Larhyss Journal, ISSN 1112-3680, n°26, Juin 2016, pp. 225-236
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MEAN DYNAMIC TOPOGRAPHY DETERMINATION OVER THE WESTERN MEDITERRANEAN SEA USING ALTIMETRY MEASUREMENTS AND GOCE GRAVITY MODEL

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RESUME

La surface de l'océan doit être surveillée afin de déterminer la topographie dynamique, les marées, de temps variations etc ....

La Topographie Dynamique Moyenne de l'océan (MDT), qui est la distance entre le géoïde et la hauteur moyenne de la surface de la mer (MSS) et qui reflète la dynamique de l'océan, est une inconnue océanographie primordiale.

Le traitement de 21 années de mesures altimétriques en calculant les effets environnementaux, géophysiques et orbitales, nous permet de déterminer la hauteur moyenne de la surface de la mer avec 1 cm de précision, en utilisant un modèle de géoïde basé sur 03 années d'observations du satellite GOCE, on peut calculer la Topographie Dynamique Moyenne de la Méditerranée occidentale. La variation de la surface obtenue est comprise entre -0,75 m et 0,75 m.

Cette surface est par la suite comparée avec RioMed qui représente une topographie dynamique sur la Méditerranée fournies par AVISO altimétrie (CNES).

Mots Clés : Topographie Dynamique Moyenne; Altimétrie, Surface Moyenne de la Mer; Géoïde; GOCE.

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ABSTRACT

The ocean surface must be surveyed in order to determine the dynamic topography, tides, time-variations etc…

The Mean Ocean Dynamic Topography (MDT), which is the distance between the Geoid and the Mean Sea Surface Height (MSS) and which reflects the ocean dynamics, is a primary oceanography unknown.

The processing of 21 years altimetry satellite measurements by the correction of the environmental, geophysical and orbital effects, permit us to determinate the mean sea surface height with 1 cm of precision, while using a Geoid model based on 03 years of GOCE satellite measurements, we can calculate the Mean Dynamic Topography over the Western Mediterranean sea. The variation of the obtained surface is between -0.75 and 0.75m.

The obtained surface is compared with RioMed which the Mean dynamic topography over the Mediterranean Sea provided by AVISO Altimetry (CNES).

Keywords: Mean Dynamic Topography; Altimetry, Mean Sea Surface Height; Geoid; GOCE.

Acronyms and abbreviations

AVISO : Archivage Validation et Interprétation des données des Satellites Océanographiques ;
CNES: Centre National des Etudes Spatiales ;
CLS: Collecte et Localisation par Satellite ;
GDR: Geophysical Data Records;
GOCE: Gravity and Ocean Circulation Explorer;
MDT: Mean Dynamic Topography;
MSS: Mean Sea Surface.

INTRODUCTION

The emergence of satellite altimetry allows us a large contribution for most applications and oceanographic activities. Among objectives of the altimetric satellites (Topex/Poseidon, Jason-1, Jason-2, Envisat, …) most specific concerns the survey of the oceans dynamic topography.

Indeed, these enormous masses of water transport with them the stored heat by the ocean and act therefore as thermal regulator. All variation in the transported water quantity or in the current direction will have an influence on the meteorological phenomena (precipitation and evaporation) or climatic for the important modifications.

Among these interests, the computation of the mean dynamic topography (MDT) which is a relief superposed on mean ocean level created by the oceanic currents (Rio et al. 2005), the slope may using the Coriolis force equation be used to compute the velocity (outside a band on the equator).

The dynamic topography is also the water height associated to the thermodynamic processes of the ocean: rain, turbulence, and thermal dilation (User handbook 2008).

Previous works based on the combination of altimetry measurements and gravity data allowed a global estimation of mean dynamic topography (Rio 2004, Maximenko et al. 2009).

On the Mediterranean Sea, the results obtained by Rio give a better determination of the mean dynamic topography (RioMed) (Rio 2005).

The purpose of this paper is to calculate the Mean Dynamic Topography over the Western Mediterranean sea using the GOCE Geoid model and the Mean Sea Surface height determinate by processing of 21 years altimetry measurements (1992-2013).

In this study, a new software (MOHEET) is developed to correct the altimetry measurements from the environmental, the geophysical and the orbital errors for Mean Sea Surface height determination.

Finally, the obtained mean dynamic topography is compared to RioMed.

