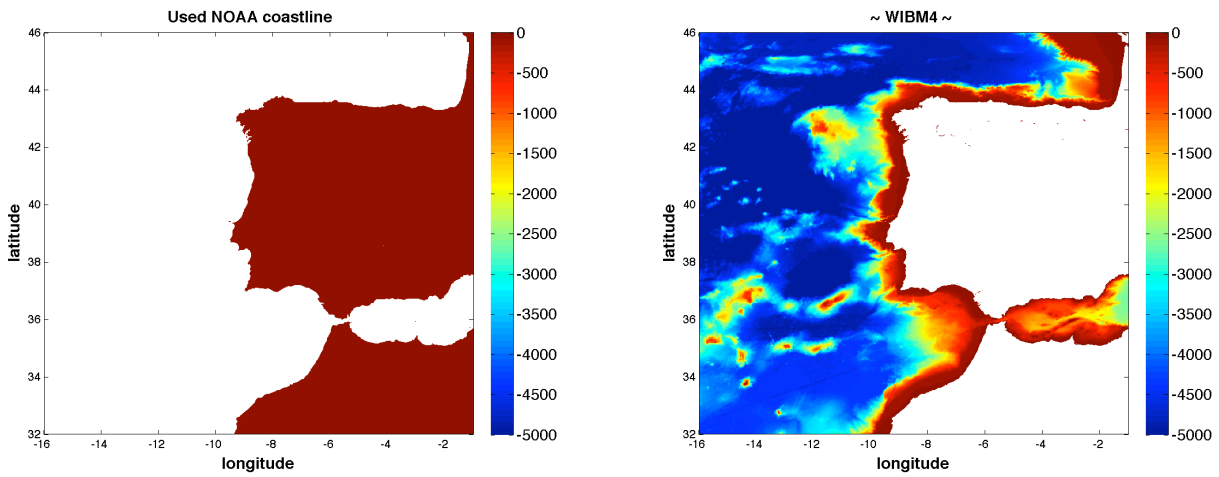


Fig.53 STEP 5: Coastline interception at WIBM4

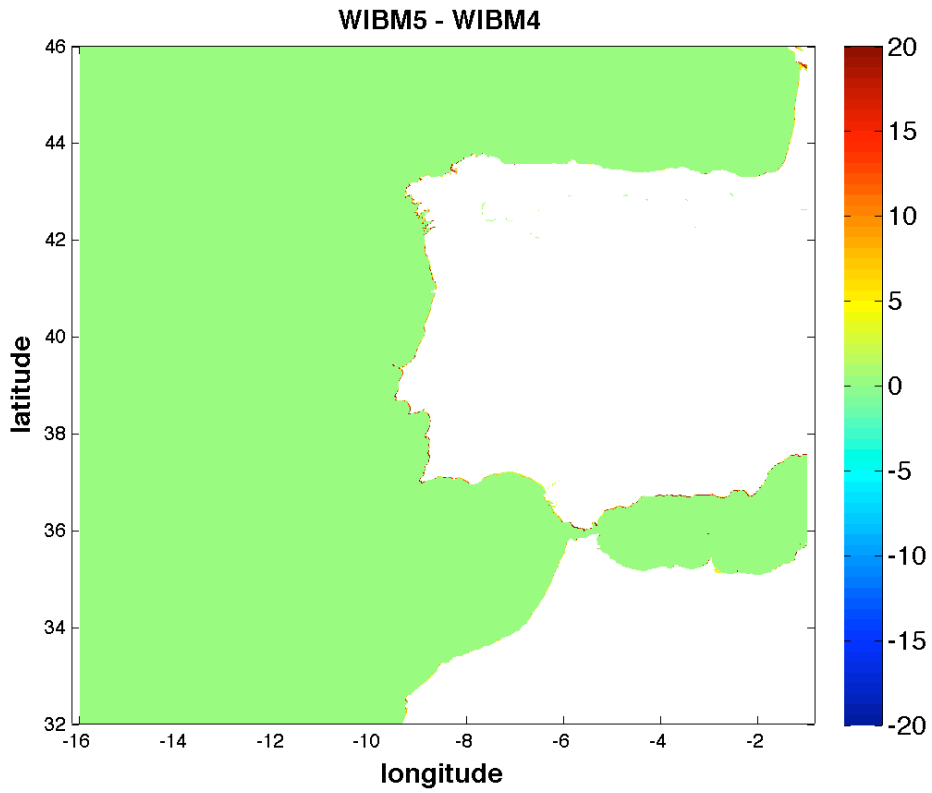


Fig.54 Control image of the Step5 transformation, showing the differences brought to the new DTM, from WIBM4. Topographic details changes can be see in Fig.55.

