Satellite altimetry data and DTU13MSS application in order to determine sea-surface anomaly on the East Sea

1. Introduction

In these current years, satellite altimetry is applied widely and effectively on the world. With satellite altimetry data, people can determine sea surface height, sea geoid, sea gravity anomaly, mean sea surface, sea level anomaly [Lee-Lueng Fu, Anny Cazenave, 2001]. In Vietnam, satellite altimetry has been applied for the researches about East Sea in these current years. There are a few number of researches. Some of them are the application of the foreign research, such as: application of mean dynamic topography model [Bui Cong Que, 2008][Bui Khac Luyen, Nguyen Van Sang, 2014], sea gravity anomaly model. Nearly years, some deeply researches about processing data of satellite altimetry on the East Sea, such as: determine crossover location, crossover adjustment, determine gravity anomaly[Nguyen Van Sang, 2012][Nguyen Van Sang, 2011][Nguyen Van Sang, 2013], determine mean dynamic topography [Nguyen Van Sang, Le Thi Thanh Tam, 2014]. Sea level anomaly is a difference between time-variable sea level and mean sea level. Determination of sea level anomaly will help for the researches of the sea level seasonal changes, climate researches on the ocean, the tide-race forecast and tide researches. The European Space Agency said that: if you knew the results of the sea level anomaly, you could determine the kinetic energy of the sea on The Mexico Bay; there had been the very high values in the 10 days before the hurricane Katrina appeared in 2005; when the tide at The Indian Ocean appeared on the 26 December 2014, the results of Jason-1 satellite observation (period 129) and ENVISAT satellite (period 352) – all set down the high value of the sea level anomaly. In this paper will present the determination of the sea level anomaly method and the experimental results on the East Sea with SARAL/ALTIKA data satellite.

2. Determination of sea level anomaly

Mean Sea Surface (MSS) was the point height between the mean sea level and Ellipsoid WGS-84 surface. Sea Surface Height (SSH) was the point height between the variable-sea level and Ellipsoid WGS-84 surface. The Sea Level Anomaly (SLA) was determined by the formula:

$$SLA = SSH - MSS \quad (1)$$

Nowadays, there are some mean sea level models, which was built in a type of grid, such as DNSC08MSS model, models DTU10MSS, DTU12MSS, DTU13MSS … The variable sea level was determined from the satellite altimetry data. These measured points were not coincided with nodes of grid in MSS models. So, determined SLA by the formula (1), have to interpolate the mean sea level of satellite altimetry points, which have been received from MSS model. Because SSH have been received at the measured time, SLA have been determined at this time, too. Ability to observe sea level anomalies (or real time) depend on the ability to provide satellite data. These have to order from the providing data centre .

A fundamental basis for estimating short and long-term changes in the sea surface is a reliable mean sea surface (MSS). Existing MSS models, derived from satellite radar altimetry, generally lack observations above 82 degrees latitude making high Arctic sea surface change estimates unreliable. Most current MSS models use ICESat data, geoid models, ocean circulation models, or a combination of these to extrapolate the MSS above 82 degrees latitude. This approach makes the MSS models unsuited for deriving sea surface anomalies from short-term observations like airborne campaigns (e.g. operation IceBridge). The new state of the art DTU13MSS is a global high-resolution MSS that includes retracked CryoSat-2 data and thereby extends the polar data coverage up to 88 degrees latitude. Furthermore, in the sea-ice covered areas, the SAR and SARin feature of the altimeter on-board CryoSat-2 increases the amount of useable observations dramatically compared to conventional altimeters like ENVISAT and ERS-1/2. Finally the continuous time-series, below 82 degrees latitude, has been extended to cover more than 20 years compared to the 17 years use for the DTU10MSS model. A comparison between DTU13MSS and DTU10MSS show an improvement of more than 20 cm between 82 and 88 degrees latitude. For the first time the three years of retracked CryoSat-2 data will, in combination with DTU13MSS, allow reliable estimation of the trend and annual variations in the high Arctic Ocean sea surface height. The DTU13 MSS was established using altimetry data spanning the 20 years after 1993 and includes combined observations of T/P, Jason-1 and Jason-2 series data, combined observations of ERS-1, ERS-2 and ENVISAT data, the Jason-1 geodetic mission observations, the SAR observations of Cryosat-2 in the polar region with a reference of the mean along-track SSH of T/P, Jason-1 and Jason-2 data between 1993 and 2012 after collinear adjustment, global coverage and spatial resolution of 1′ × 1′, and the EGM08 geoid height is used to fill the land area.

