EVALUATION OF THE EGM96 MODEL OF THE GEOPOTENTIAL IN PENINSULAR MALAYSIA

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ABSTRACT

A set of higher degree and order of spherical harmonic potential coefficients (C_{nm}, S_{nm}) plays an important part in gravity field modelling , e.g. reference model for the gravimetric solution. The satellite and terrestrial data used in the development of the global geopotential model have improves with time. For example, the most recent EGM96 model incorporate new 30' X 30' surface gravity anomalies, normal equations from direct altimetry data (TOPEX/POSEIDON, GEOSAT & ERS-1). This paper presents the accuracy of the anomalous gravity field determined from the potential coefficients of the EGM96 model over the Malaysia region. Dividing the region into 0.5° x 0.5° block and testing the mean fit for each block, it shows how well the residual gravity anomalies is modelled by EGM96 model compared to geopotential model OSU91A. To assess the quality of the estimated geoid height from EGM96(N_{EGM}) and OSU91A (N_{OSU}) , comparison are made with the corresponding height derived from 136 GPS control poinst ($N_{GPS/Lev}$). The overall results of absolute and relativen geoid height differences showed that the EGM96 is definitely the best high-order geopotential model to be used as reference gravity field modelling for the Peninsular Malaysia.

1.0 INTRODUCTION

The representation of the earth's gravitational potential by a set of spherical harmonic coefficients (C_{nm}, S_{nm}) has evolved considerably in the past 30 years. Geopotential models are needed to provide a reference field for terrestrially-derived gravity anomalies used for example, in Stokes' Integral, to find the high resolution of the geoid signal. Initial representations were of low degree harmonics and hampered by lack of surface gravity information. The improvements in data availability, mathematical developments, and computer hardware and software facilities have led to solutions that are complete to higher degree and order. The high resolution geopotential models have proven to be very useful to provide medium and long wavelength reference fields for anomalous gravity, enabling geoid determination to be carried out using local data, as demonstared by many geodesists, see Mainville, et.al., (1992) and Gil, et.al., (1993). The usefulness of high resolution geopotential models is further augmented by the increasing use of GPS data in geodetic surveying, especially in transforming the height from GPS surveys (ellipsoid height) into a meaningful physical quantity, orthometric height.

The accuracy of the local geoid solution depends partly upon how well the geopotential model matches the regional gravity field. It is therefore of interest to carry out a comparison and evaluation of the current geopotential models EGM96 and OSU91A for Peninsular Malaysia. The best fitting geopotential model therefore will be adopted as a major source of gravity field in this region. The region is divided into 0.5° x 0.5° blocks, and the mean and root mean square (RMS) of the residual gravity Δg_r are found to estimate the fit of the model to the local gravity data. The evaluation were also carried out by comparing a geoid undulation from augmented geopotential model with the ones implied by GPS survey data.

Comment [OBZ1]:

2.0 GEOPOTENTIAL MODELS AND ITS DEVELOPMENT

We start from the spherical harmonic representation of the Earth's gravitational potential, V as, Rapp and Pavlis (1990) :-

$$V(r,\theta,\lambda) = \frac{GM}{r}\left[1 + \sum_{n-2}^{\infty}\left[\frac{a}{r}\right]^{n} \sum_{m=-n}^{n} \overline{C}_{nm}^{s}\,\overline{Y}_{nm}(\theta,\lambda)\right] \qquad [\ 1\ ]$$

where r is the geocentric distance; θ is the geocentric co-latitude; and λ is the longitude; GM is the geocentric gravitational constant and a is the scaling factor associated with the fully normalizad coefficients, C_{nm}. In addition, we have

$$\overline{Y}_{nm}(\theta,\lambda) = \overline{P}_{nm}(\cos\theta)\ \cos\ m\lambda \quad \text{if } m \geq 0$$
$$\overline{Y}_{nm}(\theta,\lambda) = \overline{P}_{nm}(\cos\theta)\ \cos\ m\lambda \quad \text{if } m < 0 \qquad [\ 2\ ]$$

In $(\boldsymbol{r}), \mathbf{P}_{\mathbf{nm}}(\cos\boldsymbol{\theta})$ are the fully normalized associated Legendre functions of the first kind (Heiskance and Moritz , 1967). The disturbing potential T at a point P (r , θ , λ) is the differences between the actual gravity potential of the Earth and the normal potential associated with the a rotating equipotential ellipsoid at P. Based on equation [1] the spherical harmonic representation of T is :

$$T(r,\theta,\lambda)=\frac{GM}{r}\sum_{n-2}^{\infty}\left[\frac{a}{r}\right]^{n}\sum_{m=-n}^{n}\overline{C}_{nm}^{s}\,\overline{Y}_{nm}(\theta,\lambda) \qquad [\ 3\ ]$$