Since the West-Iberia coast has a tight intertidal sector, shorter than the resolution of this model, it is assumed that the coastline (that limits the higher tide level) can therefore represent also the lower tide level, and consequently the zero hydrographic. Here, both land and coastline nodes assumed the value zero.

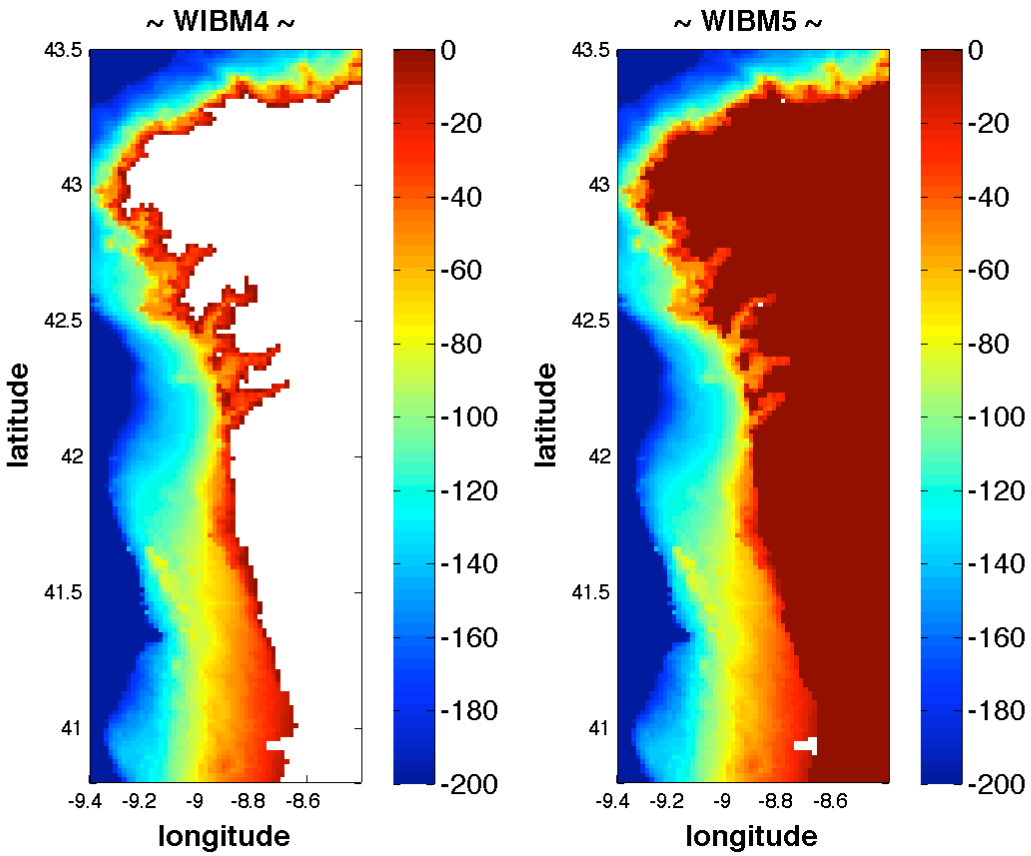


Fig.55 Topographic differences between the WIBM4 and WIBM5 model step. The coastline interception cuts some data (see as example inside the "Rías"), and puts in evidence missing data inside the ocean domain (see as example near the coast at 41ºN).

As expected, some model nodes (near the coast) missed information. To overcome this, an interpolation was made by running a mean function (3x3 matrix centred at missing nodes):

- Each missing node was replaced by the mean value of existing information (inside a 3x3 matrix centred at this point). By successive runs all the domain is filled, keeping the original detail and replace missing data by interpolation of the surrounding values (where zeros at the coast are kept the formula).

