ISSN : 2335 - 1357

Mediterranean Journal of Modeling and Simulation

MJMS 03 (2015) 087-099

Assessment of Gravity Anomaly Surfaces (DTU10, EGM2008 and ITG-Goce02) in Western Mediterranean Sea

Mahdi HADDAD [a] *, Hania HACHEMI [b] , Hebib TAIBI [a]

[a] Centre of Spatial Techniques. 1 Avenue de Palestine, BP 13 Arzew. Oran 31200, Algeria
[b] National Polytechnic School, BP 182 El Harrach. Algiers 16200, Algeria

ARTICLE INFO

Article history :
Received September 2014
Accepted January 2015

Keywords :
Outliers ;
Geopotential model ;
Altimetry-derived gravity anomalies ;
BGI marine gravity measurements.

ABSTRACT

This paper is concerned with the estimation of the quality of the global free air surfaces anomalies DTU10, EGM2008 and ITG-Goce02 in Western Mediterranean Sea. We performed comparisons between independent in-situ marine gravity measurements (a set of 162374 gravity points supplied by the BGI by the International Gravimetric Bureau - BGI) and those estimated from the three surfaces of free air anomalies. This is done by critically looking of differences between in-situ measurements and estimated values. However, in-situ marine gravity data are not free from errors. Thus, outlier data detection processes are an essential first step in this statistical analysis. In this regard, five approaches are used to identify outliers in BGI data, namely : the Grubbs Test, Generalized ESD Procedure, Z-scores and its modified version and the Box plot approach.
After removing the suspicious data identified by Boxplot testing which seems to be the bests (about 3% of data are rejected), a general result appears over the three set of comparisons. Relative to the marine data, the DTU10 and EGM 2008 offer similar differences with a standard deviation of 19.5 mgal, while the ITG-Goce02 surface offers a standard deviation of about 30.5 mgal.

1. Introduction

The Earth is a dynamic system constantly undergoing changes. The Earth's gravity field is a fundamental physical force for every dynamic process on its surface and it's interior. Since the start of the satellite era, the determination of the global gravity field has been considered a high priority goal. Knowledge of this global gravity field and the associated geoid (i.e. the reference equipotential surface which, on average corresponds to the ocean surface) is required by oceanographers, by geodesists and by surveyors.

Since the early 1990s, the geoid surface is accurately measured by altimeter satellites.

*Email : haddad_mahdi@yahoo.fr

The onboard radar altimeter transmits microwave radiation towards the sea surface which partly reflects them back to the satellite. Measurement of the round-trip travel time provides the height of the satellite above the instantaneous sea surface. The sea surface height measurement is deduced from the difference between the satellite distance to the Earth's centre of mass (deduced from precise orbitography) and the satellite altitude above the sea surface. These measurements allowed to form a marine geoid and a gravity's field grid over all the oceans [1-2] and often use for bathymetric data correction [3]. In fact, in order to characterize the variations on a small scale, the accurate geoid can be converted into gravity anomalies. The estimation of these anomalies is based on laws of physics, geometry and statistics [2].

Also, the successful launches of the dedicated satellite gravity mission CHAMP - Challanging Minisatellite Payload (2000-2010), GRACE (2002) and GOCE - Gravity field and steady-state Ocean Circulation Explorer (2009-2013) have revolutionized the mapping of the Earth's gravity field by space-borne observation techniques on a global scale. The German CHAMP mission provided a completely new opportunity to determine the long wavelength static gravity field. CHAMP-only gravity field solutions up to degree 100, corresponding to a spatial wavelength of 200 km, could be recovered.

The primary goal of the joint US/German GRACE mission is to characterize the medium and long-wavelength spatial scale mass transport at seasonal and inter-annual time-scales, due to variations in the water cycle, changes in the cryosphere, and other processes over land and oceans; and to measure the mean Earth gravity field. The recent mean gravity field models from GRACE can resolve the static field to degree 150. Furthermore, the ESA mission GOCE is the first of ESA's Living Planet Programme satellites intended to measuring the medium to short wavelengths of the static gravity field with an accuracy of 10-5 m·s-2 (1 mGal) and providing a model of the geoid with unprecedented accuracy of 1 to 2 cm at 100 km resolution [4-6]. With GOCE measurements, gravity field models up to degree 200 (minimum) could be provided.

Modeling's works on earth's gravity field have given rise to global geopotential models with a high resolution as EGM2008 model [7], that is adapted in several countries. Thus, these satellite data and geopotential models offer an overview on the gravity anomalies and can be used to supplement existing data especially overseas.

By the way, to discuss the accuracy of mean sea surface, it can be interesting to also analyze their Free Air Gravity Anomaly "companions". Because it is easier to focus on the shortest wavelength described by the gravity field, and second gravity anomaly surfaces can directly be compared to independent in-situ measurement of the Earth geopotential that is marine gravity data.

