# Computing and validating the bathymetric effect in smoothing gravity and altimeter data in the Mediterranean area

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**Introduction**

The proper modelling of the terrain effect plays a crucial role in geodetic computations. Particularly, in estimating the geoid and/or in interpolating gravity data, the high frequency components of the gravity signals are usually efficiently modelled and removed using high-resolution DTM models, e.g. the SRTM model.

The same doesn't hold for the bathymetric effect. Bathymetry models are coarser than the corresponding DTM models and are estimated by interpolating data coming from different bathymetric campaigns. In-situ bathymetry data, usually in the form of echo-sounding measurements, are in most cases inhomogeneous either in terms of their precisions and their spatial resolution. Also they are frequently referred to different coordinate systems that are not properly documented. Thus, the final gridded products that are supplied to users have quite poor standards and must be carefully checked before their use.

In this work, several bathymetric models have been tested over the Mediterranean area. The RTC effect has been computed with different methods and used for reducing marine gravity and altimetry data. Results are discussed in view of a critical use of bathymetry when computing gravity and/or altimetry data residuals.

**Data Reduction**

The data reduction has been performed according to the remove–solve–restore technique. The considered Global Geopotential Model is EIGEN-6c4 up to Degree and Order 1000. For altimetry data, in the four test areas, the EGM2008 model up to degree 1080 has been considered.

Different DTMs have been considered, with different bathymetric models. Both local and global tests have been performed. At first, local checks on four test areas have been computed, considering Emodnet, DBDBV, DTU10 and SRTMPlus. Then, since Emodnet and SRTMPlus gave the best results, only those models have been taken into account for the following computations.

| Residuals Area 03 | Emodnet | DBDBV | DTU10 | SRTMPlus |
|---|---|---|---|---|
| # | 2738 | 2738 | 2738 | 2738 |
| Mean | 2.181 | 2.132 | 2.163 | 2.176 |
| St. Dev. | 5.595 | 6.049 | 5.678 | 5.64 |
| Min | -28.503 | -25.119 | -24.166 | -25.903 |
| Max | 27.225 | 33.943 | 26.141 | 23.343 |
| RMS | 6.006 | 6.414 | 6.076 | 6.045 |

| Residuals Area 01 | Emodnet | DBDBV | DTU10 | SRTMPlus |
|---|---|---|---|---|
| # | 4031 | 4031 | 4031 | 4031 |
| Mean | 0.825 | 0.826 | 0.879 | 0.82 |
| St. Dev. | 4.478 | 4.524 | 4.552 | 4.493 |
| Min | -18.845 | -20.583 | -20.672 | -18.449 |
| Max | 24.065 | 19.117 | 23.272 | 23.454 |
| RMS | 4.553 | 4.599 | 4.636 | 4.567 |

| Residuals Area 04 | Emodnet | DBDBV | DTU10 | SRTMPlus |
|---|---|---|---|---|
| # | 2029 | 2029 | 2029 | 2029 |
| Mean | 6.133 | 6.125 | 6.143 | 6.122 |
| St. Dev. | 4.649 | 4.676 | 4.737 | 4.639 |
| Min | -7.398 | -7.406 | -7.521 | -7.371 |
| Max | 22.153 | 21.369 | 21.725 | 21.628 |
| RMS | 7.696 | 7.706 | 7.758 | 7.681 |

| Residuals Area 02 | Emodnet | DBDBV | DTU10 | SRTMPlus |
|---|---|---|---|---|
| # | 4291 | 4291 | 4291 | 4291 |
| Mean | 3.310 | 3.269 | 3.296 | 3.294 |
| St. Dev. | 5.161 | 5.372 | 5.163 | 5.105 |
| Min | -18.987 | -22.991 | -23.304 | -19.788 |
| Max | 36.219 | 31.346 | 43.081 | 36.228 |
| RMS | 6.131 | 6.289 | 6.125 | 6.076 |

Residuals after model and RTC component removal with different bathymetry models on the test areas.

**Digital Terrain and Bathymetry Models (DTBMs)**

Over land, the SRTM3 has been used. Over sea the following models have been considered.

