Optimization of global gravitational potential models with detailed gravity anomalies in Southern Vietnam

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Tối ưu hóa các mô hình thế trọng trường toàn cầu với các dị thường trọng lực chi tiết ở miền Nam Việt Nam

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ABSTRACT

This study evaluates the accuracy of several global gravity field models, specifically EGM 2008, EICGEN-6C4, SGG-UGM-1, SGG-UGM-2, and GECO, using detailed gravity anomaly data from 1968 points in the southern plains of Vietnam. The evaluation process followed a rigorous methodology to ensure precision. Results indicate that these models exhibit similar accuracy levels in the experimental area, with a mean error of approximately 6.2 mGal. Among them, The SGG-UGM-2 model, demonstrated the highest precision, with a fluctuation range of -29.2425 to +74.9010 mGal. These newer generation models, which incorporate additional satellite data, offer enhanced reliability compared to the EGM2008 model. The fluctuation ranges for other models also varied: EGM 2008 from -29.8662 to +82.2140 mGal, EIGEN-6C4 from -28.3626 to +74.2292 mGal, SGG-UGM-1 from -28.9500 to +75.5315 mGal, and GECO from -30.5641 to +73.6775 mGal. This research highlights the critical importance of accurate gravity field models for various applications, including geodesy, geophysics, natural disaster management, resource exploration, and military operations. The methodologies employed for accuracy assessment are adaptable to other regions with similar datasets, underscoring the significance of precise geophysical measurements in Vietnam's diverse geographic landscape. The findings support the essential role of gravity anomaly data in understanding Earth's physical properties and emphasize the need for continued evaluation across different regions in Vietnam to establish comprehensive applicability. This research paves the way for advanced studies and practical applications, contributing to a deeper understanding of Earth's physical properties.

Keywords:
Accuracy Evaluation, Global Gravity Field Models, Gravity Anomaly, SGG-UGM-2 Model, Southern Vietnam.

TÓM TẮT

Nghiên cứu này đánh giá tính chính xác của một số mô hình trường trọng lực toàn cầu, cụ thể là EGM 2008, EICGEN-6C4, SGG-UGM-1, SGG-UGM-2 và GECO khi sử dụng dữ liệu từ 1968 điểm dị thường trọng lực chi tiết ở miền Nam Việt Nam. Kết quả cho thấy các mô hình này có mức độ chính xác tương tự trong khu vực thử nghiệm, với sai số bình phương trung bình khoảng ±6.2 mGal. Đặc biệt, mô hình SGG-UGM-2 thể hiện độ chính xác cao nhất, với phạm vi dao động từ -29.2425 đến +74.9010 mGal. Các mô hình thế hệ mới được tích hợp thêm dữ liệu vệ tinh, có độ chính xác cao hơn mô hình EGM2008. Phạm vi dao động của các mô hình khác cũng khác nhau: EGM 2008 từ -29.8662 đến +82.2140 mGal, EIGEN-6C4 từ -28.3626 đến +74.2292 mGal, SGG-UGM-1 từ -28.9500 đến +75.5315 mGal và GECO từ -30.5641 đến +73.6775 mGal. Nghiên cứu này nhấn mạnh tầm quan trọng của các mô hình trường trọng lực chính xác trong các ứng dụng như đo đạc địa hình, địa vật lý, quản lý thiên tai, thăm dò tài nguyên và hoạt động quân sự. Phương pháp đánh giá độ chính xác có thể áp dụng cho các khu vực với dữ liệu tương tự, nhấn mạnh nhu cầu đánh giá liên tục tại các khu vực khác nhau ở Việt Nam để thiết lập tính ứng dụng toàn diện. Kết quả đã nêu vai trò thiết yếu của dữ liệu dị thường trọng lực trong việc tìm hiểu các thuộc tính vật lý của Trái đất, cho nghiên cứu và ứng dụng thực tiễn nâng cao.

Từ khóa:
Dị thường trọng lực, Đánh giá độ chính xác, Miền Nam Việt Nam, Mô hình SGG-UGM-2, Mô hình trường trọng lực toàn cầu.

