Australian Journal of Basic and Applied Sciences
2018 December; 12(12): pages 108-112
DOI: 10.22587/ajbas.2018.12.12.18
Original paper
AENSI Publications
Journal home page: www.ajbasweb.com

Performance of the global Geo-Potential models over Egypt

Mostafa H. A. Mohamed

Lecturer, Civil Department, Faculty of Engineering, Al- Azhar University, Cairo, Egypt.

Correspondence Author: Mostafa H. A. Mohamed, *Civil Department, Faculty of Engineering, Al- Azhar University, Cairo, Egypt*
E-mail: *mostafa.hassan@azhar.edu.eg*

Received date: 15 November 2018, **Accepted date:** 20 December 2018, **Online date:** 31 December 2018

Abstract

The recent Global Geo-potential Models (GGMs) achieve a huge upturn in geomatics application and geoid modeling. In order to increase the accuracy of a geoid model, a precise Global Geopotential Model (GGM) is needed. This paper aimed to investigate the accuracy assessment of the most recent GGMs over Egypt referenced to differential GPS terrestrial ground control points with knowing orthometric height. Five GGMs were selected for this study where, the GGMs are SGG-UGM-1 (2159), EIGEN-5C (360), EGM 2008 (2190), AIUB-CHAMP01S (70) and EGM 96 (360). The obtained results concluded that SGG-UGM-1 is almost the same accuracy with EGM 2008 GGM which include a GRACE data. The both GGMs models were best fits to Egypt local gravity.

Key words: Geoid, Gravity, Undulation, GGM, GPS.

INTRODUCTION

The geoid can be described as the equipotential surface of the Earth's gravity field which corresponds most closely with mean sea-level in open oceans and ignores the effects of semi-dynamic sea surface topography. Global Geopotential Model is a mathematical function which describes the gravity field of the Earth in the 3-dimensional space. Accurate performance of the Global Gravity Geopotentialmodels (GGMs) of earth, is considered a fundamental requirement for various geophysical and geodetically applications. With the increased use of GPS-based positioning, the demand for directly converting ellipsoidal heights (h) to orthometric height (H) with sufficient accuracy is also increasing for a surveying activities used. The need for high resolution, accurate global gravitational models is concentrated in GPS positioning and gravimetrically determined geoid heights over land areas offer the possibility of determining orthometric heights and height differences without the need for leveling (Schwarz et al., 1987).

A global high degree model may be used by researches, either as a reference to support the development of more detailed regional geoids, or to provide the geoid heights on its own. Furthermore, a unique, accurate, global high degree gravitational model may be used to provide the reference surface for the realization of a global vertical datum (Rapp and Balasubramania, 1992). The first decade of the new millennium has been called "The Decade of Geopotentials" and has seen the launch of three dedicated gravity field mapping missions: CHAMP (Reigber et al., 1996) launched in July 2000, GRACE launched in March 2002, and GOCE launched in March 2009. These advanced mesions produced a new generation from global gravititional geopotential earth models, from the available new GGMs five GGMs were selected to study their performance over Egypt. The selected GGMs with the model degree are SGG-UGM-1 (2159), EIGEN-5C (360), EGM2008 (2190), AIUB-CHAMP01S (70) and EGM 96 (360).There are essentially three classes of GGM:

Satellite-only GGMs are derived solely from the analysis of the orbits of artificial earth satellites. These models are limited in precision may be due to , the power-decay of the gravitational field with altitude; the inability to track complete satellite orbits using ground-based stations and incomplete sampling of the global gravity field due to the limited number of satellite orbital inclinations available.

Combined GGMs are derived from the combination of satellite data, land and ship-track gravity observations, marine gravity anomalies derived from satellite radar altimetry and more recently airborne gravity data (Rapp, 1997).This generally allows an increase in the maximum spherical harmonic degree of the GGM. However, these modelsare limited in precision if not properly highpass filtered from the solution.