As a final step, the build WIBM topography was converted to positive values, since this is the sign for the ocean bathymetry.

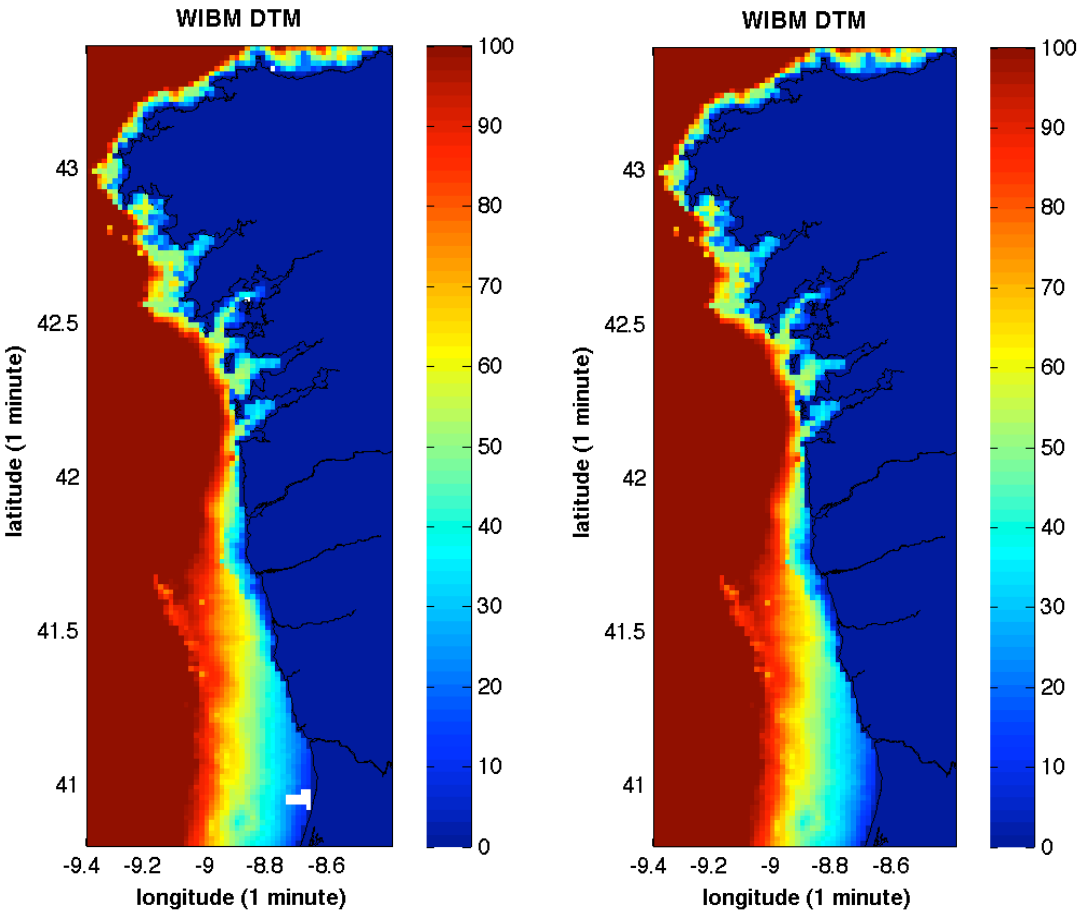


Fig.56 Pre and post stages of the running mean function applied to WIB DTM. The original coastline vector was intercepted to better visualization of the ocean-land frontier

8. FINAL REMARKS

After all the previous intermediate steps, the WIBM bathymetry model is finished (Fig. 57). By option, no filtering was applied to it, since all dataset junctions do not evidence significant bounds and, as a primitive condition of the present work, an effort was made to keep as best as possible the bathymetry details. A second version was also produced changing the WIBM DTM vertical reference to the Mean Sea-level.

Instituto Hidrográfico, em 15 de Maio de 2009.