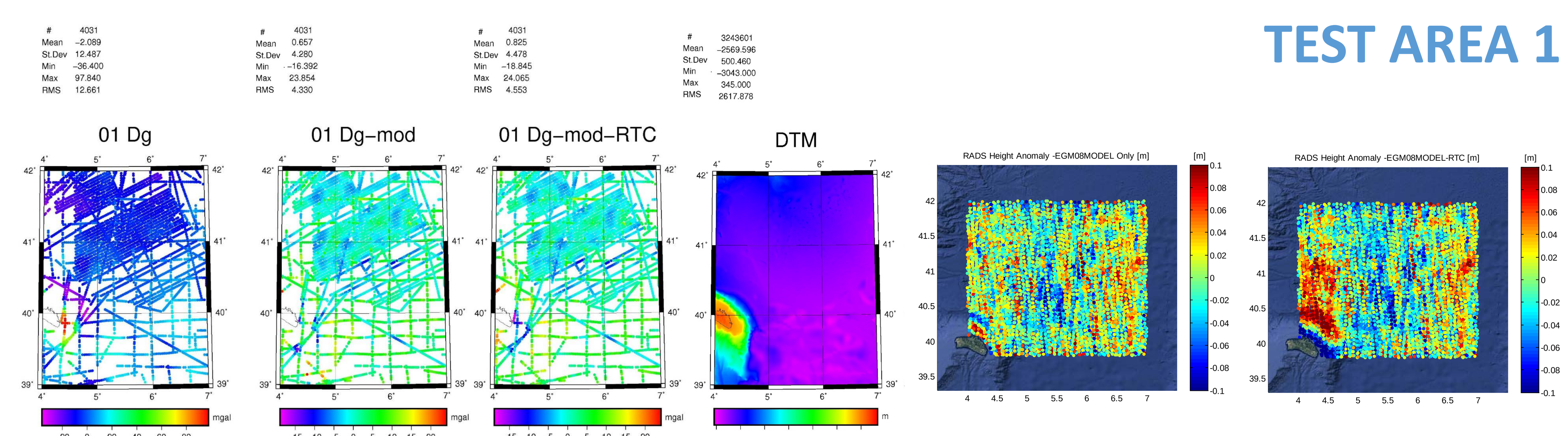
**DTU10 (1'x1')**: Bathymetry derived from satellite ERS-1 data, mapped with a resolution of 1 minute by 1 minute corresponding to 2 minute by 2 minute resolution at Equator (Andersen et al., 2008).

**DBDB-V:** The Digital Bathymetric Data Base Variable resolution (DBDBV) is a digital bathymetric data base that provides ocean depths at various gridded resolutions. DBDBV was developed by NAVOCEANO to support the generation of bathymetric chart products, and to provide bathymetric data to be integrated with other geophysical and environmental parameters for ocean modeling. Grid resolutions available include 0.5, 1, 2, and 5 minutes of latitude/longitude (1 minute of latitude = 1 nautical mile or 1.852 km).

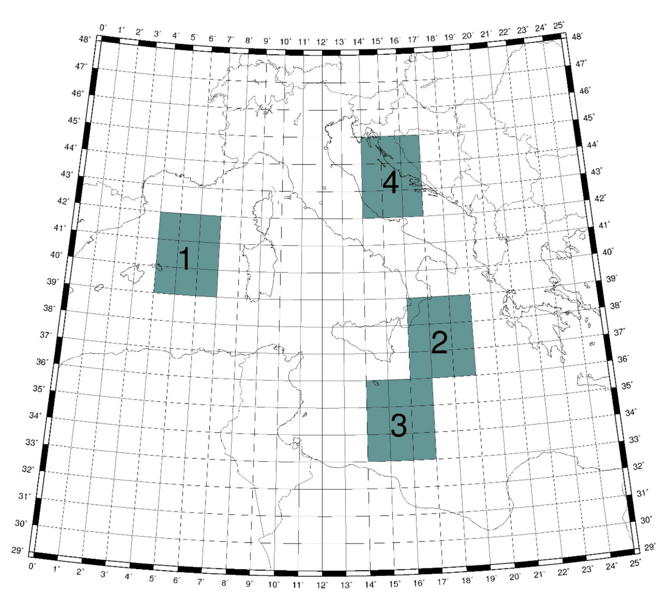
**EMODNET (7.5"x7.5")**: The EMODnet-Bathymetry portal (http://www.emodnet-bathymetry.eu) is being developed in the framework of the European Marine Observation and Data Network (EMODnet) as initiated by the European Commission. There are 4 types of organisations (Hydrographic Offices, Authorities, Research institutes, Industry) that perform bathymetric surveys, thereby partly overlapping and mostly complementing their geographical coverages. Data are collected at different frequencies and even date back to previous centuries. The partners combine expertise and experiences of collecting, processing, and managing of bathymetric data together with expertise in distributed data infrastructure development and operation and providing OGC services (WMS, WFS, and WCS) for viewing and distribution.

