Determination of Marine Gravity Anomalies in the Truong Sa Archipelago's Sea Territory Using Satellite Altimeter Data

NGUYEN Van Sang, VU Van Tri, PHAM Van Tuyen, Vietnam

Keywords: Marine gravity anomalies; Satellite altimetry; Least Squares Collocation; Truong Sa archipelago's territory.

SUMMARY

The purpose of this study is to determine the gravity anomalies on the sea within the Truong Sa archipelago's territory from satellite altimeter data. To accomplish the proposal, the authors have collected and analyzed the satellite altimeter data to propose a satellite altimeter-based gravity anomalies determination procedure. An experiment was then conducted in the Truong Sa archipelago (within the geographic coordinates 6.5°N to 12°N and 112°E to 117.5°E) to evaluate the robustness of the procedure. The experimental results were validated by comparing with the in-situ ship-measured gravity data. Results show that, in order to determine the gravity anomalies from satellite altimeter data, the following steps: (1) the removal of the long-wavelength geoid height using the Global Earth Geopotential Models; (2) the removal of the mean dynamic topography; (3) the removal of the time-varying sea surface topography; (4) the calculation of the residual gravity anomalies emerged from the collocation method; (5) the long-wavelength gravity anomalies restoration by the Global Earth Geopotential Models, must be done. The experimental calculations were done for the study area with 52 cycles of Cryosat-2 satellite (from the 31st cycle to the 82st cycle). These marine gravity anomalies are also compared to 625 points of ship-measured gravity. The comparison shows that, the standard deviation between the Cryosat-2 satellite-derived gravity anomalies and ship-measured gravity anomalies is +/- 0.67 mGal.

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1. INTRODUCTION

The latest advances and developments of growing satellite altimetric technology offer numerous applications in the fields of Geodesy, Geophysics, Oceanography, Meteorology, and Environment. A number of studies have been done to determine marine gravity anomalies from satellite altimeter data with improving accuracy and increasing spatial resolution. Hwang and Parsons (1995) determined the marine gravity anomalies using the combination of Seasat, Geosat/ERM, ERS-1, and TOPEX/POSEIDON altimeter data and ship-measured gravity over the Reykjanes Ridge, and obtained the marine gravity anomaly estimation accuracy of ± 5.76 mGal (*Hwang C. and B. Parsons, 1995*). In 2002, Hwang *et al.* used Seasat, Geosat, ERS-1, TOPEX/POSEIDON (T/P), and ERS-2 to determine global marine gravity anomalies with a resolution of 2' x 2' (*Hwang, C., H. Y. Hsu, and R. J. Jang, 2002*). The results were compared with ship-measured gravity data of 12 regions and obtained accuracy from ± 3.057 mGal to ± 13.365 mGal; In 2010, Andersen *et al.* used Geosat, ERS-1, ERS2, T/P, Jason-1, Envisat, GFO, and ICEsat altimeter data to determine the marine gravity anomalies in order to build the global gravity field model DNSC08GRA with a resolution of 1' x 1' grid (*Andersen, O.B., P. Knudsen, and P.A. Berry, 2010*). The results were compared with the 321,400 points ship-measured gravity on the Northwest Atlantic Ocean, standard deviation is ±3.91 mGal. In 2010, Andersen built the global gravity field model DTU10GRAV by upgrading the DNSC08GRAV model, with the addition of new ERS-1, ENVISAT altimeter data and improves the accuracy of the calibrations as well as geophysical, altimeter range (*Andersen, O.B., 2010*). The results of marine gravity anomalies from the DTU10GRAV model were compared with the 321,400 points ship-measured gravity on the Northwest Atlantic Ocean, obtaining the standard deviation of ±3.82 mGal. In 2016, Andersen and Knudsen built the global gravity field model DTU15GRAV based on five-year retracked altimetry data from Cryosat-2 as well as data from the Jason-2 EOL geodetic missions (*Andersen, O.B. and P. Knudsen, 2016*). The results of marine gravity anomalies from the DTU15GRAV model are compared with 54,000 points of ship-measured gravity collected by Australian Geoscience in 2009. The accuracy of altimetric Gravity calculation is 1÷1.5 mGal, and the standard deviation is ±1.81 mGal. Another study conducted by Zhang *et al.* used Geosat, ERS-1, Envisat, Jason-1, Cryosat-2 and SARAL/Altika altimeter data to determine marine gravity anomalies with a spatial resolution of 1' x 1' (*Zhang, S., et al., 2017*). The results were compared with ship-measured gravity of the National Geophysical Data Center (NGDC) survey. Root mean square gain as follows: off-shore southern coast of Taiwan (±5.22 mGal); the vicinity of Philippine’s islands (±8.279 mGal).