2.1. Interpolation the mean sea level for the satellite points by Colocation method

Guess at a researched area have n points, which has value of mean sea level MSS_i, with coordinates are (B_i, L_i), $i = 1, 2, ..., n$. $y^T = (MSS_1, MSS_2, ..., MSS_n)$ is height vector of the mean sea surface. Then, the height at mean sea surface of point P in the researched area was determined by the formula:

$$MSS_P = K_P^T K^{-1} y, \qquad (2)$$

While: K and K_P were covariance matrix

$$K = \begin{bmatrix} k_{11} & k_{12} & ... & k_{1n} \\ k_{21} & k_{22} & ... & k_{2n} \\ ... & ... & ... & ... \\ k_{n1} & k_{n2} & ... & k_{nn} \end{bmatrix}_{n,n}; \qquad \begin{matrix} k_{ij} = K(i, j) \\ i, j = 1, 2, ..., n; \end{matrix} \qquad (3)$$

$$K_P = \begin{bmatrix} k_{P_1} \\ k_{P_2} \\ \dots \\ k_{P_n} \end{bmatrix}; \quad k_{P_i} = K(P,i); \quad i = 1,2,...,n. \tag{4}$$

$K(i,j)$ and $K(P,i)$ were covariance matrix of heights at mean sea level.

The fact that, input values were the heights at mean sea surface, usually did not ensure a condition $MSS_{TB} = \sum_{i=1}^{n} MSS_i = 0$ and did not satisfy conditions of Colocation tasks. So, input data needed to be removed average value before interpolated. Therefore, interpolation the mean sea surface has been done by these steps:

1. Remove the average value MSS_{ave} from the input data as the mean sea surface height.
2. Take the covariance matrix K from its input data – covariance function $K(l)$
3. Determine the mean sea level $MSS_p$for each point P in the researched area.
4. Restore the average value MSS_{ave} for interpolation points.

When interpolated by the Colocation method, needed to inverse a square matrix, which had size of the input data points. If the number of input points was high, then it would have many difficulty in the calculated process. Otherwise, interpolation value of P had been depended on nearly points (node points). The further distance of node interpolation points, the lower influence to interpolation value of point P. Therefore, interpolation of the mean sea surface height needn't use all of n points in the researched area, just need use m points (m<n) in the R radius around point P. Follow [NguyenVanSang,Vu Trung Thanh, 2015], we can choose R= $0,5^0$. So, the number of hidden values in the standard equation was lower, but at each interpolation points needed to inverse one matrix, which has size is the number of points in the circle radius R.

2.2. Determine values of experimental covariance function of the mean sea surface heights and make it suitable with the theory function

Determination of values k in the covariance matrix K and Kp need to be done with determining of values of experimental covariance matrix. With the mean sea surface, experimental covariance matrix were determined by the formula:

$$
\begin{cases}
K(0) = \dfrac{1}{n_0}\sum_{i=1}^{n_0} MSS_i^2 \\
K(1.\Delta l) = \dfrac{1}{n_1}\sum_{m=1}^{n_1} MSS_i.MSS_j \\
K(2.\Delta l) = \dfrac{1}{n_2}\sum_{m=1}^{n_2} MSS_i.MSS_j \\
\quad \ldots \\
K(k.\Delta l) = \dfrac{1}{n_k}\sum_{m=1}^{n_k} MSS_i.MSS_j \\
\quad \ldots \\
K(p.\Delta l) = \dfrac{1}{n_p}\sum_{m=1}^{n_p} MSS_i.MSS_j
\end{cases}
\tag{5}
$$

With condition: $k.\Delta l - \dfrac{\Delta l}{2} < |l_{ij}| \le k.\Delta l + \dfrac{\Delta l}{2}$, (6)

Where

l_{ij} – distance between two points i and j

Δl- the nearest distance between points, in this issue, it is the nearest distance between node points. With MSS model, size 1’ x 1’, choose $\Delta l = 1'$; p – positive natural numbers, depended on a width of the researched area.

$R = 0.5^0$ could choose p = 10

$n_k (k = 1,2 \ldots p)$ – the number of pairs of points i and j, satisfy the condition (6)

n_0 - the numbers of points, which have had mean sea surface height in the researched area.

Condition (6) was described on a figure 1. From this, experimental covariance values were calculated by formula (5), just used j points in a cross section.

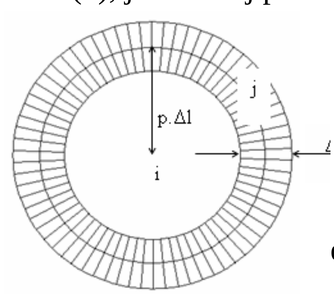

Figure 1. Scheme points, used for calculating experimental covariance values.

After receiving the experimental covariance values, parameters of the theory covariance function were calculated by coinciding the values of the theory and experimental covariance functions with principle of least squares. The theory covariance functions may be chosen by Maxkov or Gaussian.

3. Experimental results:

On the base of theory above, we calculated the sea level anomaly, and used data, which have been measured on the East Sea. (latitude from 8^0 to 22^0, longitude from 105^0 to 114^0). MSS model was DTU13MSS, which was set up by Denmark cosmos Centre. Satellite altimetry data was SARAL/ALTIKA satellite data, period 18 (working from 30th Oct. 2014 to 06 Nov. 2014). Data were provided by AVISO [AVISO,2010].

