Available online at www.humg.edu.vn

ESASGD 2016

Geoinformatics for Natural Resources, Hazards and Sustainability (GIS IDEAS 2016)

Determination of the Mean Dynamic Topography from satellite altimetry data in the East Sea

Van Sang Nguyen*

Hanoi University of Mining and Geology, Duc Thang, Bac Tu Liem, Hanoi 100000, Vietmam

nguyenvansang@humg.edu.vn

Abstract

Mean Dynamic Topography (MDT) is the difference between mean sea surface height and geoid. Satellite altimetry data are known as sea surface height, including geoid height, MDT, and dynamic sea surface topography h_t. To determine MDT from satellite altimetry data, the geoid height and dynamic sea surface topography should be removed from sea surface height. In this study, geoid height was computed from spherical harmonic coefficients of global Earth Gravity Model (EGM). h_t was determined using crossover adjustment technique. Finally, gridded MDT model was established by using Collocation interpolation method. By experimental processing and analysis, authors have successfully built 5’x5’ gridded MDT model, named HUMG16MDT, for East Sea, using data of four altimetric satellites, namely ERS-1, T/P, ENVISAT, and JASON-2. For validation, this model was compared with the measurements of 9 tidal stations, figuring out a least square error of ±0,164m.

Keywords: Satellite altimetry; mean dynamic topography.

1. Introduction

Altimetry, a new technological approach in satellite geodesy, has been widely used all over the world in many fields, namely determining geoid models of seas, estimating marine gravity anomaly, studying sea geophysics, mapping and monitoring the ice caps, and determining mean dynamic topography, and so on [10]. A number of MDT models have been built to date using satellite altimetry data such as DNSC08MDT, DTU10MDT, DTU13MDT [6], [2],... The accuracy of those models meets the requirements of many general research works in oceanic science and geodetic surveying. In Vietnam, some of previous studies have effectively applied the above-mentioned models for studying the East Sea [6], [8]. However, these studies only focused on exploiting those existing MDT models, but discussing about establishing MDT model for Vietnam. Existing MDT models, normally built using altimetry data observed in a specific time, do not meet the requirements in studying the change of MDT models in different periods. To better study the East Sea, temporal MDT models must be investigated. In this report, authors present primary result of the establishment of an MDT model for the East Sea using altimetry data.

2. MDT modeling approaches using altimetry data

2.1. An overview on altimetry derived MDT determination approaches.

Altimetry satellites fly over and transmit radar radiation to sea surface, and this signal is reflected back to satellites. By measuring the returned time of radiation transmission, the distance *(h)* between sea surface and altimeter is estimated. The exact positions of altimeters are normally determined using Global Positioning System (GPS), or other technologies, namely Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), Satellite Laser Ranging (SLR). Those technologies would determine the altitude *(H)* of altimeters above a reference ellipsoid. Hereby, sea surface height is calculated using following formula [15].

$$SSH = H - h + h_{corr} \quad (1)$$

where h_{corr} are corrections. Sea surface height is presented through geoid height *(N)* and dynamic sea surface height *(h_d)* in equation (2).

$$SSH = N + h_d \tag{2}$$

Dynamic sea surface height is divided into two components including mean dynamic topography h_{MDT} and dynamic topography h_t [1]. Accordingly, sea surface height is computed through the following equation.

$$SSH = N + h_{MDT} + h_t \tag{3}$$

As can be seen in equation (3), to determine h_{MDT}, geoid height and dynamic sea surface height h_t must be removed from sea surface height *(SSH)*. Geoid height was determined using harmonic coefficients C_{nm} and S_{nm} of EGM model. Component h_t was removed using crossover adjustment technique.

Finally, the flow chart for estimating mean dynamic sea surface height (SSH) is presented in Fig. 1.