1. INTRODUCTION

Vietnam is a country shaped from North to South in an "S" shape. Due to this specific shape, the requirements for measuring and surveying the geophysical field, including the gravity field, throughout Vietnam, especially in the South, are always important and urgent tasks. These tasks serve the development of geophysical fields, economic development, natural disaster prevention, natural resource and environment management, and the assurance of security and defense.

For geodesy, gravity anomaly data is used to study the shape, size, and gravitational potential of the Earth and establish original data for the national coordinate system. For geophysics, gravity anomaly data is used to analyze material structures in the ground and the Earth's crust, contributing to the exploration of mineral resources. For the military, gravity anomaly data is also meaningful in determining the trajectory of ballistic missiles [1, 2].

In 2003, stemming from the need to access information about global gravity models, the German GFZ Geoscience Research Center (GFZ) supported the establishment of the International Center for Global Earth Modeling (ICGEM). ICGEM was originally established to collect static global gravity field models and provide users with easy access to these models. Currently, many Global Gravity Field Models (GGF) are published by international organizations. The later models often have higher accuracy than the previously published models on a global scale. The most representative models among them are the EGM 2008, EIGEN-6C4, SGG-UGM-1, SGG-UGM-2, and GECO models. From the Internet or from GGF files, we can easily exploit the gravity anomaly, height anomaly, plumb line deviation, and gravitational potential of any point on the territory when we know the B, L coordinates of that point [3,4,5].

Between 2003 and 2011, with the strong development of absolute gravity measuring technology that allows measuring gravity with very high accuracy at ± 1-5 $mGal$, countries can build their own systems. High precision gravity without the need to connect to the international gravity system. Grasping that trend, Vietnam has built and completed the national gravity system including 11 base gravity points, including 4 old points, 31 class I gravity points, and 106 satellite gravity points. Basic gravity points and class I gravity points are measured with a Russian GBL absolute gravity meter with an accuracy of ±5 $mGal$, some class I points have an accuracy of ± (10-14) *mGal*. Satellite gravity points are measured by the American ZLS relative gravity machine with edge error < ±0.03 *mGal* (each base gravity point has 04 satellite points, each class I gravity point has 02 satellite points). Build a gravity grid of 548 points with an edge measurement accuracy of ± 0.088 *mGal* and the weakest point error of 0.078 *mGal*; Construction of Vinh Yen - Tam Dao gravity bottom road and City. Ho Chi Minh - Vung Tau with a total of 15 points, edge error ≤ ± 0.02 *mGal* [3, 4].

Once gravity measurement points have been established, these points will be integrated into global gravity potential models to enhance their accuracy for interpolating gravity points in Vietnam. Building on this foundation, the study will assess the precision of contemporary gravitational potential models using actual gravity measurement data from Vietnam.

2. RESEARCH METHODS

To evaluate the accuracy of the global gravity field model, the measured gravity anomaly value and the corresponding gravity anomaly value exploited from the global gravity field model must be in the same reference coordinate system. The global gravity anomaly values can be easily exploited in [9]. Measured gravity anomaly values will be converted from measured gravity values.

2.1. Determine gravity anomalies at detailed points

According to the ideas set forth in the classical theory of Molodensky, the gravity anomaly is the difference between the value of gravity g_M at point M on the earth's surface and the normal value of gravity γ_N at point N on the surface of the Telluroid.

$$\Delta g = g_M - \gamma_N ; \quad (1)$$

g_M - gravity at point M on the earth's surface;

γ_N : normal gravity on Telluroid.

where, γ_N : calculated using expression.

$$\gamma_N = \gamma_{N_0} - \frac{\partial \gamma}{\partial h}.H_M^\gamma ; \quad (2)$$

γ_{N_0} : normal value of gravity on the surface of the Ellipsoid;

$\frac{\partial \gamma}{\partial h}$: vertical gradient of normal gravity;

H_M^γ : normal height at point M.

The height between the Telluroid and the Ellipsoid is determined by the expression [80].

$$H_M^\gamma = \frac{C}{\gamma_{N_0}}\left[1+(1+\alpha+m-2\alpha\sin^2\varphi)\left(\frac{C}{a\gamma_{N_0}}\right)^2\right] \quad (3)$$

α : Polar compression of the ellipsoid;

a : Major axle

$$m = \frac{\omega^2 a}{\gamma_0} \quad (4)$$

$$C = \int_0^M g dh \quad (5)$$

According to [4], the anomaly in free air is determined by the expression.

$$\Delta g_o = g_{M_o} - \gamma_{N_o} \quad (6)$$

Δg_0 : gravity anomalies in free air.

