Evaluation the Performance of Recently Global Geopotential Models GGMs Over Egypt

Moamen A. Gad, Oleg R. Odalović

Abstract— In this study compares Erath Geopotential Models "EGMs" which released between 2015, up to 2017, including corporate data from the gravity satellites CHAllenging Minisatellite Payload "CHAMP", Gravity Recovery and Climate Experiment "GRACE" and The Gravity field and steady-state Ocean Circulation Explorer Mission "GOCE" dedicated satellite gravimetric mission, with terrestrial gravity anomalies data over the whole area of Egypt. The gravity anomalies which are implied by the models compared with point free air gravity anomalies on land while the geoid heights which are implied by the Models compared with discrete geometrical heights from co-located GPS and sprit-leveling.

The aim of this paper is to improve our knowledge about the performance of the satellite only tracking and combination EGMs which are generated from various satellites or only tracking "CHAMP, GRACE and GOCE" in addition to terrestrial data over the Whole area of Egypt with respect to terrestrial gravity anomaly and undulation height.

The assessment results of the comparison among the different geopotential model with the land gravity data "free air gravity anomalies and GPS\Leveling points" under investigation in this study have indicated the outstanding performance of EGM [XGM2016] to the other examined GGMs. EGM [XGM2016] has superior performance with smallest [RMSE] is [20.595 mgal] with respect to gravity anomaly and [0.577 m] with respect to geoidal height.

Keywords— Geopotential models, gravity, gravity anomalies, EGM "Earth geopotential models"

1. INTRODUCTION

The Satellite tracking data from the CHAMP, GRACE, and GOCE dedicated satellite gravimetric mission have resolved the long wave length component of the global gravity field with rather very high accuracy [7].

The geoidal heights which are producing from GGMs are quasi-geoid height, not geoid undulation, therefore, it's necessary to convert quasi-geoid height to geoid undulations by adding a correction before producing orthometric height from ellipsoidal heights. [13], [17]. Throughout taking the correction into consideration that is leading to the best fitting of gravimetric quasi-geoids to GPS/Levelling data [9].

Nevertheless, in order to improve local geoid modeling, the choice of an optimum GGM for a particular region is crucial [14], which is one of the main objectives of this investigation.

The determination o any element of gravity field is a repetitive task which, should be updated with time, as far as new gravity field data are collected and/or refined computational approaches are applied or new GGMs are released into the public domain [2], [3].

The higher accuracy of geoid computation required nowadays necessitates the need for an accurate GGM, which in turn necessitates the need for examining the performance of such newly released models in any local area to choose the best of them. Many of such studies have been done before in Egypt such as; [4], [5], [12].This study aims also to evaluate the behavior of those new models over Egypt to determine which of them is the most appropriate GGM there.

2. The Available Data

The gravity anomaly data, Figure [1] shows an irregular distribution with large gaps, especially on land while the coverage of Mediterranean and Red Sea is rather good than the land covering.

The local gravity data used in this study were grouped into two sets as shown in figure [1]. Firstly, all old available free-air gravity anomalies at [800] points, where the sources of these data their number and distribution are well documented in many previous works as shown in [4], [5], [12] free-air gravity anomaly values at [267] points were obtained from BGI [Bureau Gravimetric International], where their observational mean stander deviation is [0.24mgal], while the stander deviation estimated for older gravity anomaly data distributed all over the whole territory of Egypt is [0.73mgal] on average, secondly Marine free-air gravity anomalies at [31934] points. As can be seen from figure [1], free air gravity data distribution is not homogeneous over the land, with significant gaps, particularly in the eastern and western deserts, while it's approximately homogeneous distributed over the seas. In addition to [100] of known orthometric and ellipsoidal height "geoid undulation" as shown in figure [2].