In Vietnam, there are limited studies that use the satellite altimeter data to determine the marine gravity anomalies. Bui *et al*. combined gravity measured from Gagarinsky and Atlante ships with marine gravity anomalies calculated from satellites altimeter data to establish the Burger gravity anomaly map of Vietnam and vicinity at the scale of 1:1.000.000. The accuracy of the satellite-based gravity anomalies determination is ±8.5 mGal compared to ship-measured gravity (*Cong Que, B., et al., 2008*); In 2012, Nguyen determined marine gravity anomalies from the combination of ENVISAT altimeter data and ship-measured gravity near the shores and on islands in the East Sea area with an accuracy of about ±6 mGal (*Van Sang, N., 2012*).

In this paper, we focus on the establishing a satellites altimeter-based gravity anomaly determination method and its application in defining gravity anomalies in the sea territory of the Truong Sa archipelago using Cryosat-2 satellite altimeter data. This study a part of a board-class project funded by the Ministry of Ministry of Education and Training, the code B2016-MDA-11ĐT.

2. THE METHOD OF DETERMINING THE GRAVITY ANOMALY FROM SATELLITE ALTIMETER DATA IN THE TRUONG SA ARCHIPELAGO'S SEA TERRITORY

2.1. Study area and Data

2.1.1. Study areas

Experimental areas are geographically situated within the Truong Sa archipelago's territory (Figure 1) and is located between 6°30'N and 12°00'N in latitude and 112°00'E and 117°30'E in longitude.