This study aims to perform comparisons between three surfaces of free air anomalies, commonly used in studies requiring this type of data, and marine gravity measurements in Western Mediterranean Sea, provided by the International Gravimetric Bureau - BGI. The three considered surfaces of free air anomalies are : the first one is deduced from altimetry (DTU10 grid) and the remaining two surfaces are obtained from two global geopotential models (EGM2008 and ITG-Goce02). This analysis is the only "true" independent comparisons, commonly carried out (e.g., [2], [8]. But it has to be carefully applied since marine gravity data are not cleared of suspicious observations or outliers that are difficult to detect using informal inspection and graphical displays, particularly when there are missing values of high frequency.

Free air anomalies, interpolated from the DTU10 grid and estimated from the two gravitational models (EGM2008 and ITG-Goce02) were compared to those in the BGI file and differences were computed. The reduced free air anomalies, between the BGI gravity data and the DTU10, EGM2008 and ITG-Goce02 surfaces, are thus computed. However, prior to estimate the standard deviations and statistic's parameters of these data series of differences, a step of removing outliers is required.

A simpler approach to identify outliers in BGI data is to use Grubbs Test and Generalized ESD Procedure which are similar in nature. With the Grubbs Test detecting one outlier at a time until no outlier is left. The Generalized ESD procedure on the other hand gives a pre-specified number of outliers. Another approach is to use Z-scores and modified Z-scores which calculate a threshold to identify the potential outliers. Using the Box plot approach, one can identify the lower and upper quantile in the distribution obtained from the reduced series and any observation beyond these cut-off points are considered potential outliers. Both these methods assume the data to be normally distributed.

The rest of the paper is organized as follows. Section 2 describes the datasets used in this study. The five tests used to identify outliers in our data are briefly explained in Section 3. Section 4 describes the application of different tests for detecting outliers in BGI dataset. The empirical results are addressed in this section. Section 5 concludes.

2. Data

2.1. Marine gravity data

A set of 162374 marine free air anomalies covering the Occidental Mediterranean Sea (from 30° to 45° N and from -10° to 15° E) was supplied by the BGI. The overall task of BGI is to collect, on a world-wide basis, all measurements and pertinent information about the Earth gravity field, to compile them and store them in a computerized data base in order to redistribute them on request to a large variety of users for scientific purposes [9].

The description of the format of marine gravity data (EOS format) is detailed in the paper [10]. Each point is a recording of 150 characters. These measurements have a variable marine gravity's accuracy, which depends on multiple factors such as navigation, linking to gravimetric control mark on the ground and the drift corrections. The EOS file contains information including data origin, position and depth of points, measured value of gravity and its accuracy, free air and Bouguer anomalies. These measurements are georeferenced with respect to GRS67 datum [10].

Note that, free air anomaly (Δg) on sea surface is defined as the difference between observed gravity on the physical surface and theoretical (normal) gravity :

$$\Delta g = g - \gamma_o \tag{1}$$

where g is the observed (or measured) gravity and γ_o is the reference gravity value obtained from the gravity field of the GRS67 reference ellipsoid of revolution. γ_o is given by :

$$\gamma_{1967} = 978031.85\left[1 + 0.005278895\sin^2\varphi + 0.000023462\sin^4\varphi\right] mGal \tag{2}$$

where φ equals geodetic latitude.
Free air anomalies are reduced to the ellipsoid GRS80 using the correction formula :

$$\gamma_{1980} - \gamma_{1967} = \left(0.8316 + 0.0782\sin^2\varphi - 0.0007\sin^2 2\varphi\right) mGal \tag{3}$$

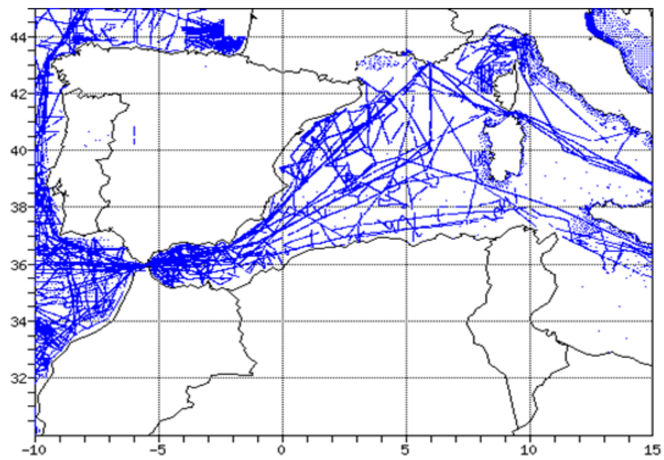

Fig. 1. Geographical distribution of BGI marine gravity measurements.

