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Change of mean dynamic topography on East Sea using satellite altimetry data

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ABSTRACT: The height of mean dynamic topography is determined from the satellite altimetry data by removing the height of geoid model and dynamic sea surface topography. By using this method, we define mean dynamic topography (MDT) and average MDT of altimetry cycle. Change of dynamic sea surface topography is assessed by following two approaches: (1) compare the difference at separate points of average MDT between experimental cycles and (2) compare the MDT surface between experimental cycles. The data of ENVISAT altimetry satellites on the East Sea are used to assess the experiment. The results show that: mean dynamic topography changes annually, specifically, the highest value is on October and November; the lowest value is on May and June. The average MDT value changes about 2.0 decimeters. The MDT value on the East Sea changes approximately decimeters between measurement cycles.

KEY WORDS: mean dynamic topography, altimetry

1. INTRODUCTION

Sea surface that is removed the influence of wave, wind, tide (including solid-earth and ocean tides) and atmospheric pressure, etc. is called the Mean Dynamic Topography (MDT). This describes the meaning "*Mean*" in the name. MDT is the difference between the Mean Sea Surface (MSS) and Geoid surface that relates to sea currents. This describes the meaning "*Dynamic*". In the end of the twenty centuries, MDT model has been applied in oceanography, meteorological and hydrographic ocean, geodesy, geophysics, etc. In oceanography field, if we determine MDT value and its change, we can determine the sea currents and its trends from time to time. These affect meteorology and hydrography. Researching the change of MDT allows researchers to study the sea level change. In geodesy, MDT model is used for merging height system on the land and sea, sea mapping establishment. In geophysics, MDT model is used for determining the structure of the earth on the sea floor because it affects sea surface.

In recent years, there have been many international organizations which have built MDT models from satellite altimetry data such as Danish National Space Center built DNSC08MDT model in 2008 (Andersen and Knudsen, 2008); The Technical University of Denmark built DTU10MDT in 2010 (Andersen, 2010), DTU13MDT in 2013 (Andersen et al., 2013), DTU15MDT in 2015 (Knudsen, 2016); French Space Agency built MDT_CNES_CL1 model in 2001, MDT_CNES_CL9 model in 2009, etc. (Cong, 2014).

In Vietnam, using satellite altimetry data for researching ocean has been applied in recent years. Almost projects focus on using available international MDT models. The DMSC08MDT model was used for comparing with tidal station data (Ha, 2012). Applying DNSC08MDT and DTU13MDT models on other fields has researched in some papers (Ha, 2015; Cong, 2014). The MDT model on the East Sea has been determined using DNSC08MSS model (Sang, 2012a). Some papers studied satellite altimetry data processing deeply. ENVISAT data has been used to determine gravity anomaly (Sang, 2012b) and built MDT model (Sang, 2015), removing dynamic topography using crossover adjustment method (Sang, 2015). MDT model on the East Sea has been created using satellite altimetry data (Sang and Thanh, 2015).

How does MDT on the East Sea change during the time? This paper presents the method and result that are used to determine the change MDT on the East Sea using ENVISAT satellite altimetry. Determining the change of the height of mean dynamic topography will contribute to investigate, assess and predict the sea level rise effect because of global warming.

2. DETERMINATION OF MEAN DYNAMIC TOPOGRAPHY CHANGE

2.1. Satellite altimetry principle

While moving on the orbit, altimetry satellite emits radar signal to the ocean surface. This signal comes back to the receiver on the satellite after it reflects from the ocean surface. The distance from the satellite to ocean surface (h) is determined by measuring the signal transmission time. The satellite position on the orbit can be determined by using GNSS or other systems such as Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS) or Satellite Laser Ranging (SLR). It is the distance from satellite orbit to reference ellipsoid (H) as Fig 1. The height of sea surface (SSH) is calculated by the following equation (Rosmorduc, 2009):

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

where, h_{corr} is residuals.

