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Deriving a Geoid Undulation Network over Egypt by Merging Data of Different Global Geo-Potential Models

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Abstract

One of the crucial research scopes of geodesy/surveying science is to identify the vertical positioning (h/H), since most applications in civil engineering projects need to a highly accurate for vertical positioning value. While the Global Positioning System (GPS) can measure the Ellipsoidal heights/Geodetic heights (h), the Orthometric heights (H) can be measured by traditional field survey techniques such as Total Station/ Spirit Levelling. Often the transformation process between the two heights, the Geodetic height (h) and the Orthometric height (H), is needed for most of civil engineering projects. The link in this transformation process is the geoid undulation/geoidal height (*N*), which can be calculated by many of the Global Geo-potential Models (GGMs). Due to the large area of Egypt (about one million Km2) and for variable data, each GGM gives different results of (*N*), therefore several attempts were conducted by geodesist researchers to evaluate, compare, develop different GGMs to achieve the best fit to reality results (*N*) in Egypt. Although the authors did many efforts to accomplish this object, but most of them are dealing directly with GGMs and they didn't trying to enhancement the results of different GGMs (*N*) values and creating a trusted undulation network. This paper aim to derive Geoid Undulation Network Values which are presenting the best fit to reality over Egypt in order to enhancement Orthometric height values there. The study area network is consisting of 346 equally distributed points which bounded by latitudes (ϕ) [22° N, 31° N] and between longitudes (λ) [26° E, 36° E] with 0.5° interval of both latitudes (ϕ) and longitudes (λ) to cover whole Egypt territories. The methodology in this paper had been based on merging eight of GGMs data, many standards were taken into considered when these eight GGMs are selected. The undulation contour map and 3D Surface were created using the final undulation network "DGUNET/2019" successfully with promising and significant harmony results. Generally, the purpose of this study was achieved.

Key words: Geoid, Undulation, GGM, Ellipsoidal heights, Orthometric heights, Egypt

INTRODUCTION

Coordinates are the values to identify a specific location on the earth and map (Tarek, 2016). Getting a highly accurate three-dimensional (3D) coordinates values for different points on earth [Longitude (λ), Latitude (ϕ) and Height (h/H)] are a most challenge research scopes of geodesy. 3D positions can be divided into two main components; horizontal (ϕ, λ) and vertical (h/H). The main concern of this paper is the vertical component (h/H).

The height and the datum are two main factors for the vertical position based on the used reference surface. The ellipsoid and the equipotential surface are two reference surfaces to compute the vertical position (Davis et al., 2011). While the Ellipsoidal datum is based on a geometric model, the Equipotential surface (the geoid) is the surface of constant gravity potential. Also, while the Ellipsoid heights values are typically realized through observations from space-based systems, the potential gravity values depend on the distribution of mass density throughout the earth. Therefore, each location on earth has two height values Ellipsoidal height/Geodetic height (h_i) is related to the geodetic reference ellipsoid surface and Orthometric height (H_i) is related to the equipotential surfaces/The Geoid. The Global Positioning System (GPS) can measure the ellipsoidal heights and the Othometric heights can be measured by traditional field survey techniques such as Total Station/ Spirit Levelling.

Equation (1) expresses the Geoid Undulation or Geoidal Height (N_i), which is the difference between the ellipsoidal height (h_i) and orthometric height (H_i) as shown in figure (1).

$$N_i = h_i - H_i \qquad (1)$$

Due to the advantages of space-based technique such as GPS which often referred to the World Geodetic System 1984

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(WGS84) ellipsoid in Egypt, the GPS observations became has a widespread in the last 20 years. On the other hand, civil engineering projects are still using orthometric heights values (H) for engineering applications/mapping processes. According to Equation (1), undulation height value (*N*) and the ellipsoid height value (h) at point (*i*) can be used to calculate the orthometric height value (H) at point (*i*) to merge the advantages and converts between the two techniques.

(N_i) Values can be calculated by several Global Geo-potential Models (GGMs). GGM is a model that is being represented by the spherical harmonic coefficient that defines the potential of gravitational in the spectral domain (Tugi et al., 2016). Egypt has an area of up to one million km^2 and due to the limited input data for different GGMs. Therefore (N_i) values for each point (*i*) will be different when using different GGMs and the accuracy of the GGMs are low (Tarek, 2018).