2.2. Earth gravitational models

The earth gravitational models used to compute values of free-air gravity anomalies at positions of the BGI marine gravity points are the EGM2008 and ITG-Goce02 models :

- The EGM2008 model is a spherical harmonic model of the Earth's gravitational potential, released by the NGA EGM Development Team [7], [11]. This model was formed by merging terrestrial, marine, altimetry-derived, and airborne gravity data. Over areas where only lower resolution gravity data were available, their spectral content was supplemented with gravitational information implied by the topography. EGM2008 is complete to degree and order 2159, and contains additional coefficients up to degree 2190 and order 2159. Full access to the EGM2008's coefficients and other descriptive files with additional details are provided within the NGA website : http ://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008.
- The ITG-Goce02 gravity field model, meanwhile, was computed from 7.5 months of GOCE gradiometer and orbit data from 2009-11-01 to 2010-06-30 [12]. This model is complete to degree 240. The ITG-Goce02's coefficients are available at the following link (Institut für Geodäsie und Geoinformation - IGG Bonn website) : ftp ://skylab.itg.uni-bonn.de/ITG-Goce02/ITG-Goce02.gfc.

Note that, point values of free-air Gravity Anomalies (Δg) are computed in a spherical approximation of the boundary condition from geopotential model coefficient set by :

$$\Delta g = \frac{GM}{r^2}\sum_{n=2}^{N_{\max}}(n-1)\sum_{m=0}^{n}\left(\overline{C}_{nm}\cos m\lambda + \overline{S}_{nm}\sin m\lambda\right)\overline{P}_{nm}(\cos\theta) \tag{4}$$

where θ and λ are the geocentric colatitude and longitude of the point where Δg will be determined; $\overline{C}_{nm}$ and $\overline{S}_{nm}$ are the fully normalised spherical geopotential coefficients of the anomalous potential; $\overline{P}_{nm}$ are the fully normalised associated Legendre functions; $N_{\max}$ is the maximum degree of the geopotential model.

All computations were performed using the Fortran program harmonic_synth_v02 developed by NGA [13]. WGS84 Geodetic Reference System (GRS) was used to define the geometry and the normal gravitational potential of the reference ellipsoid. The computed values refer to the surface of this reference ellipsoid. The free-air gravity anomalies correspond to the spherical approximation (i.e., they correspond to the selection "$isw = 1$" in the run of the harmonic synthesis program).

2.3. Gravity anomalies derived from satellite altimetry

Radar altimeters have surveyed, over many years, the marine gravity field over nearly all of the oceans with high accuracy and moderate spatial resolution. Altimetry data, collected by different satellites over many years, are combined to achieve high data density and to average out sea surface disturbing factors such as waves, winds, tides, and ocean variability. These data have been also combined and processed to form a global gravity grid [2] which was used thereafter to predict the depth of the sea floor. These early works were subsequently refined and new maps of gravity anomalies have been made available to the general public. These early works were subsequently refined and new maps of gravity anomalies have been made available to the general public.

The altimetry-derived gravity anomalies grid employed in this study is the DTU10 grid that was computed at the Danish National Space Center –DNSC. Details regarding the data used to produce DTU10 and the estimation algorithm employed can be found in [14]. DTU10 is an improvement over previous versions (DNSC07 and DNSC08) and was produced after EGM2008 was finalized and released, and thus benefited from reference values computed using the final EGM2008 model [11]. DTU10 grid extends from 90 ° N to 90 ° S with one minute resolution and is available from the site of the Technical University of Denmark : http ://www.space.dtu.dk/english/Research/Scientific_data_and_models /Global_Marine_Gravity_Field. Estimation of gravity anomalies at positions of the BGI points from the DTU 10 grid was performed using cubic interpolation.

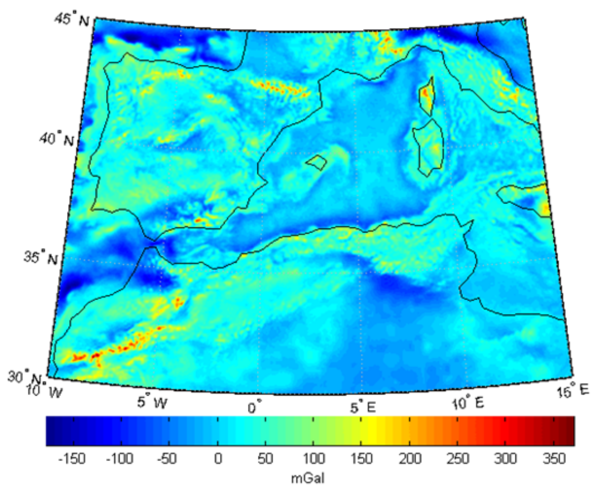

Fig. 2. DTU 1 minute gravity anomalies in Western Mediterranean Sea.

3. Tests to identify outliers

Outliers are defined as inconsistent or distinctly different data [15-16] with unusually small or large and extreme values [17-18]. Thus, data must be quantitatively pre-reviewed because outliers can skew statistical results. In addition, outliers are considered as incorrect or unique data. Judgment is required to determine whether data are incorrect or unique, and incorrect data should be removed [19]. This section shows briefly the used different techniques to identify of suspicious observations in data series as outliers.