2.2. Mean dynamic topography determination

The height of sea surface is represented by geoid height (N) and the height of mean dynamic topography (h_d) in Fig 1 by the following equation:

$$SSH = N + h_d \quad (2)$$

The height of mean dynamic topography includes two parts:

- Mean dynamic topography (h_{MDT});
- Dynamic sea surface topography (h_t).

So, the height of sea surface is presented by the equation:

$$SSH = N + h_{MDT} + h_t \quad (3)$$

From the (3), we can see that, in order to determine the mean dynamic topography (h_{MDT}), the geoid height (N) and dynamic sea surface topography (h_t) are removed from the satellite altimetry data. The geoid height and dynamic topography can be removed by using C_{nm} and S_{nm} coefficients of spherical harmonic of global gravity model EGM and crossover adjustment theory respectively.

In order to use conveniently, we need to create gridded MDT model after the mean dynamic topography is built.

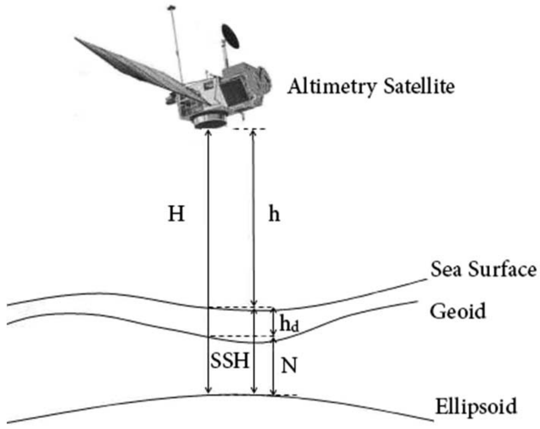

Fig 1. The height of sea surface

2.3. The interpolation of height of mean dynamic topography using Collocation method

Suppose that in the study area, n is the number of points that have the mean dynamic topography value $h_{MDT} = (h^1_{MDT}, h^2_{MDT}, \dots, h^n_{MDT})$, the mean dynamic topography at the point P is calculated by the following equation (Neuman Yu. M., 2010):

$$h^P_{MDT} = K^T(i,P).(K(i,j))^{-1}.h_{MDT} \quad (4)$$

where,

K(i,P): covariance matrix between the point P and the known point i;

K(i,j): covariance matrix between the point i and j in the known data.

If there is a measurement error, (4) can be written by equation:

$$h^P_{MDT} = K^T(i,P).(K(i,j) + C_\Delta)^{-1}.h_{MDT} \quad (5)$$

where, C_Δ is the covariance matrix of the measurement error.

After determining the height of mean dynamic topography, we calculate the mean MDT of individual cycle of the individual satellite on the East Sea. After this stage, we observe the change of this value from time to time on the East Sea.

We interpolate the MDT value of the points in the 81th cycle of ENVISAT satellite from the other cycles in order to calculate the change MDT surface, after that, the difference of MDT value between two consecutive cycles is used as input data.

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3. THE CHANGE OF DYNAMIC SEA SURFACE TOPOGRAPHY RESULT

3.1. The study data

ENVISAT's data is used in this study that has been provided by AVISO (AVISO, 2014). The data is corrected with residuals and is in the WGS-84 international reference system. The data is received in the extract repeat mission (ERM) from July 20, 2009 to April 08, 2012; this data includes 33 cycles (from the cycle 81 to 133) and is calculated in AVISO center from September 28, 2010 to May 21, 2012. In these cycles, the cycle 94 and 95 are removed before interpolating because of lack of the points.