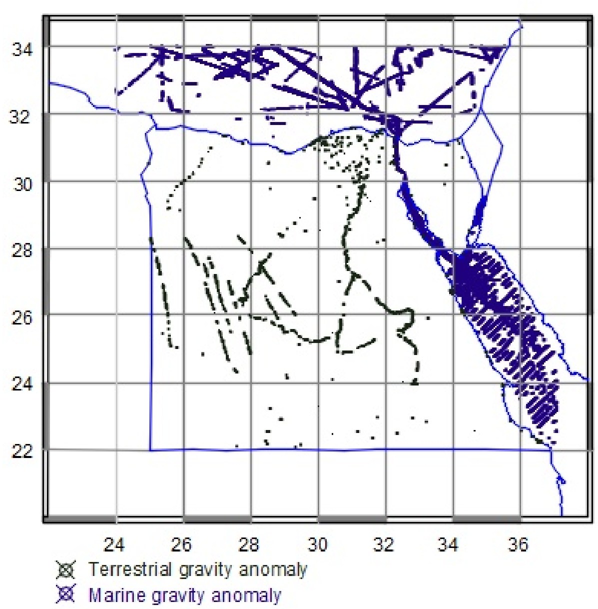

Fig. 1. Free air gravity anomaly distribution over EGYPT

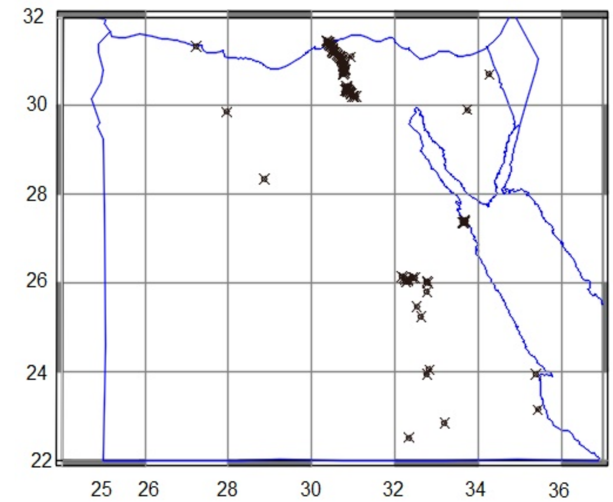

Fig. 2. GPS/Levelling pointsover 100 scattering point's distribution over EGYPT

TABLE 1

THE AVAILABLE USED DATA

Item	Data No. after filtration
Gravity anomalies [old]	800
Gravity anomalies [BGI]	267
Marine gravity anomalies	31,934
Undulation points	100

3. Methodology

Remove-restore technique consists of two steps. The first step is to remove the effect of the topographic isostatic masses and the effect of the global geopotential model from the source gravitational data.

The second step is to restore the effect of the topographic isostatic masses and the effect of the global geopotential model to the resulting geoidal heights.

Digital Terrain Models (DTM) are essential for gravity data processing and geoid model development, particularly for the computation of terrain corrections to observed terrestrial gravity data, and for downward continuation computations. Topographic height, bathymetry, and ice thickness data support the computation of analytical continuation terms, and the development of models to convert height anomalies to geoid undulations [13]. The effect of the topography (represented by a DTM) is accounted for in the calculation of reduced gravity anomalies as (ibid):

$$\Delta_g = \Delta_{gf} - \Delta g_h - \Delta g_{Ref} \quad (1)$$

Where:

Δ_{gf} is the free-air anomaly, Δg_h is the effect of the topography, and

Δg_{Ref} is the effect of reference gravity field represented by a GGM. The full geoid undulation N is then computed as:

$$N = N_{\Delta g} + N_h + N_{Ref} \quad (2)$$

Where:

$N_{\Delta g}$ is the contribution of the reduced gravity anomalies computed by

Stokes's integral,

N_h is the contribution of the topography or the terraineffect, and

N_{Ref} is the contribution of the reference gravity field computedby the spherical harmonic expansion

For more information on the FFT technique, (Sideris and Footopoulus, 2005).

The Shuttle Radar Topography Mission (SRTM) global DTM is a joint project between the U.S. National Imagery and Mapping Agency (NIMA) and the National Aeronautics and Space Administration (NASA)(http://www2.jpl.nasa.gov/strm/). A 90 m SRTM DTM for many parts of the world has been compiled and released (ibid). SRTM has been used in geoid modeling for several regions, particularly for topographic and downward continuation corrections [14].

The window of the SRTM DTM corresponding to the Egyptian territories has been downloaded (http://www2.jpl.nasa.gov/strm/) and has been considered in this study.

- SPHERICAL GRAVITY FIELD ELEMENTS

The spherical harmonic representation of the Earth's gravitational potential, [18]:- could be

$$V(r,\theta,\lambda) = \frac{GM}{r}\left[1 + \sum_{n-2}^{\infty}\left[\frac{a}{r}\right]^n \sum_{m=-n}^{n} \bar{C}_{nm}^{s}\ \bar{Y}_{nm}\ (\theta,\lambda)\right] \quad (3)$$

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 normalized coefficients, Cnm, Ynm

$$\bar{Y}_{nm}(\theta,\lambda) = \bar{P}_{nm}(\cos\theta)\ \cos m\lambda\ \text{ if } m \geq 0$$
$$\bar{Y}_{nm}(\theta,\lambda) = \bar{P}_{nm}(\cos\theta)\ \cos m\lambda\ \text{ if } m < 0 \quad (4)$$

Where:

Pnm[cosθ] are the fully normalized associated Legendre functions of the first kind [13].