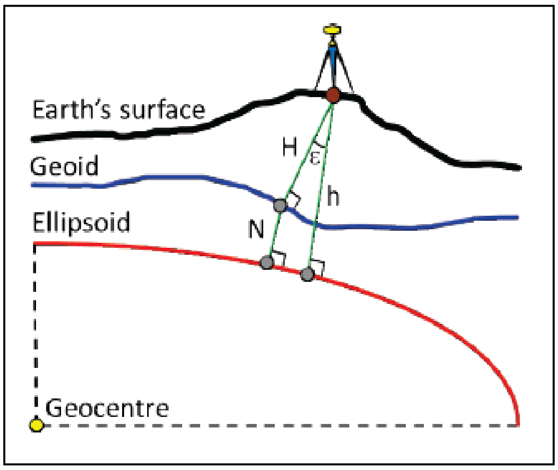

Figure (1): The relations between Ellipsoid height (h_i), orthometric height (H_i) and geoid undulation (N_i) (Yilmaz et al., 2017).

RELATED WORK

In this section, some of related studies will be highlighted. Several GGM has been developed based on data collected by satellite missions such as CHAMP, GRACE, GOCE and LAGEOS. GGMs data are classified to satellite-only models such as from CHAMP and combined model such as from LAGEOS. Due to the importance of Egypt location and its huge area, the geodesist researchers conducted several attempts to;

- find the best fit GGM for Egypt such as Mahmoud (2012),
- quantify the GGM precision in Egypt such as Al-Krargy et al. (2015),
- develop a national geoid model for Egypt such as DAWOD (1998); DAWOD (2008); Abd-Elmotaal (2008); Al-Krargy et al. (2014); Moamen (2019)
- evaluate the GGM performance generally such as Förste et al. (2009); Yilmaz et al. (2016), and
- study the relationship between different (*N*) values of most common GGMs over Egypt, such as Tarek (2018).

Based on the GGMS and available data for each of them, the authors gone to quantify the best fit, developing, evaluation and/or comparison for GGM over Egypt, they used about twenty-nine GGMs with consideration variability of data input type which varied from terrestrial gravity data, satellite tracking data and altimetry data. Mahmoud (2012) recommended 10 GGMs and Al-Krargy et al. (2015) recommended 7 GGMs to use over Egypt as shown in table (1) for a total 14 mutual GGMs by different authors. On the other hand, Tarek (2018) studied the relation between the undulations values (N_i) using 8 GGMs see table (1) as most common in Egypt recently. Tarek (2018) concluded that a significant difference values between these 8 GGMs on most of points location and he recommended study more deeply to get the main reason of these significant differences based on the location of different points (Tarek, 2018).

Table (1): The recommended GGMs to use over Egypt by different authors

<table>
<tr><th>#</th><th>Model</th><th>Degree</th><th>Data Type</th><th colspan="3">Authors</th></tr>
<tr><td>1</td><td>GGM02C</td><td>200</td><td>S(GRACE), G, A</td><td rowspan="10">(Mahmoud, 2012) 10 GGMs</td><td rowspan="2"></td><td rowspan="7"></td></tr>
<tr><td>2</td><td>EIGEN GRACE-02S</td><td>150</td><td>S(GRACE)</td></tr>
<tr><td>3</td><td>EGM 2008</td><td>360</td><td>S(GRACE), G, A</td><td rowspan="8">(Tarek, 2018) 8 GGMs</td></tr>
<tr><td>4</td><td>EIGEN-CG01C</td><td>360</td><td>S(CHAMP, GRACE),G, A</td></tr>
<tr><td>5</td><td>GGM03C</td><td>360</td><td>S(GRACE), G, A</td></tr>
<tr><td>6</td><td>EIGEN-CG03C</td><td>360</td><td>S(CHAMP, GRACE), G, A</td></tr>
<tr><td>7</td><td>EIGEN-GL04C</td><td>360</td><td>S(GRACE, LAGEOS), G, A</td></tr>
<tr><td>8</td><td>EIGEN-05C</td><td>360</td><td>S(GRACE, LAGEOS), G, A</td><td rowspan="7">(Al-Krargy et al., 2015) 7 GGMs</td></tr>
<tr><td>9</td><td>EGM96</td><td>360</td><td>S, G, A</td></tr>
<tr><td>10</td><td>EGM 2008</td><td>2190</td><td>S(GRACE), G, A</td></tr>
<tr><td>11</td><td>DGM-1S</td><td>250</td><td>S(GOCO, GRACE)</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>12</td><td>GO_CONS_GCF_2_TIM_R5</td><td>280</td><td>S(GOCO)</td></tr>
<tr><td>13</td><td>GO_CONS_GCF_2_DIR_R5</td><td>300</td><td>S(GOCO, GRACE, LAGEOS)</td></tr>
<tr><td>14</td><td>EIGEN-6C4</td><td>2190</td><td>S(GOCO, GRACE, LAGEOS), G, A</td></tr>
</table>

Where; S = Satellite Tracking Data, G = Terrestrial Gravity Data, A =Altimetry Data. and CHAMP, GOCE, GRACE, and LAGEOS are gravity satellite missions.

Although the authors did many attempts to get good results by different GGMs, most of them are dealing directly with GGMs and they didn't enhance the results of different GGMs (N_i) values and creating a correct network of (N_i) values by different ways.