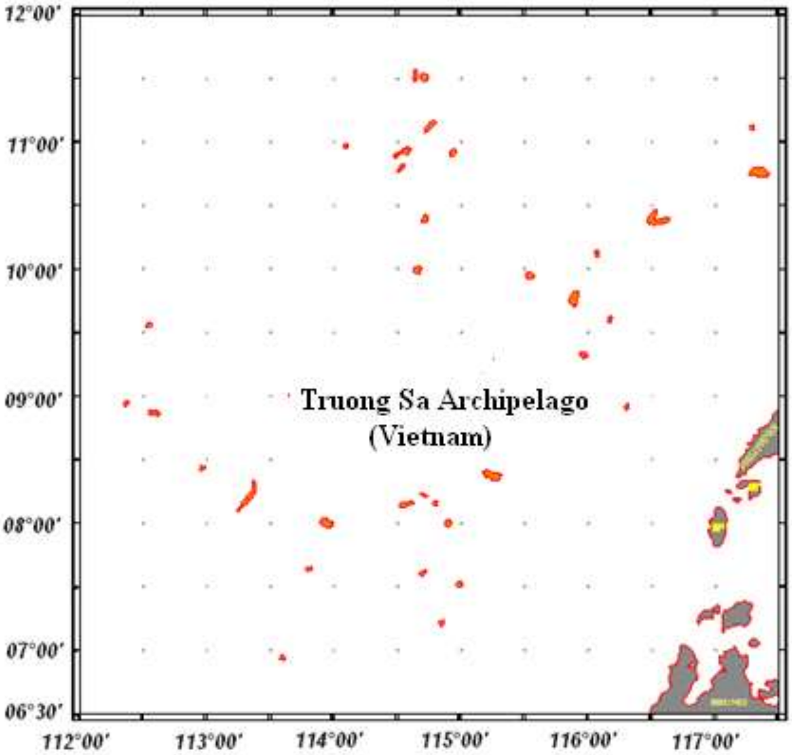

Figure 1. The experimental area

2.1.2. Satellite data

Cryosat-2 satellite altimeter data were collected and used to determine gravity anomalies in in the area. It includes 52 cycles and is measured from October 4, 2010 to September 15, 2016. The data were provided by the European Space Agency (ESA). The boundary of the data is 30' larger than the experimental area on the sides. There are 72,483 points in the area, of which the sea surface height were measured by Cryosat-2 satellite altimetry. The distribution of cryosat-2 satellite altimeter data is shown in Figure 2 with a spatial resolution of 3' x 3'.

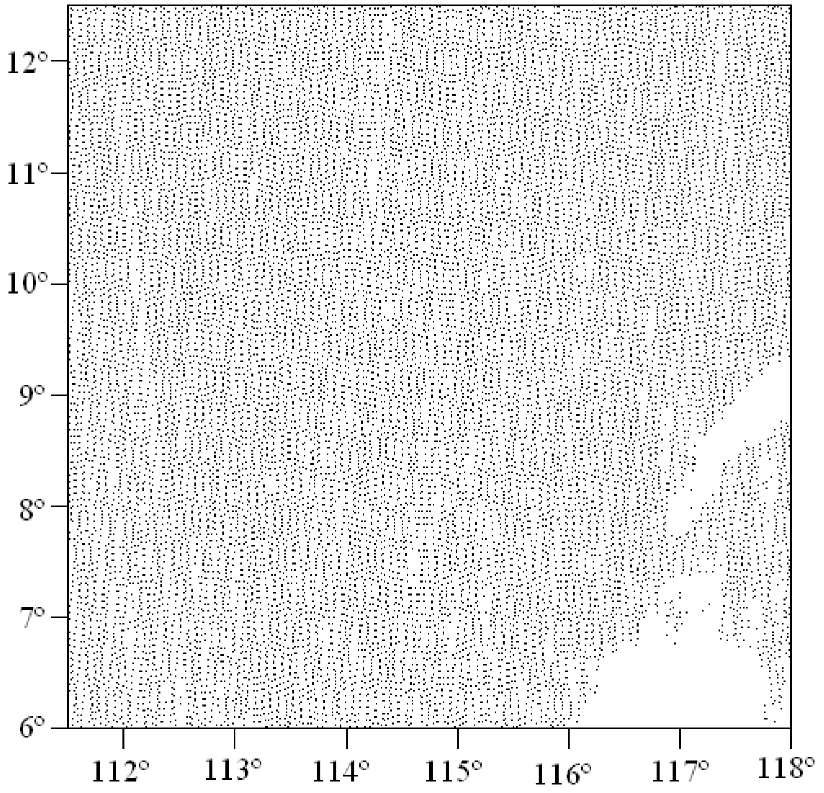

Figure 2. The distribution of cryosat-2 satellite altimeter observation points

2.1.3. The ship-measured gravity data

To interpret the results of satellite-derived gravity anomalies, we used the ship-measured gravity data which were made in 1987, 1990, and 1992 under the collaboration project between Vietnam and Russia and between Vietnam and France. The data have high reliability, very clear parameters, and accuracy of ±0.5 mGal (*Cong Que, B., et al., 2008*). This data are geo-referenced to the international coordinate system WGS-84. However, the measurements were mainly done in the western region of the study area, only 625 observation points were measured within the boundary of the study area (Figure 3).