Tailored GGMs adjust (and often extended to higher degrees) a satellite-only or combined GGM using gravity data that may not necessarily have been used before (Wenzel, 1998). This is normally achieved using integral formulas to derive corrections to the existing geopotential coefficients, as opposed to the combination at the normal equation level that is used to construct combined GGMs. Importantly, tailored GGMs only apply over the area in which the tailoring was applied, because spurious effects can occur in areas where no data are available (Kearsley and Forsberg, 1990).

OBJECTIVE

The objective of this study aims to obtain the best fit GGM for Egypt. Also to drive a trusted Geoid separation terms (N) be used for computing the orthometric height (H) from ellipsoidal height (h) at any point. For all network points with fixed vertical components the geoidal undulation has to be known to obtain ellipsoidal heights. The ellipsoidal heights are necessary for the determination of transformation parameters between the GPS reference and the local geodetic system. So, the overall objective of this study aims to evaluate the accuracy performance of several global GGMs and DEMs in order to define the best fit of them in construction applications in Egypt.

STUDY AREA

Egypt window is the main objective study area approach with extent to cover the Window [22˚<latitude (ϕ)< 32˚, 25˚<longitude(λ)< 37˚]. There are 389 deferential GPS ground control points have known it's ellipsoidal and orthometric heights are distributed over Egypt as shown in figure (1).

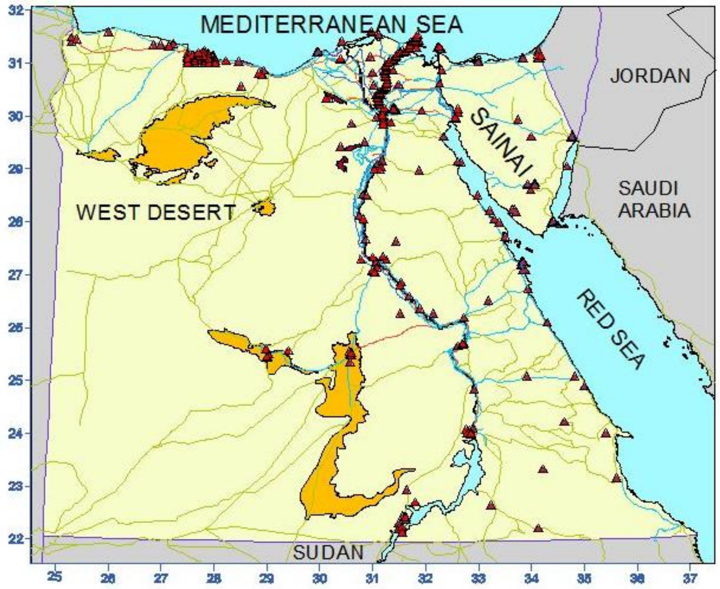

Figure (1): The Arab Republic of Egypt map with available ground control points.

GLOBAL GEOPOTENTIAL MODELS (GGM) EVALUATION

In this study five GGM models were utilizes and their accuracy were evaluatedwhen compared against GPS/levelling ground control points in Egypt. Table (1) shows the information of these five models. SGG-UGM-1 is a static gravity field model based on EGM2008 derived gravity anomalies and GOCE Satellite Gravity Gradiometry (SGG) data and the Satellite-to-Satellite Tracking (SST) observations up to degree and order 2159. Block-diagonal normal equation system up to degree and order 2159 are formed with EGM2008 gravity anomaly data using block-diagonal least squares method. Fully occupied normal equation system up to degree and order 220 are formed by GOCE SGG data and the SST observations along the GOCE orbit based on least-squares analysis. The diagonal components (Vxx, Vyy, Vzz) of the gravitational gradient tensor are used to form the system of observation equations with the band-pass ARMA filter (Liangand Zhu, 2018). The point-wise acceleration observations (ax, ay, az) along the orbit are used to form the system of observation equations up to the maximum spherical harmonic degree/order 130. SGG-UGM-1 is resolved by combination of the two normal equation systems using least squares method (Jiancheng et al., 2017)

The combined European Improved Gravity field of the Earth model by New techniques type 5C (EIGEN-5C) is an upgrade of EIGEN-GL04C. The model is a combination of GRACE and LAGEOS mission data plus 0.5 x 0.5 degrees gravimetric and altimetry surface data (Förste et al, 2008).