OBJECTIVE

The main objective of this study is to obtain the best fit Geoid Undulation values (N_i) for equally distributed points over Egypt to find a most probable value for a corrected network, which can be used later as control points for different projects or researcher works. This is based on merging data of different GGMs values (N_i) of the most common and available GGMs used in Egypt recently. Finally, any enhancement for the (N_i) values will be reflected directly and positively to enhancement Orthometric height (H_i) values.

STUDY AREA AND DATA OVER EGYPT

This study will calculate the (N_i) values for 346 equally distributed points bounded by latitudes (ϕ) [22° N, 31° N] and between longitudes (λ) [26° E, 36° E] with 0.5° interval of both latitudes (ϕ) and longitudes (λ) and the distance between points approximately is 50 Km to cover the whole area of Egypt as shown in figure (2).

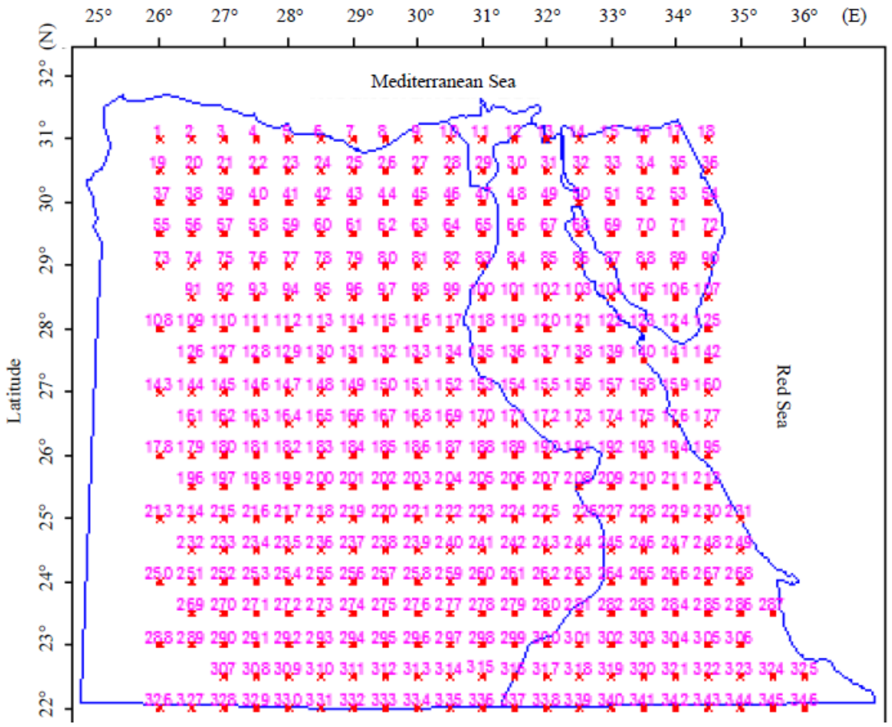

Figure (2): An available 346 ground control points are equally distributed over the Egypt map (Tarek, 2018).

Since this study will use the calculated values of geoid undulation (N_i) by different GGMs, therefore the main concept and equation use by GGMs will be described briefly here.

Mahmoud (2012) mentioned that "The geo-potential models are available with coefficients (C_{nm}) and (S_{nm}) complete up to degree and order (n, m).So the geoid undulations above the reference (normal) ellipsoid are computed from the fully normalized spherical harmonic coefficients to the degree (n) using the truncated formula" as shown in equation (2) (Mahmoud, 2012). (Tarek, 2018) mentioned more details about the methodology used to calculate values of geoid undulation (N_i) by other authors.

$$N = \left({}^{GM}/_{r\gamma}\right) \sum_{n=2}^{n=max} \left({}^{a}/_{r}\right)^n - \sum_{m=0}^{n} [(\bar{C}_{nm} \cos m\lambda) + (\bar{S}_{nm} \sin m\lambda)] \bar{P}_{nm} \sin \phi \qquad (2)$$

Where;

- G is the Newtonian gravitational Constant,
- M is the mass of the earth,
- $\bar{C}_{nm}$, $\bar{S}_{nm}$ are the fully normalized geo-potential coefficients of degree and order n, m,
- $\bar{P}_{nm}$ is the fully normalized associated Legendre function of degree and order n, m,
- a is the semi-major axis,
- n is the degree of the geo-potential model,
- γ is the normal gravity on the reference ellipsoid,
- r is the radial distance from Earth's mass center,
- ϕ, λ are the geocentric latitude and longitude.

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While this study will exposed to the most common and available GGMs in Egypt recently, also the variation for the issue year and the highest degrees were taken into consideration when selected different GGMs, the eight selected GGMs are showing in the table (2).