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 of equipotential ellipsoid at P. Based on equation [1] the spherical harmonic representation of T is:

$$T(r,\theta,\lambda) = \frac{GM}{r}\sum_{n-2}^{\infty}\left[\frac{a}{r}\right]^n \sum_{m=-n}^{n} \bar{C}_{nm}^{s}\ \bar{Y}_{nm}\ (\theta,\lambda) \quad (5)$$

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 geoidal height [N]. The relationship between the coefficient of spherical harmonic with gravity anomalies [ΔgGM] and geoidal height [NGM] is given by the following formula, respectively:

$$\Delta g_{GM} = \frac{GM}{r^2}\left[\sum_{n-2}^{n_{max}}(n-1)\left[\frac{a}{r}\right]^n \sum_{m=0}^{n}\bar{C}_{nm}^{*}\cos m\lambda + \bar{S}_{nm}\sin m\lambda\right]\bar{P}_{nm}(\sin\varphi)$$
(6)

$$N_{GM} = \frac{GM}{r\gamma}\left[\sum_{n-2}^{n_{max}}(n-1)\left[\frac{a}{r}\right]^n \sum_{m=0}^{n}\bar{C}_{nm}^{*}\cos m\lambda + \bar{S}_{nm}\sin m\lambda\right]\bar{P}_{nm}(\sin\varphi)$$
(7)

Where:

GM is the geocentric gravitational constant;

n_{max} is the maximum degree;

n, m is the degree and order;

$\bar{C}_{nm}^{*}$ is the relevant fully normalized spherical harmonic C-coefficients of degree n and order m, reduced for the even zonal harmonics of the WGS-84 reference ellipsoid

$\bar{S}_{nm}$ is the relevant fully normalized spherical harmonic S-coefficients of degree n and order m,

$\bar{P}_{nm}(\sin\varphi)$ is the fully normalized associated Legendre function of degree n and order m,

φ,λ the geocentric latitude and longitude;

γ the normal gravity;

a the scaling factor and r is the geocentric distance.

- ## RECENT GLOBAL GEOPOTENTIAL MODELS

CHAMP (CHAllenging Mini-satellite Payload) had been launched in 2000, the twin satellites GRACE (Gravity Recovery and Climate Experiment) in 2002 and the launched of GOCE (Gravity field and steady-state Ocean Circulation Explorer) in 2008, which have introduced a new era in global gravity field determination (Featherstone, 2003). The CHAMP and GRACE satellite missions improve knowledge of the long and medium wavelength features of the gravity field. The future GOCE satellite improved knowledge of the short-wavelength components. The International Center for Global Gravity Field Models (ICGEM, Potsdam, Germany) makes available a number of GGMs in the form of fully-normalized spherical harmonic coefficients that can be used to compute geodetic and gravitational quantities. http://icgem.gfz-potsdam.de/tom_longtime

It should be noted that GGMs when used in a spherical harmonic expansion, produce quasi-geoid not geoid solutions since the processing yields height anomalies, not geoid undulations. Several researchers have considered this issue and have presented solutions to convert height anomalies to geoid heights [13], [17] suggested that potential coefficient models be used first to calculate a height anomaly and then that a correction term, represented by a high degree spherical harmonic expansion, be applied to give the geoid undulation.

TABLE 2

RECENTLY EGMS BETWEEN 2015 UP TO 2017 TO BE EVALUATING IN THIS STUDY

Model	Year	Degree	Data	References
XGM2016	2017	719	A,G, S(GOCO05s)	Pailet al., 2017
NULP-02s	2017	250	S(Goce)	Marchenko et al., 2017
GOCO05c	2016	720	(see model), A, G, S	Fecheret al., 2017
GECO	2015	2190	EGM2008, S(Goce)	Gilardoniet al., 2016

Data: S=Satellite Tracking Data, G = Terrestrial Gravity Data, A = Altimetry Data

- ## THE EXPERIMENTAL GRAVITY FIELD MODEL XGM2016

In December 2015, the United States National Geospatial-Intelligence Agency [NGA] has agreed to provide the Technical University of Munich [TUM] with a new, global

15′x15′ grid of 'terrestrial' gravity anomaly area means. This grid incorporates the majority of NGA's new altimetric and terrestrial survey data, as well benefiting from new procedures for processing this data. At this early stage, TUM has agreed to provide NGA with an independent assessment of this new data grid, in terms of its suitability for supporting an improved EGM. One outcome of this effort is the Experimental Gravity Field Model 2016 [XGM2016].

XGM2016 extend to spherical harmonic degree of 719, which is maximum resolution supported by its 15′x15′ terrestrial grid For XGM2016, a significant focus will be the optimal combination of the new terrestrial data with the latest satellite gravity information. This includes 11 years of GRACE (2002-2013), and the entire GOCE mission (2009-2013). The combination is based on a full normal equation system up to the maximum degree (n=719) of the expansion [16].