3.1. Grubbs' test

Grubbs test is one of the oldest procedures for detecting outliers measurements in simples dataset assuming a normal distribution [20]. Grubbs test compares the absolute value of the reduced deviations to a limit value estimated from Student's distribution. The identified outlier is cross out from the dataset and the test is iterated until no outliers are detected. The limitations of this approach in terms of probabilities of detection, computation time and for small data simples may make the application of Grubbs' test difficult [20].

For a univariate dataset $X_n = \{x_1, x_2, ..., x_n\}$, the Grubbs' statistic to test if the minimum or maximum values are outliers has the form :

$$G = \frac{\overline{x} - x_1}{s} \text{ or } G = \frac{x_n -}{s}\overline{x} \tag{5}$$

where $\overline{x}$ is the mean and s is the sample standard deviation.

The maximal or minimal element in dataset is considered as outliers if the value of the corresponding statistic G exceeds the critical value of :

$$\frac{n-1}{\sqrt{n}} \sqrt{\frac{t^2_{\left(\frac{\propto}{2n}, n-2\right)}}{n-2+t^2_{\left(\frac{\propto}{2n}, n-2\right)}}} \tag{6}$$

where α is the set significance level and $t_{\left(\frac{\propto}{2n}, n-2\right)}$ denotes the $\frac{\propto}{2n}$ percentile of a t-distribution with $(n-2)$ degrees of fredom. For one-side tests, the percentile $\frac{\propto}{n}$ is used.

Note that there are also a Grubbs test for two opposite outliers and another to test if two largest or two smallest values are outliers.

3.2. Generalized extreme studentized deviate procedure

A similar procedure to the Grubbs' test is the generalized Extreme Studentized Deviate (ESD) to test for up to a prespecified number r outliers. This procedure is as follows [21-22] :

Firstly, we compute $R_1 = \max_i \left\{\frac{|x_i - \overline{x}|}{s}\right\}$ and we remove the observation that maximizes $|x_i - \overline{x}|$. Then, R_2 is computed in the same way but with the reduced sample of n-1 observations. We continue with the process until$R_1, R_2, \ldots, R_r$ have been computed.

Finally, using the critical values λ_i at the chosen confidence level α find l, the maximum i such that $R_i > \lambda_i$. The extreme observations removed at the first l steps are declared as outliers.

For two-sided outlier problem, the value of λ_i is defined as [23] :

$$\lambda_i = \frac{t_{(p,n-i-1)}\,(n-i)}{\sqrt{\left(n-i-1+t^2_{(p,n-i-1)}\right)(n-i+1)}};\, i=1,\ldots,r \text{ where } p = 1-\frac{\alpha/2}{n-i+1} \quad (7)$$

$t_{(p,d)}$) is the pth percentile of a t distribution with d degrees of freedom. For the one-sided outlier problem we substitute $\alpha/2$ by α in the value of p.

The tabulated values of several α, $n \leq 500$ and $r \leq 10$ are given in [23]. This approximation is very accurate when $n > 25$ with a higher number of outliers.

3.3. Z-scores and modified Z-scores tests

The Z_{scores} is a usually test for detecting possible outliers for large and small samples dataset [24-25]. If $X_n = \{x_1, x_2, ..., x_n\}$ is a univariate data set, the Z_{score} of an observation is commonly defined as :

$$Z_{score}(i) = \frac{x_i - \overline{x}}{s}, \text{ with } s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i-\overline{x})^2} \quad (8)$$

where $\overline{x}$ is the mean and s is the standard deviation.

A common rule considers observations with absolute value of Z_{scores} greater than a threshold of 3 as outliers. However, this criterion has its problems since the maximum absolute value of Z_{scores} is $(n-1)/\sqrt{n}$ and it can be possible, especially in small data sets, that none of outliers Z_{scores} would be greater than the threshold [26].

With this test, the $\overline{x}$ and s can be greatly affected by outliers. Modified Z_{scores} suggests to replace $\overline{x}$ by the sample median $(\widetilde{x})$, and s by the Median of Absolute Deviations about the median : $MAD = median\{|x_i - \widetilde{x}|\}$. Then, the Modified Z_{scores} are defined as :

$$M_i = 0.6745\frac{x_i - \widetilde{x}}{MAD} \quad (9)$$

Iglewicz and Hoaglin suggest that observations will be labeled outliers when absolute values of M_i are greater than a threshold of 3.5 [27].

3.4. Boxplot test

One of the most frequently used graphical techniques for analyzing a univariate data set is the boxplot, proposed by [28]. The main elements for a boxplot are the median (Q2), the lower quantile (Q1) and the upper quantile (Q3).

The boxplot contains a central line, and extends for Q1 to Q3. All points outside the interval [Q1 - k(Q3 - Q1) ; Q3 + k(Q3 - Q1)] are classified as outliers. Depending on the value of k, a different number of potential outliers can be selected. The standard k takes the value of 1.5 [29]. Sim and al's investigation on boxplot obtained expressions of the parameter k that yield the required some-outside rate for a normal distributed simulated simple with $9 \leq n \leq 500$ [30]. They introduced a boxplot procedure which would provide an acceptable high proportion of the population value included between its Q1 and Q3 with a specified confidence according to an error rate.