Table (2): Eight selected GGMs to use over Egypt in this study.

#	Model	Year	Degree	Data Type
1	EGM96	1996	360	S, G, A
2	EIGEN-CG01C	2004	360	S(CHAMP, GRACE),G, A
3	GGM03C	2009	360	S(GRACE), G, A
4	EIGEN-CG03C	2005	360	S(CHAMP, GRACE), G, A
5	EIGEN-GL04C	2006	360	S(GRACE, LAGEOS), G, A
6	EIGEN-05C	2008	360	S(GRACE, LAGEOS), G, A
7	EGM 2008	2008	360	S(GRACE), G, A
8	EGM 2008	2008	2190	S(GRACE), G, A

Where; S = Satellite Tracking Data, G = Terrestrial Gravity Data, A =Altimetry Data. and CHAMP, GOCE, GRACE, and LAGEOS are gravity satellite missions

Eight undulation values (N_i) were calculated for each point of the 346 points. All these output-data of different eight GGMs are available from the author, but to avoid the prolongation, a sample are shown in table (3) with 18 points only of these results on one Latitude (ϕ = 31° North) and the Point Number (ID) as original data shown in figure (5) over Egypt map. While table (3) shows just sample (18 points), but the conclusion of this research will be based on using and analysis all data for all 346 points with interval 0.5° in both latitude (ϕ) and longitude (λ).

Table (3): Calculated (N_i) values using eight GGMs for 18 points only as an example.

			Calculated (N_i) Values (m)							
		i →	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Point (ID)	**Lat. (Deg.)**	**Long. (Deg.)**	**EGM96**	**EIGEN-CG01C**	**GGM03 C**	**EIGEN-CG03C**	**EIGEN-GL04C**	**EIGEN-5C**	**EGM 2008 (360)**	**EGM 2008 (2190)**
1	31	26	21.39	20.84	21.25	21.31	21.29	21.34	21.23	20.85
2	31	26.5	20.93	20.38	20.79	20.84	20.89	21.06	20.95	20.61
3	31	27	19.84	19.25	19.77	19.64	19.78	19.99	19.66	19.25
4	31	27.5	18.50	17.77	18.30	18.07	18.29	18.36	18.21	17.96
5	31	28	17.08	16.30	16.89	16.53	16.78	16.74	16.89	16.58
6	31	28.5	16.01	15.38	15.87	15.59	15.76	15.72	15.77	15.50
7	31	29	15.29	14.65	15.07	14.91	14.92	14.96	14.86	14.72
8	31	29.5	15.43	14.81	15.18	15.14	15.05	15.20	15.02	14.62
9	31	30	15.74	15.23	15.44	15.61	15.47	15.52	15.44	15.01
10	31	30.5	15.79	15.23	15.36	15.61	15.44	15.45	15.55	15.01
11	31	31	16.02	15.36	15.59	15.71	15.58	15.59	15.80	15.34
12	31	31.5	16.36	15.49	15.96	15.77	15.76	15.70	16.03	15.64
13	31	32	16.81	15.74	16.34	15.97	16.11	16.16	16.37	15.94
14	31	32.5	17.07	16.14	16.62	16.34	16.55	16.54	16.55	16.31
15	31	33	17.79	17.22	17.25	17.41	17.58	17.47	17.20	16.80
16	31	33.5	17.79	17.41	17.27	17.58	17.64	17.55	17.30	17.01
17	31	34	17.54	17.25	17.30	17.38	17.23	17.66	17.20	17.02
18	31	34.5	18.44	18.34	18.19	18.44	18.15	18.87	18.17	17.62

METHODOLOGY

The methodology in this paper has been carried using the least-squares method as follows;

i. Each point of 346 points has ID_k been distributed equally as an array to cover whole Egypt with 0.5° interval of both latitudes (ϕ) and longitudes (λ) points $k = (1 \rightarrow 346)$.

ii. Eight undulation values (N_i) were calculated for each point of the 346 points (table (3)) $i = (1 \rightarrow 8)$.

iii. Calculate the mean/the Most Probable Value for each point $\bar{N}_k = \sum(N_i) / \sum(i)$

iv. Calculate the square of the Residual Error for each point $\sum(v^2)_k = \sum[(\bar{N}_k - N_i)^2]$

v. Calculate the Standard Deviation for each point $(SD)_k = \sqrt{\sum(v^2)_k / (i-1)}$

vi. Calculate the mean square error for each point $(m.s.e)_k = (SD)_k / \sqrt{(i)}$