3.2. The result

The following diagram illustrates the change of mean MDT value depending on the time:

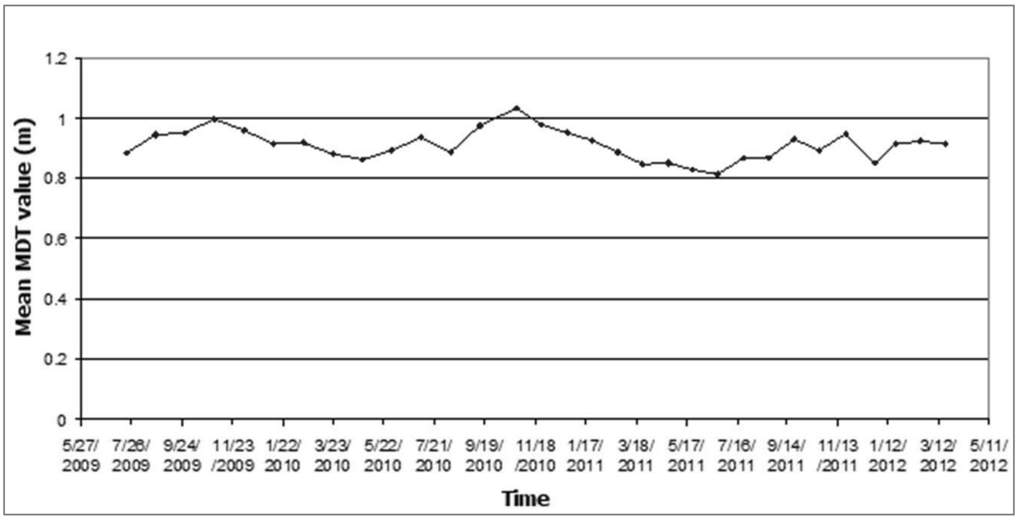

Fig 2. The change of mean MDT depending on the time from ENVISAT satellite data

We can see that the mean MDT value changes annually. It has the highest value in October and November in 2009, 2010 and 2011; the lowest value in April and May in 2010, in May and June in 2011. The highest change of mean MDT value is 0.219m.

3.3. Observation the change of MDT surface on the East Sea between the other cycles

In this part, the change of MDT surface on the East Sea between the other cycles will be observed by using the different values at the points of the 81th cycle with other cycles. After that, we use the difference of MDT values between two consecutive cycles of these points.

Figure 3 shows the difference of MDT values between the cycle 83 and 84 of ENVISAT altimetry satellite.

From the Fig 3, we see that the MDT values on the East Sea change about decimeters between the 83th and 84th cycle, these values are the difference at individual points and cycles. In consequence, the mean sea surface changes regularly, the different points are unequally, and it is also different in the different time.

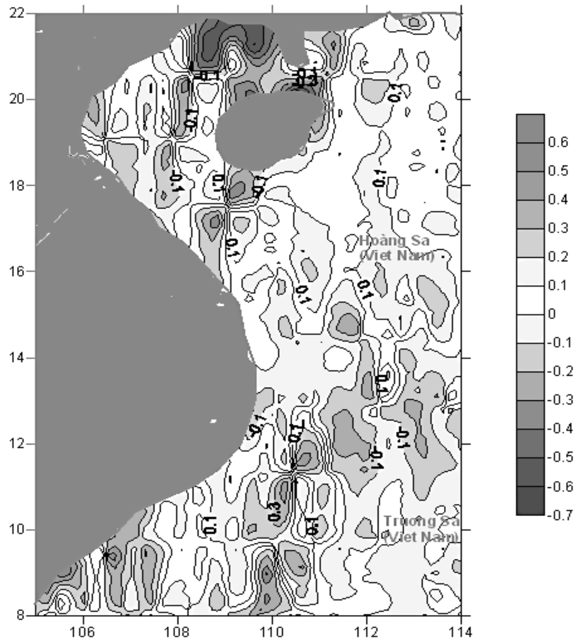

Fig 3. The different MDT values between cycle C84 and C83 of ENVISAT satellite

4. CONCLUSION

From the study result, we can show some following conclusions:

The mean dynamic topography on the East Sea change annually, the highest value in November and October, the lowest value in May and June. The change of average MDT value peaks 2.0 decimeters.

The mean dynamic topography always changes at other points. Gulf of Tonkin and coastal regions change more significantly than offshore regions.

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