Pavlis et al. (2008) has made a GGM that has the name of the Earth Gravitational Model 2008 (EGM2008). As of the recent global data EGM2008 have included all the data around the world both from satellites that remotely sense data such as gravity and altimetry and from field measurement from the old to the latest. So that this global earth model is more sophisticated than the Earth Gravitational Model 1996 (EGM1996) from Lemoine et al. (1998). Considering these advances, and in particular the expected availability of very accurate long wavelength gravitational models from GRACE, the National Geospatial-Intelligence Agency (NGA) decided to embark on the development of a new Earth Gravitational Model (EGM) to serve as a replacement of EGM96 (Lemoine et al., 1998).

AIUB-CHAMP01S is the first global gravity field model produced at the AIUB. The satellite-only model was derived from kinematic orbit positions of the CHAMP satellite, computed from GPS satellite-to-satellite data out of the period March 2002 through March 2003 (Jäggi et al., 2006).

EGM96 is a model complete to degree and order 360. It is the result of collaboration between NASA GSFC (NASA Goddard Space Flight Center), and the Defense Mapping Agency (DMA; NIMA after October 1, 1996 or National Imagery and Mapping Agency). DMA made available new and improved gravity data over regions of the globe that previously had not been available, such as China, the former Soviet Union, South America, and Africa (Lemoine et al, 1998).

Table1 (1): GGMs to be evaluated over Egypt.

NO	Model	Year	Deg ree	Data	Reference
1	SGG-UGM-1	2018	2159	EGM2008, S(GOCE)	Liang, W. and Zhu., 2018 & Xu, X. et al., 2017
2	EIGEN -5C	2008	360	S(Grace,Lageos),G,A	Förste et al, 2008
3	EGM20 08	2008	2190	S(Grace),G,A	Pavlis et al, 2008
4	AIUB-CHAMP01S	2007	90	S(Champ)	Prange, L .et al, 2007
5	EGM96	1996	360	S,G,A	Lemoine et al, 1998
• S=Satellite Tracking Data, G =Terrestrial Gravity Data, A =Altimetry Data					

Citation: MOSTAFA H. A. MOHAMED, *et al.*, Performance of the global Geo-Potential models over Egypt. Australian Journal of Basic and Applied Sciences, 12(12): 108-112. DOI: 10.22587/ajbas.2018.12.12.18

METHODOLOGY

To find the best global model which could be applied in Egypt, one will compare some global model data. The GPS-Leveling is used as reference data. The coordinates of 389 points are used for the calculated geoid undulations (N) which computed using the following spherical harmonic expansion (1) **(**Sideris, 1994**)**:

$$N_{GM}\ (\phi,\lambda) = R\sum_{n=2}^{N}\sum_{m=0}^{n}(\bar{C}_{nm}\ \ cos\lambda\ + \bar{S}_{nm}\sin\lambda)\ P_{nm}\ (\sin\phi) \qquad (1)$$

Where ϕ and λ are the coordinates of point to be calculated, R is the distance from the center of the earth to the point to be calculated, N is the maximal rates of degree (m) and order (n) of the global model, and ($\bar{C}_{nm}, \bar{S}_{nm}$)are the harmonic coefficients while P_{nm} the is a Legendre polynomial function.

A comparison should be made between the calculated geoid based on a spherical harmonic coefficient for the tested GGMs against a local height shift from an observed ground elevation data by at GPS/ leveling stations according to the (Heiskanen and Moritz 1967) following equation(2).

$$H = h + N \qquad (2)$$

The obtained difference value will determine the validation accuracy of the tested GGMs. Manipulating the two values (N) for each ground station to calculate the difference in geoid shift (ΔN) as explained in equation (3), where (ΔN) can be considered the value of GGM errors at the specific location. Then calculating the root mean square error values for ΔN at each GGM as shown in equation (4). Comparing root mean square error values for all models to validate the best model fit over Egypt which is the major goal of this research.

$$\Delta N_i = N_{iG} - N_{iM} \qquad (3)$$

$$\text{RMSE} = \sqrt{\textstyle\sum_i^n (\Delta N\ i)^2 / n} - 1 \qquad (4)$$

Where : N_{iG}: The reference GPS/levelling undulation at the i^{th} point
N_{iM} : The GGM undulation at the i^{th} point
ΔN_i : The undulation difference at point i
n : The number of data set points.