TABLE 3

THE PARAMETER OF EGM [XGM2016]

product_type	gravity_field
Model name	XGM2016
earth_gravity_constant	3.9860044150e+14
radius	6.3781363000e+06
max_degree	719
errors	formal
norm	fully_normalized
tide_system	zero_tide

- NULP-02s

The gravity field NULP-02s to degree/order 250 based on radial derivatives EGG_TRF_2 of satellite mission GOCE. NULP-02S gravity field model up to degree/order 250 was developed based on EGG_TRF_2 GOCE radial gradients and Gauss quadrature formula in the frame of space-wise approach by National University "Lviv Polytechnic" (Institute of Geodesy, Laboratory for Theoretical Geodesy and Data Processing).

- Additional Information

Input Data

GOCE EGG_TRF_2 gradients from November 2009 to October 2013.

Radial derivatives of the EGM2008 model to d/o 360 for both polar gaps as additional information at the Gaussian grid nodesto avoid these polar gaps instability.

Calculation method:

Kalman filtration of the radial derivatives with additional smoothing by Gauss filtering

Formation of Gaussian grid of radial gradients using modified local non-smooth splines.

Estimation of harmonic coefficients via Gauss quadrature formula

TABLE 4

THE PARAMETER OF EGM [NULP-02S]

product_type	gravity_field
Model name	NULP-02s
earth_gravity_constant	3.9860044150e+14
radius	6.3781363000e+06
max_degree	250
errors	fully_normalized
norm	fully_normalized
tide_system	tide_free

- GOCO05c

GOCO05c: A New Combined Gravity Field Model Based on Full Normal Equations and Regionally Varying Weighting, it is the first combined gravity field model independent of

EGM2008 that contains GOCE data of the whole mission period.

It has been elaborated by the GOCO Group (TU Munich, Bonn University, TU Graz, Austrian Academy of Sciences, University Bern). GOCO05c is a combination model based on the satellite-only gravity field model GOCO05s and several gravity anomaly datasets, constituting a global 15'x15' data grid. The combination is carried out in term of full normal equation systems.
Contributing Institutions are:

(1) TU Muenchen, DE, Institute of Astronomical and Physical Geodesy;
(2) University of Bonn, DE, Institute of Geodesy and Geoinformation;
(3) TU Graz, AU, Institute of Theoretical and Satellite Geodesy;
(4) Austrian Academy of Sciences, Space Research Institute, and
(5) University of Bern, CH, Astronomical Institute [10].

TABLE 5

THE PARAMETER OF EGM [GOCO05C]

product_type	gravity_field
Model name	GOCO05c.gfc
earth_gravity_constant	0.39860044150D+15
radius	0.63781363000D+07
max_degree	720
errors	formal
norm	fully_normalized
tide_system	zero_tide

- GECO

A global gravity model by locally combining GOCE data and EGM2008
The EGM2008 model is nowadays one of the descriptions of the global gravitational field at the highest resolution. It is delivered with two, not fully consistent, sources of information on its error: spherical harmonic coefficient variances and a geographical map of error variances, e.g. in terms of geoid undulation. In the present work, the gravity field information derived from a GOCE satellite-only global model is used to improve the accuracy of the EGM2008 model in the low to medium frequencies, especially in areas where no data were available at the time of EGM2008 computation. Due to computational reasons, the combination is directly performed in terms of geoid values over a regular grid of local areas. Repeating the combination for overlapping areas all over the world and then performing a harmonic analysis, a new combined model is obtained. It is called GECO and extends up to the EGM2008 maximum degree.
GOCE is actually more informative than EGM2008 in the areas where no ground gravity data were available at the time of EGM2008 computation, such as Africa, South America [11].

TABLE 6

REPRESENTS THE STATISTICS COMPUTATION FOR FREE AIR GRAVITY ANOMALY OVERGRID POINTS [1'X1'] OF THE FOUR MODELS OVER THE WHOLE TERRITORY OF EGYPT.

Free air gravity anomaly	Min mgal	Max mgal	Mean mgal	Std. Dev. mgal	RMSE mgal
GOCO	-165.165	145.631	0.904	29.945	29.959
XGM2016	-166.041	148.706	0.886	29.914	29.927
NULP-02s	-165.573	114.714	0.934	28.468	28.483
GOCO05c	-165.920	145.299	0.863	29.803	29.815

TABLE 7

REPRESENTS THE STATISTICS THE COMPARISON AMONG THE TERRESTRIAL GRAVITY ANOMALIES AND THOSE COMPUTED FROM THE DIFFERENT HARMONIC MODELS AT SCATTERING POINTS THREE MODELS OVER THE WHOLE TERRITORY OF EGYPT.

