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Global Geopotential Models Assessment Using Accurate DGPS/Precise Levelling Observations Along the Mediterranean Coastal Line, Egypt: Case Study

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Abstract The performance of Global Geopotential Models (GGMs) to calculate Geoid undulation, along the Mediterranean Western Coastal Line from El- Salloum to El- Alameen, Egypt, has been evaluated. The selected region has the both tourism and geodetic of interests. The quality of geoid undulation (N) will obviously affect the resulting orthometric height (H) determined from Differential Global Positioning System (DGPS). The EGM96 and EGM08 (Bi-Linear Interpolation, Bi-Quadratic Interpolation, Triangulation, Nearest Neighbour) have been tested in this study. NGGMs was computed from “AllTrans v.3.002” EGM08 geoid calculator and free website of “ICGEM” while Nobs was computed from the relationship N= h-H. Over 52 DGPS/Precise Levelling Stations, the computed standard deviation (σ) of differences in (Nobs – NGGMs) is used as an accuracy indicator. The standard deviation “RMSE” of the undulation differences has been estimated to be ±24cm for EGM08-Bi-Linear Interpolation to ±45cm for EGM08-Nearest Neighbour and ±1.393m for EGM96. There is a marked improvement in the overall RMSE from (EGM08-Nearest Neighbour) to (EGM08-Bi-Linear Interpolation) by 54%. This study showed that EGM08-Bi-Linear Interpolation model has made significant improvement over other models for such like this Northern-coastal line objects. Such a practice presents a suitable alternative, from an economical point of view, to substitute the expensive traditional levelling technique particularly for linear topographic projects with intermediate accurate survey.

Keywords Global Geopotential Models (GGMs), Precise leveling, DGPS, Undulation

1. Introduction

GNSS (Global Navigation Satellite System) has become an important technology because it certifies the presence of positions, from collected and designed items, in a global reference system (Bernabe et al., 2012). When GPS data are first used for the monitoring of vertical ground movement, the height differences between the monitoring sites, obtained by using both GPS and leveling measurements, are normally compared to realize the accuracy of height achieved by GPS (Parks and Dial, 1997; Ollikainen, 1998). Nowadays, GNSS/leveling can be considered as an alternative for practical height determination (Featherstone, et al., 1998; Erol, 2011).

Several authors have evaluated EGM96 and EGM08 in different parts of the world (e.g. Huang and Vernneau, 2009; Claessens et al., 2009; Hirt et al., 2010; Pavlis et al., 2012; Featherstone and Olliver, 2013; Odera and Fukuda, 2013; Abeho et al., 2014). Most of the comparative studies show that EGM08 has made significant improvement over EGM96. However, such studies have not been carried out in Egypt especially, northern-coastal line.

This paper carries out an initial assessment of EGM96 and EGM08 using four different methods (Bi-Linear Interpolation, Bi-Quadratic Interpolation, Triangulation, Nearest Neighbour). Refer to (http://docs.geotools.org/latest/javadocs/org/opengis/coverage/InterpolationMethod.html) for more assumptions and mathematical explanations about the used interpolation methods. These models have been compared with accurate DGPS/precise leveling derived undulations over 52 station in the Northern-Coastal line of Mediterranean Sea, Egypt.

Many researches have been carried out and discussed the geoid determination using different interpolation methods (ARANA et al., 2017; Chymyrov and Busics 2014; Janssen and Watson 2010; Lambrou 2018; Soycan 2014).

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2. The Global Gravitational Models (GGMs)

The Global Gravitational Models (GGMs) are geopotential models of the Earth consisting of spherical harmonic coefficients published by the Office of Geomatics at National Geospatial-Intelligence Agency (NGA). Three models of EGM are used to calculate geoid undulation of an area. First version is EGM84 with n=m=180. Second version is EGM96 with n=m=360. Third version is EGM08 with n=m=2160. Where (n) and (m) are the degrees and orders of harmonic coefficients. The higher degrees and orders of harmonic coefficients give more parameters to the models, which lead to high precision. EGM08 also contains expansions to n=2190.

The NGA provides the model in two formats: in a raster image recording the geoid height at each coordinate at a given resolution, or in a format providing the numerical parameters – the coefficients – defining the model.

EGM96 is the result of a collaboration between the National Imagery and Mapping Agency (NIMA), the NASA Goddard Space Flight Center (GSFC), and the Ohio State University. It took advantage of new surface gravity data from many different regions of the globe, including data newly released from the NIMA archives. Major terrestrial gravity acquisitions by NIMA since 1990 include airborne gravity surveys over Greenland and parts of the Arctic and the Antarctic. These collection efforts have improved the data holdings over many of the world's land areas, including Africa, Canada, parts of South America and Africa, Southeast Asia, Eastern Europe, and the former Soviet Union. In addition, there have been major efforts to improve NIMA's existing 30' mean anomaly database through contributions over various countries in Asia. EGM96 also included altimeter-derived anomalies derived from ERS-1 by Kort & Matrikelstyrelsen (KMS), (National Survey and Cadastre, Denmark) over portions of the Arctic, and the Antarctic. The raster from EGM96 is provided at 15'x15' resolution.