2.2. The method of determining the marine gravity anomalies from the satellite altimeter data

Sea surface height is calculated through a geoid height (*N*) and dynamic topography (h_d) using the following formula:

$$SSH = N + h_d \quad (1)$$

Dynamic topography is divided into 2 parts: the mean dynamic topography (h_{MDT}) and the time-varying sea surface topography (h_t) (*Van Tri V., Van Sang N., et al., 2017*). Meanwhile, sea surface heights are represented by the formula:

$$SSH = N + h_{MDT} + h_t \quad (2)$$

Geoid height was also divided into 2 components: the long-wavelength geoid height (N_{EGM}) and the residual geoid height. Hence, the formula (2) is re-written as:

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

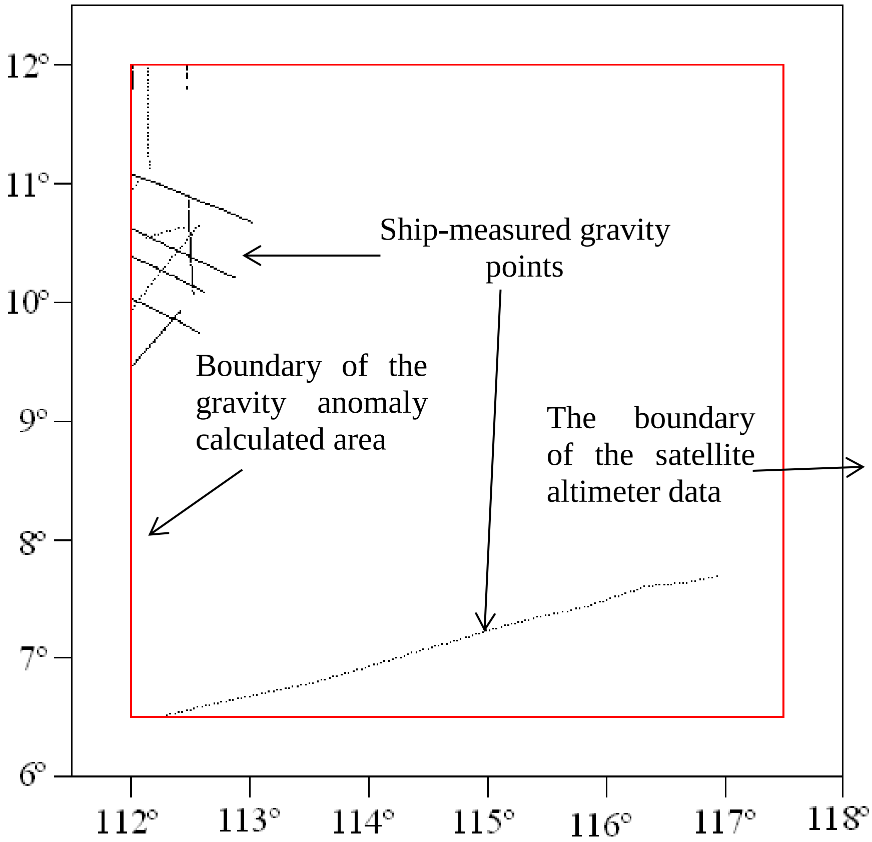

Figure 3. Distribution of ship-measured gravity points in the experimental area

From formula (3), to determine the residual geoid height from satellite altimeter data, we needs to firstremove the long-wavelength geoid height (N_{EGM}) from the spherical harmonic coefficients ($\bar{C}_{n,m}, \bar{S}_{n,m}$) of the global Geopotential models by the "remove-restore" technique, then remove the global mean dynamic topography h_{MDT}, and finally remove the time-varying sea surface topography (h_t) by the crossover adjustment method.