PERFORMANCE THE GGM'S SET OVER EGYPT

The available ground control stations were used to validate the computed undulations based on the tested Global Geoid Models. All GPS points are distributed over whole Egypt window. Table (2) manipulates the minimum, maximum, mean, and RMS error for the undulation difference resulted from the GGMs and the terrestrial GCP's.

Table (2): Statistics of undulation difference between GGMs and GCPs.

NO.	MODEL	Year	Degree	Data	ΔN MIN (m)	ΔNMAX. (m)	ΔN MEAN (m)	RMSE. (m)
1	SGG-UGM-1	2018	2159	S(Grace),G,A	-1.10	0.57	-0.22	0.413
2	EIGEN-05C	2008	360	S(Grace,Lageos),G,A	-1.514	0.514	-0.306	0.424
3	EGM2008	2008	2190	S(Grace),G,A	-0.870	0.938	-0.021	0.415
4	AIUB-CHAMP01S	2007	90	S(Champ)	-3.246	2.060	-0.559	1.370
5	EGM96	1996	360	EGM96S,G,A	-1.404	0.805	-0.490	0.529

From table (2), the most recent SGG-UGM-1 2159 and EGM 2008 2190 have the smallest (RMSE) values 0.413m and 0415m respectively which indicates that both GGMs can map the long and medium wavelength gravity field structure with high accuracy and fits best to the earth's gravity field on the territory of Egypt performing better than other GGM's. The results confirm also that the new SGG-UGM-1 has almost the same RMSE compared with the EGM 2008.

From the above tabulated results and by applying F-statistical test, for 388 degree of freedom and confidence level 99 % the $F_{crit} = 1.27$. From that, it can be concluded that the three GGMs SGG-UGM-1 2159, EGM 2008 2190 and EIGEN-05C 360 considered the same performance over Egypt and doesn't exist a significant difference in their performances. AIUB-CHAMP01S with 90 degrees is the worst GGM over Egypt so, it recommended to discard any application that will be based this GGM. The EGM 96 gives good results over Egypt although it is old and it has only 360degree. This may be because it has a shared satellite and terrestrial gravity data during its mission.

Contour maps with interval of one meter of undulation are drawn in figure (2, 3, and 4) for SGG-UGM-1, EGM 2008 GGM, and EIGEN-05Cmodels respectively. From the figure it is clear that there is significant change in undulation at Matrouh governorate at North West part of Egypt which gives indication there is a high gravity effect in this part. Also the centre part of Sinai at El-Galala plateau has a high undulation which may returns to the huge mass of this big hill. On the contrary the South-East corner (Red Sea) has the smallest undulation over Egypt.

Citation: MOSTAFA H. A. MOHAMED, *et al.*, Performance of the global Geo-Potential models over Egypt. Australian Journal of Basic and Applied Sciences, 12(12): 108-112. DOI: 10.22587/ajbas.2018.12.12.18

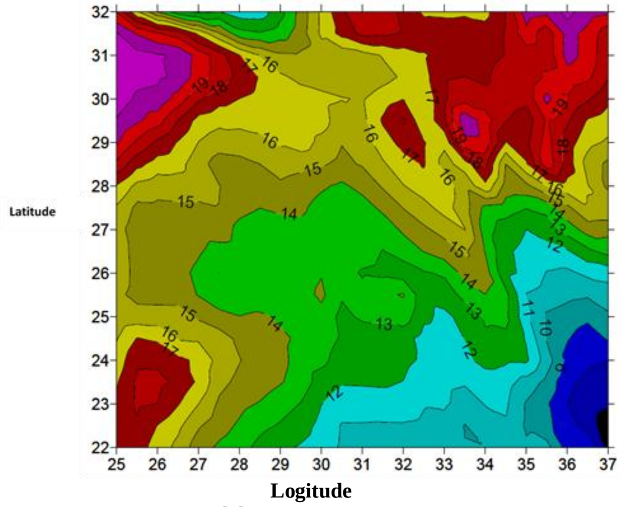

Figure (2): Undulation contour usingSGG-UGM-1.

