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Accuracy Assessment of High-Degree Geopotential Models in Peninsular Malaysia

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The selection of the accurate geoid model is essential for geoid determination in specific regions. Many improvements to the basic theory of more reliable data are available for numerical modelling studies. All of the innovations have led to the development of a sequence of global geopotential models of increasing spherical harmonic degree and order and the resolution of the geopotential models. There are hundreds of geopotential models that can be downloaded in ICGEM. All geopotential ICGEM models have accuracy and resolution based on the degree and order of spherical harmonic coefficients. This study has two high-degree geopotential models: the latest one, XGM2019e_2159, and another geopotential model, EGM2008. The accuracy evaluation of two geopotential models needs to be evaluated based on terrestrial gravity data and existing GPS points data to choose which geopotential model is the best-fit geopotential models with different degrees and order in terms of spherical harmonic coefficients using the Root Mean Square method. The statistical analysis of the geopotential model derived based on the existing GPS points shows that the degree and order 720 for XGM2019e_2019 are the best-fit geopotential models in Peninsular Malaysia. The result also indicates that the gravity anomaly derived from EGM2008 with the maximum degree and order of 2190 regarding the spherical harmonic coefficient is the most accurate geoid model that can be used as a reference over Peninsular Malaysia. Overall, it can be concluded that XGM2019e_2019 and EGM2008 are the best-fit geopotential models for Peninsular Malaysia.

Keywords: Global Geopotential Model; Geoid height; Gravity anomaly; GNSS

I. INTRODUCTION

Global Geopotential Model (GGM) is one of the data sources for geoid determination. The Geopotential model is essential in developing high-resolution geoid models across local regions. The Geopotential model also offers a reference area for local gravimetric geoid. The Geopotential model is used to derive parameters such as height anomaly and gravity anomaly. However, geoid height is the primary interest of many people, especially surveyors, to get the orthometric height from GPS (Othman *et al.,* 2016).

Geopotential models are divided into three classes. The first class is satellite-only, which is from the study of the orbits of artificial satellites such as Challenging Mini Satellite Payload (CHAMPS), Gravity and Climate Experiment recovery (GRACE), and Gravity field and steady-state Ocean Circulation Explorer (GOCE) satellite. The next class combines gravity sources such as satellite data, land and ship-track gravity and marine gravity anomalies, and airborne gravity data, which can generate a high-degree combined geopotential model. Lastly is the third class of the geopotential model, a tailored geopotential model. The tailored geoid model is a satellite-only model modified using unused higher-resolution gravity data (Pa'suya *et al.,* 2018). A collection of fully normalised spherical harmonic coefficients describes the Global Geopotential Model. Many efforts have been made to produce the best fit and more accurate geopotential model.

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The accurate geoid models are required to be used as a guideline for evaluating the geopotential model (Sulaiman *et al.,* 2011). In this study, the statistical analysis of the geoid heights and gravity anomalies derived from global geopotential models will be used to differentiate which geoid model best fits and is most accurate and can be used as a reference geoid model in Peninsular Malaysia.

II. STUDY AREA AND METHODOLOGY

A. Study Area

Malaysia is between 0 and 8 degrees north and 99 and 120 degrees west. Malaysia covers 329.758 square kilometres of land and 582.610 square kilometres of water. Malaysia's shoreline is 4714 kilometres long, and there are several islands in Malaysian waters, including about 1370 islands off the coast of geographical entities. Only two geopotential models will be used to choose which geopotential models are the best models with the maximum degree and order in terms of spherical harmonic coefficients. The examination and comparison of the high-degree geopotential model for West Malaysia (WM) are presented in this research.

B. Data Used

1. Global Geopotential Model (GGM)

A collection of fully normalised spherical harmonic coefficients describes the Global Geopotential Model. Many efforts have been made to produce the best fit and more accurate geopotential model (Sulaiman *et al.,* 2011). Two types of geopotential models in ICGEM can be used to extract the quantity of the Earth: the satellite-only model and the combined model. Satellite-only geopotential models are derived from monitoring Earth's artificial satellites such as CHAMP, GRACE, GOCE, and LEGIOS satellite-only models (Sulaiman *et al.,* 2013). The geopotential models, satellite-only or combined, are truncated to a maximum degree. This truncation of the coefficients above the maximum degree causes the error of omission (Wang, 2012). Besides, an accurate geopotential model can be used as a reference surface for implementing a global vertical datum (Pavlis *et al.,* 2012). The Earth's gravitational potential can be interpreted beyond the Earth's mass by a collection of spherical harmonic coefficients Cnm and Snm, called a geopotential model. These potential coefficients measure different gravimetric quantities based on the Earth's gravitational potential (Benahmed Daho, 2010). In the GGM evaluation, the geoidal heights centred on the ellipsoid heights and the orthometric heights were used to determine the precision of the geopotential models. The geopotential model can be used as a reference model. The geopotential models' geoid height estimations can be calculated by GPS / levelling (Yilmaz *et al.,* 2016). Nowadays, geoid height derived from GGM can be used for GPS / levelling and navigation purposes in countries that do not have accurate geopotential models (R. Kiamehr & Eshagh, 2008). Recent satellites such as CHAMP and GRACE have contributed to notable changes in the long-wavelength portion of the gravity of the Earth and the geoid. It provides complete global coverage of the area of gravity details. Still, the estimate blunder for the geopotential models is too conservative and viewed as global averages and, therefore, not generally indicative of the output of the geopotential model in a given area (Rapp, 1997).