Free air gravity anomaly	Min mgal	Max mgal	Mean mgal	R.M.S. mgal	STD. DEV.Of the residual mgal
G.A$_{terrs}$- XGM2016	-133.272	119.353	-4.129	20.595	20.177
G.A$_{terrs}$- NULP-02s	-192.935	161.272	-5.540	44.424	44.078
G.A$_{terrs}$ - GOCO05c	-134.747	120.088	-5.428	21.975	21.295
G.A$_{terrs}$ - GOCO	-142.302	95.702517	-5.701	22.940	22.221

TABLE 8

REPRESENTS THE STATISTICS THE COMPARISON AMONG THE GPS/LEVELLING POINTS AND THOSE COMPUTED FROM THE DIFFERENT HARMONIC MODELS AT SCATTERING POINTS.

Geoid undulation	Min m	Max m	Mean m	R.M.S. m	STD. DEV. Of the residual m
N_{obs} - $N_{XGM2016}$	-0.411	0.916	0.426	0.577	0.391
N_{obs} - $N_{NULP-02s}$	-0.615	0.996	0.414	0.620	0.463
N_{obs} - $N_{GOCO05c}$	-0.890	0.571	-0.393	0.567	0.410
N_{obs} - N_{GOCO}	-0.916	0.607	-0.394	0.569	0.412

In table [6] shows the statistical computation of the gravity anomaly derived from different harmonic models over grid [1'x1'] by using gravsoft package software.

Tables [7] shows the statistics of the comparison among the terrestrial gravity anomalies and those computed from the different harmonic models at scattering points of over whole area of EGYPT by using ordinary kriging technique for interpolation, while table [8] describes the comparison among the terrestrial GPS\Levelling points and those computed from the different harmonic models at scattering points with week distributions over Egypt.

The values, of [R.M.S] and [Std. Dev.] shown in columns four and five in tables [6 and 7], are related to the area between 24: 37 E and 22: 34 N which is larger than Egypt territory. The chosen area to be larger than EGYPT territory, therefore to illustrate the performance of those EGMs not only on the land but also on the marine.

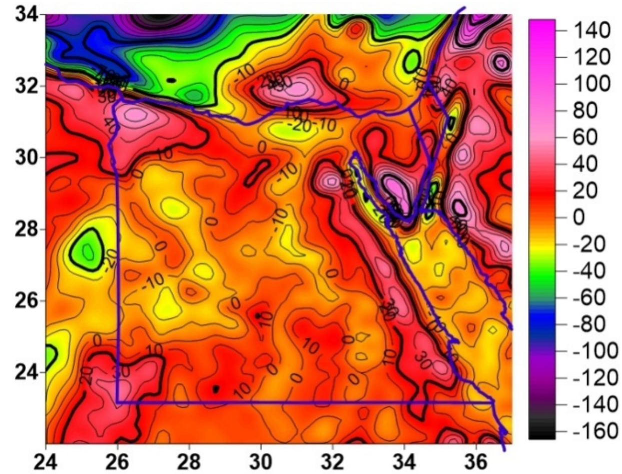

Fig.3 Free air gravity anomaly [Δg_{fa}] referred to EGMXGM2016for the whole area of Egypt.

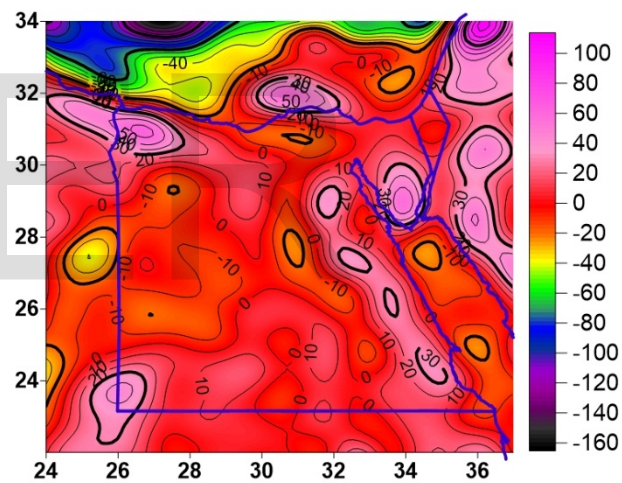

Fig. 4 Free air gravity anomaly [Δg_{fa}] referred to EGMNULP-02s for the whole area of Egypt.

