MARINE GEOID UNDULATION ASSESSMENT OVER SOUTH CHINA SEA USING GLOBAL GEOPOTENTIAL MODELS AND AIRBORNE GRAVITY DATA

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ABSTRACT:

Global geopotential models (GGMs) are vital in computing global geoid undulations heights. Based on the ellipsoidal height by Global Navigation Satellite System (GNSS) observations, the accurate orthometric height can be calculated by adding precise and accurate geoid undulations model information. However, GGMs also provide data from the satellite gravity missions such as GRACE, GOCE and CHAMP. Thus, this will assist to enhance the global geoid undulations data. A statistical assessment has been made between geoid undulations derived from 4 GGMs and the airborne gravity data provided by Department of Survey and Mapping Malaysia (DSMM). The goal of this study is the selection of the best possible GGM that best matches statistically with the geoid undulations of airborne gravity data under the Marine Geodetic Infrastructures in Malaysian Waters (MAGIC) Project over marine areas in Sabah. The correlation coefficients and the RMS value for the geoid undulations of GGM and airborne gravity data were computed. The correlation coefficients between EGM 2008 and airborne gravity data is 1 while RMS value is 0.1499.In this study, the RMS value of EGM 2008 is the lowest among the others. Regarding to the statistical analysis, it clearly represents that EGM 2008 is the best fit for marine geoid undulations throughout South China Sea.

1. INTRODUCTION

1.1 Background of the study

Geoid generally can be defined as a level surface and also as being everywhere perpendicular to gravity (Talone et al., 2014). The shape of the geoid is actually relatively close to the shape of an ellipsoid with an equatorial radius 21.4 km longer than the polar radius (Hughes and Bingham, 2008). Therefore, the global geoid undulations from EGM 2008, ITG GOCE 02, AIUB CHAMP 03s and ITG GRACE 02s are employed in this study for data derivation and verification.

Global Geopotential Model (GGM) can be described as the mathematical model that clarifies gravitational potential in a spectral domain by using spherical harmonic expansions. GGM has been published by the International Center for Global Earth Models (ICGEM).Besides, these models can provide the medium and long wavelength part of a gravimetric geoid in the resolution and accuracy aspect (Sadiq & Ahmad, 2009)and comprise data mainly from CHAMP (Reighber et al., 1999) and GRACE (Reighber et al., 2000) satellite gravity missions. Generally, GGMs are comprised of two main types, so called satellite only GGM and combined GGM for the determination of global, regional and local geoid models. According to Sulaiman (2016), the development of GGM consists of the combining of two existing GGMs called tailored GGMs but these GGMs do not published by ICGEM. Thus, this study is concerted on the main types of GGMs published by ICGEM (Satellite-only and Combined). Satellite-only GGMs are derived from the assessment of satellite-based gravity observations (CHAMP and GRACE), or combined with other satellite missions such as Laser Geodynamic Satellite (LAGEOS), European Remote Sensing Satellite (ERS) and Geodetic Satellite (GEOSAT). Figure 1 represents a sample of spectral evaluations of satellite-only and combined GGM, which is compared to the most recent combined model. Each spectral evaluation model consists of the signal amplitudes per degree of the model and the differences in amplitudes with the recent combined model.

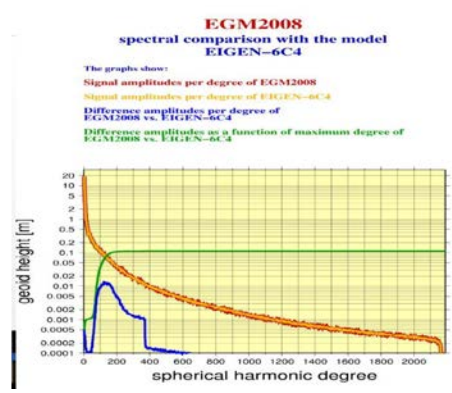

Figure 1. Spectral Comparison of EGM 2008 with the Model EIGEN-6C4 (ICGEM, 2015)

Featherstone and Rummel (2002) emphasized that the accuracy of satellite-only GGMs are weak at the higher degree of coefficients due to power decay of the gravitational field with altitude, incomplete tracking of satellite orbits using ground stations, less precise modeling of non-Earth gravity field induced satellite motion, such as atmospheric drag and third body influences, and poor coverage of sampling global gravity fields.

Combined GGMs are derived from combinations of satellite-only GGMs with terrestrial gravity data (Land and Marine), gravity anomaly for satellite altimetry, airborne gravimeter, topography and bathymetry. By combining all the gravity data, some of the limitations on the higher degree expansion can be diminished; however the errors in terrestrial data still remain. Generally, combined GGMs provide better fits to the terrestrial gravity data than satellite-only models. Besides, these combinations leads towards the best approximation of the Earth's gravitational field.(Sadiq & Ahmad, 2009).In this study, both (combine and satellite-only) GGMs are required. GGMs will be used to improve the deficiencies in land and marine gravity data, while satellite only GGMs will be used in the LSMS formula in the determination of precise, seamless geoid models

Moreover, the medium to wavelength geoid signal is the main component of the geoid, *N* and its value can be assessed from GGM. It can be expressed in terms of a set of spherical harmonic coefficients up to a certain degree and order. The localised geoid undulations can be achieved when a best fit GGM is chosen for a certain area (Sadiq & Ahmad, 2009)

1.2 Geoid Undulations of Global Geopotential Model (GGM)

The geoid is an equipotential surface of the Earth's gravity field that is closely associated with the location of the mean sea surface (Picot et al., 2003). Geoid also can be defined as a level surface defined as being everywhere perpendicular to gravity (Talone et al., 2014). Therefore, in a motionless ocean, the sea surface would be everywhere parallel to the geoid (Talone et al., 2014). The shape of the geoid is actually relatively close to the shape of an ellipsoid with an equatorial radius 21.4km longer than the polar radius (Hughes and Bingham, 2008).