From the residual geoid height, using least-squares collocation method to determine residual gravity anomalies. And then, using the global Geopotential models to restore the long-wavelength gravity anomalies (Δg_{EGM}) by the "remove-restore" technique. The final results will be the gravity anomalies Δg. The residual gravity anomalies (Δg_{res}) are the difference between gravity anomalies (Δg) and the long-wavelength gravity anomalies (Δg_{EGM}) computed from the global Geopotential models. This relationship is represented by the following formula:

$$\Delta g_{res} = \Delta g - \Delta g_{EGM} \tag{4}$$

The interpolation of residual gravity anomalies from the residual geoid height were done in the similar way as the interpolation of the gravity anomalies from the geoid height, but reduce the influence of the far region data to get more accurate results. The flowchart of the determination of marine gravity anomalies from the satellite altimeter data is illustrated in Figure 4.

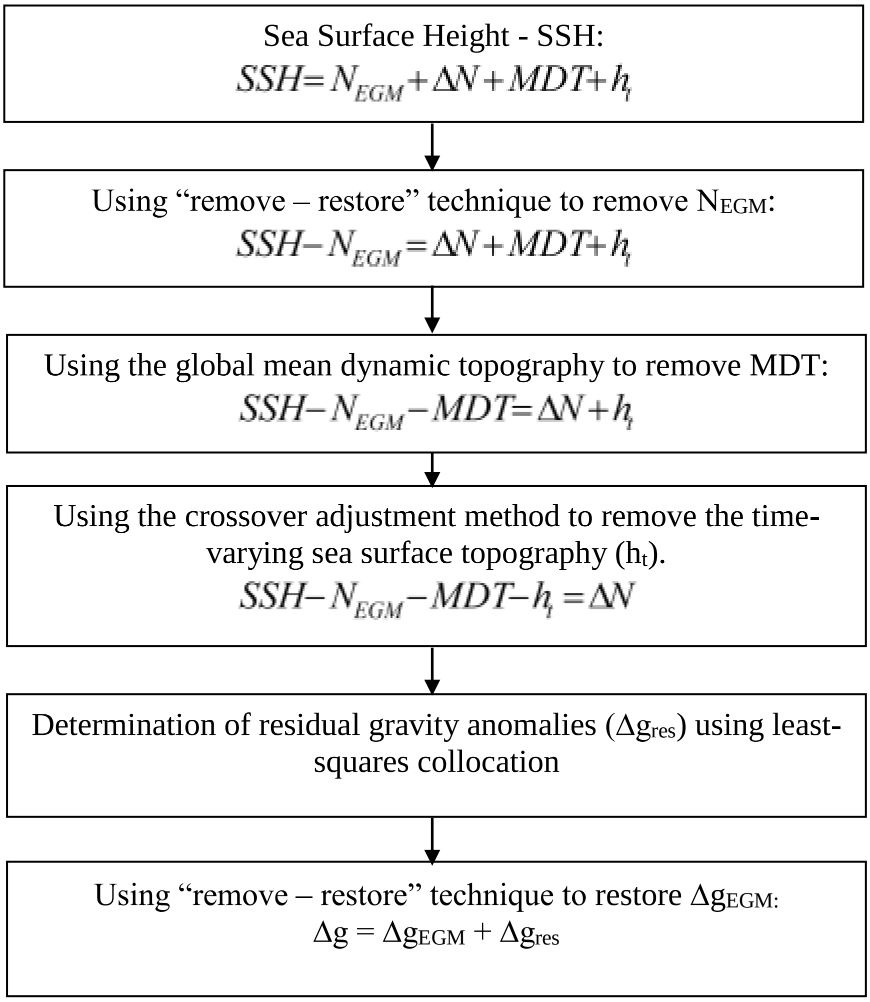

Figure 4. The flowchart of the determination of marine gravity anomalies from the satellite altimeter data

3. RESULTS AND DISCUSSION

On the basis of the theory presented above, we have conducted empirical calculations for the study area (latitude: from 6°30' to 12°00'; longitude: from 112°00' to 117°30') with the Cryosat-2 satellite altimeter data. The "remove – restore" technique was applied to remove the long-wavelength geoid height (N_{EGM}) from the global Geopotential model (EGM2008). The global mean dynamic topography (DTU13MDT) of the Technical University of Denmark was then used to remove MDT. After using the crossover adjustment method to remove the time-varying sea surface topography (h_t), the residual geoid height map is presented in Figure 4.