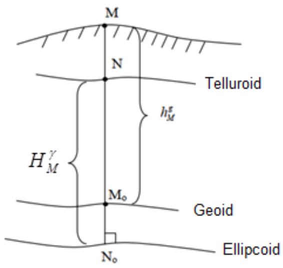


Figure 1. Geoid surface

As we know:

$$\lambda = \frac{2\pi}{n_{\max}} \quad (7)$$

$n_{\max}$ The highest level and class of the global gravity model.

From (2) and (6):

$$\Delta g_o = g_M - \gamma_{N_o} + \frac{\delta\gamma}{\delta h} H_M^\gamma \quad (8)$$

Assuming that the Earth is a homogeneous sphere, the quantity.

$\frac{\partial \gamma}{\partial h} \approx \frac{\partial g}{\partial h} = 0.3086\left(\frac{mgal}{m}\right)$ and $h_M^\gamma \approx h_M^g$,

From (7) and (8) we can be done $\Delta g \approx \Delta g_0$

According to [4], expression (8) is rewritten

$$\gamma_{N_0} = 978032.5(1+0.0053024\sin^2 B - 0.0000058\sin^2 2B) \quad (9)$$

$$\begin{aligned}\frac{\partial g}{\partial h} H_M^\gamma &= 0.308562(1+0.0007\cos 2B)H_M^\gamma - 0.07213.10^{-6}(H_M^\gamma)^2 \\ &-(0.8658-9,727.10^{-5}H_M^\gamma + 3.482.10^{-9}(H_M^\gamma)^2)\end{aligned} \quad (10)$$

So from formula 10 we can determine the gravity anomaly of detailed measurement points We rewrite formula (8).

$$\begin{aligned}\Delta g_o &= g_M - \left(978032.5(1+0.0053024\sin^2 B - 0.0000058\sin^2 2B)\right) + \\ &+\begin{pmatrix}0.308562(1+0.0007\cos 2B)H_M^\gamma - 0.07213.10^{-6}(H_M^\gamma)^2 \\ -(0.8658-9,727.10^{-5}H_M^\gamma + 3,482.10^{-9}(H_M^\gamma)^2)\end{pmatrix}\end{aligned} \quad (11)$$

Δg_0 : gravity anomalies in free air; H_M^γ : normal height at point M.

2.3. Methods

To evaluate the accuracy of the global gravity field model, we compare the measured gravity anomaly value (according to formula 10) and the corresponding gravity anomaly value exploited from the global gravity field model bridge.

$$\Delta g = \Delta g_o - \Delta g_M \qquad (12)$$

where,

Δg : difference between gravity anomalies in free air and gravity anomalies in global Earth gravity models;

Δg_0 : gravity anomalies in free air;

Δg_M : gravity anomalies in global Earth gravity models.

From the gravity anomaly deviation values, calculate the average gravity anomaly deviation according to the formula:

$$\Delta g_{aver} = \frac{1}{n}\sum_{n}^{1} \Delta g_i \qquad (13)$$

Calculate the difference value between the gravity anomaly deviation and the average gravity deviation anomaly of the points (symbolized as $\delta\Delta g_i$) according to the following formula:

$$\delta\Delta g_i = \Delta g_i - \Delta g_{aver} \qquad (14)$$

The mean square error of the data series is calculated according to the formula:

$$m = \pm\sqrt{\frac{[\delta\Delta g \delta\Delta g}{n-1}} \qquad (15)$$

3. RESULTS AND DISCUSSION

3.1. Experimental area

Southern Vietnam is located between 8°30' and 12°20' North latitude and between 104°30' and 107°30' East longitude. This area includes 19 provinces and cities, notably Ho Chi Minh City, Dong Nai, Binh Duong, Ba Ria-Vung Tau, and the Mekong Delta provinces such as Can Tho, An Giang, Dong Thap, and Kien Giang. The South has a strategic geographical location, bordering Cambodia to the Northwest, the East Sea to the East and South, and Central Vietnam to the North. This location not only brings favorable conditions for trade and economic development but also creates a rich natural environment with diverse ecosystems, especially the river and canal systems of the Mekong Delta.