This ellipsoid gives the plane normal to the local effective gravity, which is no more than the vector addition of the Earth's gravity acceleration and the Earth's centripetal acceleration (a function of latitude, associated with the rotation of the Earth around its axis) (Talone et al., 2014). However, the geoid may locally depart from this ellipsoid by up to 100m because of regional changes in the gravitational field (Hughes and Bingham, 2008).

The global geoid heights also can be extracted from the International Center for Global Earth Model (ICGEM) conducted spectral evaluations by comparing the existing GGMs with the new combined GGM such as ITG-GRACE 02s, EGM 2008, ITG-GOCE 02s and AIUB CHAMP 03s. From the current (Oct 2012) global evaluation, EGM 2008 is the best fit GGM for a combined solution. However, the results from global evaluation should not be used directly as a suitable GGM model for the determination of localised geoid model. (Kiamehr, 2006).

Global evaluation results can be used as a guide for selecting the most appropriate GGM for localised geoid undulations model determination. Therefore, in the determination of localised geoid undulations models, the localised evaluation of the most suitable model should be performed. Thus, this study will assist to ascertain the most feasible GGM which best matches for the local marine geoid undulations covering South China Sea.

1.3 Airborne Gravity Data

In this study, the accuracy of GGMs are evaluated with airborne gravity data under the Marine Geodetic Infrastructures in Malaysian Waters (MAGIC) project in Sabah. This project involves some recent (2014-2015) airborne gravity surveys undertaken by the Department of Survey and Mapping Malaysia (DSMM) (JUPEM, 2014/2015).

Airborne gravity data from previous field campaign carried out in 2002-2003 over land area in Sabah has been combined with the present marine airborne gravity data to provide a seamless land-to-sea gravity field coverage (JUPEM, 2003). The airborne gravity survey database for land and marine areas of Sabah is considered complete and has been compiled in ArcGIS geo-database format. Some geological inferences also has been presented to initiate further research on the application of gravity field in marine geology and geophysics.

Airborne gravimetry is an effectual implement for mapping local gravity fields using a combination of airborne sensors, aircraft and positioning system. It is appropriate for gravity surveys over difficult terrains and areas mixed with land and ocean. The development of airborne gravimetry has been made possible by the employment of the kinematic Global Positioning System (GPS) technique as well as improvement in airborne gravity acceleration sensor system. The best accuracy of the airborne gravimetry is 1-2 mGal at 5km resolution for fixed-wing aircraft (Forsberg et al, 1999 and Olesen et al, 2007).

Gravity measurements from an airborne are performed on the background of inertial disturbing accelerations which are caused by the vehicle's dynamics (Childers *et al*, 1999). The value of inertial accelerations may be several hundred thousand times as high as the valid signal and can overlap with it in the spectral frequency domain (Sokolov, 2011). The analysis of spectral characteristics of marine inertial acceleration allows the methods of low-frequency filtering to be used in practice to eliminate the effect of vertical disturbing accelerations during marine survey (Zheleznyak ,2002).Thus, this purpose can be achieved with the employment of coprocessing of gravimetric data and navigation information (Stepanov et al, 2005).

The assessment of marine geoid undulations by using GGMs; EGM 2008, ITG-GRACE 2010s, ITG-GOCE 02s and AIUB CHAMP 03s is useful for the determination of the best GGM for Malaysian seas. This can be utilised for further research in order to determine the localised marine geoid undulations for Malaysian seas. Nevertheless, the significance of the GGM are useful for the determination of global geoid undulations and gravity anomaly.

2.0 RESEARCH APPROACH

2.1 Study Area.

The area under study is bounded between latitude 1°N to 9°N and longitude 109°E to 120°E as represented in Figure 2. This study area is focused on South China Sea. The study area is chosen based on the airborne gravity data provided by DSMM covering this area.

Figure 2. The map of the study area

2.2 Data Preparation and Processing

Currently, there are more than 50 geopotential models available at the International Center for Global Gravity Earth Models (ICGEM) and an open source for the global scientific community at http://icgem.gfz-potsdam.de/ICGEM/. In this study, discussion is emphasised on the GGM from satellite-only and the combined. Four (4) GGM have been selected which are EGM 2008, ITG-GRACE 2010s, ITG-GOCE 02s and AIUB CHAMP 03s as shown in Table 1.

This selection is based on necessity for evaluation so that a match could be achieved in both medium and long wavelength with the ground truth data (Sadiq & Ahmad, 2009). Among these EGM 2008 is the developed combined GGM with very high degree of spherical harmonic expansion which is up to 2190 degree. EGM 2008 is the only combined model that is selected in this study. This is based on the earlier research,(Pavlis et al., 2008; Sadiq & Ahmad, 2009; Yi & Rummel, 2014) where EGM 2008 is the most comprehensive representation and the highest resolution of the Earth's gravitational field.

Model	Year	Degree	Data
EGM 2008	2008	2190	S(Grace),G,A
AIUB-CHAMP03S	2010	100	S(Champ)
ITG-Grace2010s	2010	180	S(Grace)
ITG-Goce02	2013	240	S(Goce)

Table 1. The list of GGMs for Evaluations

Nevertheless, the computation of GGMs is compressed with a set of fully normalized spherical harmonic coefficients that represent the Earth's gravitational potential outside relevant masses. Each geopotential model will provide the information regarding to the Newtonian gravitational constants (G) and the mass of the earth (M), normal gravity on the surface of the reference ellipsoid (γ), a reference radius (R), fully normalized Stokes' Coefficients for each degree n and order m ($\bar{C}_{nm}$ and $\bar{S}_{nm}$) and its respective standard errors ($\sigma\bar{C}_{nm}$ and $\sigma\bar{S}_{nm}$). Thus, the geoid heights and gravity anomalies can be computed based on these equations.