4. Data analysis

All of the results in this section are obtained by means of the outlier_library_external Toolbox [31]. This library is a set of Matlab functions for data series analysis. Using different techniques, it allows the identification of suspicious observations that would require further analysis and also tests to determine if some observations are outliers. This library is useful for data series with normal distribution and for non normal data (exponential and log-normal distribution).

The marine free air gravity anomalies from BGI are compared with corresponding values interpolated from DTU10 surface and computed from the two geopotential models EGM2008 and ITG-Goce02. The results for these comparisons are summarized in Table 1. The standard deviation (σ) in table 1 shows how much variation or dispersion from the average exists. A low standard deviation indicates that the data differences tend to be very close to the mean and then the free air anomaly surface is closest to the in-situ measurements; a high standard deviation indicates that the data differences are spread out over a large range of values and then the model is less adequate to the reality.

Table 1. Statistics of the reduced data between the BGI gravity data and the DTU10, EGM2008 and ITG-Goce02 surfaces (mgal).

Surface	**Min (mgal)**	**Max (mgal)**	**Mean (mgal)**	σ **(mgal)**
DTU10	-815.230	207.300	-7.607	22.967
EGM2008	-815.660	206.228	-7.610	22.965
ITG-Goce02	-806.870	174.121	-11.247	33.788

Figure 3 shows the histograms of the differences between BGI free air anomalies and those obtained from DTU10, EGM2008 and ITG-Goce02. The similitude of the two histograms obtained from DTU10 grid and EGM2008 model is due in fact that DTU10 has been processed using EGM2008 as reference.

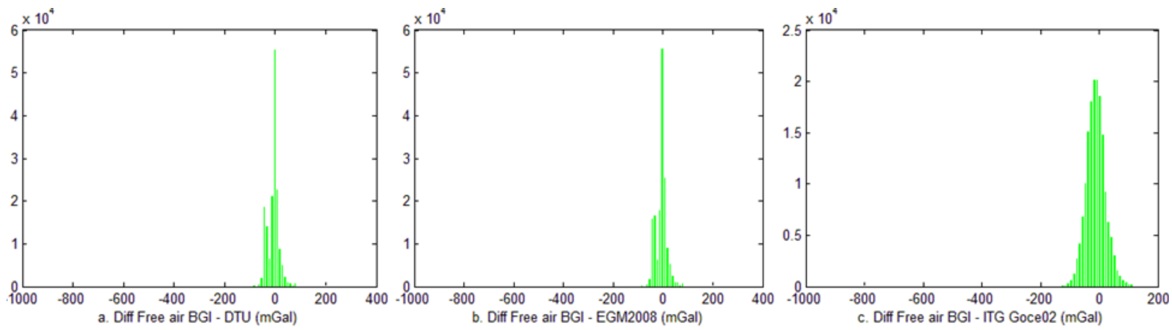

Fig. 3. Histograms of differences between BGI free air anomalies and those computed from DTU grid and EGM2008 and ITG-Goce02 geopotential models.

The Grubbs test and GESD procedure have been tested in reduced free air anomalies data described in Section 2. As presented in Tables 2 and 3, they have yielded no satisfactory results in most cases. There are only a small number of identified missing values.

Table 2. Statistics of the reduced data after removing detected outliers by Grubbs test ; alpha = 0.05.

	Detected outliers	%	Min (mgal)	Max (mgal)	Mean (mgal)	σ (mgal)
DTU10	18	0.011	-123.21	104.65	-7.62	22.81
EGM2008	19	0.012	-123.85	108.54	-7.62	22.80
ITG-Goce02	7	0.004	-161.77	159.46	-11.25	33.71

Table 3. Statistics of the reduced data after removing detected outliers by GESD procedure, alpha = 0.05.

	Detected outliers	%	Min (mgal)	Max (mgal)	Mean (mgal)	σ (mgal)
DTU10	16	0.010	-123.38	107.49	-7.62	22.81
EGM2008	17	0.010	-123.88	108.98	-7.62	22.81
ITG-Goce02	7	0.004	-161.77	159.46	-11.25	33.71

Figure 4 shows the detected outliers by Grubbs test with significant level alpha of 0.05 and histograms of differences between BGI free air anomalies and those computed from DTU grid and EGM2008 and ITG-Goce02 models after removing detected outliers.