**SRTM15_PLUS (15"x15")**: Land elevations are based on the best available data from SRTM, ASTER digital elevation models while the ice topography of Greenland and Antarctica is based on CryoSat-2 and IceSat. Ocean bathymetry is based on bathymetric predictions from the latest global gravity model from CryoSat-2 and Jason-1 along with 494 million edited depth soundings at 15 arcsec resolution. Bathymetry of the Arctic seafloor is based on the IBCAO grid with improved resolution in areas of multibeam coverage. This SRTM15_PLUS provides the foundational bathymetry layer for Google Earth and is freely available at the topex.ucsd.edu ftp site (Olson and Sandwell, 2016).

## TEST AREA 1

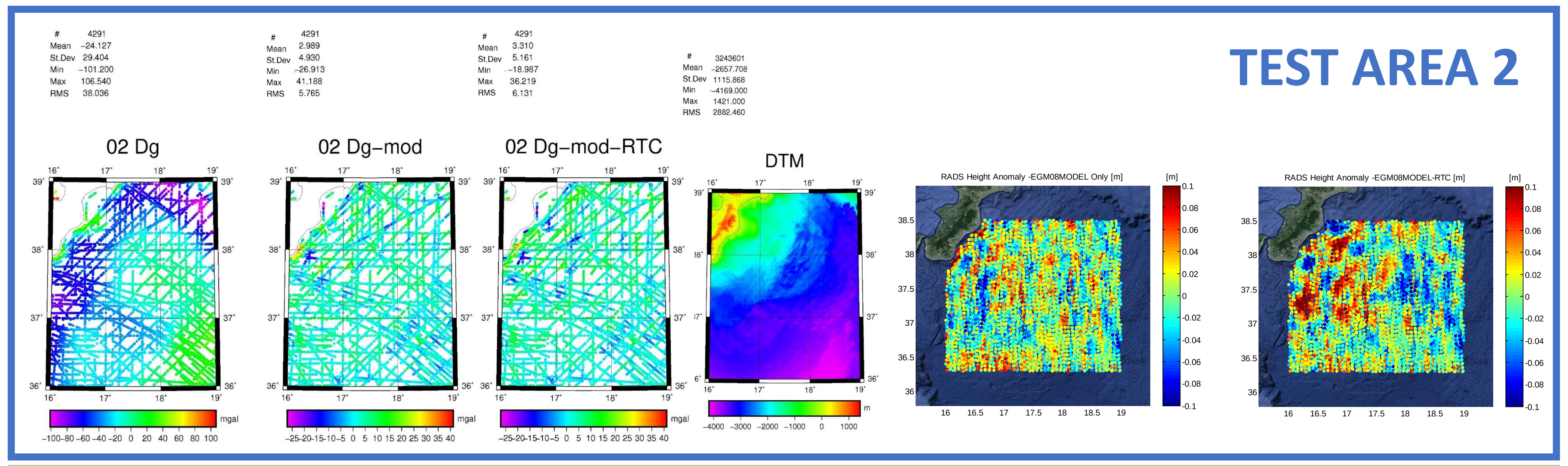



## TEST AREAS

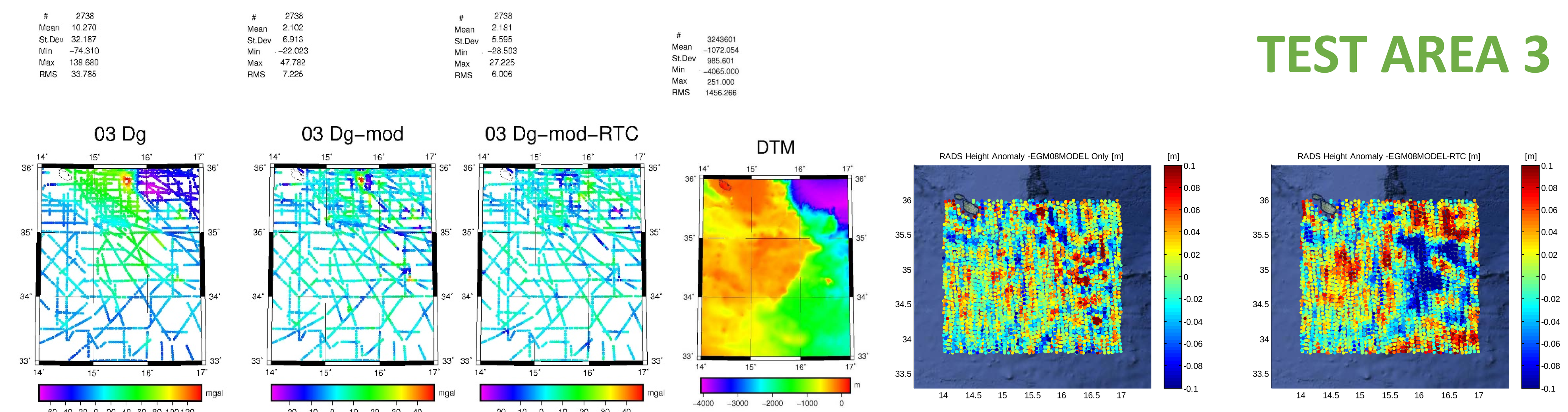



In these figures, the reductions after the REMOVE phase, using the EMODNET bathymetry, are shown. In addition, the effect of RTC on Altimetry undulation data is shown. On the $\Delta g$, the effect of RTC is consistent, contributing to effectively reduce the signal. On the contrary, with respect to the undulation component, coming from altimetry, the RTC is introducing an effect which we are currently trying to explain, analysing how the RTC is computed. This effect does not seem to be linked to the choice of the bathymetry.