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vii. P-value ($t_{(i-1)}$) was gotten using the t-Test table with degree of freedom ($df = i - 1$) and the confidence level = 99 %. (Walpole et al., 2012)
viii. Calculate the acceptable range ($\mu_{k(Max)}$ and $\mu_{k(Min)}$) for each point (N_k) by $\mu_k = N_k \pm t_{(i-1)} \times (m.s.e)_k$
ix. Checking if each of $(N_i)_k$ is accepted or rejected according to ($\mu_{k(Max)}$ and $\mu_{k(Min)}$) range.
x. Count how many points are accepted and the ratio for every GGMs
xi. All the previous steps called "1st trial".
xii. Ignore one GGM only, which has the lowest number of accepted points in "1st trial".
xiii. Starts the "2nd trial" and repeats the whole process for the rest of GGMs. Note that should be using the whole 346 points of each accepted GGMs for the next trial.
xiv. The process is stopped if 100 % of points (346 points) are accepted from all GGMs which used in this trial, then this $(Ni)_k$ are accepted from different GGMs.
xv. Getting the final value (N_F) by calculating the average value for each point of only the accepted GGMs

$$N_k = \Sigma(N_i) / \Sigma(i)$$

xvi. The final network called "Deriving a Geoid Undulation Network over Egypt by Tarek/2019" (DGUNET/2019).

TESTS AND RESULTS

According to the methodology in this paper, the tests and results will be mentioned parallel in this section. Since the methodology needs to series of sequential trials, four trials were needed in this study. Each trial was needed to apply constant parameters for all points in this trial such as {[k], [i], degree of freedom [df], the Confidence Level [CL], [α] and [$[t_{(i-1)}]$} as shown in table (4). Also, each point, inside one trial, needed to variable parameters which can be calculated using the eight values (N_i) such as $\{[\bar{N}_k], [\Sigma(v^2)_k], [(SD)_k], [(m.s.e)_k], [\mu_{k(Max)}]$ and $[\mu_{k(Min)}]\}$. Table (5) presents a sample of variable parameters values which were calculated for each point, 18 points of total 346 points in "1st trial".

Table (4): The parameters values were used for each trial

Parameters	k	i	df	CL	$\alpha/2$	$t_{(i-1)}$
1st Trials	346	8	7	99 %	0.005	3.499
2nd Trials		7	6			3.707
3rd Trials		6	5			4.032
4th Trials		5	4			4.604

Table (5): Sample of calculated variable parameters values for each point in "1st trial".

Point ID (k)	Lat. (Deg.)	Long. (Deg.)	$\bar{N}_k$	$\sum(v^2)_k$	$(SD)_k$	$(m.s.e)_k$	$\mu_{k(Max)}$	$\mu_{k(Min)}$
1	31	26	21.19	0.327	0.216	0.076	21.4542	20.9193
2	31	26.5	20.81	0.334	0.218	0.077	21.0756	20.5352
3	31	27	19.65	0.508	0.269	0.095	19.9797	19.3130
4	31	27.5	18.18	0.388	0.236	0.083	18.4744	17.8916
5	31	28	16.72	0.424	0.246	0.087	17.0269	16.4176
6	31	28.5	15.70	0.288	0.203	0.072	15.9518	15.4497
7	31	29	14.92	0.276	0.199	0.070	15.1682	14.6768
8	31	29.5	15.05	0.433	0.249	0.088	15.3625	14.7473
9	31	30	15.43	0.352	0.224	0.079	15.7118	15.1567
10	31	30.5	15.43	0.393	0.237	0.084	15.7233	15.1369
11	31	31	15.62	0.343	0.221	0.078	15.8972	15.3495
12	31	31.5	15.84	0.511	0.270	0.095	16.1735	15.5053
13	31	32	16.18	0.757	0.329	0.116	16.5858	15.7720
14	31	32.5	16.51	0.541	0.278	0.098	16.8571	16.1692
15	31	33	17.34	0.610	0.295	0.104	17.7054	16.9753
16	31	33.5	17.44	0.426	0.247	0.087	17.7477	17.1375
17	31	34	17.32	0.288	0.203	0.072	17.5713	17.0697
18	31	34.5	18.28	0.864	0.351	0.124	18.7129	17.8436

Each (N_i) value was checked be to accepted or rejected based on the ($\mu_{k(Max)}$ and $\mu_{k(Min)}$) range, as shown in table (6). The total numbers and ratios of accepted points were collected after each trial for each GGM and that GGM which has the

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lowest number of accepted points, as shown in figure (3), were ignored and exclusion from the next trial as shown in table (7).

Table (6): Checking the accepted or rejected (N_i) values in "1st trial" only for 18 points as an example.