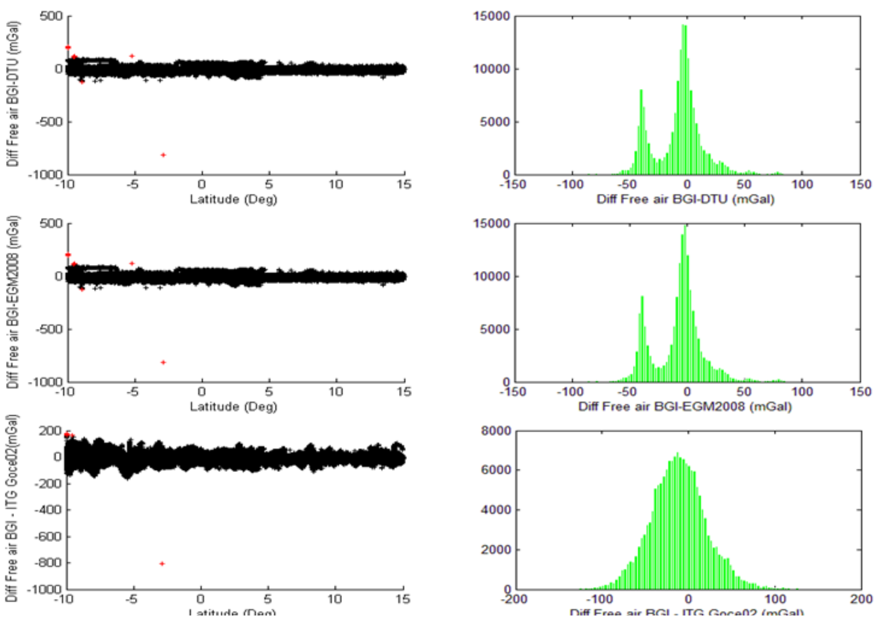

Fig. 4. Detected outliers by Grubbs test with significant level alpha of 0.05 and histograms of differences between BGI free air anomalies and those computed from DTU grid and EGM2008 and ITG-Goce02 surfaces after removing detected outliers. Outliers in red color and retained ones in black.

Tables 4, 5 and 6 present the results of the Z_{score}, Modified Z_{score} and Boxplot testing for the reduced free air anomalies data. The results show that these three tests gave a high rate of aberrant points compared to Grubbs' and GESD procedures. Consequently, using these tests improve the quality of dataset, by removing a high amount of potential outliers. Note that the Boxplot testing seems to provide the best results. The rejection rate relative to the tree surfaces is substantially the same unlike those obtained by the use of Z_{score} and Modified Z_{score} tests : 3.3% with respect to DTU10 and EGM2008 and 2.2% with respect to ITG-Goce02 (see, table 6).

Table 4. Results of the Zscore testing for the reduced data with a threshold of 3.

	Detected outliers	%	Min (mgal)	Max (mgal)	Mean (mgal)	σ (mgal)
DTU10	1868	1.150	-76.49	61.27	-8.07	21.16
EGM2008	1873	1.154	-76.47	61.27	-8.08	21.15
ITG-Goce02	1356	0.835	-112.51	90.12	-11.59	32.07

Table 5. Results of the Modified Zscore testing for the reduced data with a threshold of 3.5.

	Detected outliers	%	Min (mgal)	Max (mgal)	Mean (mgal)	σ (mgal)
DTU10	5196	3.200	-54.33	45.91	-8.32	19.64
EGM2008	5222	3.216	-54.17	45.80	-8.32	19.62
ITG-Goce02	1004	0.618	-119.62	95.83	-11.49	32.40

Table 6. Results of the Boxplot testing for the reduced data with a multiplier of the interquantile range of 1.5.

	Detected outliers	%	Min (mgal)	Max (mgal)	Mean (mgal)	σ (mgal)
DTU10	5418	3.337	-57.33	39.70	-8.73	19.53
EGM2008	5391	3.320	-57.25	39.65	-8.73	19.53
ITG-Goce02	3551	2.187	-95.05	71.04	-11.90	30.47

Figures 5 and 6 show the detected outliers modified Z_{scores} test and Boxplot test and histograms of differences between BGI free air anomalies and those computed from DTU grid and EGM2008 and ITG-Goce02 surfaces after removing detected outliers.

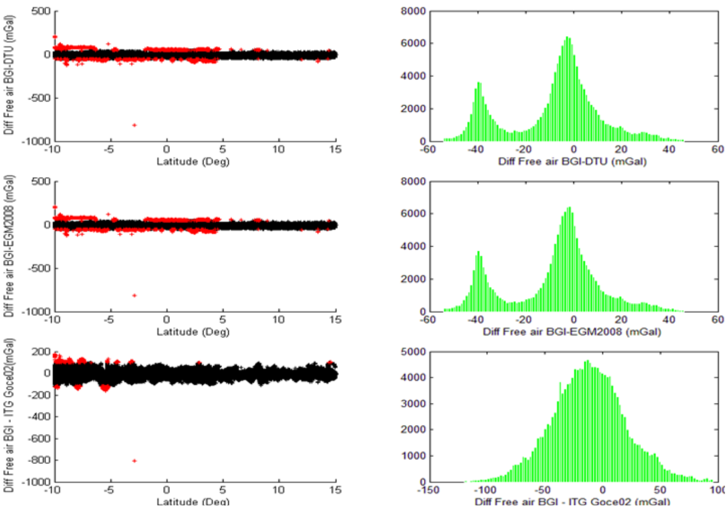

Fig. 5. Detected outliers by modified Z-scores test with threshold of 3.5 and histograms of differences between BGI free air anomalies and those computed from DTU grid and EGM2008 and ITG-Goce02 surfaces after removing detected outliers. Outliers in red color and retained ones in black.