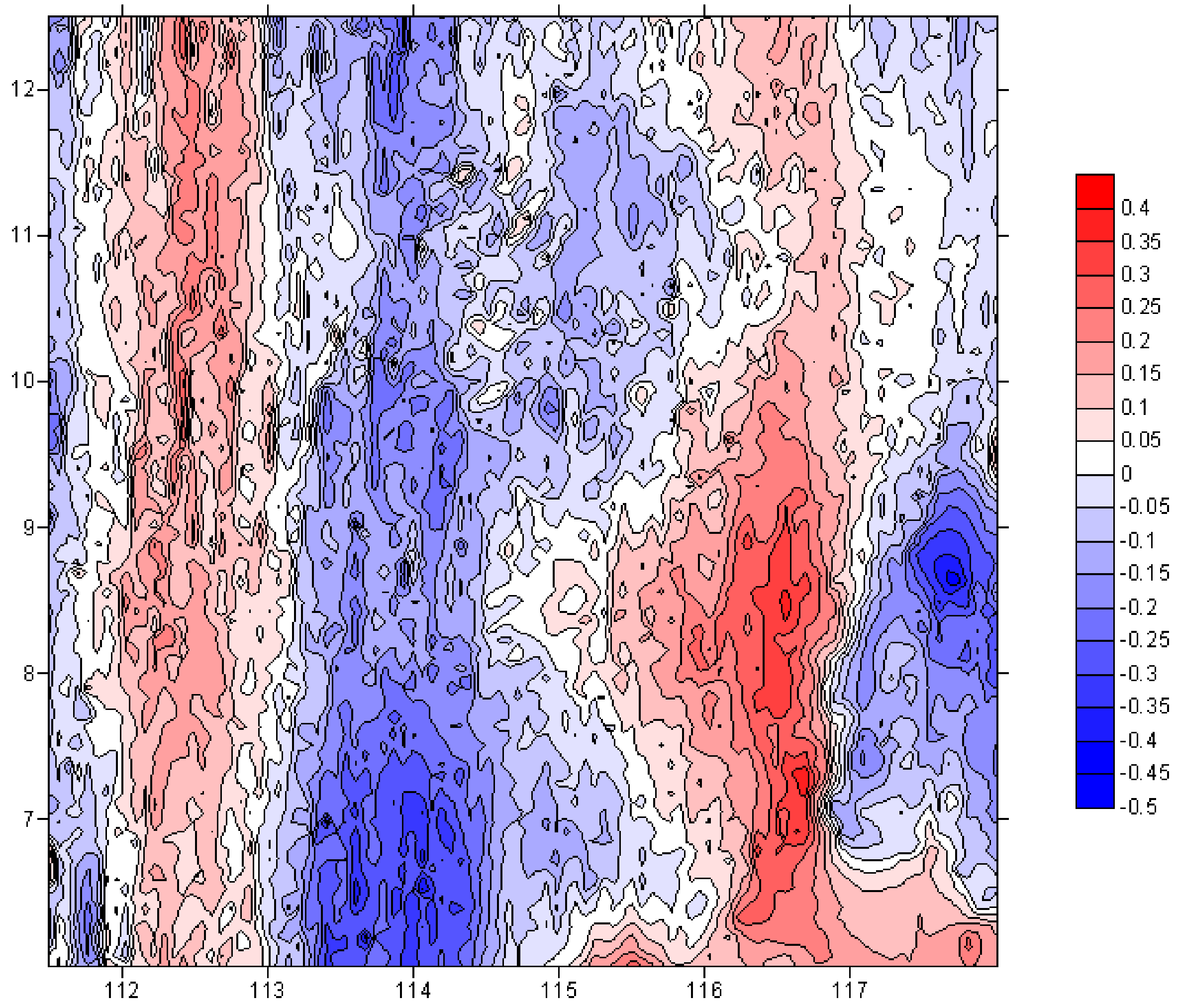

Figure 5. The residual geoid heights (ΔN)