			Accepted or Rejected (N_i) values (m)							
i →			**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Point (ID)	**Lat. (Deg.)**	**Long. (Deg.)**	**EGM96**	**EIGEN-CG01C**	**GGM03C**	**EIGEN-CG03C**	**EIGEN-GL04C**	**EIGEN-5C**	**EGM 2008 (360)**	**EGM 2008 (2190)**
1	31	26	21.387	Rejected	21.25	21.305	21.291	21.34	21.23	Rejected
2	31	26.5	20.93	Rejected	20.786	20.839	20.886	21.063	20.954	20.607
3	31	27	19.836	Rejected	19.771	19.642	19.778	Rejected	19.659	Rejected
4	31	27.5	Rejected	Rejected	18.304	18.073	18.291	18.362	18.208	17.961
5	31	28	Rejected	Rejected	16.886	16.527	16.779	16.737	16.89	16.581
6	31	28.5	Rejected	Rejected	15.872	15.592	15.761	15.72	15.769	15.504
7	31	29	Rejected	Rejected	15.07	14.91	14.921	14.961	14.856	14.722
8	31	29.5	Rejected	14.81	15.178	15.138	15.05	15.197	15.017	Rejected
9	31	30	Rejected	15.233	15.444	15.613	15.468	15.519	15.441	Rejected
10	31	30.5	Rejected	15.227	15.364	15.612	15.443	15.451	15.545	Rejected
11	31	31	Rejected	15.364	15.588	15.707	15.581	15.59	15.801	Rejected
12	31	31.5	Rejected	Rejected	15.964	15.773	15.757	15.697	16.033	15.643
13	31	32	Rejected	Rejected	16.335	15.969	16.109	16.159	16.368	15.942
14	31	32.5	Rejected	Rejected	16.62	16.336	16.545	16.536	16.549	16.311
15	31	33	Rejected	17.222	17.248	17.406	17.582	17.471	17.202	Rejected
16	31	33.5	Rejected	17.414	17.267	17.579	17.635	17.545	17.304	Rejected
17	31	34	17.539	17.245	17.296	17.375	17.231	Rejected	17.197	Rejected
18	31	34.5	18.438	18.344	18.193	18.436	18.15	Rejected	18.174	Rejected

The whole process was sequentially repeated several times using the rest of GGMs data. After four trials, 100 % of points were accepted for five GGMs as shown in figure (4). Table (7) presents the total numbers and ratios of accepted points after each trial. The final undulation value (N_F) for each point of 346 points "DGUNET/2019" is calculated the average value for each point (N_i) from the five accepted GGMs only as shown in table (8).

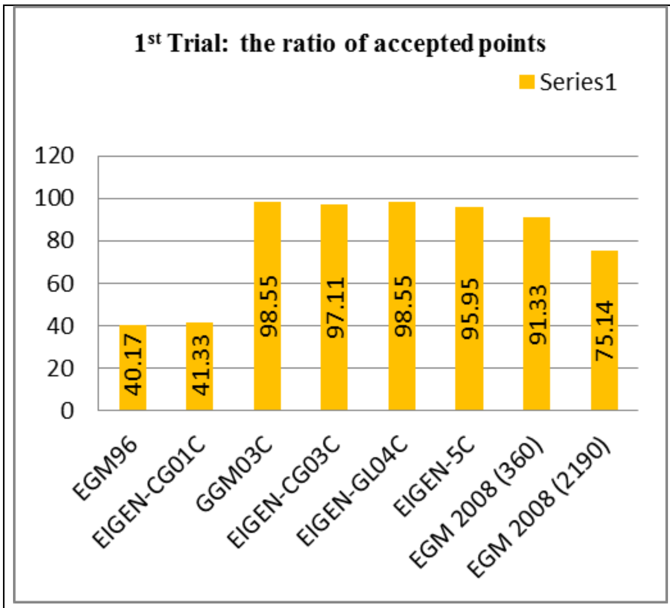

Figure (3): The accepted point's ratios of each GGM after finishing the "1st trial".

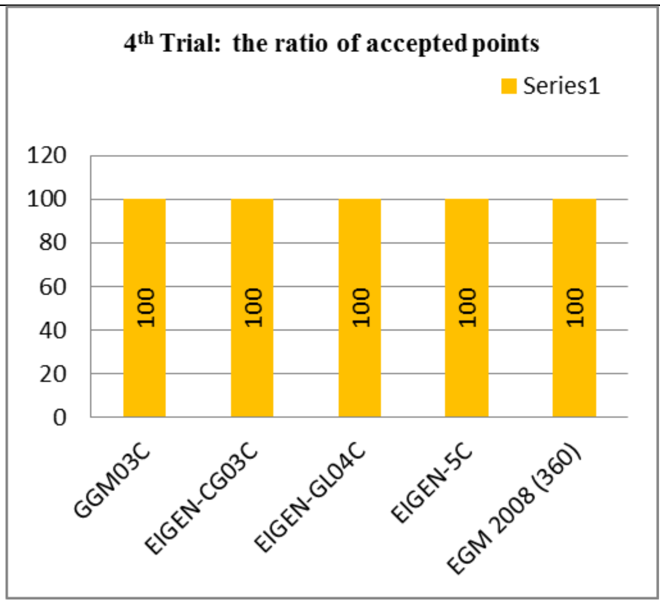

Figure (4): The accepted point's ratios of each GGM after finishing the "4th trial".