The above formula have been expanded for several numerous processes to get the element of the Earth’s gravity field such as gravity anomalies (Δg) and geoid height (N). The relationship between the coefficient of spherical harmonic with gravity anomalies (Δg_{GM}) and geoidal height (N_{GM}) is given by the following formula, respectively:

$$\Delta g_{GM} = \frac{GM}{r^{2}}\left[\sum_{n-2}^{n_{\max}}(n-1)\left[\frac{a}{r}\right]^{n}\sum_{m=0}^{n}\overline{C}_{nm}^{*}\cos m\lambda+\overline{S}_{nm}\sin m\lambda\right]\overline{\mathrm{P}}_{nm}(\sin\varphi) \qquad [\ 4\ ]$$

$$N_{GM} = \frac{GM}{r\gamma}\left[\sum_{n-2}^{n_{\max}}(n-1)\left[\frac{a}{r}\right]^{n}\sum_{m=0}^{n}\overline{C}_{nm}^{*}\cos(m\lambda)+\overline{S}_{nm}\sin m\lambda\right]\overline{\mathrm{P}}_{nm}(\sin\phi) \qquad [\ 5\ ]$$

where GM is the geocentric gravitational constant; $n_{\max}$ is the maximum degree; n , m is the degree and order; C_{nm}, S_{nm} is the geopotential coefficients; P_{nm} is the Legendre function; ϕ, λ is the geocentric latitude and longitude; γ is the normal gravity; a is the scaling factor and r is the geocentric distance.

The data set for use in the development of geopotential models slowly improves with time. The development of accurate potential coefficient models is dependent on accurate analyses of the pertubations of the orbits of artificial satellites (e.g. GPS) and from the combination of such information with surface gravity data, and relatively recently with satellite altimeter data (e.g. GEOS-3, SEASAT, GEOSAT and ERS-1). The original combination solutions were to low degree harmonics but data availability, mathematical developments, and significant computer software improvements have led to solution up to degree 50 in some cases, e.g. GEM-T3, and up to degree 360 in others, e.g. OSU91A and EGM96. These potential coefficient models can be used to calculate various gravimetric quantities that depend on the earth's gravitational potential. The foremost of these quantities is the geoid height.

3.0 SOURCES OF DATA

There are many different kinds of data types which can be used to estimate the geoid height. In principle, the gravity field information of data types can be evaluated and represented in the form of a series of spherical harmonic expansions. For land areas, fairly reliable gravity data can be obtained through gravity measurements and these gravity points should be tied to a global gravity reference so that they referred to a uniform world gravimetric system.

3.1 GRAVITY ANOMALIES

The detail structure of the gravimetric geoid is resolved using a set of free-air gravity anomalies. For the past 15 years, about 5000 gravity data have been surveyed by various agencies covering all accessible areas within the region of Peninsular Malaysia. The area containing the terrestrial observed gravity points is basically plateau, lying between 5 to 1000 metres altitude. The occupation of 180 gravity base stations were carried out by the Department of Geomatic Engineering, University Technology Malaysia (UTM) and Directorate Surveying and Mapping (DSMM) to form the Gravity Base Network throughout the country. The classification of the netowrk was initiated by the geophysics group of the University of Science, Malaysia (USM) in the north-western part of the Peninsula for the geological studies. The collection of gravity data by the UTM was carried out for geodetic purposes. Finally, the substantial data has been received in stages from the Geological Survey of Malaysia (GSM). About more than 300 points were collected at 5 km spacing covering the southern and some eastern parts of the Peninsular. Details of gravity database for Peninsular Malaysia can be found in Shahrum et.al. (1998). The distribution of gravity points extracted from these agencies over the land area of the Peninsula is shown in Figure: 1.0. The observed gravity data is given in IGSN71 with an exepected accuracy of 0.1 mGal.