Southern Vietnam is mainly composed of lowland plains, with some low mountainous areas and plateaus. The Mekong Delta is the flattest region, occupying an area of about 40,000 km². This is one of the largest rice granaries in the country, with an intricate system of rivers and a complex network of canals. Southeast provinces such as Binh Duong, Dong Nai, Ba Ria-Vung Tau, and Ho Chi Minh City have a more diverse terrain, including plains, hills, and plateaus.

The altitude of Southern Vietnam is usually not very high, mainly ranging from 0 to 200 meters above sea level. Some areas, such as the Di Linh plateau in Lam Dong, have elevations from 800 to 1,500 meters, creating diversity in climate and landscape.

Figure 2. Experimental area (yellow border)

3.2. Gravity anomaly data

3.2.1. Gravity anomaly data in Southern Vietnam

A total of 1968 detailed gravity points in Southern Vietnam were collected and used in the VN2000 coordinate system and use formula (11) to convert to gravity anomaly values.

Table 1. Gravity anomaly in Southern Vietnam

No	Lat (^{0})	Long (^{0})	Gravity (*mGal*)	Gravity anomaly (*mGal*)	No	Lat (^{0})	Long (^{0})	Gravity (*mGal*)	Gravity anomaly (*mGal*)
1	10.3736	103.8446	978200.4800	4.0185	…..	…	…	…	…
2	10.2229	103.9712	978197.1600	2.2095	1962	11.4035	108.0919	978066.3080	146.3495
3	10.0558	104.0177	978192.9100	7.6894	1963	10.9228	108.0928	978201.7620	-15.5750
4	10.4129	104.0289	978195.1270	-4.6314	1964	11.3977	108.0936	977977.0190	61.1980
5	10.1816	104.0423	978193.1690	-0.5048	1965	11.3086	108.0937	978038.2850	36.9013
6	10.6275	105.0118	978170.8900	-36.2050	1966	10.9258	108.0937	978204.3100	-13.6993
7	9.3518	105.0922	978160.1880	-9.1258	1967	11.3034	108.0943	978046.2410	29.7233
8	9.1823	105.1406	978155.5430	-8.8053	1968	11.2952	108.0949	978065.7380	23.0858

Gravity anomaly after calculation reaches the highest value is 147.2806 *mGal*, the smallest value is -36.2050 *mGal*, and the average value is -1.4693 *mGal*. The large difference between the maximum and minimum values may indicate unevenness in gravity distribution and may also reflect the complex geophysical and geological environment in the Southern Vietnam.

3.2.2. Gravity anomaly of the global gravitational potential models

Gravity anomaly data from global gravity models EGM 2008, EICGEN-6C4, SGG-UGM-1, SGG-UGM-2, and GECO corresponding to 1968 points are exploited from [6]. Specific data of these points are presented in Table 2.

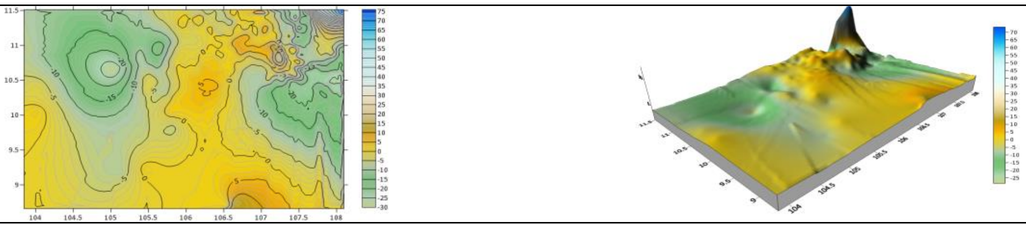
Table 2. Gravity anomaly of the global gravitational potential models