Table 1. Global Geopotential Models used in this study.

GGMs	Year	Max Degree & Order	Class	Ref.
		Combined Model		
XGM2019e-2159	2019	2190	Combined	Zingerle *et al,* 2019
EGM2008	2008	2190	Combined	Pavlis *et al.,* 2012

More than 100 geopotential models in ICGEM can be downloaded freely on the ICGEM website, including EGM2008 and XGM2019e_2019. Today, the EGM2008, where the combined models are built based on the combined model, is one of the highest-resolution representations of the global gravitational field. It is given with two is not entirely compatible. There are two sources of error information: spherical harmonic coefficient variances and a geographical map of error variances, such as in the corrected geoid (Gilardoni *et al.,* 2016). EGM2008 is a geopotential model that has been established by combining the ITG-GRACE03S gravitational model and its associated error covariance matrix to the gravity information obtained from a global series of area-mean free-air gravity anomalies specified on a 5' equiangular grid (Kim *et al.,* 2020). This model has a maximum degree of 2190 and an order of 2159 spherical harmonic coefficient (Sulaiman *et al.,* 2011). XGM2019e is also one of the latest geopotential models with a combined global gravity field model. This model is represented through spheroidal harmonics up to d/o 5399, corresponding to a spatial resolution of 2' (~4 km) (Zingerle *et al.,* 2019). It was released in 2019 and has a degree and order of 2190 regarding spherical harmonic coefficients.

In this study, the latest combined geopotential models, which are XGM2019e_2019 and another geopotential model, EGM2008, are selected with the different maximum degrees and orders 180, 360, 720, 1000, 1500,1800,2159, and 2190 in terms of spherical harmonic coefficient for accuracy evaluation.

2. GNSS Levelling

The GNSS levelling data are used to determine the precision of the geopotential model. Verification is necessary to choose the accurate model that needs to be used for geopotential model determination (Pa'suya *et al.,* 2018). GNSS levelling data is used to evaluate the geoid models (Erol *et al.,* 2009). 54 GNSS points have been collected, processed, and produced high-accuracy GNSS coordinates, which are each point's latitude, longitude, and ellipsoidal height. The reference coordinate system used in this study is the Geodetic Reference System 1980 (GRS80). Figure 1 shows the GPS documentation points that are used. The distribution of the points is shown in Figure 2. The reference coordinate system used in this study is the Geodetic Reference System 1980 (GRS80).

Figure 1. Monument of Standard Benchmark and Benchmark of JUPEM.

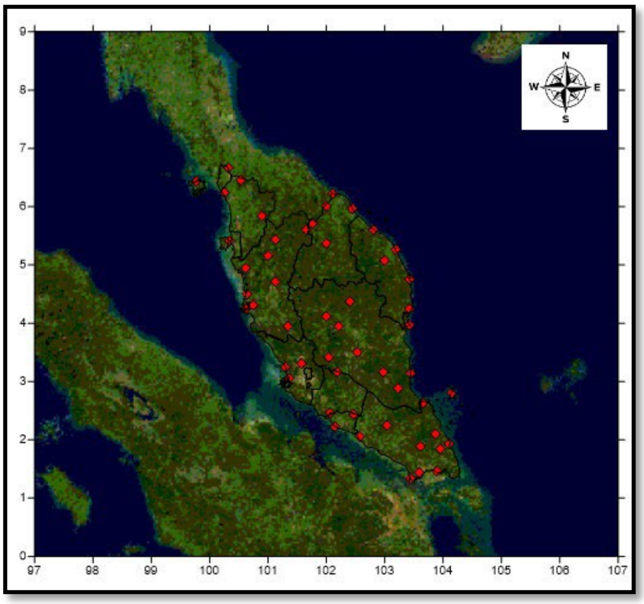


Figure 2. Distribution of GNSS Levelling on benchmark.

In this study, the GPS points were collected using TRIMBLE 5700. The number of satellites should be more or equal to 5 to get the same correction for each point. The value of Geometric Dilution of Precision (GDOP) should be less than 6 GDOP to specify the error propagation of the navigation satellite geometry on positional measurement precision. The field parameter used in this study is shown in Table 2.

Table 2. Field Parameter used for GPS points used in this study.

Parameter	**Selected**
Recording Interval	15"
Number of satellites	More than five satellites
GDOP	Less than 6 GDOP
Sky Clearance	More than 90%
Cut off angle	15°

The observations were conducted on the 21st, 22nd, 25th, and 26th of August, 2019. The base station, Port Klang STAPS, has been designated the command centre. On August 21 and 22, 2019, six STAPS stations were simultaneously observed: Penang, Langkawi, Geting, Tg Gelang, Lumut, and Chendering. On the 24th and 25th of August 2019, three new stations were discovered, namely Kukup, Tg Keling, and Tioman. There is also a need to set the post-processing parameter for baseline processing using dual-frequency, L1 and L2, to get accurate GPS points. Each GPS point has the standard precision. The standard precision is divided into two types: horizontal and vertical. The standard horizontal precision accuracy is 5 millimetres + 0.5 ppm and 5 millimetres + 1.0 ppm for vertical precision. The parameter is shown in Table 3.

Table 3. The post-processing parameter used for GPS points.