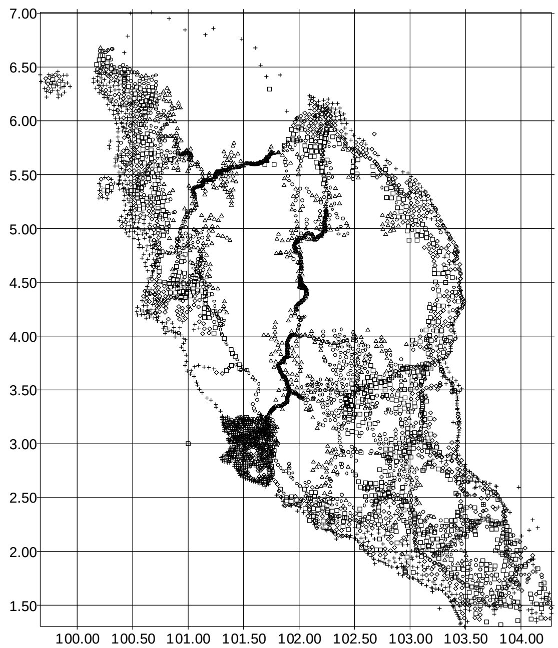


Figure 1.0 :- Distribution of the Gravity Data in 0.5° X 0.5° Peninsular Malaysia

3.2 COEFFICIENT OF THE GEOPOTENTIAL MODELS

The OSU91A and EGM96 are the higher degree and order geopotential models of the earth. These consist of a set of spherical harmonic expansion coefficients complete to degree and order 360 with an effective wavelength of 1°. These global models have been developed from the combination of satellite pertubation analysis with both surface garvity and satellite altimetry data. The development of these models is fully described in Rapp et.al.,(1991) and Rapp, et.al., (1997), respectively. The only substantial differences between the OSU91A model and the EGM96 model is the improvement of data source i.e most recent and comprehensive data set of gravity field information. The development of EGM96 model took the advantage of new 30' mean anomaly database through contributions over various countries around the globe. Other data that contributed to EGM96 are the 30'x30' mean altimeter derived gravity anomalies from the GEOSAT, TOPEX/POSEIDON and ERS-1, and satellite tracking to over 20 satellites using satellite laser ranging (SLR), the Global Positioning System (GPS), DORIS and TRANET. The EGM96 coefficients are in the tide free system and refer to a mean Earth Ellipsoid with an estimated semi-major axis length of 6378136.46m.

3.3 GPS DATA

The geoid heights implied by each geopotential model can be evaluated by comparing such heights to external height estimates such as geoid heights derived from GPS surveys. The comparisons are also can be made at the GPS stations using height differences. This differencing removes some of the long wavelength errors in the OSU91A and EGM96 models. Therefore, in this experiment, the geoid height were computed from both OSU91A and EGM96 models at the 136 GPS stations, and compared against the geoid heights found from GPS-derived elliposidal heights and orthometric heights from levelling data. The distribution of the 136 GPS stations in the test region is presented in Figure: 2.0. If this figure is compared with the gravity points distribution (Figure: 1.0), it is obvious that there is a deficiency of gravity stations around some GPS control points.

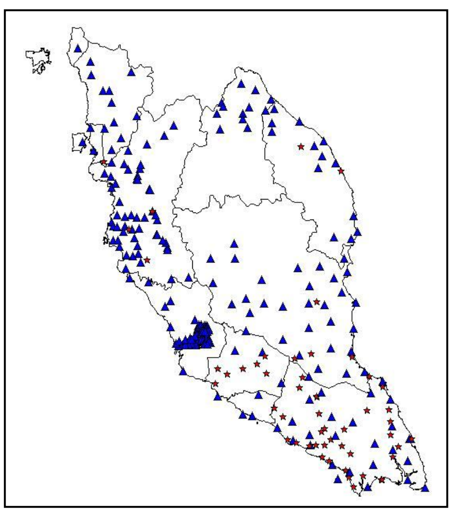


Figure 2.0 :- Distribution of the GPS stations in Peninsula Malaysia

4.0 METHOD OF MODEL EVALUATION

Point gravity anomalies were computed from both the OSU91A and EGM96 models using equation [4], and then the residual gravity anomalies (Δg_r) for all points in the network is found by subtracting the gravity anomalies from the geopotential models (Δg_{GM}) from the terrestrial gravity point anomalies (Δg_o), i.e.

$$\Delta g_r = \Delta g_o - \Delta g_{GM} \qquad [\ 6\ ]$$

A set of 0.5° X 0.5° blocks was constructed for the whole region. The distribution of the gravity data is shown in Figure 1.0, with a maximum of 417 and minimum of 1 points in any of the 0.5° x 0.5° blocks. The mean residual anomalies were obtained by taking a simple average of the point anomalies for each blocks which will give an indication of the bias between the observed gravity data and model-derived data in the region of interest. The mean residual values is given by :

$$\Delta g' = \frac{\sum_{i=1}^{n} \Delta g'_i}{n} \qquad [\ 7\ ]$$

The aim of this test is to evaluate the closeness of fit to mean anomalies for each model with respect to gravity density and coverage and the terrain types over Peninsular Malaysia. This approach also will suggest how good the coverage of long wavelength is, per model, in this region.