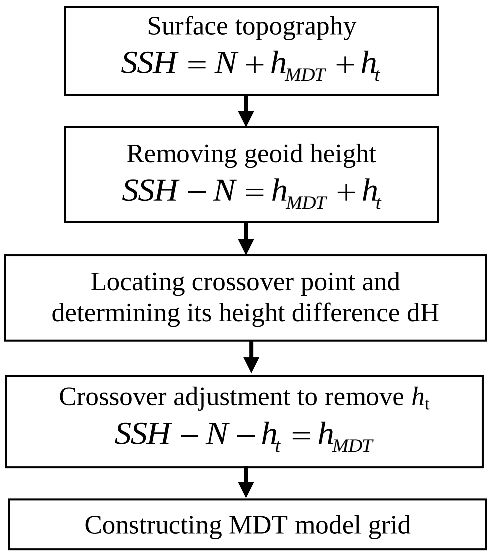

Fig. 1. The flow chart for estimating mean dynamic sea surface height (SSH)

2.2. Determining geoid height from harmonic coefficients

For each EGM model, if harmonic coefficients C_{nm} and S_{nm} are known, then geoid height is calculated in the equation [13].

$$N = \frac{GM}{\gamma . r}\left[\sum_{n=2}^{N}\left(\frac{a}{r}\right)^{n}\sum_{m=0}^{n}\left(c_{n,m}\cos m\lambda + s_{n,m}\sin m\lambda\right)\overline{P}_{n,m}(\sin\phi)\right] \tag{4}$$

2.3. Locating the positions of crossover point of altimetry tracks and determining the sea surface height difference at crossover point using polynomial simulation approach.

+) Altimetry data distribution

An Altimetry satellite is designed for all the altimetric points form long point tracks (named bowstrings) on the sea surface. Those tracks intersect each other to form crossover points. Crossover points are normally not coincident with observed points; hence, the first and important work need to be done in altimetry data processing is to locate the positions of crossover points and calculate the sea surface height difference at those points. This is the basis of other following processing such as the determination of mean dynamic sea surface height, calculation of geoid height, and estimation of sea gravity anomaly, and so on.

+) Modeling trajectory of ascending and descending tracks using quadratic function.

Assuming point $i(B_i, L_i)$ on a track (either ascending or descending track) is simulated by the following quadratic function.

$$L = aB^2 + bB + c \tag{5}$$

where *a, b, c* are unknown parameters. To determine these parameters, there should have at least three known points on a track (namely altimetric points). If the number of points is larger than 3, the least square principle is applied.

+) Locating approximate position of crossover points.

If ascending and descending track are simulated by the quadratic function $L_t = a_t B^2 + b_t B + c_t$ and $L_g = a_g B^2 + b_g B + c_g$, respectively; then the coordinate of crossover points are the roots of the following system of equations.

$$\begin{cases} L = a_t B^2 + b_t B + c_t \\ L = a_g B^2 + b_g B + c_g \end{cases} \tag{6}$$

There are two roots in the system of equations (9) or there are two crossover points. These points are situated on the two opposite branch of parabola of the quadratic function simulating ascending and descending track. The reasonable point is the one situates on the ascending and descending track. Comparing these two points with the starting and ending points of the ascending or descending track, the crossover point should be found.

+) Exactly locating the crossover positions.

The above-found location is just approximate position of the crossover point. Comparing these coordinates with those of points on ascending and descending track, four vicinity points were found. Based on these four points, the exact position of crossover points is found using Cramer algorithm [12].

2.4. Crossover adjustment for determining dynamic sea surface height component.

+) Modeling the dynamic sea surface height component.

There is a difference in height on ascending and descending track *dH* (Fig. 2) because of the existence of dynamic sea surface height component at crossover points. The crossover adjustment algorithm is based on the *dH* component to determine the dynamic sea surface height h_t.