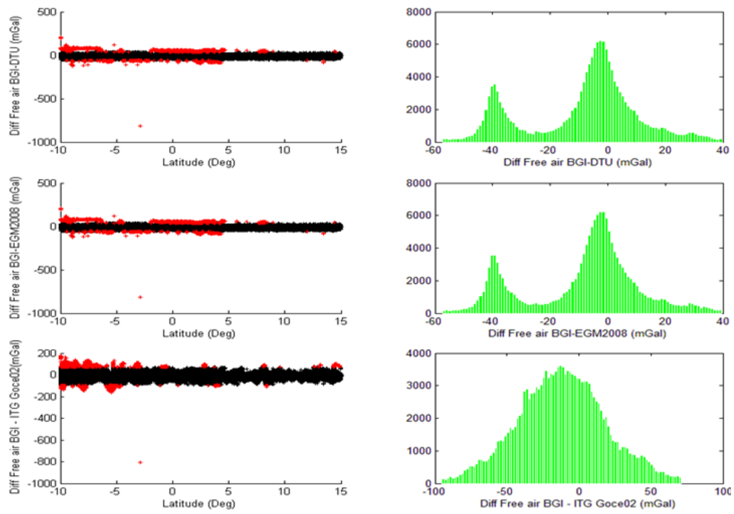

Fig. 6. Detected outliers by Boxplot test with k equals to 1.5 and histograms of differences between BGI free air anomalies and those computed from DTU grid and EGM2008 and ITG-Goce02 surfaces after removing detected outliers. Outliers in red color and retained ones in black.

5. Conclusion

In this paper, the in-situ measurements of marine free air anomalies in Western Mediterranean Sea (a set of 162374 gravity points supplied by the BGI by the International Gravimetric Bureau - BGI) are compared with corresponding values that interpolated from DTU10 surface and computed from the two geopotential models EGM2008 and ITG-Goce02.

Since in-situ marine gravity data are not cleared of errors, we apply at first stage five approaches to identify outliers in our in-situ measurements : the Grubbs Test, Generalized ESD Procedure, Z_{scores} Test and its modified version and the Box plot approach.

By considering differences between BGI marine free air anomalies data and those corresponding values from DTU10, EGM2008 and ITG-Goce02, the Grubbs test and GESD procedure have yielded no satisfactory results in most cases (less than 20 points are detected as outliers). Z_{scores}, modified Z_{scores} test and the Box plot approach detected a high rate of aberrant points compared to the first two procedures.

The Boxplot testing seems to provide the best results. The rejection rate relative to the tree surfaces is substantially the same : 3.3% with respect to DTU10 and EGM2008 and 2.2% with respect to ITG-Goce02. After removing the suspicious data identified by Boxplot testing, a general result appears over the three set of comparisons. Relative to the marine data, the differences are in the range of -57 to 40 mgal with respect to DTU10 and EGM2008 (a standard deviation of about 20 mgal) and in the range of -95 to 71 mgal with respect to ITG-Goce02 model (a standard deviation of about 30 mgal).

REFERENCES

[1] Cazenave, A., Schaeffer, P., Bergé, M., Brossier, C., 1996. High-resolution mean sea-surface computed with altimeter data of ERS-1 (Geodetic mission) and Topex/Poseidon, Geophys. J. Int. 125, pp. 696-704.

[2] D. T. Sandwell, W. H. F. Smith, *Marine gravity anomaly from Geosat and ERS-1 satellites*, J. Geophys. Res. 102, pp. 10039-10054, 1997.

[3] D. T. Sandwell, W. H. F. Smith, *Bathymetric prediction from dense satellite altimetry and sparse shipboard bathymetry*, J. Geophys. Res. 99, pp. 21803-21824, 1994.

[4] European Space Agency, 12 November 2013. ESA's gravity mission GOCE. Retrieved 26 October 2013.

[5] http ://www.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet _Programme/Earth_Explorers/GOCE/ESA_s_gravity_mission_GOCE

[6] M. R. Drinkwater, R. Floberghagen, R. Haagmans, D. Muzi, A. Popescu, *GOCE : ESA's first Earth Explorer Core mission*, Space Science Reviews 108, pp. 419-432, 2003.

[7] J. A. Johannessen, G. Balmino, C. Le Provost, R. Rummel, R. Sabadini, H. Sünkel, C. C. Tscherning, P. Visser, P. Woodworth, C. Hughes, P. Legrand, N. Sneeuw, F. Perosanz, M. Aguirre-Martinez, H. Rebhan, M. Drinkwater, *The European Gravity Field and Steady-State Ocean Circulation Explorer Satellite Mission Its Impact on Geophysics*, Surveys in Geophysics 24 (4), pp. 339-386, 2003.