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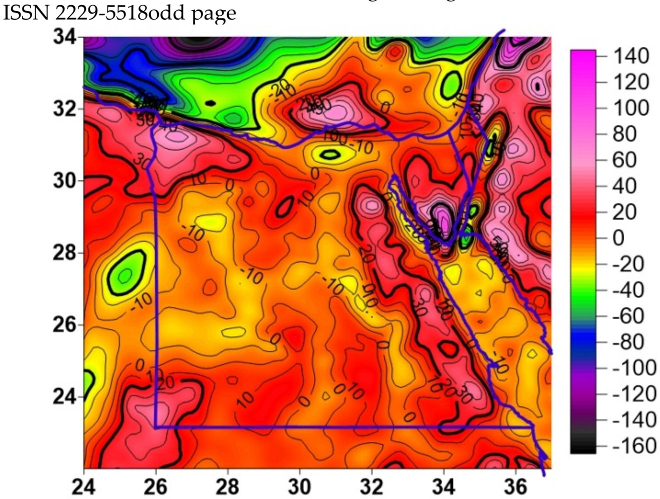

Fig.5 Free air gravity anomaly [Δgfa] referred to EGMGOCO05c for the whole area of Egypt

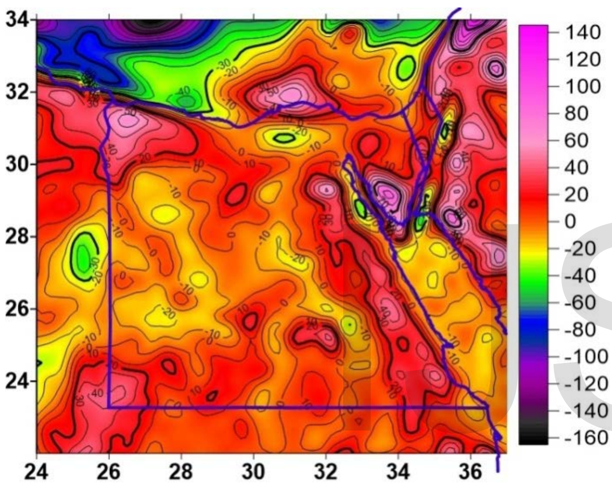

Fig.6 Free air gravity anomaly [Δgfa] referred to EGMGOCO for the whole area of Egypt

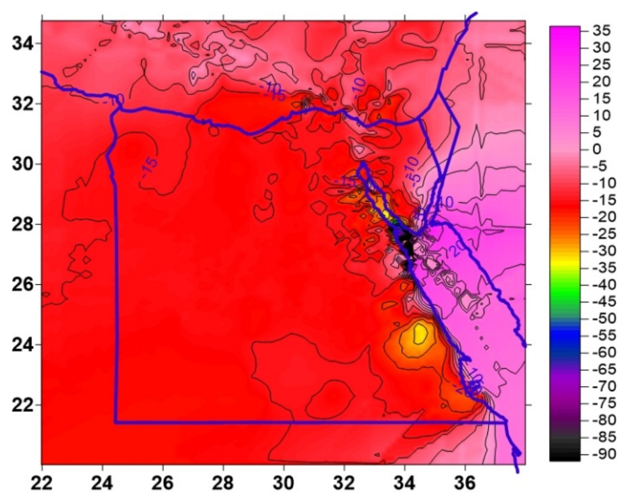

Fig.7 Δg_{fa} residuals referred to EGMXGM2016 with terrestrial data for the whole area of Egypt.

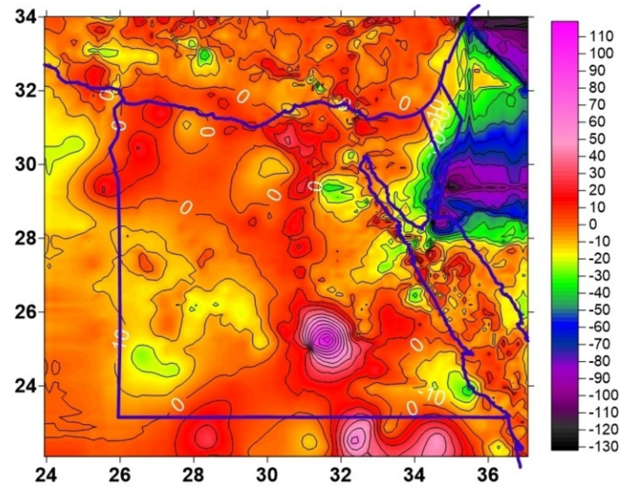

Fig.8 Δg_{fa} residuals referred to EGMNULP-02swith terrestrial data for the whole area of Egypt.