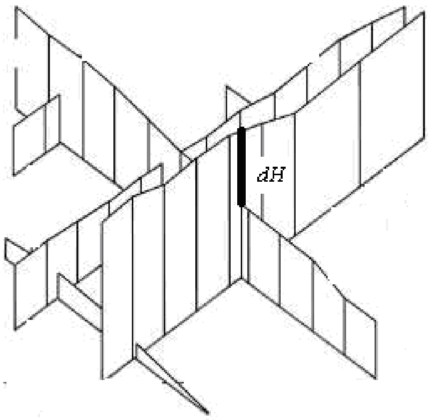

Fig. 2. Height difference at crossover point.

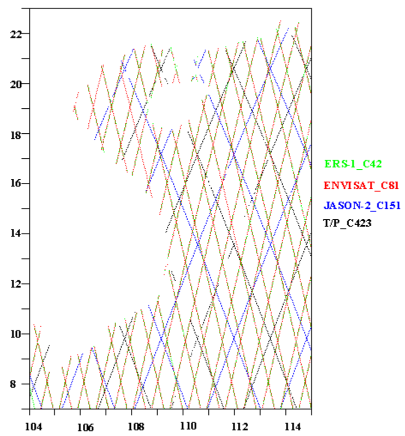

Fig. 3. The distribution of observation points of four satellites ERS-1, T/P, ENVISAT và JASON-2 at the East Sea.

Within this study area (the length of a track is shorter than 2000 km), h_t is simulated through two parameters, difference *a* and slope *b*. Hereby, the component h_t of a point k on the i[th] track ($h_t^{i,k}$) is presented in the following formula.

$$h_t^{i,k} = (a_i + b_i.\mu_i^k) \tag{7}$$

where: a_i, b_i are the difference and slope at i[th] track;

μ_i^k is the relative longitude of point k to the mean longitude of i[th] track.

+) Conducting crossover adjustment to determine parameters of the model.

To model dynamic sea surface topography, the height difference at crossover point *C* of track *i* and *j* is.

$$dH_{ij}^c = (a_i + b_i.\mu_i^c) - (a_j + b_j.\mu_j^c) + v_{ij} \tag{8}$$

where a_i, a_j are height difference; b_i, b_j are slopes; μ_i^c, μ_j^c are relative longitudes to the mean longitude of track *i* and track *j* at crossover point *C*, respectively.

The system of the equation (18) is rewritten as the matrix structure as follow.

$$L = A.x + V \qquad (9)$$

where *x* is unknown matrix that contains parameters *a* and *b*, there are two unknowns at each track; if the number of ascending track is *m* and the number of descending track is *n*, there will be *2(m+n)* unknowns; *V* is the matrix of correction, each crossover point has one correction; *L* contains *dH*, each crossover point has one *dH* value.

This is a modal equation. To solve this equation, the track-fixed algorithm must be applied. However, the altimetry accuracy of the two tracks are similar that make it difficult to choose which one is the fixed one. The equation could also be solved using least square principle $V^T PV = \min$ with a normalization condition $x^T P_x x = \min$.

However, the disadvantage of the two aforementioned approaches is that the mean dynamic topography derived from the adjustment is not suitable to geoid model. To avoid this weakness, it is needed to model the sea surface topography at observation points on track *l* through deviation (a_l^0) and slope (b_l^0), and fit those track with geoid model. Thereby, the correction equation for point i_i on track *l* is illustrated as follow.

$$SSH'_{l\,i_1} = a_l^0 + b_l^0.\mu_{li_1} + V_{li_1} \qquad (10)$$

Here μ_{li_1} is the relative longitude of point i_l; V_{li_1} is the height correction of i_l; $SSH'_{l\,i_1}$ is sea surface height after removing geoid height and mean dynamic topography. Before having mean dynamic topography, geoid height removed mean sea surface height is used, then mean dynamic topography computing process is conducted using iterative algorithm.

Parameters a_k^0 and b_k^0 of track *l* is determined using least square principle with condition $\sum_{i_1=1}^{n_1} V_{li_1}^2 = \min$, n_1 is the number of points on track *l*.