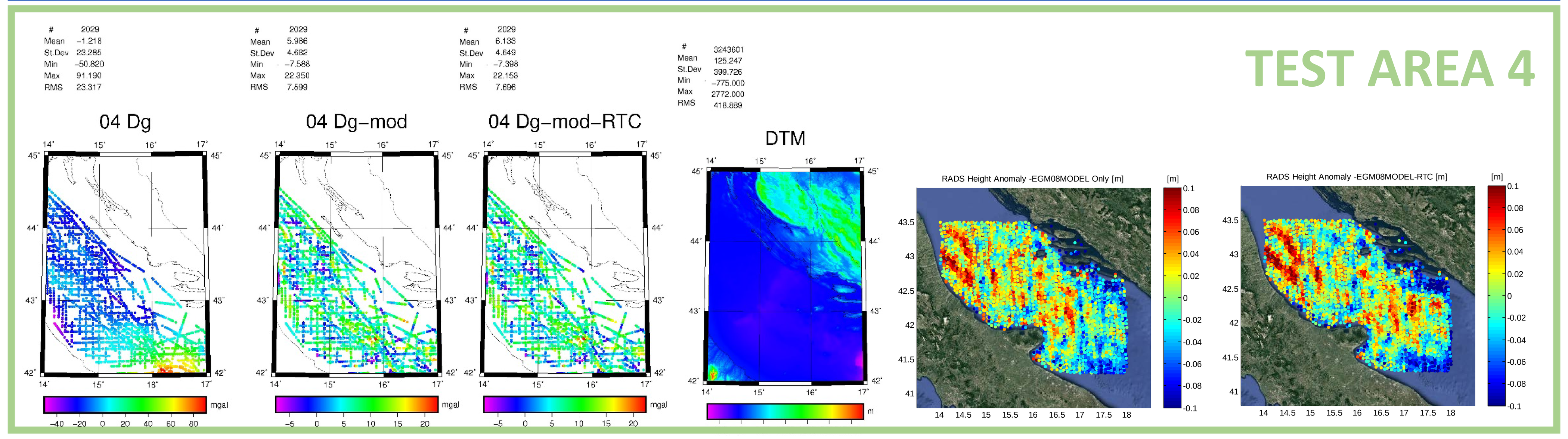
## TEST AREA 2




## TEST AREA 3

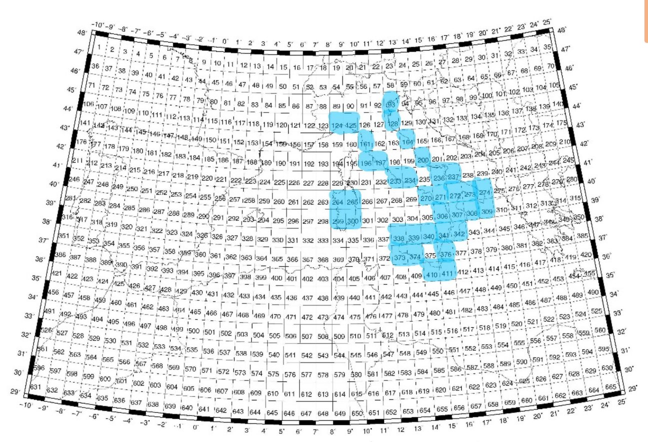



## TEST AREA 4




## TEST OVER ITALIAN COASTLINE

A test has been performed to verify the performances of two DTMs (SRTM combined with EMODNET bathymetry and SRTMPlus) over the coastline. The aim of this test was to check if the SRTMPlus has been produced with particular attention to the land to bathymetry transition. Statistics of the residuals