The root mean square (rms) of the residual anomalies for each blocks are also calculated when testing these two models. The rms value is also a significant statistical test, and gives some measure of the variations or fluctuations of residual gravity field from the global geopotential model and is given by:

$$\Delta \boldsymbol{g}_{rms} = \sqrt{\frac{\sum_{i=1}^{n} \left(\Delta \boldsymbol{g} - \overline{\Delta \boldsymbol{g}}\right)^2}{\boldsymbol{n} - 1}} \qquad [\ 8\ ]$$

where $\overline{\Delta \boldsymbol{g}}$ = mean anomaly

The geopotential geoid height at 136 GPS control points located in the peninsula region have been computed using equation [5], denoted as N_{GM}. Only by testing against independent estimates of ΔN from GPS and levelling we will know which model is the best reference surfaces for the local gravity field in Peninsular Malaysia. Therefore, the comparison between the 136 GPS derived-geoid heights (N_{GPS}) and the corresponding N_{GM} was made for both OSU91A and EGM96 geopotential models.

5.0 RESULTS AND ANALYSIS

The mean and rms of the residual gravity, for a population of 67 of the 0.5° x 0.5° blocks across the Malaysia Peninsular, are calculated when testing the OSU91A and EGM96 models. The values of the mean residual anomalies as derived from equation [7] are categorised into seven bins while the values of rms as computed by equation [8] are placed into five bins.

5.1 MEAN OF RESIDUAL GRAVITY ANOMALIES

The seven chosen bins of the mean fit differences for OSU91A and EGM96 models are summarised in Table: 1.0 and are reflected in the form of pie chart in Figure: 3.0 and Figure 4.0, respectively. Their distributions of their corresponding mean residual anomalies analysed on all 0.5° x 0.5° blocks for the peninsula are also illustrated in Figure: 5.0 and Figure: 6.0, respectively.

Table 1.0 :- The mean values of the distribution of gravity data.

BIN	GEOPOTENTIAL MODEL	EGM96		OSU91A	
	BIN CATEGORY (mGal)	FREQUENCY	(%)	FREQUENCY	(%)
1	5 To 10	4	6.35	5	7.94
2	0 To 5	7	11.11	8	12.70
3	0 To –5	16	25.40	7	11.11
4	-5 To –10	11	17.40	15	23.81
5	-10 To –20	4	6.35	10	15.87
6	-20 To –30	9	14.29	5	7.94
7	>-30	12	19.05	13	20.63

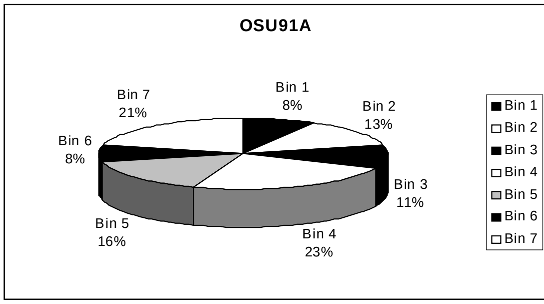


Figure: 3.0 – Pie Chart of Mean Residual Anomalies of OSU91A Model

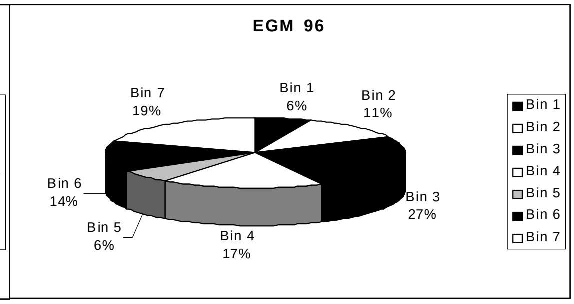


Figure: 4.0 – Pie Chart of Mean Residual Anomalies of EGM96 Model

Figure: 3.0 and Figure: 4.0 indicates that for both EGM96 and OSU91A, more than half (60% for EGM96 and 55% for OSU91A) of the blocks lie within 5 to –10 mGal, and about 20% within –10 to –30 mGal for EGM96 and 23% for OSU91A, 19% of the blocks have more than –30 mGal for EGM96 compared to 20% for OSU91A. A noticeable feature in the distribution of mean fit is the dominance of the negative biases with EGM96 having about 82% and OSU91A 79% of negative blocks. This negative bias suggest that the long wavelenght features of the model are underestimated for the Peninsula Malaysia region, which is what we expect because of the lack of data from this region which have been used in the solution of the potential coefficients for both geopotential models.