Parameter	**Selected**
Ephemeris type	Precise
Solution type	Fixed
1 baseline	2 epochs
Cut off angle	15˚
Antenna type	Zephyr TRM412249

3. Terrestrial Gravity

Gravity data is collected from the Department of Survey and Mapping Malaysia (DSMM). DSMM uses gravity data for two purposes: calculating the gravimetric correction in orthometric heights for precise levelling networks and calculating and producing the precise gravimetric geoid models.

DSMM has three types of accuracy of the gravity data network: first-order, second-order, and third-order. The First Order Gravity Network has a precision of 0.03 mGal. These data are collected using a high-precision relative gravimeter along the precise levelling route at 40-50 km intervals for MSL below 100 metres and 10-20 km intervals for MSL over 100 metres. The network is based on the absolute gravity values of the IGSN71 (International Gravity Standardisation Net 1971) station at the University of Malaya and the absolute station at the DSMM Headquarters. The Second Order Gravity Network has a precision of 0.05 mGal. These data are also measured using a high-precision relative gravimeter at 1-5 km intervals along the precise levelling route, referred to as the First-Class Order Gravity Network. The accuracy of the Third Order Gravity Network is 0.1 mGal. These data are measured on a 5-10 km grid, which is referred to as Second-Order Gravity Network.

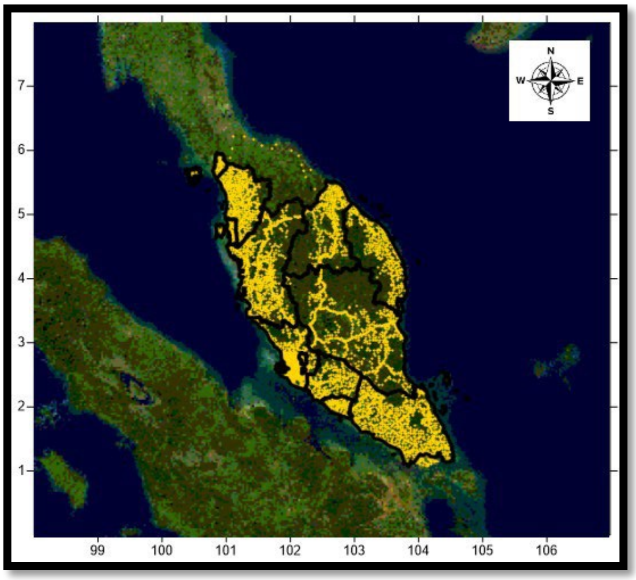


Figure 3. Terrestrial gravity data points over Peninsular Malaysia.

The gravity data was collected using Lacoste and Romberg gravimeters and the local base gravity. The local base gravity is connected to the International Standard Net 1971 (ISGN 71) (Sulaiman *et al.,* 2011). In this study, there are 5,011 gravity data points is used to calculate the gravity anomaly differences derived from terrestrial gravity data of the geopotential models used for accuracy evaluation.

III. GRAVITYVITY AND GEOID COMPUTATION

In this study, th↑h is from the spherical harmonic model in ICGEM (Sulaiman *et al.,* 2011). The formula is shown in Equation (1).

$$\zeta_{e1}(\lambda,\emptyset) = \frac{GM}{r_e\gamma}\sum_{l=0}^{lmax}\left(\frac{R}{r_e}\right)^l\left(\sum_{m=0}^{l}\left(C_{lm}^{T}cosm\lambda + S_{lm}^{T}sinm\lambda\right)P_{lm}\left(sin\,\theta\right)\right)$$

Where;

GM : Newtonian gravitational constant

R : Reference radius

Φ : Latitude of geodetic coordinates

Λ : Longitude of geodetic coordinates

r : Radius of geodetic coordinates

lm : Degree and order of spherical harmonic

P_{lm} : Fully normalised Legendre functions

C, S_{lm} : Fully normalised Stokes' coefficients.

The gravity anomaly of the global geopotential model can be derived by using the formula of gravity anomaly based on *Molodensky's* theory in ICGEM (Sulaiman *et al.,* 2011). The formula is shown in Equation (2) and Equation (3).

$$\Delta g_{mGal} = g_p - \gamma_o$$

or

$$\Delta g_{mGal} = g_p - \gamma_o + 0.8086H_{(meters)}$$

Where;

Δg : Gravity anomaly

g_p : Gravity measured on the surface

γ_0 : Normal gravity

H : Height (m)

The next formulae which are in Equation (4) are to find the normal gravity (γ_0) of each station based on Geodetic Reference System 1980 (GRS80) gravity formulae (Sulaiman *et al.,* 2011).

$$\gamma_o = 9.7808267714 \left(\frac{1 + 0.00198185188689\, sin^2\lambda}{\sqrt{1 - 0.00669487999018\, sin^2\lambda}}\right)$$

The gravity anomaly calculation derived from geopotential model in ICGEM can be computed using Equation (5) (Sulaiman *et al.,* 2011).

$$\Delta g_{GM} = \frac{GM}{r_e\gamma}\sum_{n=2}^{m}\left(\frac{a}{r}\right)^n\left(\sum_{n=0}^{m}(C_{nm}cosm\lambda + S_{nm}\,sinm\lambda)P_{nm}\,(sin\,\theta)\right)$$

Where;

GM : Newtonian gravitational constant

a : Semi-major axis of geodetic reference ellipsoid

θ : Latitude of geodetic coordinates

λ : Longitude of geodetic coordinates

r : Radius of geodetic coordinates

nm : Degree and order of spherical harmonic

P_{lm} : Fully normalised Legendre functions C,

C, S_{lm} : Fully normalised Stokes' coefficients.