The above least square process and crossover adjustment could be conducted simultaneously. Thereby, $a^0 = a$, $b^0 = b$ and the system of correction equation is shown as follow.

$$\begin{cases} v_{ij} = (a_i + b_i.\mu_j) - (a_j + b_j.\mu_i) - dH_{ij} \\ V_{li_1} = (a_l + b_l.\mu_{li_1}) - SSH'_{l\,i_1} \end{cases} \qquad (11)$$

Parameter *a* and *b* are derived using least square principle with the following condition.

$$\sum v_{ij}^2 + w \sum V_{li_1}^2 = \min \qquad (12)$$

Here *w* is relative weight. After figuring out parameters *a* and *b*, mean dynamic topography is computed in the following equation.

$$h_{MDT} = SSH - N - (a + b.\mu) \qquad (13)$$

The gridded MDT model was established by using Collocation interpolation method.

3. Experimental results of determining MDT model at the East Sea using satellite altimetry data.

3.1. Satellite altimetry data.

For academic research purposes, data from four types of satellites was collected including ERS-1, T/P, ENVISAT và JASON-2. Those data was all provided by AVISO [3], [4]. The dataset has been primarily corrected and geo-referenced to the WGS-84 coordinate system. The above-mentioned data was collected with exact repeat observation method. The information about these dataset is shown in Table 1.

Table 1. Data statistics

No.	Satellite	Number of cycle	Observation time	Total observation time (month)
1	ERS-1	12	09/4/1995 ÷ 02/6/1996	14
2	T/P	56	24/3/2004 ÷ 04/10/2005	19
3	ENVISAT	33	20/7/2009 ÷ 08/4/2012	33
4	JASON-2	73	28/7/2012 ÷ 22/7/2014	24
Total		197		90

3.2. Data classification and selection.

Data was collected with exact repeat observation method (Exact Repeat Mission – ERM), it is implied that previous tracks are repeated by following tracks. To enhance the density of observations, the combination of different satellites is necessary. The distribution of track lines of four types of satellite is illustrated in Fig. 3. With this density, 5’x 5’ resolution MDT model could be constructed.

The study area is situated between 8^0 and 22^0 in latitude and 105^0 and 114^0 in longitude. To assure the accuracy, dataset was collected to a larger extent (between 7^0 and 23^0 in latitude and 104^0 and 115^0 in longitude).

3.3. Result of building MDT model from data of four different satellites.

The MDT modeling result at 5’x 5’ spatial resolution grid is stored in ***HUMG16MDT.txt*** with the following statistics.

- The highest MDT value: 1.194m
- The smallest MDT value: 0.549m
- The mean MDT value: 0.891m

In Fig. 4, MDT modeling result is illustrated in contour with different colours.