Therefore, to compute the geoid undulations regarding to the GGMs data, Equation 1 is referred.

$$\Delta N_{GGM} = \frac{GM}{r\gamma}\sum_{n=2}^{m}\left(\frac{a}{r}\right)^{n}\sum_{m=0}^{n}(\bar{C}_{nm}\cos m\lambda + \bar{S}_{nm}\sin m\lambda)\bar{P}_{nm}(\cos\theta) \quad (1)$$

Where ΔN_{GGM} = the geoid heights derived from the global geopotential model (GM).
GM = the product of the Earth's mass and the gravitational constant
r = the radial distance to the computation point, a is the semi-major axis of the reference ellipsoid
$\bar{C}_{nm}$ and $\bar{S}_{nm}$ = fully normalized harmonic coefficients
$\bar{P}_{nm}$ = the fully normalized Legendre function
θ and γ = the geodetic latitude and longitude of the computation point

The spatial resolution of geoid heights provided by GGM on the Earth's surface is determined by the maximum number of complete harmonic expansions (max).

The geoid undulations from GGMs are computed by EGMlab1 software programmed by Mehdi Eshagh and Ramin Kiamehr from Division of Geodesy, Royal Institute of Technology, Stockholm, Sweden in year 2012. This program computed the anomalies quantities such as geoidal height, gravity anomaly east-west and north-south components of deflection of verticals using GGMs.

There are some considerations must be counted while making the assessment of the GGMs with the ground truth data (Sadiq & Ahmad, 2009):

i. The scale difference between the GGM and adopted reference ellipsoid parameters, eg. Earth-gravity mass constant GGM and semi-major axis, etc. provide towards the difference in the results.

ii. The collected terrestrial gravity data may have medium and long wavelength errors and GGM derived quantities are relatively less prone to this type of error as mentioned by Heck (1990).

As mentioned by Kiamehr (2006) and Sulaiman (2016) the assessment of the global geoid undulations should not be directly employed to nominate the most appropriate GGM for the determination of a geoid model. This due to the global statistics does not essentially signify the valid information about the region. In finalising the most suitable GGM for the localised geoid undulations modelling, the following approaches are commonly depleted:

i. Analysing the differences between the geoid undulations from airborne gravity data and GGM.
ii. Compute the root mean square (RMS) different between the geoid undulations from GGM and airborne gravity data.

Thus, the assessment of the mentioned approach is analysed in order to ascertain the most appropriate GGM suited for Malaysian seas Then, four (4) GGM were evaluated as represented in Table 1. The assortment criteria are generally based on which of the GGMs is the closest fit to the geoid undulations from airborne gravity data.

Normally, geoid undulations are derived from GGM based on Equation 1. The assessment of the best fit GGM for local use are required to compare the derived geoid undulations from GGMs with the airborne gravity data. Therefore, the best fit GGM is determined based on the lowest RMS in the statistical analysis of the geoid undulations residual. The geoid undulations residual is computed by using Equation 2.

$$\Delta N_{residual} = N_{GGM} - N_{airborne} \qquad (2)$$

Where $\Delta N_{residual}$ is the residual geoid undulations, N_{GGM} is the geoid undulations from GGM and $N_{airborne}$ is the geoid undulations from the airborne gravity data.

Subsequently, the RMS different for the $\Delta N_{residual}$ was computed based on Equation 3:

$$RMS = \sqrt{\frac{\sum_{i=0}^{n}(\Delta N_{residual})^2}{n}} \qquad (3)$$

Where n = the total number of points

Thus, the lowest RMS different for the assessment of N_{GGM} with $N_{airborne}$ indicate the best fit GGM for the South China Sea.

2.3 Marine Geoid Undulations from Airborne Gravity Data

The geoid undulations from GGM are evaluated with airborne gravity data from DSMM. The GGM that present closest statistical fit to the ground truth data can be implicit as the most suitable model to adopt for the determination of local marine geoid undulation for South China Sea. Nevertheless, the best fit of the GGM with airborne gravity data is the lowest standard deviation of the differences and the lowest R.M.S but not the best model (Rudriguez-Caderot et al., 2006) Figure 3 represents the airborne track covering the South China Sea. Figure 4 corresponds to the map of the airborne gravity data covering the South China Sea.

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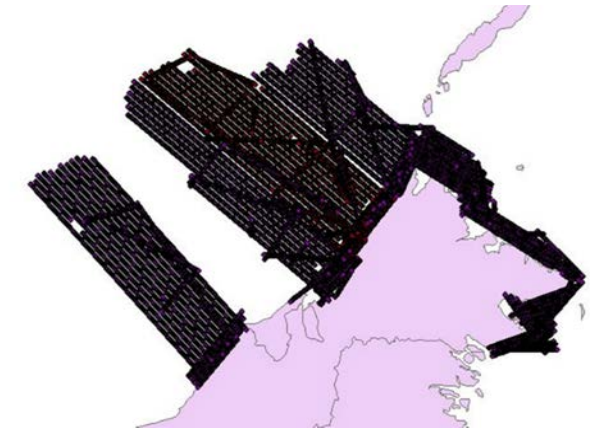