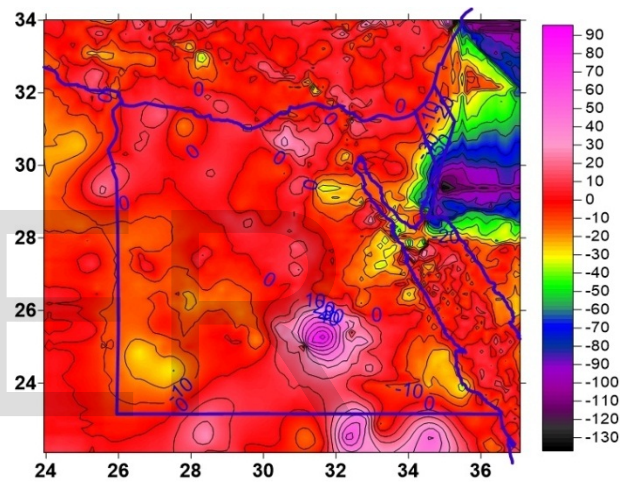

Fig.9 Δg_{fa} residuals referred to EGMGOCO05cwith terrestrial data for the whole area of Egypt.

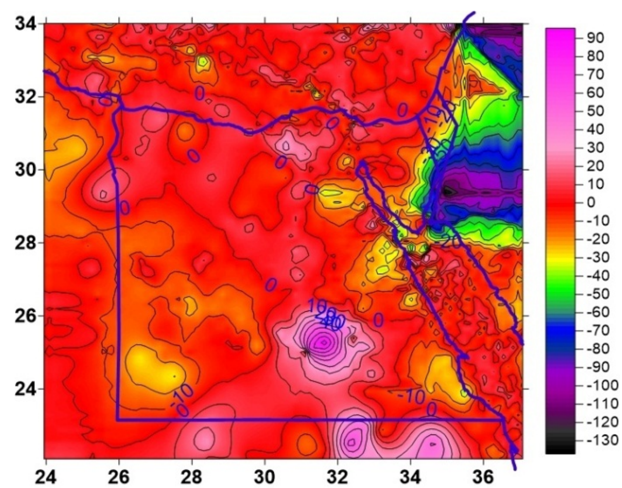

Fig.10 ,Δg_{fa} residuals referred to EGMGOCOwith terrestrial data for the whole area of Egypt.

Figure [3 to 6] illustrated the free air gravity anomaly derived from XGM2016, NULP-02s, GOCO05cand GOCO harmonic models respectively over a grid [1'x1'] for whole Egypt territory.

Figure [7 to 11] shows the difference between scattering observed terrestrial free air gravity anomaly and XGM2016, NULP-02s, GOCO05c and GOCO, harmonic models, respectively.The dark blue area between 35: 37 E and 28: 34 N which appears in figure [8 to 9] due to the lake of terrestrial data in this area and the residuals are related only to the long wave length of the model but if the model has contributions of correct terrestrial data which covered the short wavelength effect, the mentioned dark area will be illuminated as shown in figure [7].

Unfortunately, the performance of EGM 2008 which is considered as the main part of EGM GOCO with high spherical harmonic coefficient up to 2190 has imperfect performance all over EGYPT as it was expected, while the accepted accuracy from this model mostly because GOCE data included into it. The week performance of this model comparing to the others due to wrong terrestrial data which are included in EGM 2008 model [1], especially with GPS\levelling points data were most of them are wrong but for the free air gravity anomaly values they vary from region to another [6] within Egypt territory.

The four EGMs under investigations have from the results good performance over EGYPT and areas extends by approximate two degrees from each side, but the model XGM2016 has more accuracy than the other model as seen in table [5], [6], and from the results shown in figure [5] Δgfa residuals referred to EGM XGM2016 with terrestrial data over the land area of Egyptian territory has an extremely accuracy reached to [12 mgal] on average.

The results shown in tables [5-6] of the GGMs evaluation over the whole area of Egypt have indicated that the smallest [R.M.S.] is [20.595 mgal] w.r.t gravity anomaly and [R.M.S.] is [0.577 m] w.r.t geoidal height, referred also to EGM XGM2016, which confirms the conclusion the previous paragraph i.e. this model is the best of the four models. The reason for this smallest values of [R.M.S.] is an enhancement of GOCE observation and the correct terrestrial data included in the composites this model.

Finally, it is recommended to use EGM [XGM2016] in determining the gravimetric geoid for Egypt.

4. Conclusion and Recommendations

CHAMP and GRACE mission successes have already led to considerable improvement in our knowledge of the geoid at long wavelengths, as well as time variations in the Earth's gravity field. The GOCE mission allowed recovery of a high-resolution static gravity field with homogeneous quality and of unprecedented accuracy and very high resolution.

As seen from the results in tables [5], [6] according to standard deviation and root mean square error of the residuals, it's obvious when Goce data included in the model the results become more reliability and covered the short wave length trend of earth gravitational field.

5. References

[1] Abd-Elmotaal, H. (2008). Evaluation of the EGM2008 geopotential model for Egypt. IAG International Symposium on Gravity, Geoid and Earth Observation "GGEO 2008", Chania, Greece, June, 2008. [ResearchGate]

[2] Alnaggar, D. (1986). Determination of the geoid in Egypt using heterogeneous geodetic data, Ph.D. Dissertation, Cairo University, Cairo, Egypt.