No	Lat (^{0})	Long (^{0})	Gravity anomaly (*mGal*)				
			EGM 2008	EICGEN-6C4	SGG-UGM-1	SGG-UGM-2	GECO
1	10.3736	103.8446	-4.4796	-4.8291	-3.8326	2.0793	-2.7066
2	10.2229	103.9712	-3.4108	-3.1800	-1.5911	0.6038	0.0678
3	10.0558	104.0177	0.4862	2.9914	2.5484	4.3094	4.3667
4	10.4129	104.0289	-3.8225	-4.8948	-2.5454	-4.7068	-1.2562
5	10.1816	104.0423	-2.9865	-2.0839	-1.3058	-1.9453	0.9747
6	10.6275	105.0118	-29.8662	-28.3626	-28.9500	-29.2425	-25.6673
7	9.3518	105.0922	-7.2514	-11.0737	-7.7237	-7.5119	-6.2681
8	9.1823	105.1406	-6.6732	-11.9251	-7.4198	-6.9248	-5.6758
…	…	…	…	…	…	…	…
1962	11.4035	108.0919	66.5418	58.3115	60.4033	59.6080	59.2921
1963	10.9228	108.0928	-18.6660	-23.1233	-21.1683	-27.7769	-19.2885
1964	11.3977	108.0936	63.5331	55.2890	57.5070	56.6622	56.3895
1965	11.3086	108.0937	28.5638	20.2313	22.9341	21.8735	22.6948
1966	10.9258	108.0937	-18.2629	-22.7640	-20.7792	-27.2568	-18.9119
1967	11.3034	108.0943	26.7726	18.4407	21.1301	20.0948	20.9873
1968	11.2952	108.0949	24.1861	15.8561	18.5325	17.5487	18.5240

From gravity anomaly data of global gravitational potential energy models, we proceed to create 2D and 3D maps for gravity anomaly values (Figure 3).

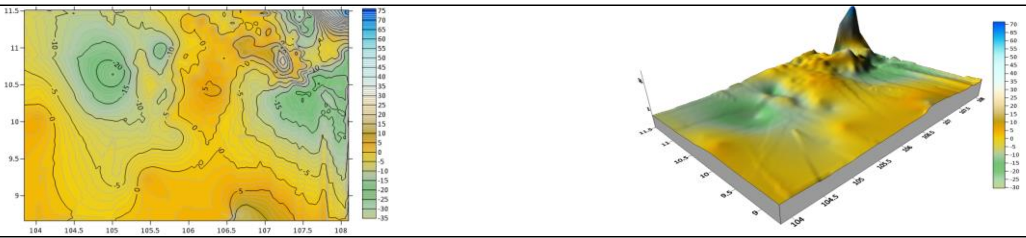
a

b



c

d



e

Figure 3. Gravity anomaly values from global gravity models

(a: EGM2008, b: EICGEN-6C4, c: SGG-UGM-1, d: SGG-UGM-2, e: GECO)

The results in Table 2 and Figure 3 show that the gravity anomaly fluctuation range of the EGM 2008 model from -29.8662 *mGal* to + 82.2140 *mGal*, of the EICGEN -6C4 model from -28.3626 *mGal* to + 74.2292 *mGal*, of the SGG - UGM1 model from -28.9500 *mGal* to + 75.5315 *mGal*, of the SGG -UGM2 model from -29.2425 *mGal* to + 74.9010 *mGal*, of the GECO model from -30.5641 *mGal* to + 73.6775 *mGal*.

3.3. Results of evaluating global gravitational potential models

When formula 12 is applied, Table 3 illustrates the deviation between the detailed gravity anomaly and the gravity anomaly derived from global gravity models.

Table 3. The difference in gravity anomaly values between different models

No	Lat	Long	The deviation values				
			EGM 2008	**EICGEN-6C4**	**SGG-UGM-1**	**SGG-UGM-2**	**GECO**
1	10.3736	103.8446	8.4981	8.8476	7.8511	1.9392	6.7251
2	10.2229	103.9712	5.6203	5.3895	3.8006	1.6057	2.1417
3	10.0558	104.0177	7.2032	4.6980	5.1410	3.3800	3.3227
4	10.4129	104.0289	-0.8090	0.2634	-2.0861	0.0753	-3.3752
5	10.1816	104.0423	2.4817	1.5791	0.8010	1.4405	-1.4795
6	10.6275	105.0118	-6.3388	-7.8424	-7.2550	-6.9626	-10.5377
7	9.3518	105.0922	-1.8744	1.9479	-1.4021	-1.6139	-2.8577
8	9.1823	105.1406	-2.1321	3.1198	-1.3855	-1.8805	-3.1295
…	…	…	…	…	…	…	…
1962	11.4035	108.0919	79.8077	88.0379	85.9462	86.7415	87.0573
1963	10.9228	108.0928	3.0910	7.5483	5.5933	12.2019	3.7136
1964	11.3977	108.0936	-2.3350	5.9091	3.6911	4.5358	4.8085
1965	11.3086	108.0937	8.3375	16.6699	13.9672	15.0277	14.2065
1966	10.9258	108.0937	4.5635	9.0646	7.0799	13.5574	5.2126
1967	11.3034	108.0943	2.9507	11.2826	8.5932	9.6285	8.7360
1968	11.2952	108.0949	-1.1002	7.2297	4.5533	5.5371	4.5619