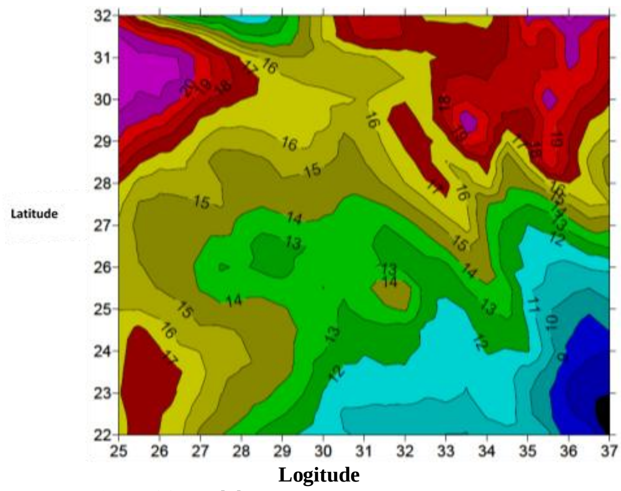

Figure (3): Undulation contour usingEGM2008.

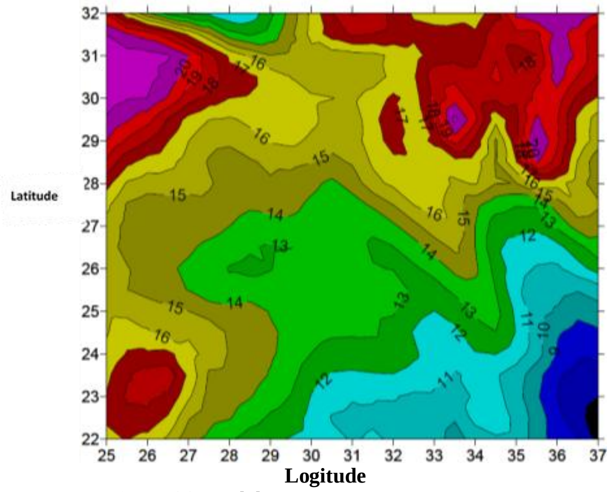

Figure (4): Undulation contour using EIGEN-05C.

CONCLUSIONS

Accuracy assessment was investigated to the most used global geopotential models in Egypt using GPS terrestrial data sets. The performances of five GGMs with known spherical harmonic coefficients data for each model have been compared against 389 ground stations with known geoid shift value (N) for each station from observed GPS/levelling Surveys. The calculated (N) value coming from the GGMs compared with the observed (N) coming from GPS / levelling the accuracy of these models is related to the computed RMSE values. The smallest (RMSE) value0.413 m ofSGG-UGM-1 and 0.415 m of the (EGM 2008 degree 2160) models. It means that these two models fit best the earth's gravity field on the territory of Egypt and perform better than other models. The closest GGM model to SGG-UGM-1 and EGM08 is EGM96with 0.529 m RMSE value. Three undulation contour maps were created for the best GGM models (SGG-UGM-1,

Citation: MOSTAFA H. A. MOHAMED, *et al.*, Performance of the global Geo-Potential models over Egypt. Australian Journal of Basic and Applied Sciences, 12(12): 108-112. DOI: 10.22587/ajbas.2018.12.12.18

EGM 2008, and EGM96). From these maps, it is clear that there is high undulation values at Matrouh and Sinai, while, smallest undulation is located in South-East corner of Egypt.

REFERENCES

Förste, C., Flechtner, F., Schmidt, R., Stubenvoll, R., Rothacher, M., Kusche, J., Neumayer, K.H., Biancale, R., Lemoine, J.M., Barthelmes, F., Bruinsma, S.L.
König, R. and Meyer, U., (2008). EIGEN-GL05C - A new global combined high-resolution GRACE-based gravity field model of the GFZ-GRGS cooperation. Geophysical Research Abstracts, Vienna, Austria, Vol. 10, EGU2008-A-03426, SRef-ID: 1607-7962/gra/EGU2008-A-03426.