	Visto
O adj. do chefe da Div. de Oceanografia	O Chefe da Divisão de Oceanografia
Luis Quaresma dos Santos	José Mesquita Onofre
2TEN TSN	CTEN EH

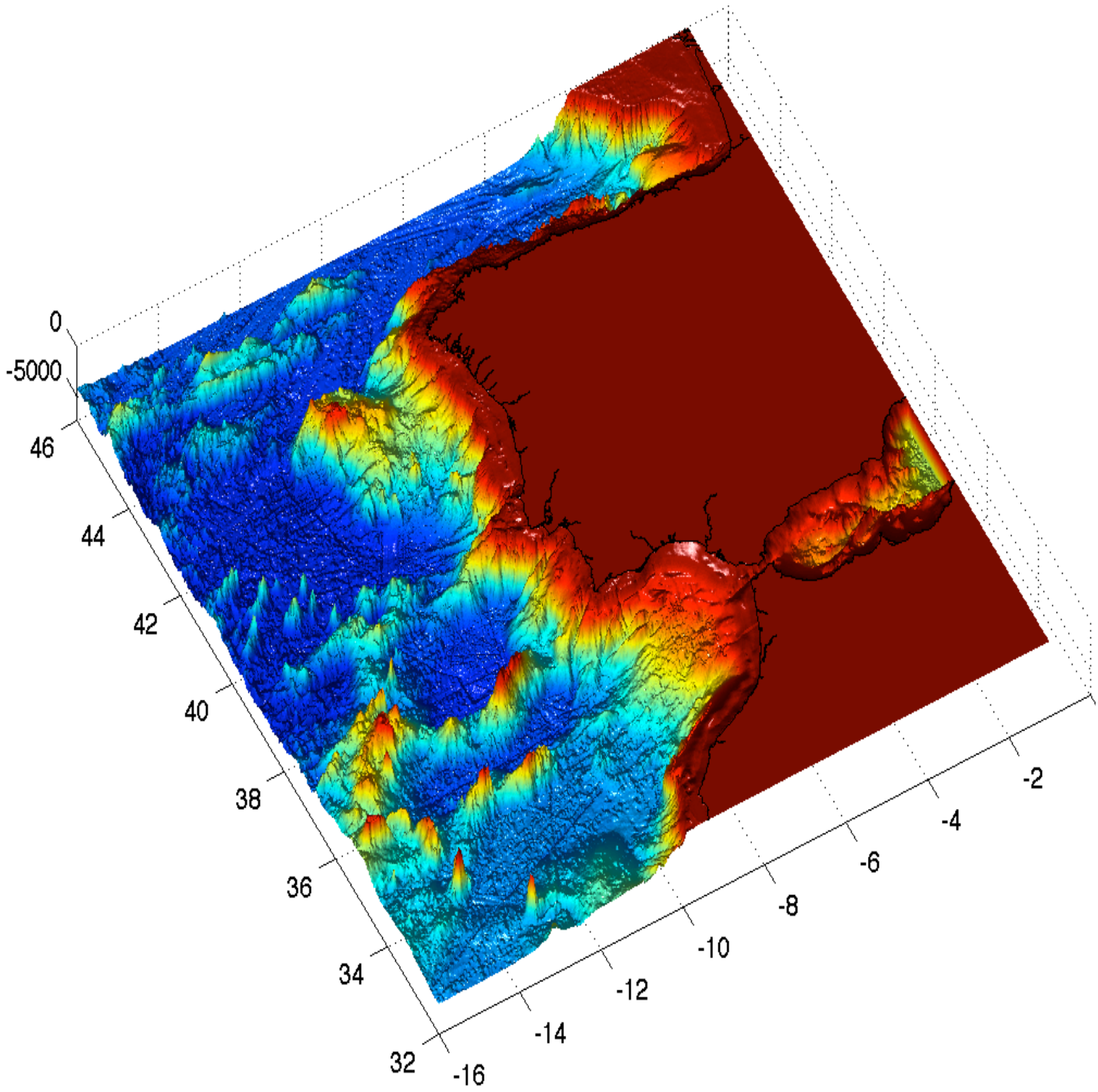


Fig.57 The WIBM 2009 (WEST IBERIAN BATHYMETRY MODEL)

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