obtained with the two DTMs have been computed on 1° x 1° zones over the Italian coastline. As it is possible to see in the table, the statistics obtained with the two DTMs are equivalent. In addition, out of 36 considered zones, 18 times the RMS of EMODNET was minor and 18 times the RMS of the SRTMPlus was minor.

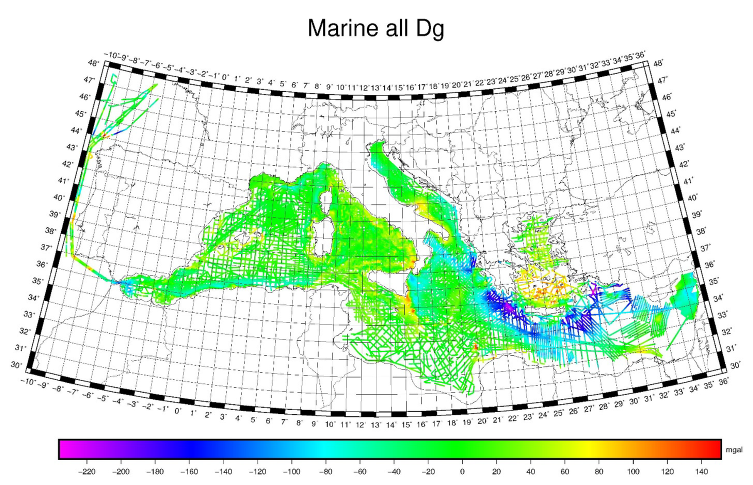


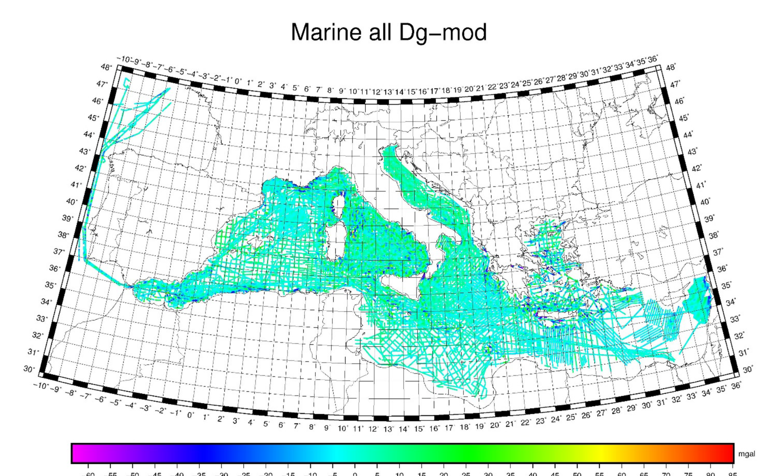
Zones where the statistics of the residuals have been computed