From Figure: 5.0 and Figure: 6.0, they can be seen that the areas of poorest mean residual representation with respect to terrestrial gravity implied by both models are in the central northern Peninsula Malaysia and where the three main islands, namely Pulau Pinang, Langkawi and Tioman, are located. The main centribution to this bias over the mainland is because no gravity was supplied over the area that cover the Titiwangsa Range. Offshore, the result may reflect the fact that for the ocean regions, the gravity anomalies used in the model was found by collocation from oceanic geoid undulation derived from satellite radar altimetry.

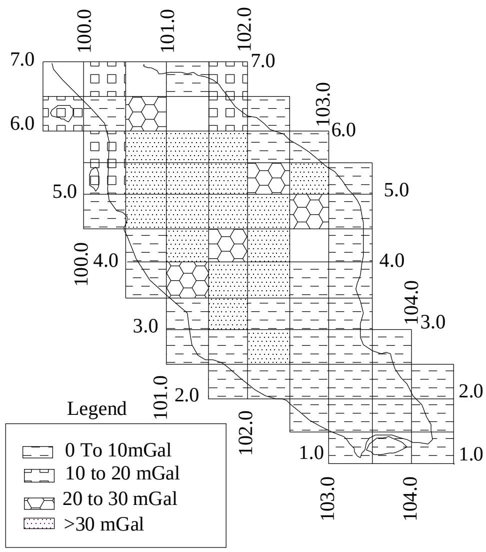


Figure 5.0 : Mean Residual Gravity Anomaly Map for EGM96

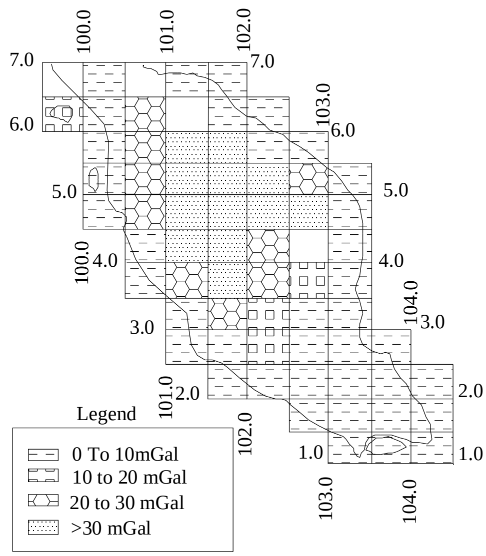


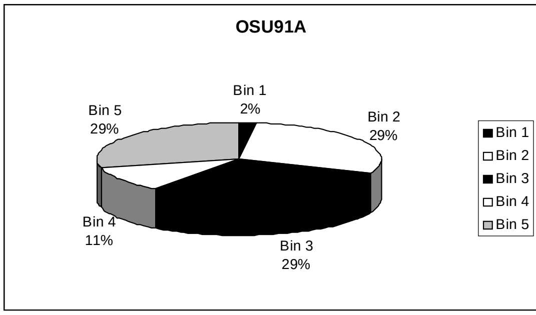
Figure 6.0 : Mean Residual Gravity Anomaly Map for OSU91A

5.2 RMS OF THE RESIDUAL ANOMALIES

The values of rms for both geopotential models are placed in five bins and the corresponding frequency rms distriubutions is indicated in Table 2.0. Figure: 7.0 and Figure: 8.0 show the pie charts of these rms bin categories for OSU91A and EGM96 models over the Peninsula region, respectively.