- From the difference in gravity anomaly values, we proceed to create 2D and 3D maps (Figure 4).

The average gravity anomaly deviation calculated according to formula (13) has the following value:

$$\Delta g_{aver}^{EGM\,2008} = -0.9440 mGal\ ;$$

$$\Delta g_{aver}^{EIGEN-6C4} = -0.7979 mGal\ ;$$

$$\Delta g_{aver}^{SGG-UGM1} = -0.8903 mGal\ ;$$

$$\Delta g_{aver}^{SGG-UGM2} = -0.8244 mGal\ ;$$

$$\Delta g_{aver}^{GECO} = -1.9637 mGal\ ;$$

The difference between the detailed gravity anomaly Δg and the average gravity anomaly deviation is calculated according to formula (6), the square error is determined according to formula (15):

$$m^{EGM\,2008} = \pm\sqrt{\frac{[\delta\Delta g \delta\Delta g}{n-1}} = \pm 6.397 mGal\ ;$$

$$m^{EIGEN-6C4} = \pm\sqrt{\frac{[\delta\Delta g \delta\Delta g}{n-1}} = \pm 6.230 mGal\ ;$$

$$m^{SGG-UGM1} = \pm\sqrt{\frac{[\delta\Delta g \delta\Delta g}{n-1}} = \pm 6.277 mGal\ ;$$

$$m^{SGG-UGM2} = \pm\sqrt{\frac{[\delta\Delta g \delta\Delta g}{n-1}} = \pm 6.210 mGal\ ;$$

$$m^{GECO} = \pm\sqrt{\frac{[\delta\Delta g \delta\Delta g}{n-1}} = \pm 6.386 mGal\ ;$$

The mean square error values of models EGM2008, EIGEN-6C4, SGG-UGM-1, SGG-UGM-2 and GECO are ± 6.397 *mGal*, ± 6.230 *mGal*, ± 6.277 *mGal*, ± 6.210 *mGal*, ± 6.386 *mGal*, respectively in the experimental area. These mean square error values are not much different, but partly show the trend of the models: EIGEN-6C4, SGG-UGM-1, SGG-UGM-2 and GECO are newer generation models EGM2008 model, which built based on data from EGM2008 model with additional satellite data.

In this study, detailed gravity anomaly counts were used to evaluate the accuracy of the models has dense density (1968 points), distributed in narrow space (concentrated in the southern delta region of Vietnam), so it can be said that the accuracy of the SGG-UGM-2 model in this study is highly reliable.