As a result, the calculated gravity anomalies are as follows: a resolution of 3' x 3' grid, the total score of 12,321 points, the gravity anomalies with the maximum, minimum, and averaged values of +135.44 mGal, -64.11mGal, and 18.11 mGal, respectively. Gravity anomaly map is presented in Figure 6.

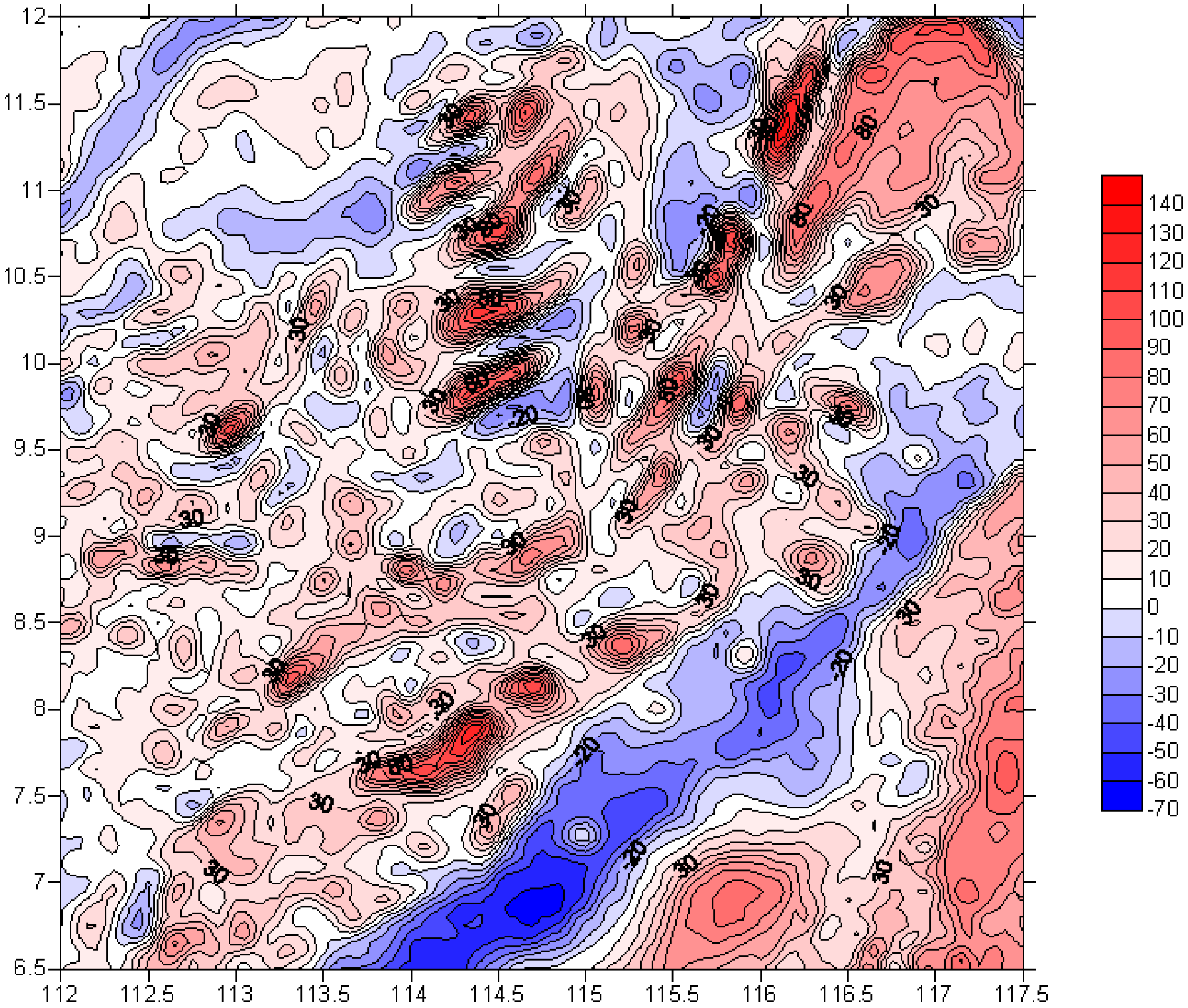

Figure 6. Marine gravity anomalies determined from Cryosat-2 altimeter data

3.1. Accuracy assessment of the results by comparing with a ship-measured gravity points

To assess the accuracy of the satellite-derived marine gravity anomalies, we compared the results with the in-situ gravity of 625 points measured on a ship and the comparison statistics are as follows:

The maximum deviation: +1.30 mGal
The minimum deviation: -1.82 mGal
The average deviation: +0.03 mGal

The Standard deviation between the satellite-derived gravity anomalies and ship-measured gravity anomalies are ±0.67 mGal. In Figure 7, the line graph indicates the frequency of occurrence of the deviation.