The differences of geoid heights derived from geopotential models and the existing data produced by Department Surveying and Mapping Malaysia using the latitude and longitude of Ground Positioning System (GPS) points can be computed by using Equation (6) (Sulaiman *et al.,* 2013).

$$\Delta N = N_{gravimetric} - N_{GGM}$$

Where;

N_{GGM} : Geoid height derived from geopotential model

$N_{gravimetric}$: Geoid height derived from the existing data produced by Department Surveying and Mapping Malaysia using Ground Positioning System (GPS) points.

Next, the calculation of gravity anomaly needs to be evaluated based on the differences between observed gravity anomaly (Δg_{obs}) and computed gravity anomaly from the geopotential model (Δg_{GM}) using Equation (7) (Sulaiman *et al.,* 2011).

$$\Delta g_{ano} = \Delta g_{obs} - \Delta g_{GGM}$$

Lastly, the statistical analysis needs to be evaluated from the differences geoid heights derived from geopotential models and the existing GPS points from DSMM using The Root Mean Square (RMS) method (Sulaiman *et al.,* 2013). The lowest RMS value will be choosing as the best fit geopotential model used in Peninsular Malaysia. The analysis can be concluded using Equation (8).

$$RMS = \pm\sqrt{\sum_{m=1}^{n}\left(\frac{\Delta V^2}{n}\right)}$$

Where;

n, m : Degree and order of spherical harmonic coefficient

ΔV : Residual geoid heights

n : Number of GGM models.

IV. RESULTS AND DISCUSSION

A. Geoid Height

The value of the geoid heights depends on the geopotential models with the degree and order used. The geoid heights derived from the existing GPS points used were calculated to evaluate the geopotential models' accuracy using the Root Mean Square (RMS) method. In this study, the latest geopotential models, XGM2019e_2159, and another geopotential model, EGM2008, were derived using different degrees and orders 180, 360, 720, 1000, 1500, 1800, 2159, and 2190 in terms of spherical harmonic coefficients. The residual geoid heights derived between existing GPS points and geopotential models were calculated to get the maximum, minimum, mean, and standard deviation values. 54 GPS points were used to evaluate the value of RMS value. The range RMS value of XGM2019e_2159 is between 0.551 metres and 0.666 metres, while for EGM2008, the range of RMS value is between 0.561 metres and 0.666 metres. Based on the analysis in Table 3, it can be concluded that EGM2008 and XGM2019e_2159, with a degree and order 720 in terms of spherical harmonic coefficients, have the lowest RMS value with the RMS value 0.561 metres and 0.551 metres, respectively. Overall, XGM2019e_2159 with degree and order 720 has the lowest RMS value and automatically will be chosen as the best-fit geopotential model for Peninsular Malaysia.

Table 4. Statistical information of the residual geoid height derived from geopotential models and the existing GPS points using the RMS method

MAX DEGREE & ORDER	MAX (m)	MIN	MEAN	STD DEV	RMSE (m)
EGM2008					
180	0.840	-0.629	-0.629	0.220	0.666
360	0.484	-0.543	-0.543	0.171	0.569
720	0.374	-0.538	-0.538	0.161	0.561
1000	0.371	-0.543	-0.543	0.148	0.563
1500	0.358	-0.551	-0.551	0.135	0.567
1800	0.350	-0.555	-0.555	0.130	0.569
2159	0.345	-0.558	-0.558	0.126	0.572
2190	0.341	-0.569	-0.569	0.113	0.580
XGM2019e_2159					
180	0.861	-0.630	-0.630	0.219	0.666
360	0.551	-0.545	-0.545	0.150	0.565
720	0.208	-0.541	-0.541	0.106	0.551
1000	0.158	-0.547	-0.547	0.086	0.554
1500	0.142	-0.557	-0.557	0.068	0.561
1800	0.135	-0.561	-0.561	0.064	0.565
2159	0.129	-0.565	-0.565	0.061	0.568
2190	0.121	-0.579	-0.579	0.056	0.582

Table 4 shows the rank of the geopotential models for the geoid height differences based on RMS value. The rank of the geopotential models used was selected based on the lowest RMS value with different degrees and orders in terms of spherical harmonic coefficients. The table below shows XGM2019e_2159 and EGM2008 with degree and order 720 have the RMS values 0.551 metres and 0.561 metres, respectively. In conclusion, XGM2019e_2159 with degree and order 720 will be selected as the best-fit geopotential model over Peninsular Malaysia. EGM2008 and XGM2019e_2159 follow the rank with degree and order 1000, 1500, 1800, 360, 2159, 2190, and 180 regarding spherical harmonic coefficients.