Figure 3. Airborne track in Sabah

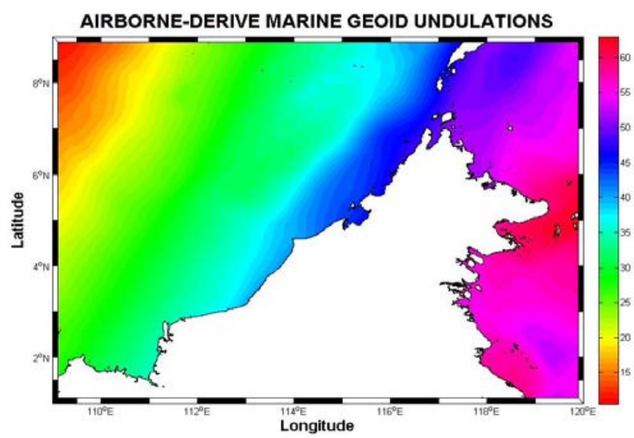

Figure 4: Airborne-derived marine geoid map covering South China Sea

3.0 RESULTS AND DISCUSSION

3.1 Global Geopotential Models (GGMs); EGM 2008, ITG-GRACE 2010s, ITG-GOCE 02s and AIUB CHAMP03s

The geoid undulations from GGMs have been extracted for the Malaysian region covering the South China Sea on 0.25º by 0.25º regular grids. These extractions are vital in order to evaluate the geoid undulations from GGM and airborne gravity data. The ICGEM format accommodates the GGM in terms of spherical harmonic coefficients, the ocean and atmosphere tides. Figure 5 illustrates the EGM 2008, ITG-GRACE 2010s, ITG-GOCE 02s and AIUB CHAMP 03s. These evaluations will assist the clarification of the best GGM that is merged to the South China Sea. Based on Figure 5, it seems very similar performances in terms of mapping. However, there are differences for each GGM as explained in Figure 6, 7 and Table 2.

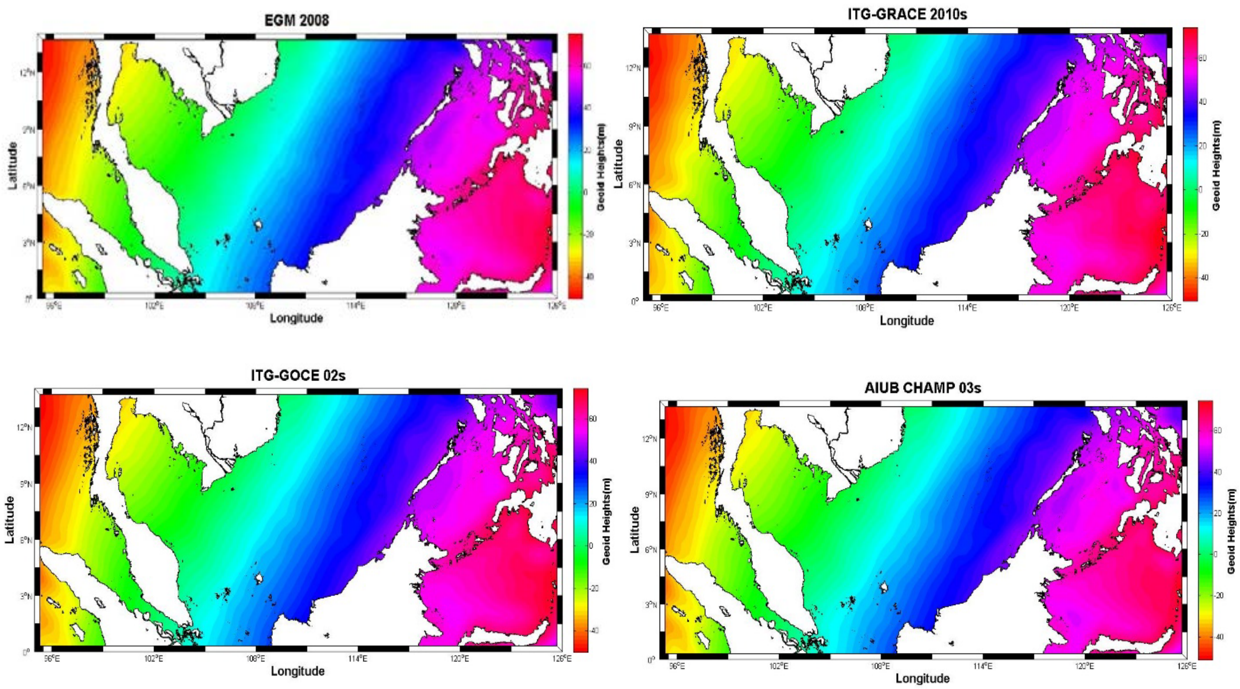

Figure 5. The geoid undulations from GGM (EGM 2008, ITG-GRACE 2010s, ITG-GOCE 02s and AIUB CHAMP 03s)

3.2 Comparisons of Marine Geoid Undulations from GGMs and Airborne Gravity Data

The information on the top rankings of GGMs based on Root Mean Square (RMS) difference between GGM compared to airborne gravity data from Department of Survey and Mapping Malaysia (DSMM) as display in Table 2. This assessment is comprised of well distributed 130 selected points covering the South China Sea.

As mentioned in Section 1.1, the advantage will be achieved in the localised geoid undulations modelling process when a best fit GGM is chosen for a certain region. This will contribute towards the reduction of the geoid entailed from regional integration of Stoke's formula or other amendments (Sadiq & Ahmad, 2009). Besides, some errors contained in GGMs which are distinguished with the evaluation from airborne gravity data.