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Table (7): The total numbers and ratios of accepted points with the excluded GGM after each trial

Trial No.		*i* →	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
		GGMs	**EGM96**	**EIGEN-CG01C**	**GGM03C**	**EIGEN-CG03C**	**EIGEN-GL04C**	**EIGEN-5C**	**EGM 2008 (360)**	**EGM 2008 (2190)**
1st	The accepted points of 346 points from each GGM	$\sum k$ (Points)	139	143	341	336	341	332	316	260
		Ratio (%)	40.17	41.33	98.55	97.11	98.55	95.95	91.33	75.14
2nd		$\sum k$ (Points)	Excluded	139	345	334	344	335	321	261
		Ratio (%)	Excluded	40.17	99.71	96.53	99.42	96.82	92.77	75.43
3rd		$\sum k$ (Points)		Excluded	346	346	346	344	326	256
		Ratio (%)		Excluded	100	100	100	99.42	94.22	73.99
4th		$\sum k$ (Points)			346	346	346	346	346	Excluded
		Ratio (%)			100	100	100	100	100	Excluded

Table (8): Calculating the final values (N_F) from the accepted GGM for 18 points only as an example.

			The final accepted (N_i) Values (m)					
i →			**3**	**4**	**5**	**6**	**7**	
Point (ID)	**Lat. (Deg.)**	**Long. (Deg.)**	**GGM03C**	**EIGEN-CG03C**	**EIGEN-GL04C**	**EIGEN-5C**	**EGM 2008 (360)**	**(N_F) Values**
1	31	26	21.25	21.305	21.291	21.34	21.23	21.2832
2	31	26.5	20.786	20.839	20.886	21.063	20.954	20.9056
3	31	27	19.771	19.642	19.778	19.992	19.659	19.7684
4	31	27.5	18.304	18.073	18.291	18.362	18.208	18.2476
5	31	28	16.886	16.527	16.779	16.737	16.89	16.7638
6	31	28.5	15.872	15.592	15.761	15.72	15.769	15.7428
7	31	29	15.07	14.91	14.921	14.961	14.856	14.9436
8	31	29.5	15.178	15.138	15.05	15.197	15.017	15.116
9	31	30	15.444	15.613	15.468	15.519	15.441	15.497
10	31	30.5	15.364	15.612	15.443	15.451	15.545	15.483
11	31	31	15.588	15.707	15.581	15.59	15.801	15.6534
12	31	31.5	15.964	15.773	15.757	15.697	16.033	15.8448
13	31	32	16.335	15.969	16.109	16.159	16.368	16.188
14	31	32.5	16.62	16.336	16.545	16.536	16.549	16.5172
15	31	33	17.248	17.406	17.582	17.471	17.202	17.3818
16	31	33.5	17.267	17.579	17.635	17.545	17.304	17.466
17	31	34	17.296	17.375	17.231	17.662	17.197	17.3522
18	31	34.5	18.193	18.436	18.15	18.867	18.174	18.364

Surfer program was used to draw undulation contour map with interval of half meter as shown in figure (5), and also to draw a 3D surface as shown in figure (6), using the final undulation values (N_F) of “DGUNET/2019”. The figures (5 and 6) showed the highest values of undulation at both of the extreme North-West (El-Salloum city) and the south of Sinai. On the other side, the smallest undulation values is located at the extreme South-East of Egypt (Hala’ib Triangle), which is harmonic with the known information about the nature ground surface in Egypt. Finally, there are a significant harmonic with the known information about the nature ground surface in Egypt, which led us to accept the final undulation network values.