Table 5. The rank of the geopotential models with different degrees and orders for the geoid height differences based on the RMS value

RANK	MAX DEGREE & ORDER	RMSE (m)
EGM2008		
1	720	0.561
2	1000	0.563
3	1500	0.567
4	1800	0.569
5	360	0.569
6	2159	0.572
7	2190	0.58
8	180	0.666
XGM2019e_2159		
1	720	0.551
2	1000	0.554
3	1500	0.561
4	1800	0.565
5	360	0.565
6	2159	0.568
7	2190	0.582
8	180	0.666

The residual surface map of the geoid heights for geopotential models with different degrees and orders is computed based on the residual values of the geoid heights derived from existing GPS points and geoid height derived from geopotential models. All the GPS points were interpolated to perform the residual surface maps of each geopotential model. Figure 4 and Figure 5 show the 1' gridded residual surface maps of geopotential models used with different degrees and orders in terms of spherical harmonic coefficients. The value of degree and charge for each geopotential model can affect the resolution of the residual surface maps. Based on the figure below, the result shows that XGM2019e_2159 with a degree and order 720 has the highest resolution with the lowest RMS value among the geopotential models with degree and order 180, 360, 720, 1000, 1500, 1800, 2159, and 2190 in terms of spherical harmonic coefficients.

Lastly, the statistical analysis of geoid height will be evaluated based on the RMS value derived from geopotential models used with different maximum degrees and order in terms of spherical harmonic coefficient. The line graph shows the RMS value differences of EGM2008 and XGM2019e_2159 with other degrees and orders. The graph in Figure 6 shows how to concentrate the data around the line of best fit to determine which geopotential model has the lowest RMS value. The lowest RMS value will be selected as the best-fit geopotential model for Peninsular Malaysia.

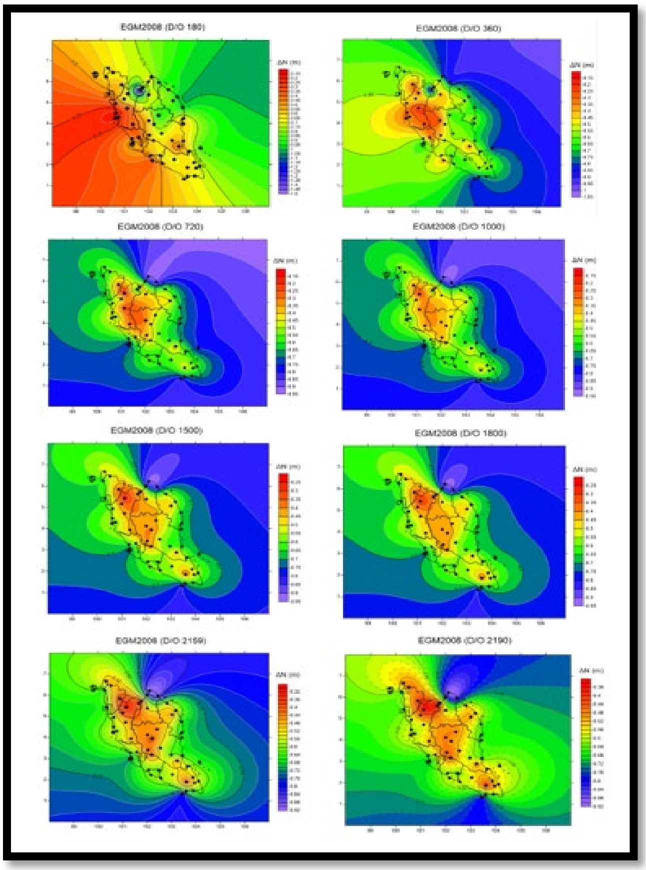


Figure 5. The 1' gridded residual geoid height derived from XGM2019e_2159 with different degrees and order in terms of spherical harmonic coefficients

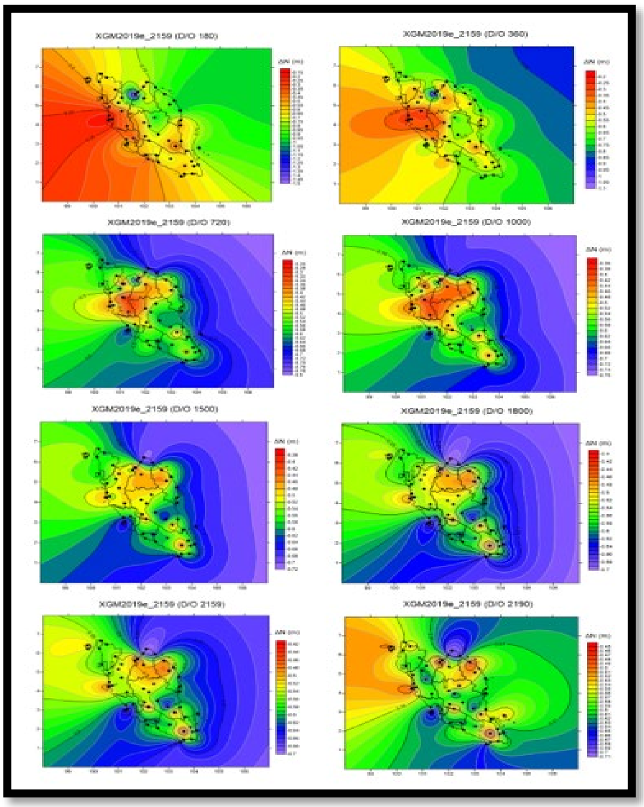


Figure 4. The 1' gridded residual geoid height derived from EGM2008 with different degree and order in terms of spherical harmonic coefficients