The correlation between the airborne gravity data and the GGMs as shown in Figure 6. Thus, EGM 2008 represents the highest correlation compared to the other GGMs. The correlation between EGM 2008 and airborne gravity data is equal to 1. Thus, it can be described as the relationship or association between EGM 2008 and airborne gravity data is so related with each other. Nevertheless, ITG-GRACE 2010s is the lowest correlation coefficients compared to the others. Therefore, it is the most suitable GGM to adopt for the determination of local marine geoid undulations for Malaysian Sea. However, the verification towards the assessment of GGMs and airborne gravity data need to be discussed using statistical analysis.

The value of RMS for GGM both combined and satellite-only fluctuates are represented on Table 2. Nevertheless, the value still can be recognized. The range value of RMS is 0.1499m to 0.6157 for combined and satellite-only. EGM 2008 had the lowest RMS value compared to ITG-GRACE 2010s, ITG-GOCE 02s and AIUB CHAMP 03s. AIUB CHAMP03s represents the highest which is out to 0.6157m compared to the EGM 2008 which is only 0.1499. EGM 2008 is from the combined GGM that the accuracy of the combined GGM may be combined in terms of less omission errors in the characteristics of the models, and not necessarily in the improvement in low frequency measurements (Amos & Featherstone, 2003).

Besides, EGM 2008 is also from the combined GGMs which generally provide better fits to the gravity data than the satellite-only models (Sadiq & Ahmad, 2009). Nevertheless, it is conceivable that the satellite-only GGMs are more precise than the combined GGMSs because the later have infectivity from long and medium wavelength errors in the terrestrial gravity-data.

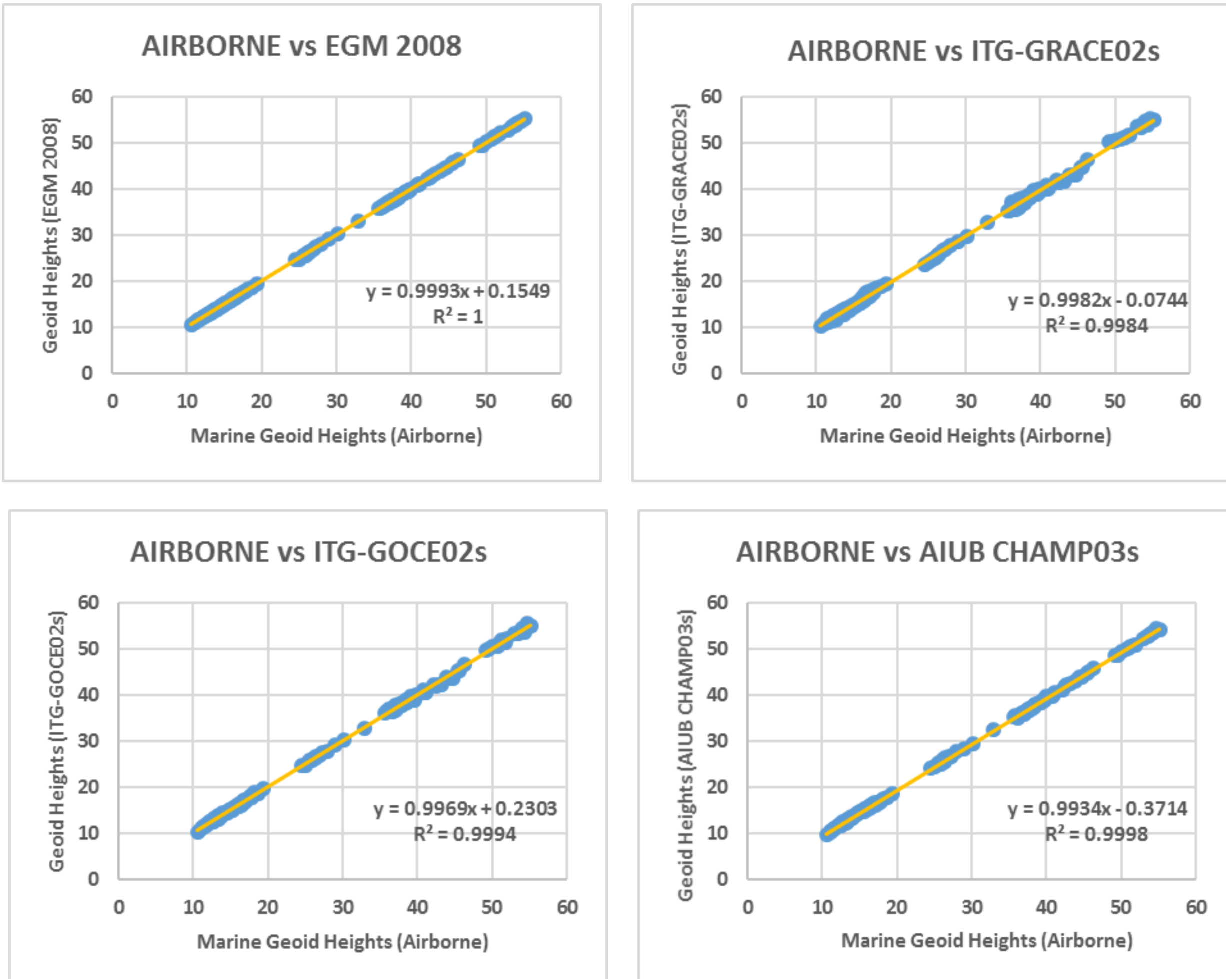

Figure 6. The correlation between the airborne gravity data and the GGMs (EGM 2008, ITG-GRACE 2010s, ITG-GOCE 02s and AIUB CHAMP 03s