Mean sea level height DTU13MSS and sea level height, measured by satellite SARAL/ALTIKA on the East Sea.

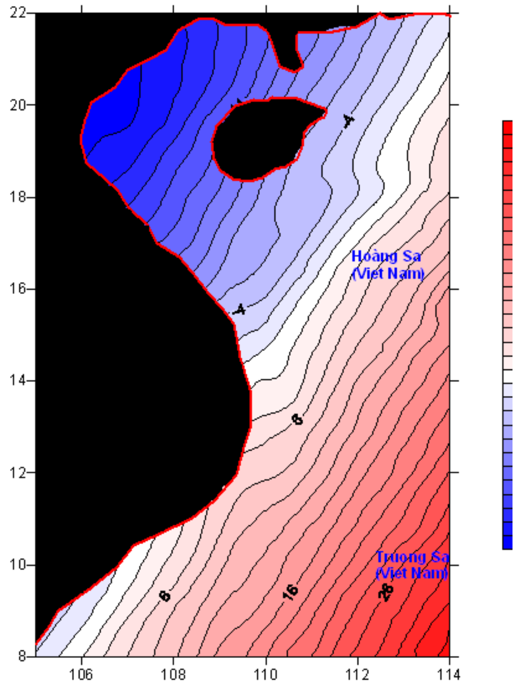

Figure 2: Mean sea level height on the East Sea from DTU13MSS model

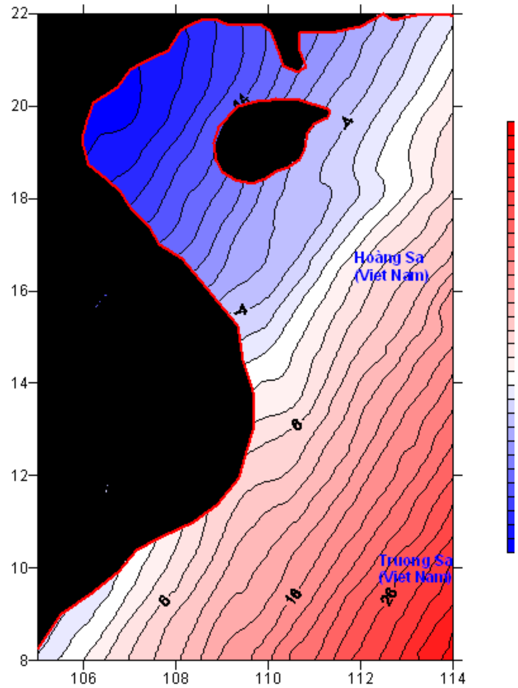

Figure 3: Sea surface height – have been determined from satellite altimetry SARAL/ALTIKA, period 18.

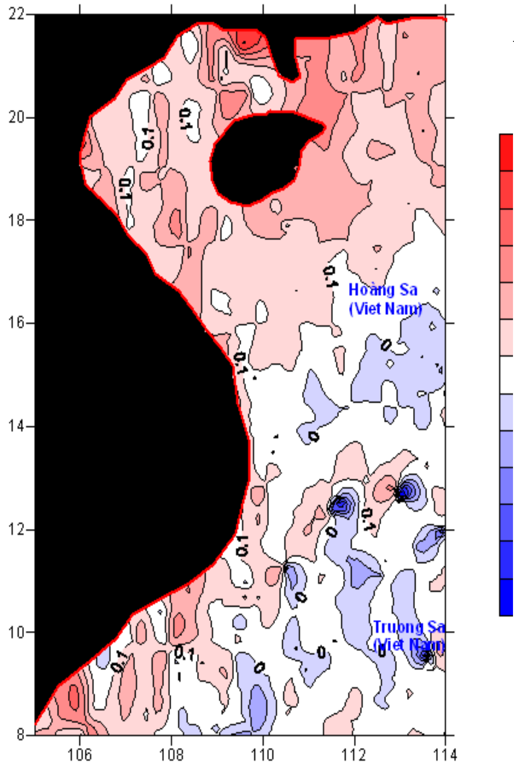

Figure 4: sea level anomaly – have been determined from DTU13MSS model and satellite altimetry data SARAL/ALTIKA, period 18 on The East Sea.

On the figure 4, SLA have been determined on The East Sea from satellite altimetry data SARAL/ALTIKA period 18 and mean sea surface model DTU13MSS, with satistics: SLA value was minimum at -1.581 m, SLA value was maximum at 0.649 m, and its average value was 0.108 m.

4. Conclude:

SLA on The East Sea could be determined from mean sea surface MSS and satellite altimetry data. For SARAL/ALTIKA data at period 18 and the mean sea surface model DTU13MSS, SLA changed its values from -1.581 m to 0.649 m, average value was 0.108 m.

Interpolated sea surface height for satellite altimetry points, could use Colocation method. To decrease the calculated quantity, when interpolate the mean sea surface height for 1 point, just use data in the circle radius $R=0.5^0$, needn't use all the data in the researched area.

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