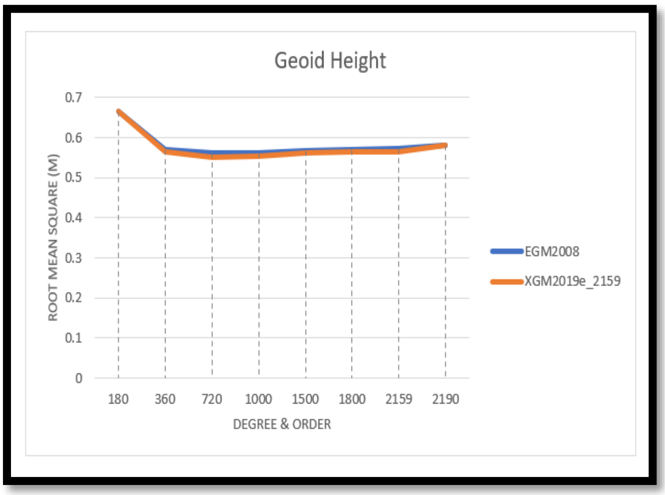


Figure 6. The statistical analysis of the RMS value differences between existing GPS/Levelling points and geopotential models (EGM2008 and XGM2019e_2159)

B. Gravity Anomaly

The gravity anomaly derived from terrestrial gravity data was calculated to evaluate the geopotential models' accuracy using the Root Mean Square (RMS) method. In this study, the latest geopotential models, XGM2019e_2159, and another geopotential model, EGM2008, were derived using different degrees and orders 180, 360, 720, 1000, 1500, 1800, 2159, and 2190 in terms of spherical harmonic coefficients. The residual gravity anomaly value derived between terrestrial gravity data and geopotential models used were calculated to get each geopotential model's maximum, mean, and standard deviation value with different maximum degrees and order. The range RMS value of XGM2019e_2159 is between 13.603 mGal and 23.411 mGal, while for EGM2008, the range of RMS value is between 13.330 mGal and 23.500 mGal. Based on the analysis shown in Table 5, it can be concluded that EGM2008 and XGM2019e_2159, with a maximum degree and order 2190 in terms of spherical harmonic coefficients, has the lowest RMS value with the RMS value of 13.330 mGal and 13.603 mGal respectively. Overall, EGM2008 with a maximum degree and order 2190 has the lowest RMS value and automatically will be chosen as the most suitable geopotential model used as a reference for Peninsular Malaysia.

Table 6. The rank of the geopotential models with different degrees and orders for the gravity anomaly differences based on the RMS value

MAX DEG & ORD	MAX	MIN	MEAN	STD DEV	RMSE (mGal)
EGM2008					
180	122.891	-118.174	8.981	21.718	23.500
360	110.852	-104.724	9.981	20.026	22.374
720	88.968	-101.066	8.923	18.498	20.536
1000	82.961	-99.162	8.264	17.320	19.189
1500	75.353	-95.915	7.392	15.900	17.533
1800	67.940	-94.742	6.940	15.223	16.729
2159	63.423	-92.632	6.445	14.496	15.863
2190	92.417	-162.230	3.929	12.739	13.330
XGM2019e_2159					
180	122.553	-118.381	8.872	21.667	23.411
360	109.173	-108.571	10.044	19.722	22.131
720	87.303	-104.293	8.960	17.937	20.049
1000	79.833	-102.604	8.197	16.844	18.731
1500	70.267	-100.412	7.195	15.566	17.147
1800	61.628	-99.779	6.686	14.950	16.375
2159	60.064	-98.117	6.130	14.278	15.538
2190	100.798	-167.096	3.292	13.200	13.603

Table 6 shows the geopotential models' rank for the gravity anomaly differences based on RMS value. The rank of the geopotential models used was selected based on the RMS value with different degrees and orders in terms of spherical harmonic coefficients. Table 7 shows XGM2019e_2159 and EGM2008 with the maximum degree, and order 2190 has the RMS value of 13.603 mGal and 13.330 mGal, respectively. In conclusion, EGM2008, with a maximum degree and order 2190, will be selected as the most suitable geopotential model that can be used as a reference for Peninsular Malaysia. EGM2008 and XGM2019e_2159 follow the rank with degree and order 2159, 1800, 1500, 1000, 720, 360, and 180 regarding spherical harmonic coefficients.

Table 7. Statistical information of the residual gravity anomaly derived from geopotential models and terrestrial gravity data using the RMS method

RANK	MAX DEGREE & ORDER	RMSE (mGal)
	EGM2008	
1	2190	13.330
2	2159	15.863
3	1800	16.729
4	1500	17.533
5	1000	19.189
6	720	20.536
7	360	22.374
8	180	23.500
	XGM2019e_2159	
1	2190	13.603
2	2159	15.538
3	1800	16.375
4	1500	17.147
5	1000	18.731
6	720	20.049
7	360	22.131
8	180	23.411

The residual surface map of the gravity anomaly for geopotential models with different degrees and orders is computed based on the residual values derived from terrestrial gravity data and gravity anomaly derived from geopotential models. All the gravity data were interpolated to perform the residual surface maps of each geopotential model. Figure 7 and Figure 8 show the 1' gridded residual surface maps of geopotential models used with different degrees and orders in terms of spherical harmonic coefficients. The value of degree and order for each geopotential model can affect the resolution of the residual surface maps. Based on the figure below, the result shows that EGM2008 with a maximum degree and order 2190 has the highest resolution with the lowest RMS value among the geopotential models with degree and order 180, 360, 720, 1000, 1500, 1800, 2159, and 2190 in terms of spherical harmonic coefficients.