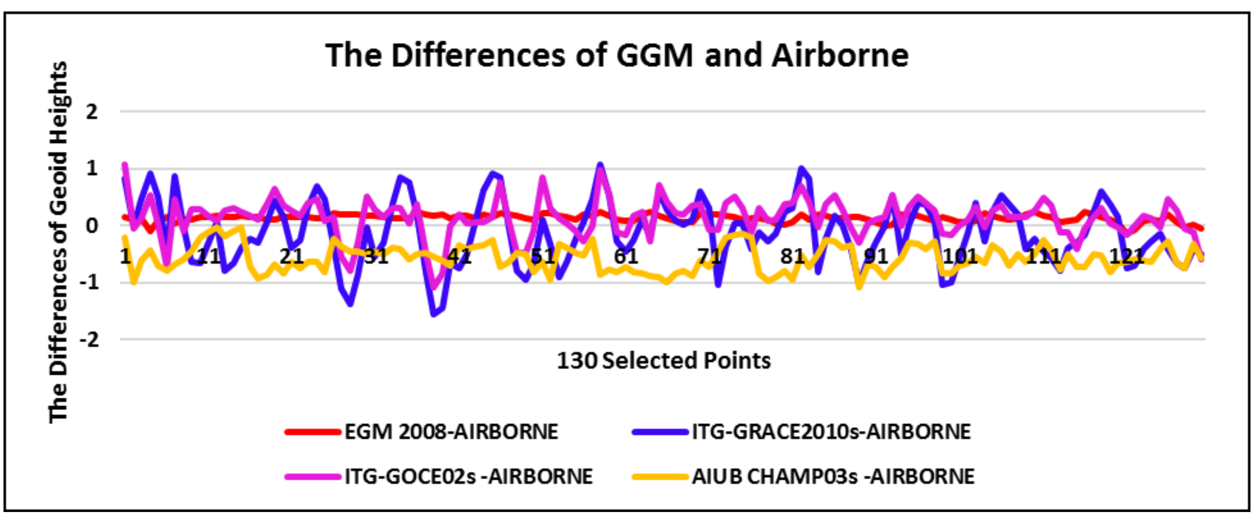

Figure 7. The difference of GGM data (EGM 2008, ITG-GOCE02s, ITG-GRACE2010s and AIUB CHAMP03s) with airborne gravity data

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	EGM 2008	ITG-GRACE 2010s	ITG-GOCE 02s	AIUB CHAMP 03s
Min(m)	10.79153	10.3726	10.4963	9.8198
Max(m)	55.2856	55.1672	55.1193	54.1808
Max Difference (m)	0.2475	-1.5645	1.0779	-1.0756
RMS (m)	0.1499	0.5694	0.3641	0.6157

Table 2. Statistic of geoid heights from GGMs compared to airborne gravity data

According to Figure 6, 7 and as shown in Table 2, EGM 2008 have very similar performances with the highest correlation (1m), the smallest maximum difference value (0.2475 m) and the smallest RMS value (0.1499) to airborne gravity data. EGM 2008 also being less than the ITG-GRACE 2010s, ITG-GOCE02s and AIUB CHAMP 03s. This is due to the free-air anomalies from airborne ellipsoid heights, converted to orthometric heights by the EGM2008 geoid undulations. Besides, the orthometric heights of the airborne is also referred to the EGM 2008.

Therefore, this provides the high correlation, the smallest maximum differences and the smallest RMS value between EGM 2008 and airborne gravity data. Thus, it clearly represents that EGM 2008 have the best fit for marine geoid undulations throughout the South China Sea. It could be indicated that the ITG GOCE 02, AIUB CHAMP 03s and ITG GRACE 2010s do not fit the region. Thus, it could be sufficient to prove the geoid undulations from EGM 2008 is the best GGM for Malaysian sea. EGM 2008 can be employed to enhance the deficits in the marine gravity data. This statistical results can be corroborated based on earlier studies (Sadiq & Ahmad, 2009) which is EGM 2008 is the very high degree of spherical harmonic expansion in relation to the new data addition.

Nevertheless, it should be emphasised that the results just a global evaluation test on the selected areas only. Thus, the results from the global evaluation should not be used directly as a suitable GGM model for localised marine geoid determination(Kiahmehr, 2006). This can be verified based on the previous research, the EGM 2008 is the most comprehensive representation and the highest resolution of the Earth’s gravitational field currently available. (Yi & Rummel, 2014) It combines the GRACE satellite gravitational model ITG-GRACE 03s (Mayer-Gürr, 2007) with a global set of an area-mean free-air gravity anomalies given on a 5 arc-minute equiangular grid.

However, in the other regions such as South America, Africa, South-East Asia or China, where the surface gravity data available for the development of EGM 2008 were poor. The RMS differences in this region are on a level of 30 cm. Besides, Sulaiman (2016) conducted a study related to land gravity observation throughout Peninsular Malaysia. Therefore, it is found that EGM 2008 represents the top of the list of GGM for land gravity data with .RMS 0.095m. Therefore, it can be concluded that EGM 2008 is the most suitable GGM for the marine and land regions for Malaysian Seas.

4. CONCLUSIONS

As such this assessment of ground truth data with GGM has presented important information towards the best fit GGM for subsequent gravimetric geoid. Based on the statistical analysis, this study can be concluded that EGM 2008 is the best fitting GGM which has the lowest RMS and standard deviation latter the assessment with the airborne gravity data. The statistical results are used to advocate the EGM 2008 in all aspects. The reasons of this due to the high degree of spherical harmonic expansion in relation to the addition of new data. If the localised geoid undulations based on the satellite-only GGM, ITG-GOCE 02s could be appropriate to replace EGM 2008. Since, ITG-GOCE 02s is the second best GGM for this study.