[8] N. K. Pavlis, S. A. Holmes, S. C. Kenyon, J. K. Factor, *An Earth Gravitational Model to Degree 2160 : EGM2008*, presented at the 2008 General Assembly of the European Geosciences Union, Vienna, Austria, April 13-18, 2008.

[9] O. B. Andersen, P. Knudsen, *Global marine gravity field from the ERS-1 and Geosat geodetic mission altimetry*, J. Geophys. Res. 103, C4, pp. 8129-8137, 1998.

[10] BGI, The International Gravimetric Bureau, In "*The Geodesist's Handbook 2012*", H. Drewes, H. Hornik, J. Adam, S. Rozsa, Eds. (International Association of Geodesy). Journal of Geodesy 86, 10, 2012.

[11] BGI, EOL/EOS format, 2012.

[12] N. K. Pavlis, S. A. Holmes, S. C. Kenyon, J. K. Factor, *The Development and Evaluation of the Earth Gravitational Model 2008 (EGM2008)*, J. Geophys. Res. 117, B04406, 2008.

[13] J. Schall, A. Eicker, J. Kusche, *The ITG-Goce02 gravity field model from GOCE orbit and gradiometer data based on the short arc approach*, submitted to Journal of Geodesy, 2013.

[14] S. A. Holmes, N. K. Pavlis, *Spherical harmonic synthesis software harmonic_synth_v02.f*, http ://earth-info.nga.mil/GandG/wgs84/gravitymod/new_egm/new_egm.html, 2006.

[15] O. B. Andersen, P. Knudsen, P. Berry, *The DNSC08GRA global marine gravity field from double retracked satellite altimetry*, Journal of Geodesy 84(3), pp. 191-199, 2010.

[16] V. Barnett, T. Lewis, *Outliers in Statistical Data*, Wiley Series in Probability and Mathematical Statistics, 3rd ed, 1994.

[17] J. F. Jr. Hair, W. C. Black, B. J. Babin, R. E. Anderson, *Multivariate Data Analysis, A Global Perspective*, Seventh Edition, Chapter 2, New Jersey, USA : Pearson Education, Inc., p. 800, 2010.

[18] A. Agresti, C. Franklin, *Statistics, The Art and Science of Learning from Data*. Pearson Education, Inc., p. 693, 2007.

[19] W. L. Martinez, A. R. Martinez, *Exploratory Data Analysis with Matlab, Computer Science and Data Analysis Series*, Chapman & Hall/CRC, p. 405, 2005.

[20] H. Y. Cho, J. H. Oh, K. O. Kim, J. S. Shim, *Outlier detection and missing data filling methods for coastal water temperature data*, In : Conley, D.C., Masselink, G., Russell, P.E. and O'Hare, T.J. (eds.), Proceedings 12th International Coastal Symposium (Plymouth, England), Journal of Coastal Research, Special Issue No. 65, pp. 1898-1903, 2013.

[21] F. E. Grubbs, *Procedures for Detecting Outlying Observations in Samples.* Technometrics 11 (1), pp. 1-21, 1969.

[22] B. Rosner, *On the Detection of Many Outliers*, Technometrics 17, pp. 221-227, 1975.

[23] P. Prescott, *Critical values for a sequential Test for many outliers*, Appl. Statist 28 (1), pp. 36-39, 1979.

[24] B. Rosner, *Percentage Points for a Generalized ESD Many-Outlier Procedure*, Technometrics 25 (2), pp. 165-172,.

[25] M. Koestenberger, B. Nagel, W. Ravekes, A. Avian, B. Heinzl, P. Fritsch, A. Fandl, T. Rehak, A. Gamillscheg, *Left ventricular long-axis function : Reference values of the mitral annular plane systolic excursion in 558 healthy children and calculation of z-score values*, American Heart Journal 164(1), pp. 125-131, 2012.

[26] Q. Liu, L. Wong, J. Li, *Z-score biological significance of binding hot spots of protein interfaces by using crystal packing as the reference state*, Biochimica et Biophysica Acta 1824 (12), pp. 1457-1467, 2012.

[27] R. E. Shiffler, *Maximum Z scores and outliers*, The American Statistician 42 (1), pp. 79-80, 1988.

[28] B. Iglewicz,D. C. Hoaglin, *How to Detect and Handle Outliers*, ASQC Basic References in Quality Control 16, Wisconsin, US., p.87, 1993.

[29] J. W. Tukey, *Exploratory Data Analysis*, Addison-Wesley, Reading, 1977.

[30] D. C. Hoaglin, B. Iglewicz, *Fine-Tuning Some Resistant Rules for Outlier Labeling*, Journal of the American Statistical Association 82 (400), pp. 1147-1149, 1987.

[31] C. H. Sim, F. F. Gan, T. C. Chang, *Outlier Labeling With Boxplot Procedures*, Journal of the American Statistical Association 100(470), pp. 642-652, 2005.

[32] F. A. A. Garcia, *Tests to identify outliers in data series*, Matlab Central File Exchange. http ://www.se.mathworks.com/matlabcentral/fileexchange/28501, Retrieved December 19th, 2013.