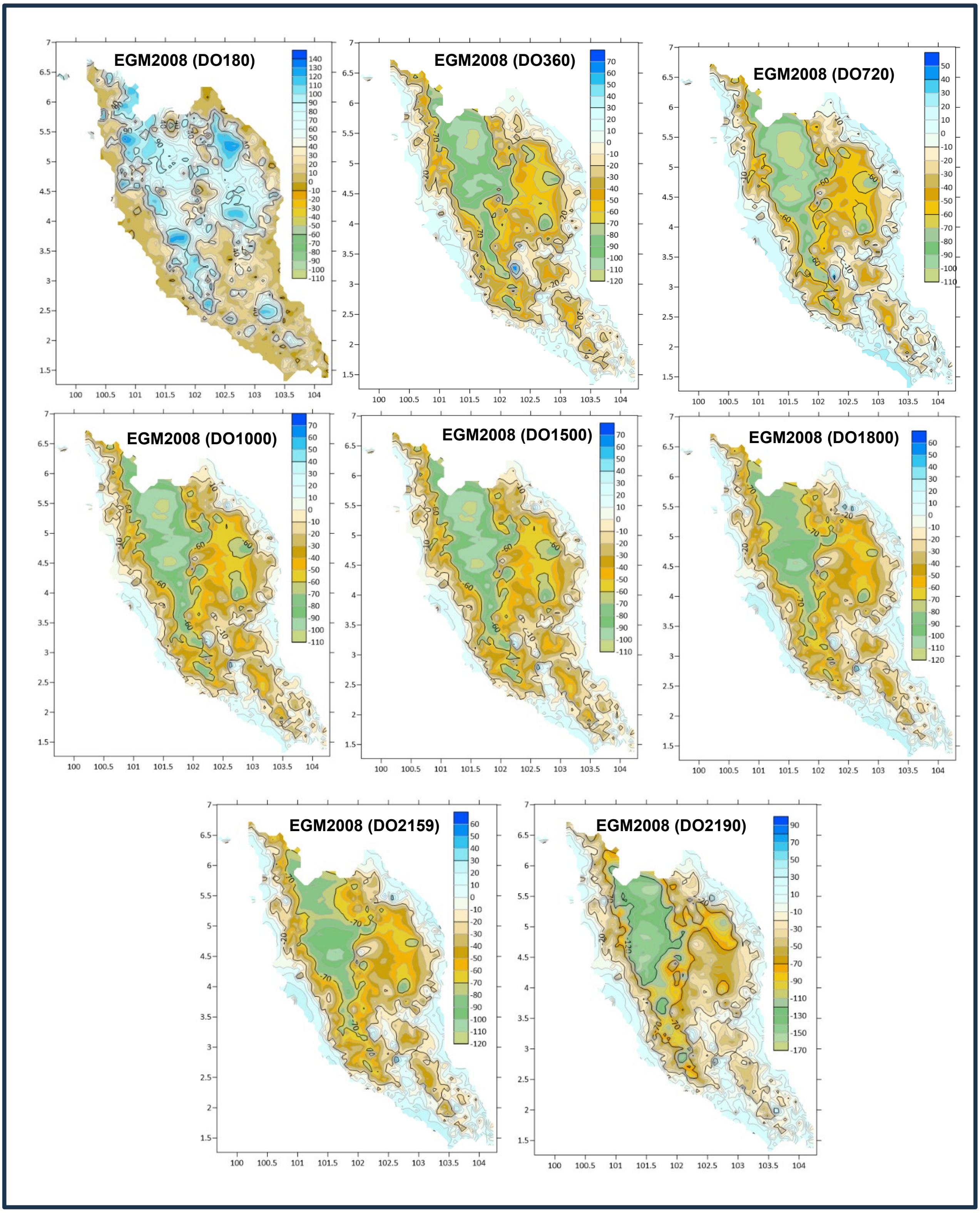


Figure 7. The 1' gridded residual gravity anomaly derived from EGM2008 with different degrees and order in terms of spherical harmonic coefficients