The outline of this paper is as follows: "Reseach method" introduces the geometric principle of altimetry and the used model to compute the MSS and MDT. "Data used" describes datasets used in this study, Following this description, the results are presented in "Results and Analysis". Finally, the conclusions are provided.

RESEARCH METHOD

The Mean Dynamic Topography of the ocean provides information about the ocean's surface circulation; it is the difference between the sea surface and the Geoid height (figure 1).

The Geoid is one particular equipotential surface of the gravity potential of the Earth. Among all equipotential surfaces, the geoid is those which is equal to the undisturbed sea surface and its continuation below the continents (Barthelmes 2013)

Combining GOCE geoid models with satellite altimetric observations of the sea surface height substantial improvements in the modeling of the ocean circulation and transport are foreseen (Benveniste et al. 2007).

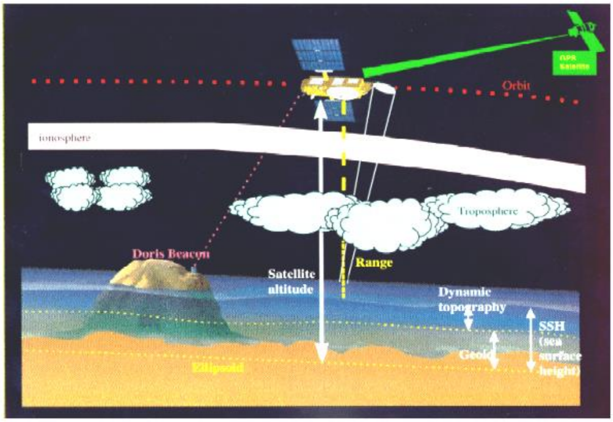

Figure 1 : Basic principles of satellite altimetry (CLS, Cnes)

The practical task of computing a Mean Dynamic Topography from a Mean Sea Surface (MSS) and a Geoid (N) is conceptually very simple; however there are some issues that must be considered in order to obtain a good MDT product. Both the sea surface and the Geoid must be represented relative to the same reference ellipsoid and in the same tidal system. Then the MDT is expressed by (Freiwald and losch 2012):

$$MDT = MSS - N \tag{1}$$

Where MSS represent the mean sea surface height above the reference ellipsoid and N is the Geoid height relative to the same reference ellipsoid.

The MSS is associated with a specific time period. When using the MDT together with satellite altimetry, it is important that the altimetry used for the MSS in the MDT calculation has the same corrections applied as the altimetry that is used for the computation of the sea level anomalies (Knudsen and Andersen 2012).

The formulation of the processing model of the MSS is given as follows (Rami et Haddad, 2014):

$$\mathrm{MSS} = \mathrm{h}_{\mathrm{Sat}} - (\mathrm{h}_{\mathrm{Alt}} + \Sigma) \tag{2}$$

Where:

h_{Sat} : Altitude of the satellite above the reference ellipsoid;

h_{Alt} : Altimeter range;

Σ : Whole corrections to be added to the altimeter range, given by (User Handbook 2008):

$$\Sigma = \Delta h_{trop} + \Delta h_{iono} + SSB + Inv_{bar} + \Delta \mathrm{h}_{OT} + \Delta \mathrm{h}_{ST} + \Delta \mathrm{h}_{PT} \tag{3}$$

With: $\Delta h_{trop} = +\Delta h_d + \Delta \mathrm{h}_w$

Where:

Δh_{trop} : Tropospheric correction;

Δh_w : Dry tropospheric correction;

$\Delta \mathrm{h}_w$: Wet tropospheric correction;

Δh_{iono} : Ionospheric correction;

SSB : Sea state bias;

Inv_{bar} : Inverse barometer correction for altimetry measurements;

h_{OT} : Height of the elastic ocean tide at the measurement point;

$\Delta \mathrm{h}_{ST}$: Height of the solid earth tide at the measurement point;

$\Delta \mathrm{h}_{PT}$: Geocentric pole tide height at the measurement point.