Besides, EGM 2008 also represents the highest correlation coefficients compared to the others. However, ITG-GRACE 2010s represent the worst correlations coefficients with airborne gravity data Therefore, it can be concluded that EGM 2008 is the best matches of GGM with the local marine geoid undulations of the South China Sea. It is highly recommended that the assessment of GGM with airborne gravity data can assist towards the determination of local marine geoid undulations by using the latest technology. For example the satellite radar altimeter. The combination between the satellite altimeter and satellite gravity missions data could grant the high dense data.

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APPENDIX

THE LIST OF THE 130 POINTS USED FOR THE ASSESSMENT OF MARINE GEOID UNDULATIONS BETWEEN GGMS AND AIRBORNE GRAVITY DATA

	Latitude	Longitude	AIRBORNE	EGM 2008	ITG-GRACE 2010s	ITG-GOCE 02s	AIUB CHAMP 03s
1	1.25	119.25	54.596	54.75537	55.4136	55.67394	54.3899
2	1.5	119.25	55.173	55.28564	55.16727	55.11926	54.1808
3	1.5	119.5	54.068	54.18852	54.53846	54.199	53.4512
4	1.75	119.25	53.921	53.83353	54.82978	54.44681	53.4837
5	1.75	119.5	53.573	53.66774	54.07631	53.61763	52.8645
6	1.75	119.75	54.371	54.51857	53.9119	53.64043	53.5828
7	2	119.5	52.887	52.93668	53.76737	53.36181	52.2125
8	2	119.75	53.545	53.6536	53.52032	53.45576	52.9613
9	3	109.5	26.217	26.33376	25.57608	26.49298	25.7647
10	3.5	109.75	25.992	26.14231	25.33658	26.28298	25.7937
11	3.5	110	26.956	27.10744	26.62602	27.12438	26.8338
12	3.5	110.25	27.894	28.06517	27.94675	27.98627	27.8598
13	3.75	109.5	24.551	24.70645	23.75504	24.82092	24.3731
14	3.75	109.75	25.467	25.61858	24.79991	25.78482	25.371
15	3.75	110	26.414	26.58105	26.01786	26.6586	26.3833
16	6.5	109	16.161	16.30745	15.92407	16.3433	15.4353
17	6.5	109.25	17.086	17.24093	16.78504	17.18762	16.1689
18	6.5	109.5	17.644	17.74512	17.70967	18.01564	16.7948
19	6.5	109.75	18.221	18.33638	18.65469	18.86641	17.5418
20	6.5	110	19.413	19.56407	19.56666	19.76585	18.5843
21	6.75	109	15.583	15.74164	15.20608	15.84136	14.954
22	6.75	109.25	16.373	16.51793	16.12619	16.5448	15.6332
23	6.75	109.5	16.777	16.92077	17.11635	17.18425	16.1386
24	6.75	109.75	17.419	17.54866	18.11835	17.87405	16.7773
25	6.75	110	18.612	18.74397	19.06864	18.70623	17.7925
26	6.75	115.25	39.967	40.18163	39.62065	40.12424	39.7443
27	6.75	115.5	42.448	42.65544	41.33411	41.89402	42.0803
28	6.75	115.75	44.42	44.62396	43.04049	43.61766	43.9589
29	6.75	116	45.58	45.78489	44.71131	45.28551	45.1203
30	6.75	116.25	46.345	46.51129	46.31785	46.85542	45.8478
31	7	109	14.952	15.12652	14.41094	15.23453	14.5048
32	7	109.25	15.701	15.86222	15.39733	15.85451	15.1957
33	7	109.5	16.075	16.21132	16.46108	16.37659	15.6848
34	7	109.75	16.668	16.79236	17.52675	16.97319	16.2657
35	7	110	17.753	17.87365	18.521	17.78389	17.164
36	7	115.25	38.47	38.70292	38.67207	38.83792	37.9638
37	7	115.5	40.975	41.16045	40.15915	40.4956	40.4867
38	7	115.75	43.234	43.41638	41.66951	42.15944	42.6779
39	7	116	44.646	44.84142	43.20761	43.80774	44.0245
40	7	116.25	45.423	45.55412	44.77169	45.41204	44.7242
41	7.25	109	14.339	14.51212	13.58589	14.54542	13.9896