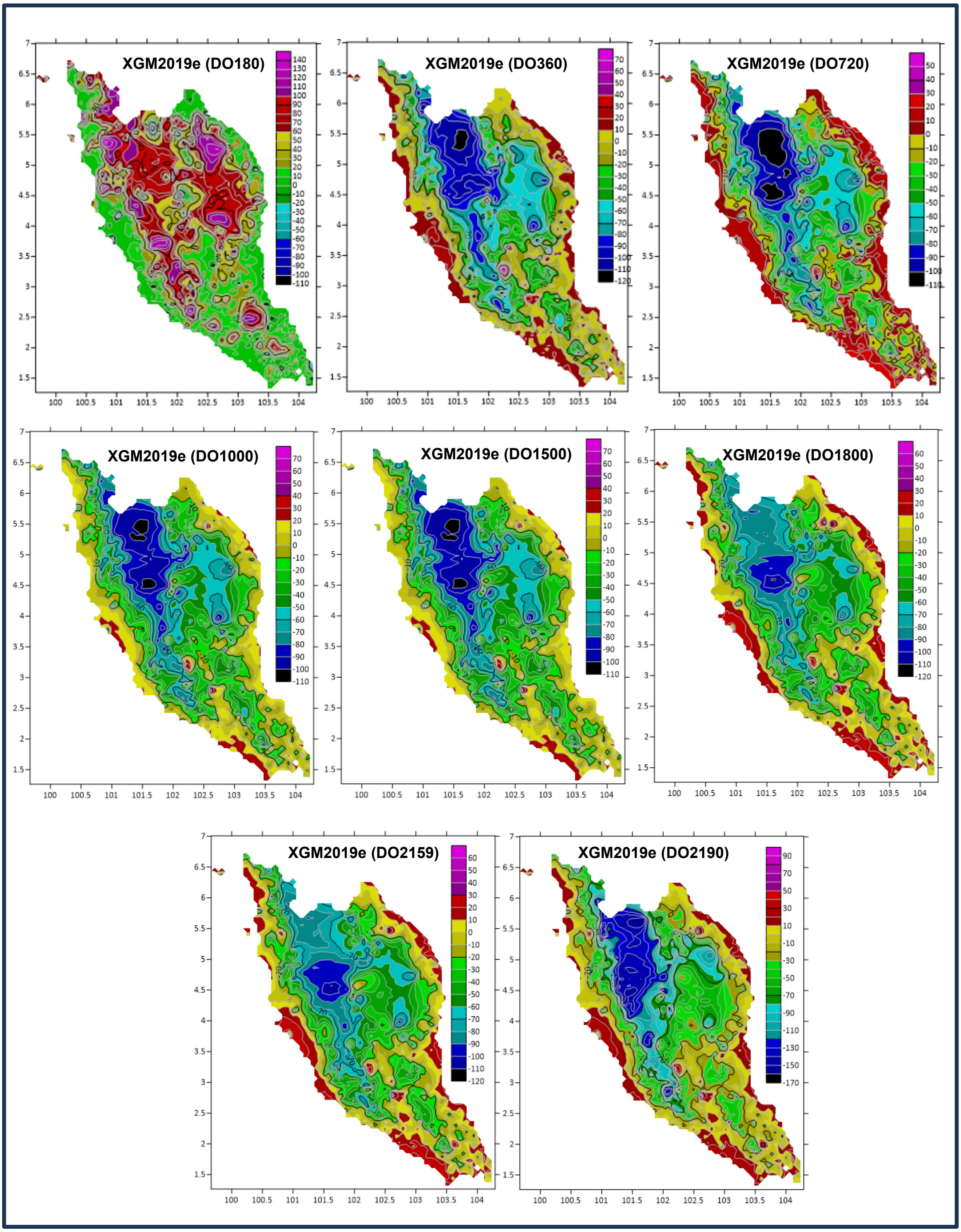
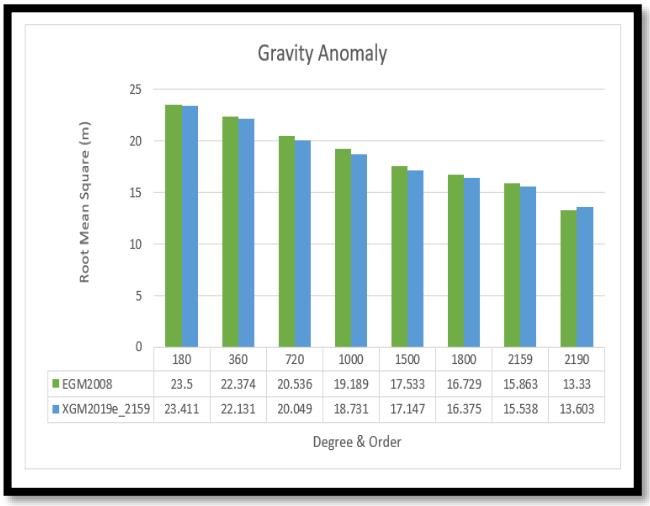


Figure 8. The 1' gridded residual gravity anomaly derived from XGM2019e_2159 with different degrees and orders in terms of spherical harmonic coefficients

Finally, the statistical analysis will be evaluated based on the RMS value derived from geopotential models used with different maximum degrees and orders regarding the spherical harmonic coefficient. The bar graph shows the RMS value differences of EGM2008 and XGM2019e_2159 with different maximum degree and order. Based on the bar graph in Figure 9 shows how precise the data is around the line of best fit to determine which geopotential model has the lowest RMS value. The lowest RMS value will be selected as the most accurate geopotential model that can be used as a reference for Peninsular Malaysia.



	180	360	720	1000	1500	1800	2159	2190
EGM2008	23.5	22.374	20.536	19.189	17.533	16.729	15.863	13.33
XGM2019e_2159	23.411	22.131	20.049	18.731	17.147	16.375	15.538	13.603

Figure 9. The statistical analysis of the RMS value differences between terrestrial gravity data and geopotential models

V. CONCLUSION

In conclusion, the aim of this study has been achieved. This study aims to determine a precise and best-fit geopotential model for Peninsular Malaysia. There are two geopotential models analysed. Based on the geoid height results, it shows that the latest geopotential model, XGM2019e_2159, with a maximum degree and order 720, has the lowest RMS value compared to EGM2008. In contrast, for gravity anomaly, EGM2008 with maximum degree and order 2190 is the most accurate geoid model used as a reference in Peninsular Malaysia for accuracy evaluation. Hence, it can be concluded that XGM2019e_2159 and EGM2008 are the best fit and the most accurate geopotential models for Peninsular Malaysia.

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