To determine the atmospheric and geophysical parameters and orbital error in order to obtain the mean Sea surface height over the Western Mediterranean sea, software called "MOHEET" is developed and provided by Rami (2011):

All of the standard corrections (atmospheric, geophysical, and orbital corrections) to the altimeter range were applied to the MSS including ionosphere delay determined from the dual frequency measurements from the altimeter (Rummel 1993), dry tropospheric correction obtained from ECMWF (European Centre for Medium range Weather Forecasts) Model, wet tropospheric correction computed by TMR (TOPEX Microwave Radiometer) for TOPEX data (DAAC and NASA Physical Oceanography 2006) and JMR (Jason Microwave Radiometer) for Jason data (Brown et al. 2003), inverse barometer using low-frequency signals (Pascual et al. 2008), ocean tide estimated using GOT4.7 model (Ray 1999), solid tide computed as described by Cartwright and Edden (1973), pole tide easily computed as described in (Wahr 1985), sea state bias computed using CLS Collinear v. 2009 (Tran et al. 2010), orbital error is obtained by STD0905 model (Lemoine et al. 2010) and instrumental corrections.

Global gravity field models used in this study is based on GOCE satellite data which are developed to a maximum order and degree of spherical harmonics varying between 200 and 250 (corresponding to a spatial resolution ranging between 80 and 100km) (Barthelmes 2013).

Since March 2009 to November 2013, GOCE evolves into low Earth orbit at an unusually low altitude for a research satellite.

Its gradiometer, sensitive instrument that measures the gravity in 3D, is the first ever sent into space. It allowed to map variations in Earth's gravity with unrivaled precision. The result is a unique model of the 'Geoid', which represents the theoretical shape of the Earth if it was covered with oceans at rest (Bruinsma et al. 2010).

This model is essential for accurately measuring ocean circulation and changes in sea level (Barthelmes 2013).

Regarding the topography and ocean circulation, GOCE has provided continuous data with a quality and a resolution never achieved until now, which has improved our understanding of ocean dynamics.

The GOCE satellite mission is a new type of Earth observation satellite that measures the Earth gravity field with unprecedented accuracy (Benveniste et al. 2007).

The objective of GOCE mission is:

- to determine gravity-field anomalies with an accuracy of 1 mGal (where 1 mGal = 10–5 ms–2).
- to determine the geoid with an accuracy of 1-2 cm.
- to achieve the above at a spatial resolution better than 100 km.

DATA USED

For this study, we use the Geophysical Data Records (GDR) of several altimetric satellites measurements: TOPEX/Poseidon (1992–2002), Jason-1 (2002–2008), and Jason-2 (2008 -2013) provided by CLS (Aviso). For a detailed description of GDR contents, readers are referred to OSTM/Jason-2 Products Handbook (Aviso 2011). Our interest area is defined by the following coordinates: 34°N-45°N, 5°W-12°E.

In the other hand the used Geoid is based on 3 years of GOCE satellite observation (figure2), this model is determined with calculation of Gravity Field Functionals on Ellipsoidal Grids (Gatti et al, 2014), it is provided by the International Centre for Global Earth Models (ICGEM) (http://icgem.gfz-potsdam.de/ICGEM).

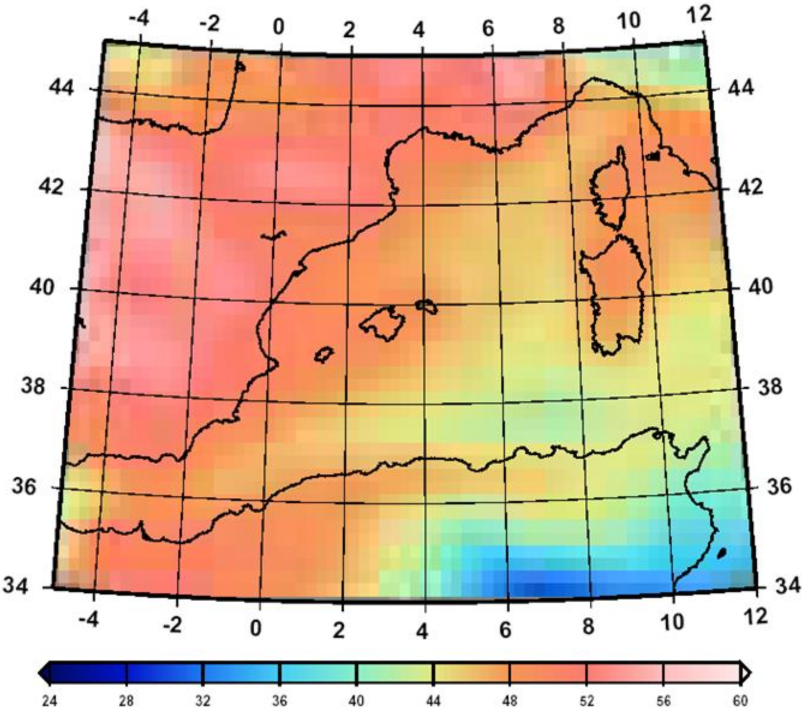

Figure 2: The Geoid model (m) calculated using GOCE satellite data (Gatti et al, 2014)

RESULT AND ANALYSIS

The processing of all satellite data permits us to obtain the MSS with 1 cm of precision.