The comparison also shows that the marine gravity anomalies determined from satellite altimeter data match well with the ship-measured gravity with very small deviations. Small average deviations (0.03 mGal) demonstrates no systemic error between the satellite-derived gravity anomalies and ship-measured gravity anomalies. The trend deviations follow the standard distribution, random nature of the deviation. The accuracy of gravity anomalies in the study area (with the evaluation of 625 measuring points) reaches at ±0.67 mGal.

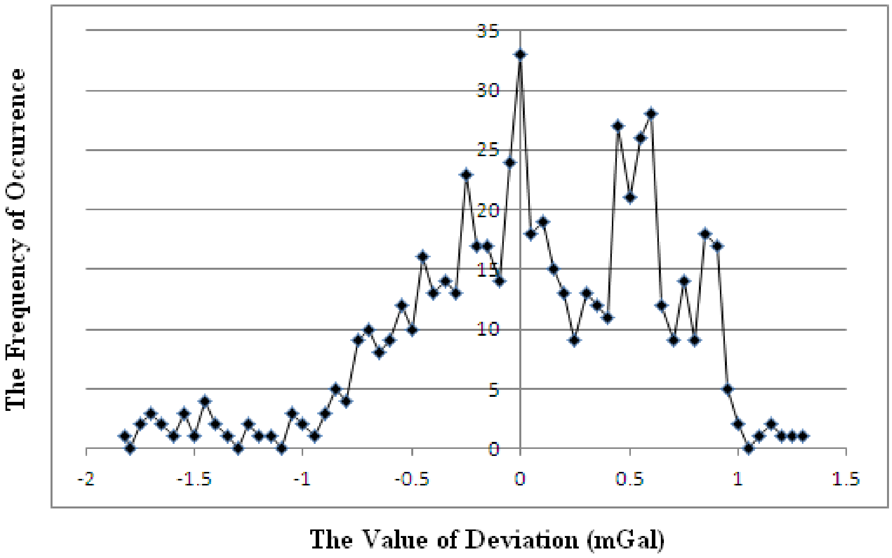

Figure 7. The frequency of occurrence of the deviation

4. CONCLUSION AND RECOMMENDATIONS

– From the the satellite altimeter data, we can calculate the marine gravity anomaly under process as shown in Figure 4. This determination process is built based on the analyses of the components of the satellite altimeter data with a least-squares collocation method.

– The marine gravity anomalies on the sea within the Truong Sa archipelago’s territory are determined from Cryosat-2 satellite altimeter data achieves accuracy of ± 0.67 mGal when compared with 625-point ship-measured gravity.

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BIOGRAPHICAL NOTES

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