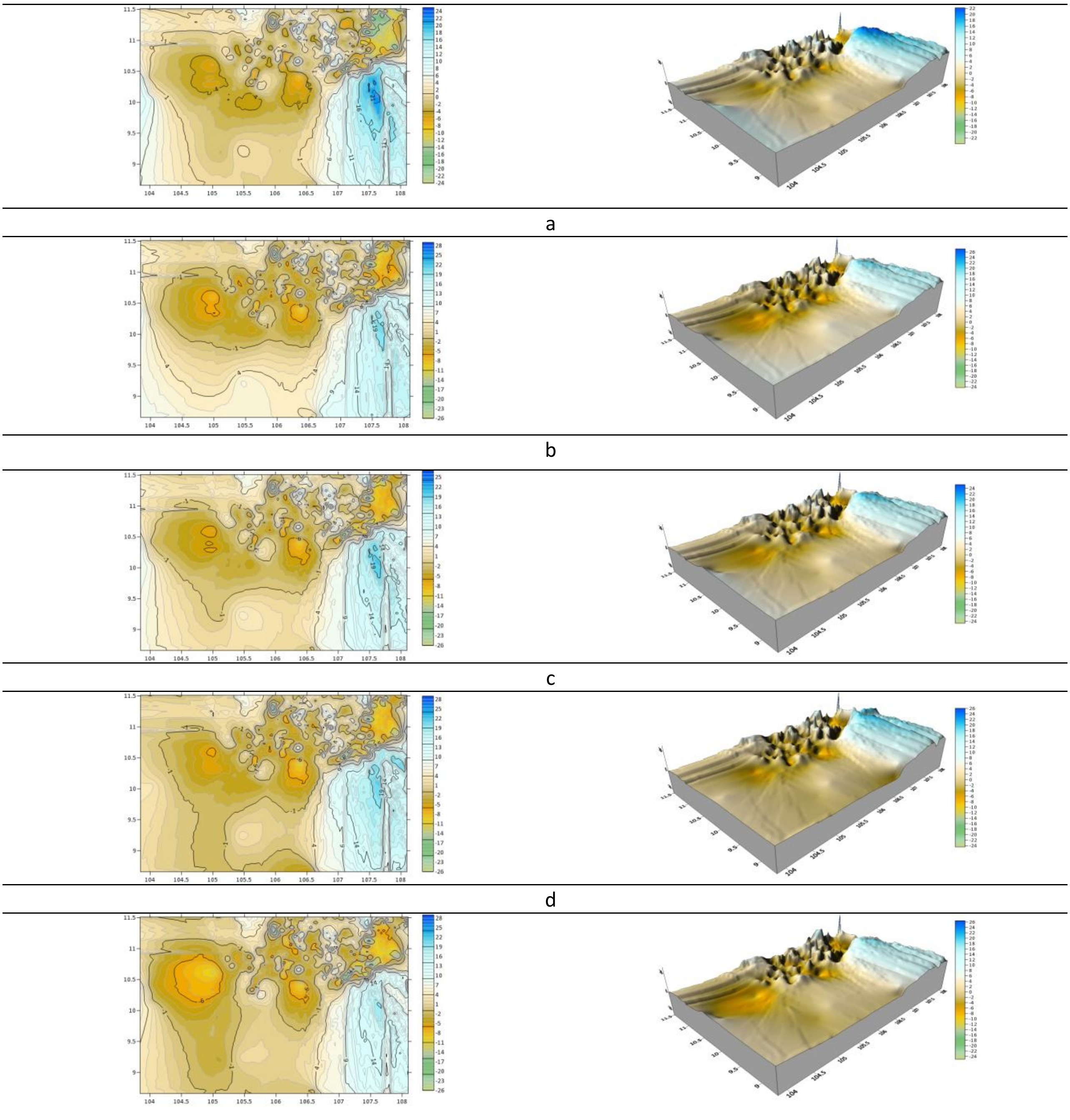

a
b
c
d
e

Figure 4. The deviation value between the detailed gravity anomaly and the gravity anomaly from global gravity models

(a: EGM2008, b: EICGEN-6C4, c: SGG-UGM-1, d: SGG-UGM-2, e: GECO)

4. CONCLUSION

Through the research process, some opinions were drawn as follows:

- Detailed gravity anomaly data for 1968 points are used to evaluate the accuracy of the global gravity field models EGM 2008, EICGEN-6C4, SGG-UGM-1, SGG-UGM-2 and GECO in the southern plains of Vietnam. The procedure for evaluating the accuracy of the global gravity field model follows strict and clear steps.

- In the experimental area, the accuracy of the global gravity field models EGM 2008, EICGEN-6C4, SGG-UGM-1, SGG-UGM-2 and GECO can be considered similar, about 6.2 *mGal*. This is important information for scientists and managers when applying these models in practice.

Within the framework of the research, the SGG-UGM-2 model is considered to be the best in terms of accuracy in the southern plains of Vietnam.

However, there is a need to further evaluate the accuracy of these models for other areas in Vietnam's territory, thereby providing a basis for using the gravity anomaly value of this model in practice.

The steps to evaluate the accuracy of the global gravity field model based on detailed gravity anomaly data in this study can be fully applied to other regions beyond similar data sources.

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