The mapping of obtained Mean Sea Surface by regular grid of 0.25° x 0.25° in longitude and latitude is done using a linear interpolation (Delaunay triangulation). This interpolator is heavily employed in mathematics (particularly in numerical analysis).

Figure 3 represents the Mean Sea Surface height over the Western Mediterranean Sea.

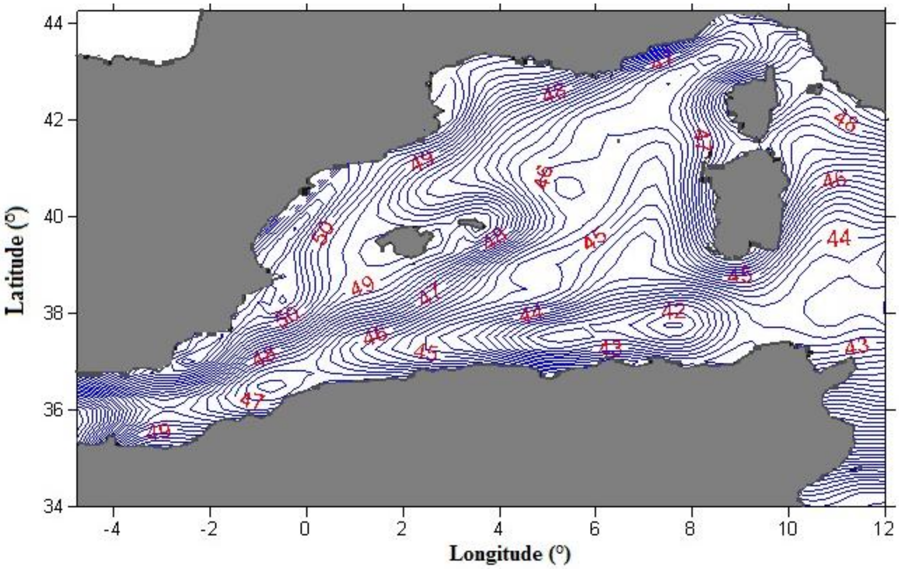

Figure 3: Mean Sea Surface Height (m) (1992-2013)

Figure 5 exhibits the Mea Sea Surface height and the GOCE Geoid model.

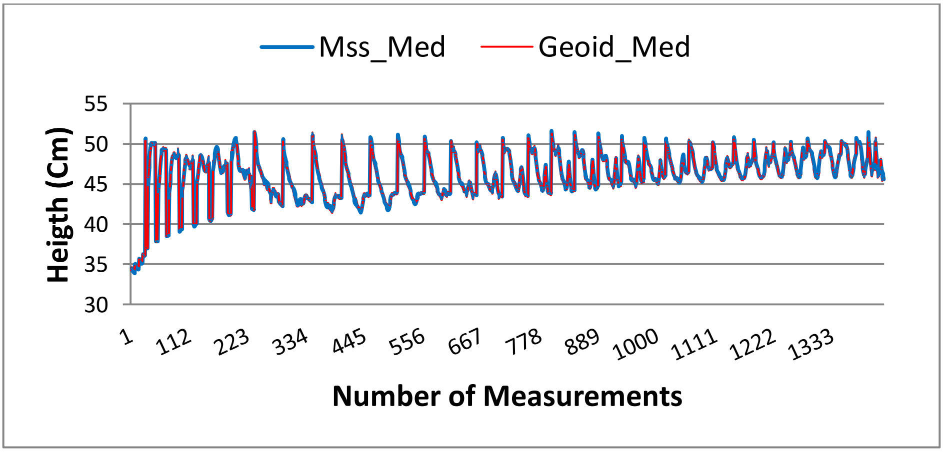

Figure 4: Mean sea surface (Bleu) and Geoid (Red) above the Western Mediterranean Sea

The mean dynamic topography which is the mean sea surface height above Geoid and determinate from the obtained MSS (eq.1) is represented in the follow figure:

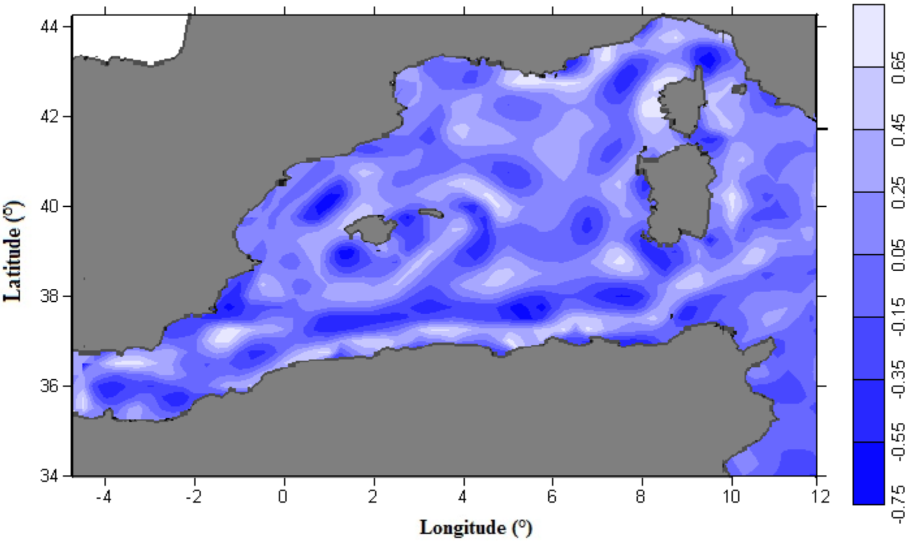

Figure 5: Mean Dynamic Topography

We note firstly, that the dynamic topography is much important in the open sea (between -075 and -0.35 meters and between 0.35 and 0.75meters) relatively to the coastal region (between -0.35 and 0.35 meters) and secondly, this area is important on the north of western Mediterranean Sea than on the south.

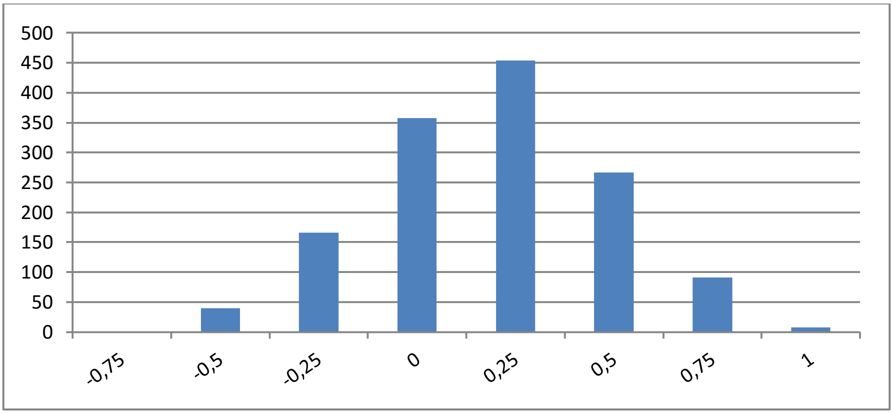

Figure 6: Topography dynamic frequencies histogram

We also note, from figure 6, that the dynamic topography varies between -0.75 m and 0.75 m, with an average of 6.4cm and RMS = 0.29 m. Figure 6 shows that over 95% of data are between -0.25 and 0.5 m.

Moreover, our results are in agreement with previously published results obtained by other smoothing methods for example RioMed 2005 which is produced by CLS Space Oceanography Division and distributed by Aviso, the mean dynamic topography of RioMed varies between -0.30 m and 0.45 meter with an average of 8.1cm (Rio et al. 2005).

CONCLUSION

The obtained results are satisfactory because the difference between the provided dynamic topography variation interval and the calculated interval is very small (< 2 mm).

This difference is mainly due to the lack of precise altimetry measurements on the coastal region which requires an extrapolation.

The combination of long-term observation of Jason-1, Jason-2 and Envisat data will allow us to have a more accurate mean dynamic topography.

ACKNOWLEDGMENTS

The authors are grateful to Aviso Altimetry for providing the altimetric data. The authors thank also the International Centre for Global Earth Models (ICGEM) of the International Association of Geodesy (IAG) for providing the GOCE Geoid model. The authors greatly appreciate the anonymous reviewers for their valuable and constructive comments.

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