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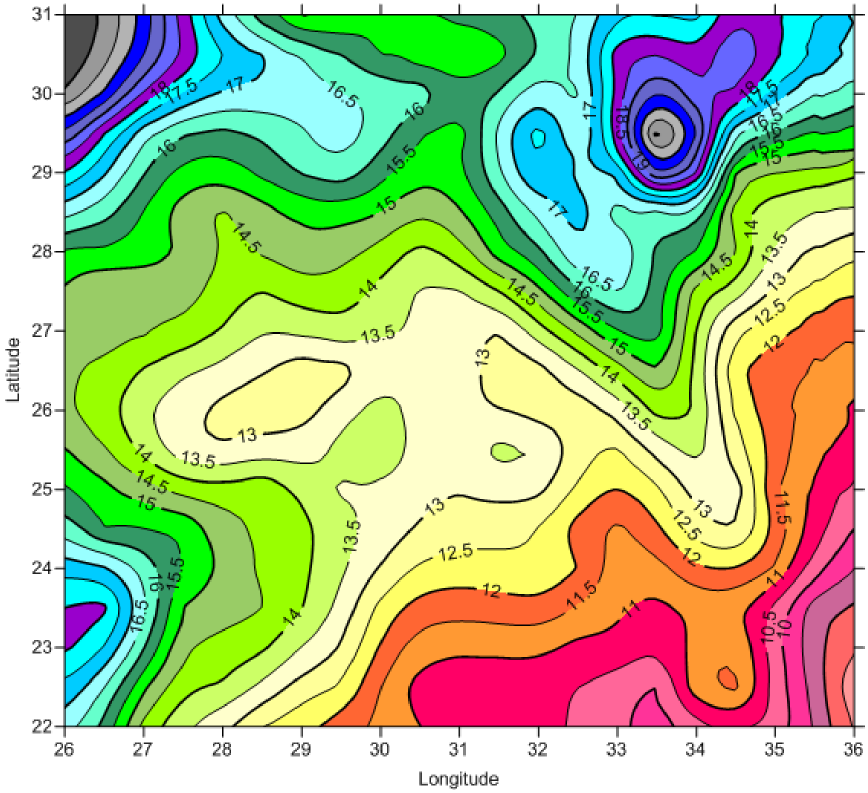

Figure (5): Undulation contour map for Egypt using final undulation values (N_F) of "DGUNET/2019".

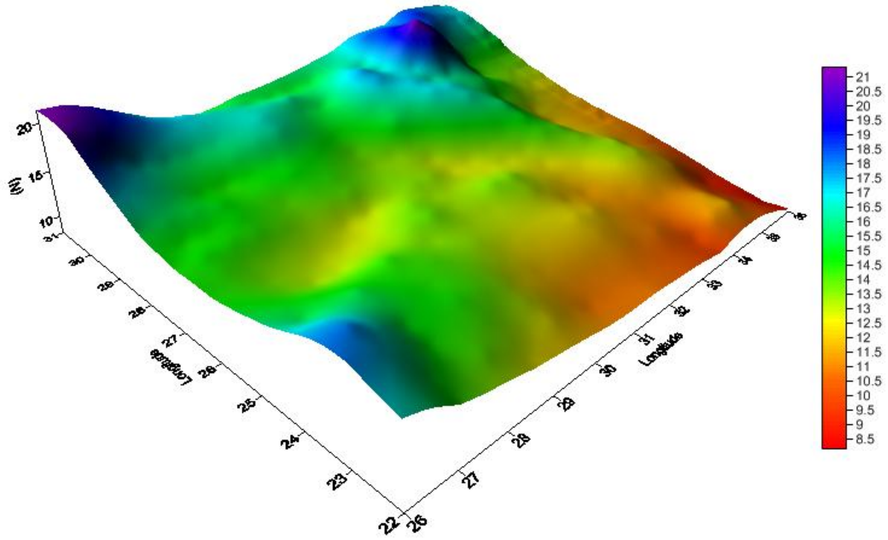

Figure (6): 3D Surface map for Egypt using final undulation values (N_F) of "DGUNET/2019".

CONCLUSIONS

The main objective of this paper is deriving Geoid Undulation Network Values "DGUNET/2019", which are presenting the best fit to reality over Egypt to enhancement Orthometric height values. The methodology in this paper had been based on merging eight several Global Geo-potential Models data (GGMs). Many standards were considered when different GGMs are selected, such as the most common, availability, accurate, the variation in the issue year and spherical harmonic coefficient. The study area network is consisting of 346 equally distributed points bounded by latitudes (ϕ) [22° N, 31° N] and between longitudes (λ) [26° E, 36° E] with 0.5° interval of both latitudes (ϕ) and longitudes (λ) and the distance between points approximately is 50 Km to cover a whole Egypt's area.

The tested data in this paper, Undulation Values for 346 points, were calculated by eight different GGMs. The final undulation network values (N_F) consisting of 346 points "DGUNET/2019" were calculated after a series of sequential trials, therefore the main objective of this paper is achieved successfully. The undulation contour map and 3D Surface were created using the enhancement values of undulation network "DGUNET/2019". The created maps are logical when compared with other contour maps which can be created by other GGMs such as GGM03C, EIGEN-CG03C, EIGEN-5C and EGM 2008. Also the

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maps showed highest values of undulation at both of the extreme North-West (El-Salloum City) and the South Sinai in Egypt. On the other side the smallest undulation values is located at the extreme South-East of Egypt (Hala'ib Triangle). According to the previous analysis for contour maps of "DGUNET/2019", there are a significant harmonic with the known and published information of Egypt territories, therefore the purpose of this study was achieved.

The future recommendation of this paper is to evaluate this geoid undulation network values and the Orthometric height values more deeply by different statistical ways and by the field survey. Also utilization different other methods to enhancement the undulation network values until the best fit to reality is achieved.

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