42	7.25	109.25	15.135	15.30221	14.63468	15.18378	14.7209
43	7.25	109.5	15.652	15.78882	15.76319	15.70429	15.287
44	7.25	109.75	16.252	16.45626	16.88091	16.30498	15.917
45	7.25	110	16.998	17.14418	17.90914	17.14396	16.7425
46	7.25	115.25	37.041	37.26626	37.88184	37.8099	36.3136
47	7.25	115.5	39.109	39.30793	39.06048	39.16704	38.4682
48	7.25	115.75	41.107	41.27911	40.32158	40.62442	40.6389
49	7.25	116	42.662	42.79534	41.7059	42.18069	42.1695
50	7.25	116.25	43.914	44.03029	43.23294	43.82074	43.0915
51	7.25	118	51.206	51.42618	51.30697	52.0485	50.5595
52	7.25	118.25	51.994	52.22212	51.66483	52.29276	51.0333
53	7.5	109	13.728	13.91234	12.81344	13.85152	13.4028
54	7.5	109.25	14.543	14.69783	13.91136	14.59317	14.1504
55	7.5	109.5	15.311	15.42188	15.08078	15.21073	14.8331
56	7.5	109.75	16.16	16.35353	16.22263	15.89458	15.637
57	7.5	110	16.793	16.97705	17.26096	16.793	16.5633
58	7.5	115.25	36.185	36.42265	37.24708	37.1584	35.3311
59	7.5	115.5	37.577	37.75958	38.10801	38.12406	36.804
60	7.5	115.75	39.398	39.51211	39.12724	39.28241	38.5931
61	7.5	116	40.839	40.91919	40.37569	40.67721	40.113
62	7.5	116.25	42.133	42.21014	41.8844	42.31236	41.3143
63	7.5	118.25	51.127	51.32983	51.22478	51.37273	50.2891
64	7.5	118.5	51.8	52.04058	51.60982	51.51561	50.9085
65	7.75	115.25	36.124	36.30435	36.73077	36.8444	35.2131
66	7.75	115.5	37.045	37.1666	37.33845	37.45564	36.059
67	7.75	115.75	38.09	38.1643	38.17652	38.31245	37.2629
68	7.75	116	39.309	39.38043	39.33247	39.51038	38.5076
69	7.75	116.25	40.728	40.79458	40.83863	41.08059	39.8361
70	7.75	118.25	50.118	50.34244	50.72216	50.49956	49.507
71	7.75	118.5	50.677	50.87307	50.99593	50.60771	49.9506
72	8	109	12.759	12.9644	11.72048	12.68786	12.2983
73	8	109.25	13.224	13.3886	12.8472	13.62524	13.0192
74	8	109.5	13.942	14.09685	13.98928	14.45928	13.7801
75	8	109.75	15.02	15.13645	15.06022	15.32438	14.8792
76	8	110	16.425	16.54703	16.01985	16.31463	16.2232
77	8	115.25	36.419	36.54215	36.29384	36.72164	35.5823
78	8	115.5	37.044	37.14072	36.76561	37.12106	36.078
79	8	115.75	37.661	37.69987	37.5131	37.75756	36.7525
80	8	116	38.389	38.41437	38.62317	38.76592	37.6055
81	8	116.25	39.806	39.8601	40.12223	40.21234	38.8542
82	8	118.25	49.188	49.37688	50.20295	49.86781	48.6752
83	8	118.5	49.504	49.60573	50.33864	49.92514	48.7676
84	8.25	109	12.232	12.42501	11.41634	12.19376	11.7403
85	8.25	109.25	12.739	12.91614	12.51536	13.11934	12.4826
86	8.25	109.5	13.425	13.56278	13.58809	13.9569	13.1604
87	8.25	109.75	14.549	14.67794	14.56814	14.82635	14.1689
88	8.25	110	15.869	16.03123	15.4452	15.80747	15.5202
89	8.25	115.25	36.941	37.08556	35.92056	36.63973	35.8654
90	8.25	115.5	36.978	37.0872	36.39127	37.01446	36.2953
91	8.25	115.75	37.443	37.51174	37.13783	37.55301	36.7271

92	8.25	116	38.246	38.23435	38.23001	38.40468	37.3426
93	8.25	116.25	39.154	39.17204	39.68651	39.67634	38.4217
94	8.5	109	11.689	11.87977	11.17087	11.68057	11.119
95	8.5	109.25	12.203	12.38699	12.21946	12.52984	11.8986
96	8.5	109.5	12.795	12.96919	13.20009	13.29819	12.4703
97	8.5	109.75	13.699	13.83022	14.07097	14.10801	13.2925
98	8.5	110	14.779	14.85991	14.85382	15.04191	14.508
99	8.5	115.25	36.673	36.82291	35.62187	36.52189	35.8257
100	8.5	115.5	37.2	37.30645	36.20606	37.03481	36.3612
101	8.5	115.75	37.594	37.65256	37.01366	37.58636	36.8833
102	8.5	116	38.202	38.26389	38.08518	38.31372	37.5529
103	8.5	116.25	39.044	39.12885	39.43521	39.36606	38.5019
104	8.75	109	11.132	11.35306	10.85775	11.11207	10.4714
105	8.75	109.25	11.608	11.79309	11.84773	11.87571	11.2567
106	8.75	109.5	12.208	12.34409	12.73501	12.55173	11.7481
107	8.75	109.75	13.124	13.23205	13.50128	13.27382	12.4268
108	8.75	110	13.992	14.12741	14.19692	14.13828	13.5007
109	8.75	112.75	26.335	26.52814	25.93124	26.49467	25.702
110	8.75	113	27.242	27.48386	27.00661	27.51365	26.7526
111	8.75	115.25	35.869	36.04829	35.41484	36.36479	35.6177
112	8.75	115.5	36.749	36.90553	36.17922	37.10785	36.3067
113	8.75	115.75	37.852	37.91401	37.06921	37.73872	37.0785
114	8.75	116	38.47	38.55388	38.08987	38.36158	37.9619
115	8.75	116.25	39.565	39.66272	39.25812	39.16214	38.8291
116	9	109	10.544	10.79153	10.37259	10.49634	9.81985
117	9	109.25	11.066	11.26546	11.31685	11.21844	10.5583
118	9	109.5	11.525	11.67477	12.13463	11.83491	11.0022
119	9	109.75	12.445	12.55282	12.82446	12.48638	11.6384
120	9	110	13.313	13.36243	13.45701	13.28098	12.6522
121	9	112.5	25.05	24.90229	24.30062	24.8941	24.411
122	9	112.75	25.813	25.74825	25.11479	25.80926	25.2195
123	9	113.5	29.026	29.11852	28.61132	29.19352	28.4135
124	9	113.75	30.152	30.25427	29.87513	30.26972	29.524
125	9	114.5	32.926	33.00073	32.77926	32.88821	32.5061
126	9	115.25	35.708	35.90085	35.29147	36.17533	35.4259
127	9	115.5	36.902	36.97301	36.24634	37.1589	36.2493
128	9	115.75	37.952	37.91849	37.20444	37.89045	37.1983
129	9	116	38.546	38.55429	38.13475	38.42817	38.2145
130	9	116.25	39.558	39.50601	39.06176	38.97735	38.9924