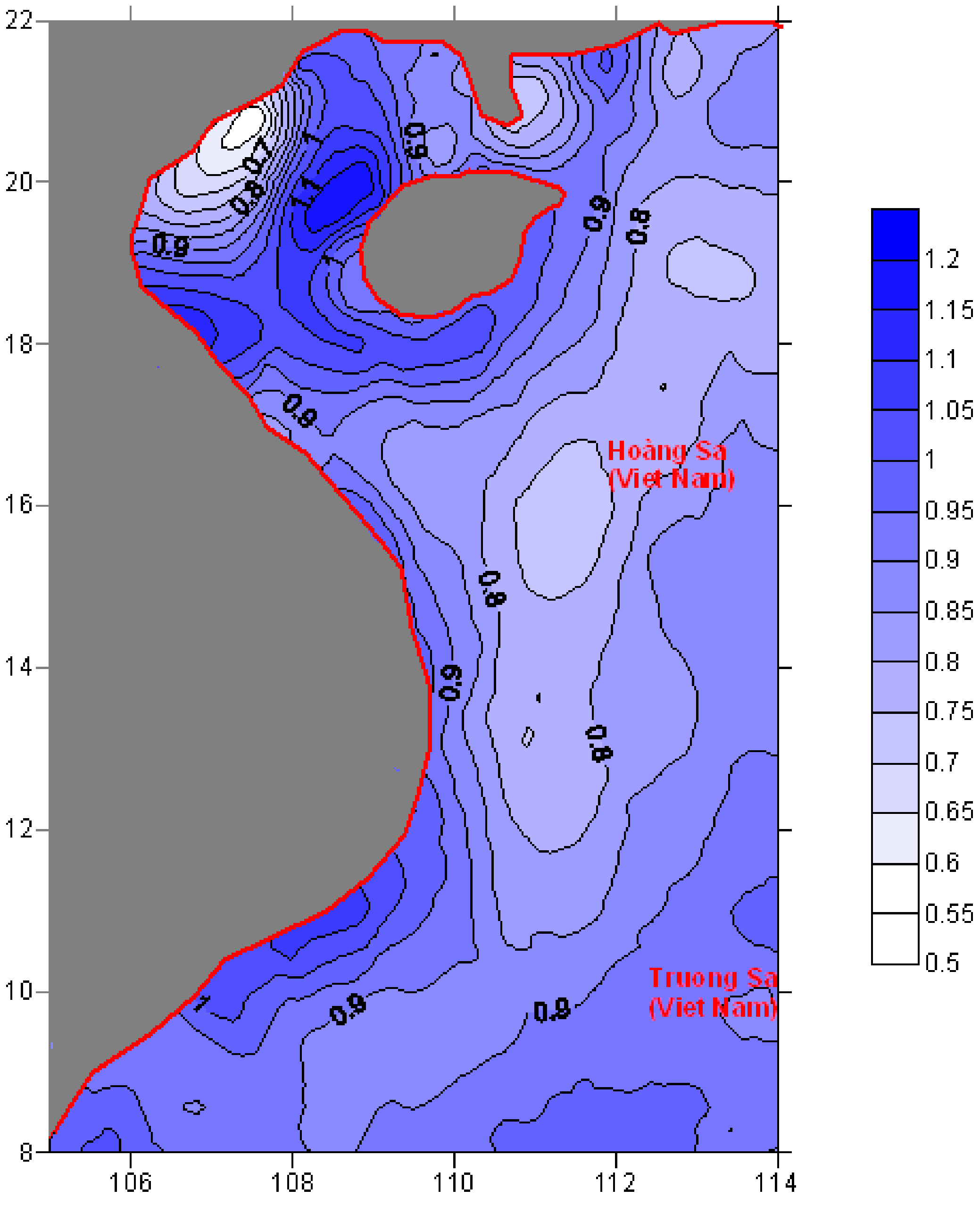

Fig. 4. MDT result computed from data of four satellites.

3.4. Validating MDT model by comparing with tidal measurements.

+) Introduction to MDT model established from tidal measurements.

Data from 9 tidal stations were used in this study including Co To, Hon Dau, Hon Ngu, Tien sa, Quy Nhon, Nha Trang, Vung Tau, Con Dao, Phu Quoc. All stations had been installed and monitored tide for over 18.6 years. Those data was provided by Prof. Sc.D. Minh Hoa Ha through a national scientific project [1]. Tide derived MDT data was geo-referenced to VN2000 coordinate system, and zero-tide system, and referenced to regional quasigeoid of Vietnam. For comparison, all MDT data were transferred to WGS-84 coordinate system, independent tidal system, and global quasigeoid.

+) Comparing MDT constructed from data of four satellites with tidal measurement.

To compare the two datasets, the MDT value at tidal stations were interpolated from MDT model, those values were then compared with tidal measurements at corresponding stations. The standard deviation is m = ±0,164m.

4. Conclusion

This report presents an MDT modeling approach using altimetry observations. Accordingly, to obtain MDT values, geoid height was removed, and dynamic topography component was also excluded by utilizing crossover adjustment technique. MDT values of grid points were interpolated using Collocation method.

HUMG16MDT was constructed using data from four different altimeters, namely ERS-1, T/P, ENVISAT, and JASON-2, acquired over the East Sea between 8^0 and 22^0 in latitude and 105^0 and 114^0 in longitude, with the grid size of 5'x 5'.