Table: 2.0 - Distribution of the RMS and Frequency

BIN	GEOPOTENTIAL MODEL	EGM96		OSU91A	
	BIN CATEGORY (mGal)	FREQUENCY	(%)	FREQUENCY	(%)
1	0 TO ± 5	7	11.11	1	1.59
2	±5 TO ±10	18	28.57	19	30.16
3	±10 TO ±15	14	22.22	18	28.57
4	±15 TO ±20	1	1.59	7	11.11
5	> ±20	23	36.51	18	28.57



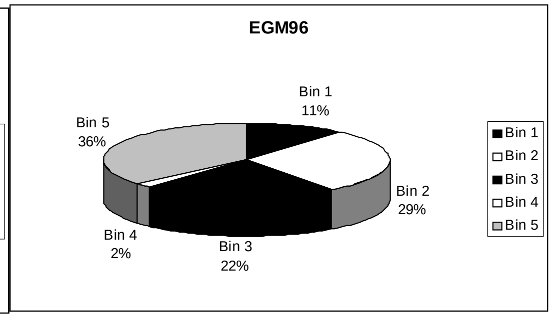
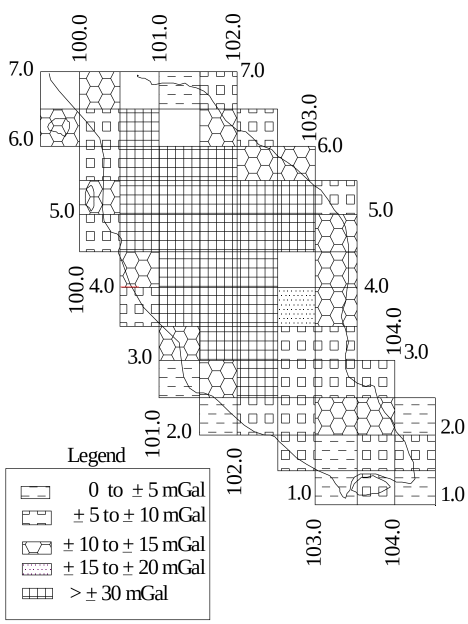


Figure: 7.0 - Pie Chart of RMS Resisual Anomalies of OSU91A Model

Figure: 8.0 – Pie Chart of Mean Residual Anomalies of EGM96 Model

From Figure: 7.0 and Figure 8.0, it can be seen that the rms of residual anomalies of both models are quite good, with about 40% for EGM96 and 32% for OSU91A for the values of less then or equal to ± 10 mGal. About 24% for EGM96 and 40% for OSU91A are within ± 10 mGal to ± 20 mGal, and 36% for EGM96 and 29% for OSU91A is greater than ± 20 mGal. From the rms analysis it appears that EGM96 are quite superior across the region compared to OSU91A.



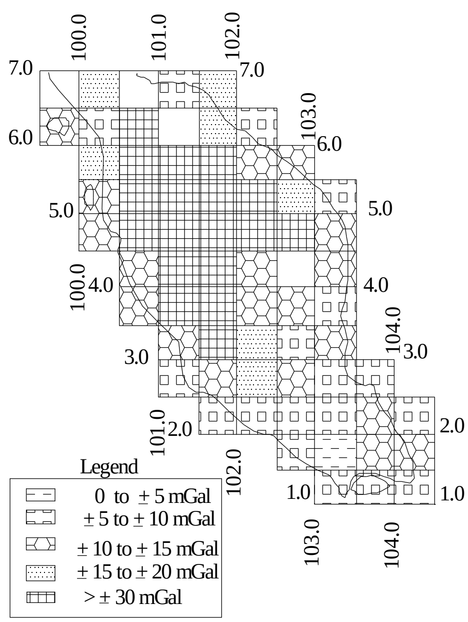


Figure 9.0 : RMS for the Residual Gravity Anomalies for EGM96

Figure 10.0 : RMS for the Residual Gravity Anomalies for OSU91A

Figures: 9.0 and 10.0 indicated that the blocks of poorest representation are the western side of the state of Kelantan which is bordering the Titiwangsa range and the lsland of the Pergau River. The main contribution to this poorest is because no gravity was supplied over the area. All of the areas neighbouring the high ranges, namely the Bintang and Titiwangsa Range, have a relative by high rms values of over ± 30 mGal. These areas do have a reasonable number of sample points for each 0.5° x 0.5° blocks, although most of these are not well distributed, mainly along the access road and none are located on the mountain tops.The eastern side of Negeri Sembilan, which is part of the Titiwangsa Range and the swampy areas of Mersing, Endau and Rompin, show rms values of more than ± 10mGal.