[3] Amin, M. M. (1983). Investigation of the Accuracy of some Methods of Astrogravimetric Levelling using an Artificial Test Area", Ph.D. Thesis in Physical Geodesy, Geophysical Institute, Czechoslovak Acad. Sci., Prague.

[4] Amin, M. M., El-Fatairy, S. M., Hassouna, R. M. (2002). The "EGM96EGIT" Geopotential Model Tailored to Egypt by the Stokes' Integral Technique. Scientific Bulletin of Matarya Faculty of Engineering, Helwan University, Cairo, Egypt.[Research Gate]

[5] Amin, M. M., El-Fatairy, S. M., Hassouna, R. M. (2003). Two techniques of tailoring a global harmonic model: operational versus model approach applied to the Egyptian territory. Port-Said Engineering Research Journal PSERJ.

[6] Amin, M. M., Zaky, K. M.,EL Fatairy, S. M., Gad, M. A. (2013). Fetching the Most Appropriate Global Geopotential 2013 Model for Egypt. Civil Engineering Research Magazine CERM, 35 (3). [ResearchGate]

[7] Ellmann, A., Jurgenson, H. (2008). Evaluation of a GRACE-based combined geopotential model over the Baltic countries. Geodesy and Cartography, 34(2), 35-44. http://dx.doi.org/10.3846/1392-1541.2008.34.35-44

[8] Featherstone, W. (2003). Improvement to long-wavelength Australian gravity anomalies expected from the GRACE, CHAMP and GOCE dedicated satellite gravimetry missions. Exploration Geophysics, 34(2), 69-76. http://dx.doi.org/10.1071/EG03069

[9] Featherstone, W. (2006). Fitting geoids to GNSS-levelling: You're fooling yourself and fooling others.The International Congress Center Munich (ICM),Munich, Germany.[Google scholar]

[10] Fecher, T., Pail, R., Gruber, T. (2017). GOCO Consortium. GOCO05c: A New Combined Gravity Field Model Based on Full Normal Equations and Regionally Varying Weighting. Surveys in Geophysics, 38 (3), 571–590. http://dx.doi.org/10.1007/s10712-016-9406-y

[11] Gilardoni, M., Reguzzoni, M., Sampietro, D. (2016). GECO: a global gravity model by locally combining GOCE data and EGM2008. Studia Geophysica et Geodaetica, 60(228), 228–247.http://dx.doi.org/10.1007/s11200-015-1114-4

[12] Hassouna, R. M. (2003). Modeling of Outer Gravity Field in Egypt using Recent Available Data. Ph.D. Thesis, Department of Civil Engineering, Faculty of Engineering in Shebin El-Kom, Menoufia University, Egypt.

[13] Heiskanen, W., Moritz, H. (1967). Physical geodesy, San Francisco: W. H. Freeman and Company. [Google Scholar]

[14] Kiamehr, R., Sjoberg, L. E. (2005). Comparison of the qualities of recent global and local gravimetric geoid models in Iran, Studia Geophysica et Geodaetica, 49(3), 289-304. http://dx.doi.org/10.1007/s11200-005-0011-7

[15] Marchenko, Alexander, N., Dmitriy, A., Lopyshansky. (2017). The gravity field NULP-02s to d/o 250 based on radial derivatives EGG_TRF_2 of satellite mission GOCE. GFZ Data Services. http://doi.org/10.5880/icgem.2017.001

[16] Pail, R., Fecher, T., Barnes, D., Factor, J., Holmes, S., Gruber, T., Zingerle, P. (2017). The experimental gravity field model XGM2016. GFZ Data Services. http://doi.org/10.5880/icgem.2017.003

[17] Rapp, R. H. (1997). Use of potential coefficient models for geoid undulation determinations using a spherical harmonic representation of the height anomaly/geoid undulation difference. Journal of Geodesy, 71(5), 282–89. http://dx.doi.org/10.1007/s001900050096

[18] Rapp, R. H., Pavlis, N. K. (1990).The development and analysis of geopotential coefFcient Models to spherical harmonic degree 360. Journal of Geophysical Research, 95(B13), 21885–21911. http://dx.doi.org/10.1029/JB095iB13p21885

[19] Sideris, M., Footopoulus, M. (2005). Geoid determination by FFT, Presented in the International Geoid School, Budapest, Hungary.

- *Moamen Gad*
  PhD candidate
  University of Belgrade , Belgrade · Faculty of Civil Engineering
  Geodesy and Surveying
  Email Eng_moamen205@hotmail.com

- *Oleg Odalovic*
  Associate professor
  University of Belgrade , Belgrade · Faculty of Civil Engineering
  Geodesy and Surveying
  Email odalovic@grf.bg.ac.rs