| | Zone 124 | | Zone 125 | | Zone 161 | | Zone 196 | |
|---|---|---|---|---|---|---|---|---|
| | EMODNET | SRTMPlus | EMODNET | SRTMPlus | EMODNET | SRTMPlus | EMODNET | SRTMPlus |
| # | 2902 | 2902 | 2591 | 2591 | 2134 | 2134 | 2017 | 2017 |
| Mean | 1.057 | 1.121 | -1.516 | -1.531 | 0.739 | 0.726 | 1.933 | 2.049 |
| St. Dev. | 8.095 | 8.067 | 6.153 | 6.151 | 8.661 | 8.66 | 6.918 | 6.834 |
| Min | 32.782 | 32.143 | 26.243 | 26.054 | 25.638 | 25.511 | 26.623 | 26.708 |
| Max | -28.255 | -28.252 | -21.198 | -21.197 | -23.795 | -23.907 | -37.479 | -37.376 |
| RMS | 8.164 | 8.145 | 6.336 | 6.339 | 8.693 | 8.69 | 7.183 | 7.135 |

Statistics of the residuals after the REMOVE (model and RTC effect) over some of the considered zones for the test, obtained with SRTM combined with EMODNET and SRTMPlus

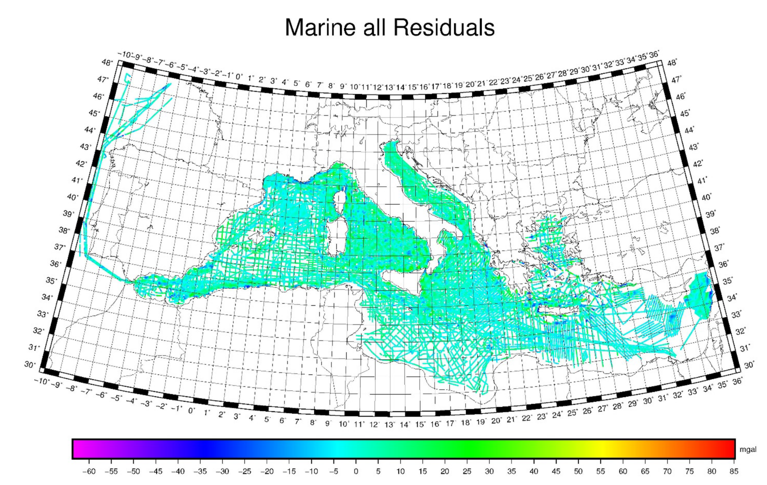
## RESULTS OVER MARINE DATA




The $\Delta g$ reduction has been performed over the available data on the Mediterranean sea. The SRTM combined with Emodnet and the SRTMPlus have been considered.

The statistics show the equivalence of the two DTMs.




| | Dg | Dg-mod | Residuals using SRTMPlus | Residuals using EMODNET |
|---|---|---|---|---|
| # | 768489 | 768489 | 768489 | 768489 |
| Mean | -21.375 | -0.980 | -0.08 | -0.096 |
| StDev | 47.661 | 8.942 | 6.976 | 6.960 |
| Min | -236.300 | -63.675 | -61.288 | -61.354 |
| Max | 151.500 | 85.169 | 74.166 | 75.299 |
| RMS | 52.235 | 8.996 | 6.977 | 6.961 |

**Conclusions**

Tests have been performed reducing gravity anomalies according to the remove-solve-restore technique to evaluate the performances of different bathymetric models, used for the RTC computation.

SRTM3 model has been used on land, while for bathymetry Emodnet, DBDB-V, DTU10 and SRTMPlus have been considered.

Both local and global checks have been performed. The bathymetry models gave similar results, with slightly better outcomes with Emodnet and SRTMPlus. Additional tests, made with Emodnet and SRTMPlus only, showed substantial equivalence between these two models.

Some issues have been presented on the REMOVE phase considering the RTC with altimetry data. This problem is currently being addressed, analysing how the RTC is computed. However, these issues does not seem to be linked to the choice of the bathymetry model.

**Bibliography**

Andersen et al., 2008. The DTU10 global Mean sea surface and Bathymetry. Presented EGU-2008, Vienna, Austria.

Christopher J. Olson Joseph J. Becker David T. Sandwell (2016). SRTM15_PLUS: Data fusion of Shuttle Radar Topography Mission (SRTM) land topography with measured and estimated seafloor topography (NCEI Accession 0150537). Version 1.1. NOAA National Centers for Environmental Information.