Heiskanen, W. and Moritz, H., (1967). Physical geodesy. WH Freeman, San Francisco, 364 pages.

Jäggi, A., U. Hugentobler, and G. Beutler (2006). Pseudo stochastic orbitmodeling techniques for low-earth orbiters. Journal of Geodesy, Vol. 80, p:47-60, doi: 10.1007/s00190-006-0029-9.

Jiancheng, L. I., Yonghai, C. H. U., and Xinyu, X. U., (2017). Determination of vertical datum offset between the regional and the global height datum. Acta Geodaetica et CartographicaSinica, vol. 46(10), p:1262-1273.

Kearsley, A. H. W., and Forsberg, R., (1990). Precise gravimetric geoid computations over large regions. In: FOUR-Dimensional Geodesy, Lecture Note in earth sciences, Springer-Verlag, Vol . 15, p:151-158.

Lemoine, F.G., Kenyon, S.C., Factor, J.K., Trimmer, R.G., Pavlis, N.K., Chinn, D.S., Cox, C.M., Klosko, S.M., Luthcke, S.B., Torrence, M.H., Wang, Y.M., Williamson, R.G., Pavlis, E.C., Rapp, R.H. and Olson, T.R., (1998). GSFC Goddard Space Flight Center; The Development of the Joint NASA GSFC and the National IMagery and Mapping Agency (NIMA) Geopotential Model EGM96. Greenbelt, Md.

Liang W., Xu X., Li J. and Zhu G., (2018). The determination of an ultra-high gravity field model SGG-UGM-1 by combining EGM2008 gravity anomaly and GOCE observation data. Acta GeodaeticaetCartographicaSinica, Vol. 47(4), p:425-434. DOI:10.11947/j.AGCS.2018.20170269.

Pavlis NK, Holmes SA, Kenyon SC, Factor JK (2008). An earth gravitational model to degree 2160: EGM2008. Presented at the 2008 Genera Assembly of the European Geoscience Union, Vienna, Austria, April 13–18, 2008.

Prange, L., Jäggi, A., Beutler, G., Dach, R., Mervart, L., Sideris, M., (2009). Gravity Field Determination at the AIUB – The Celestial Mechanics Approach. Springer, Perugia, Vol. 133, p:353-362, doi: 10.1007/978-3-540-85426-5_42.

Rapp, R.H.,(1997). Past and future developments in geopotential modelling, in: Forsberg, R., Feissl, M. and Dietrich, R. (eds.) Geodesy on the Move, Springer, Berlin, p:58-78.

Rapp, R. H., and Balasubramania, N., (1992). A conceptual formulation of a world height system. Department of Geodetic Science and Surveying, Ohio State University,Vol. 421.

Reigber, C., Z. King, R. Konig, and P. Schwintzer (1996). CHAMP, A minisatellite mission for geopotential and atmospheric research, Spring AGU Meeting, Baltimore.

Rosen, P., Eineder, M., Rabus, B., Gurrola, E., Hensley, S., Knoepfle, W., Breit, H., and Werner, M., (2001). SRTM-Mission-cross comparison of X and C band data properties. In geoscience and remote sensing symposium, IGARSS'01. IEEE 2001 International , Vol. 2, p:751-753.

Schwarz, K. P., Sideris, M. G., and Forsberg, R., (1987). Orthometric heights without leveling. Journal of Surveying Engineering, Vol. 113(1), p:28-40.

Sideris, G. (1994). Geoid determination by FFT techniques. Lecture notes, Department of Geomatics Engineering University of Calgary.

Wenzel, H.G., (1998). Ultra-high degree geopotential model GPM93E97A to degree 1800 tailored to Europe, Report 98:4, Finnish Geodetic Institute, Masala, 71-80.

Xu X., Zhao Y., Reubelt T., Robert T., (2017: A GOCE only gravity model GOSG01S and the validation of GOCE related satellite gravity models.Geodesy and Geodynamics,Vol. 8(4), p: 260-272.