5.3 COMPARISONS OF THE GEOID HEIGHT (N)

These GPS control points was used for the comparison with the corresponding N_{GM}, i.e. N_{OSU} and N_{EGM}. For this test, the geoid heights were computed from both OSU91A and EGM96 models at 136 GPS points, and compared against the geoid heights found from GPS – derived ellipsoidal heights and orthometric heights from levelling data, i.e. $\Delta N = N_{GPS} - N_{OSU91A}$ and $\Delta N' = N_{GPS} - N_{EGM96}$. The results of these comparisons are summarised and illustrated in Table: 3.0 and Figure: 11.0, respectively. The difference in geoid heights ΔN were also computed over the selected baselines from both solution, using the following expressions:

$$\delta\Delta N' = \Delta N'_i - \Delta N'_j \quad \text{for EGM96} \qquad [9]$$

$$\delta\Delta N = \Delta N_i - \Delta N_j \quad \text{for OSU91A} \qquad [10]$$

The relative geoid height is divided by the length of the line and expressed in part per million (ppm) :

$$\frac{\delta\Delta N'}{S} \times 10^{-6} \quad \text{for EGM96} \qquad [11]$$

$$\frac{\delta\Delta N}{S} \times 10^{-6} \quad \text{for OSU91A} \qquad [12]$$

where, S is the distance between point 1 to point 2.

Table: 4.0 summarises details of these relative geoid differences.

Table: 3.0 - Values of the $N_{GPS} - N_{EGM96}$ and $N_{GPS} - N_{OSU91A}$

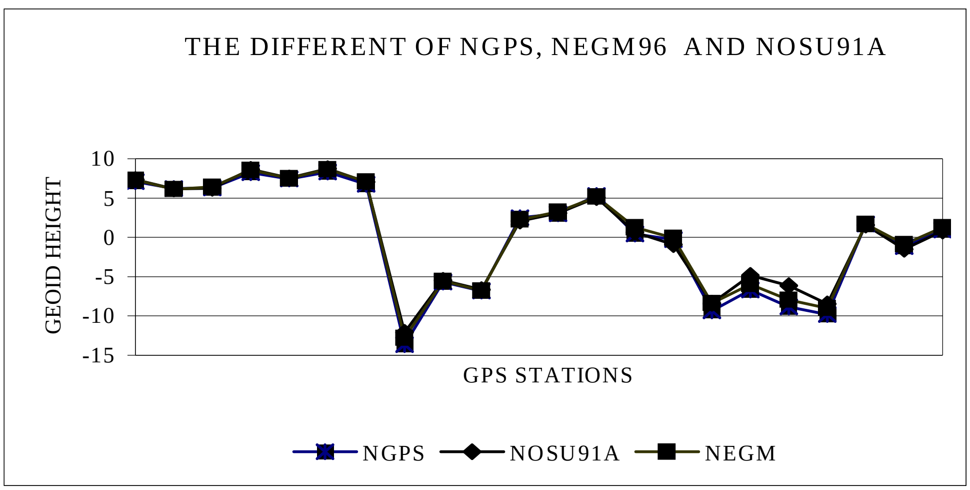
	Mean	RMS	Standard Deviation	Min	Max
ΔN	-0.31	0.99	0.95	-2.69	1.8
ΔN'	-0.35	0.61	0.50	-1.80	1.36

Table: 4.0 - The result of the relative geoid height differences expressed in ppm

Geoid Model	Mean	RMS	Standard Deviation (σ)	Min	Max
PPM@ N_{OSU91A}	1.30	2.69	2.37	0.01	19.75
PPM@ N_{EGM96}	0.89	1.36	1.03	0.00	7.04

From Table: 3.0 and Figure: 11.0, it is apparent that EGM96 model has a great improvement over the OSU91A model. For example, the standard deviation for the EGM96 is 0.5m compared to 0.95m for OSU91A, and the rms value is 0.61m for N_{EGM96} and 0.99m for N_{OSU91A}. One of possible reasons for this improvement might be caused by the difference in data density and data distribution within the test region.

Figure 11 : Result of the comparison of N_{GPS},N_{EGM96} and N_{OSU91A}



It is interesting to see from Table: 4.0 that EGM96 model, while showing a a small mean value compared to corresponding value of OSU91A model (0.89m cf. 1.36m), also indicate a good improvement in the standard deviation of the differences (1.03m cf. 2.37m). Similarly, the rms valus also numerically show how much better EGM96 model fits the control data than does OSU91A, i.e. 1.36m cf. 2.69m.