The standard deviation of HUMG16MDT model reaches ±0,164m, by comparing with the measurements of nine tidal monitoring stations.

Acknowledgements

Authors would like to thank AVISO for providing us satellite altimetry data using in this study. This study is financially supported by Vietnam Ministry of Education and Training and Hanoi University of Mining and Geology through the board-class project number B2014-2-18.

Authors would like to express our deepest appreciation to Prof. Rene Forsberg, Geodynamics Dept. National Space Institute (DTU-Space) for providing us the GeoEGM module of GravSoft for calculating geoid height from harmonic coefficients and Prof. Sc.D. Minh Hoa Ha in the Vietnam Institute of Geodesy and Cartography for providing us tidal monitoring data. Valuable advice and suggestions from Sir. Ole Baltazar Andersen in Geodynamics Dept. National Space Institute (DTU-Space) is also appreciated.

References

[1]. Andersen O.B., 2010. Marine Gravity and Geoid from Satellite Altimetry. Geodetic Department, DTU – Space, Juliane Maries Vej 30, DK – 2100, Denmark.

[2]. Andersen. B, Knudsen. P., 2008. The DNSC08MDT Mean Dynamic Topography. Danish national Space Center, Denmark.

[3]. AVISO, 2010. DT CorSSH and DT SLA Product Handbook, Toulouse – France.

[4]. AVISO, 2014. Altimetry Mission.

[5]. Bernhard Hofmann-Wellendof, Helmut Moritz, 2005. Physical Geodesy. SpringerWien NewYork.

[6]. Dương Chí Công, 2015. Báo cáo kết quả nghiên cứu đề tài cấp bộ: nghiên cứu đánh giá và đề xuất sử dụng mô hình mặt biển tự nhiên MDT ở Việt Nam. Viện Khoa học Đo đạc và Bản đồ. Hà Nội.

[7]. Gunter Seeber, 2003. Satellite Geodesy, Walter de Gruyter – Berlin – New York.

[8]. Hà Minh Hòa, 2015. Nghiên cứu đánh giá các mặt chuẩn mực nước biển (mặt "0" độ sâu, trung bình và cao nhất) theo các phương pháp trắc địa, hải văn và kiến tạo hiện đại phục vụ xây dựng các công trình và quy hoạch đới bờ Việt Nam trong xu thế biến đổi khí hậu, mã số: KC.09.19/11-15. Viện Khoa học – Đo đạc và Bản đồ, Hà Nội.

[9]. http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/index.html

[10]. Lee-Lueng Fu, Anny Cazenave, 2001. Satellite Altimetry and Earth Sciences. ACADEMIC PRESS, San Diego – San Francisco – New York – Boston – London – Sydney –Tokyo.

[11]. Nguyễn Văn Sáng, 2011. Tính toán độ cao mặt biển từ số liệu đo cao vệ tinh ENVISAT trên vùng biển Việt Nam, Tạp chí khoa học kỹ thuật Mỏ - Địa Chất (số 35, tr 81-85), trường Đại học Mỏ - Địa Chất, Hà Nội.

[12]. Nguyễn Văn Sáng, 2013. Xác định vị trí điểm giao cắt trong xử lý số liệu đo cao vệ tinh bằng cách mô phỏng đa thức bậc hai. Tạp chí khoa học kỹ thuật Mỏ – Địa Chất (số 41, tr 43 – 47), trường Đại học Mỏ – Địa Chất, Hà Nội. ISSN: 1859 – 1469.

[13]. NIMA. Department of Defense World Geodetic System 1984. National Imagery and Mapping Agency, American. 2000.

[14]. Rene Forsberg, C.C. Tscherning, 2008. Geodetic Gravity Field Modelling Programs. National Space Institute and Niels Bohr Institute, University of Copenhagen, Denmark.

[15]. Rosmorduc V., 2009. Basic Radar Altimetry Toolbook practical. Bergen, Norway.