6.0 CONCLUSION

This paper has carried out a comparison and evaluation of two higher degree and order geopotential models (OSU91A and EGM96) over the Peninsular Malaysia. From the statistical analysis of the mean and rms of the residual anomalies, it can be concluded that the EGM96 geopotential model appears to recover the long wavelength signals better than OSU91A model. The evaluation of the models in terms of geoid height quantities was carried out through comparisons with 136 GPS derived geoid heights. Tests within the Peninsular Malaysia region show that significant differences in ΔN and $\delta\Delta N$ occur, depending upon whether OSU91A or EGM96 are used as the reference model. In the meantime, we have found that EGM96 fits the gravity field across the Peninsular Malaysia better tha does OSU91A strongly suggesting that the former is the preferable reference model for geoid studies in this region.

ACKNOWLEDGEMENTS

We would like to thank to all who have support this project especially to Professor Richard Rapp, who are supporting by provided the potential coefficient for the OSU91A and the NIMA which have provided the EGM96 and also for his valuable comments.

REFERENCES:

Ahmad,Z. and Kearsley, A.H.W. (1993). 'Geoid Evaluation Over Malaysia Peninsula Region – Test On High-Order Geopotential Model.' Technical Report 1,School Of Surveying, Universiti New South Wales, Australia.

Dehlinger, P. (1978). 'Marine Gravity'.Elsevier Scientific Publishing Company, New York.

Diggelen, V.F. (1998). 'GPS Accuracy:- Lies, Damn Lies and Statistik.' GPS World, January, pp 41-44.

Gil, A, Sevilla, M. and Rodriques, G.(1993) : ‘Geoid Determination in Central Spain From Gravity and height Data’. Bulletin Geodesique, Vol 67, pp 41-50.

Heiskanen,W. and Moritz,H (1967). ‘Physical Geodesy’.W.H.Freeman and Company, San Francisco.

Kearsley, A.H.W. (1991). ‘ Geoid Evaluation in Australia Status And Problems.’ Technical Report, School Of Surveying, University New South Wales, Australia.

Kasenda A and Kearsley A.H.W (1992). ‘A Preliminary Geoid For Irian Jaya.’ Technical Report,Unisurv S-41, School Of Surveying, University New South Wales, Australia.

Lemonine,F.G,Smith ,D.E.,Kunz,L., Smith, R., Pavlis, E.C., Pavlis,N.K, Klosko, S.M., Chinn,D.S.,Torrence,M.H., Williamson,R.G., Cox,M.C., Rachlin,R.E., Wang,M.Y.,Kenyon,S.C., Salman,R., Trimmer,R.,Rapp,R.H., and Nerem,R.S. (1997). ‘The Development of the NASA GSFC and NIMA Joint Geopotential Model’. International Association of Geodesy Symposia, Vol. 117: Segawa et.al.(eds),Gravity,Geoid and Marine Geodesy,Springer-Verlag,Berlin.

Lerch, F.J.,Klosko, S.M.,Laubscher,R.E & Wagner, C.A. (1977). ‘ Gravity Model Improvement using GEOS-3 (GEM9 and 10)’. Result presented at the Fall Annual Meeting of the American Geophysic Union,Washington D.C. USA

Mainville, A., Forsber, R. and Sideris, M.,(1992) : ‘Global Positioning System Testing of Geoids Computed from Geopotential Models and Local Gravity Data : A case Study’. Journal of Geophysical Research, Vol.97, No.B7, pp 11137-11147.

Rapp, R.H. (1997). ‘Past and Future Developments in Geopotential Modeling’. Proceedings Of Symposium 2 : Gravity and the Geoid IAG 97, Rio de Janeiro,Brazil.

Rapp, R.H. and Pavlis, N.K. (1990). ‘The Development And Analysis Of Geopotential Models To Spherical Harmonic Degree 360’. Journal Of Geophysical Research,Vol 95,B13,pp 21,885-21,911.

Sanso,F. and Rummel,R. (1990). ‘Theory Of Satelit Geodesy and Gravity Field Determination’. Lecture Notes in Earth Sciences, No. 25, Springer-Verlag, Berlin.

Shahrum,S.; Majid, K; and Gilliland,J, (1998) : 'Gravity Database for Peninsular Malaysia'. Geomatics Research Australia. No.69, pp 19 - 34 – Disember.

Torge, W.(1980). 'Geodesy An Introduction'. Walter de Grunter, New York.