The National Geospatial-Intelligence Agency (NGA) has developed the new Earth Gravitational Model EGM08, completed to degree 2160. This model, incorporates an improved version of 5' × 5' global gravity anomaly database, an improved ocean-wide set of altimetry-derived gravity anomalies, and has benefited from the latest GRACE-based satellite-only solutions (Pavlis et al., 2012). EGM08 provides an unprecedented resolution and accuracy, exposing even the smallest of incompatibility errors. The official Earth Gravitational Model EGM08 has been publicly released in 2008 as Zero Tide model. This model contains additional coefficients extending to degree 2190 and order 2159. Full access to the model's coefficients and other descriptive files with additional details about EGM2008 are provided on web pages. All synthesis software, coefficients, and available pre-computed geoid grids assume a Tide Free system, as far as permanent tide is concerned.

3. Study Area

The study area is located in the northern Egypt from El-Salloum to El- Alameen cities, along the Mediterranean north coast "Figure 1". It extends from longitude 25° 09' 45"E to 28° 49' 37"E, and from latitude 30° 57' 10"N to 31° 37' 07"N. The study has been carried out using 52 GPS/Leveling data points as shown in "Figure 1". This data set comes from research project carried out by the Survey Research Institute (SRI), Egypt. The precise leveling observations were performed as closed loops, run between known high precision benchmarks established by The Egyptian Survey Authority (ESA) based on the national vertical datum of Egypt, whose origin is based on Mean Sea Level (MSL) at Alexandria tide gauge 1906. In addition, GPS measurements were carried out relative to ESA national geodetic reference framework of Egypt.

4. Data Sets

The datasets acquired for this study from station L1 to L52, see "Figures 1,2", include: station name; projected coordinates (ETM); geographic coordinates; orthometric height (H) from precise levelling; ellipsoidal height (h) from static DGPS measurements by relative technique as shown in Table 1.

"AllTrans v.3.002" EGM08 geoid calculator software developed by Hans-Gerd Duenck-Kerst, has been used to calculate geoid undulations for EGM08 model using four different methods; and for EGM96 model geoid undulations, ICGEM website has also been used.

4.1. Precise Levelling (Orthometric Height (H))

The orthometric heights are required for survey, mapping, as well as engineering/environmental projects. These heights are referred to the geoid surface which is a surface that is at all places on the surface at right angles to the gravity vector direction (Awka, et. Al. 2018).

The orthometric heights of the stations have been obtained through tying the first-order levelling loops to the national vertical datum of Egypt that is based on the mean sea level at Alexandria tide gauge of 1906.

4.2. DGPS measurements (Ellipsoidal Height (h))

The dual frequency Trimble 5700 GPS receivers were used in static mode for average 2 hours' session, minimum elevation angle of 15 degrees, Geometric Dilution of precision of 2-4, and epoch interval of 15 seconds, see Figure. 3 for the Number of satellites covered in site fieldwork. During the field work on a primary control base reference station in relative technique mode, the base receiver was constantly logging data throughout the duration of collecting fieldwork. Online post-processing

TBC planning software was used to post-process DGPS data.

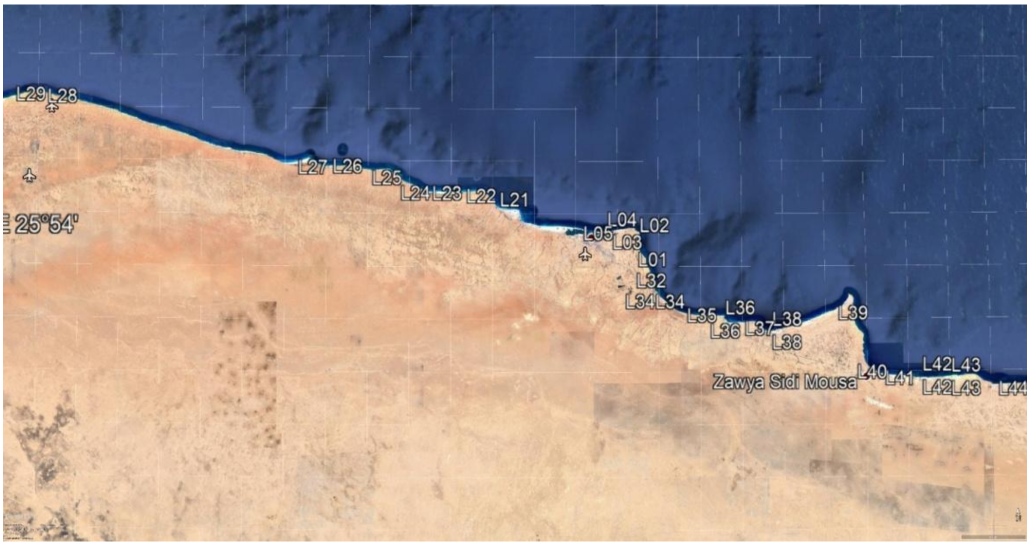

Figure 1. DGPS/Precise levelling observed stations

Figure 2. Station L1

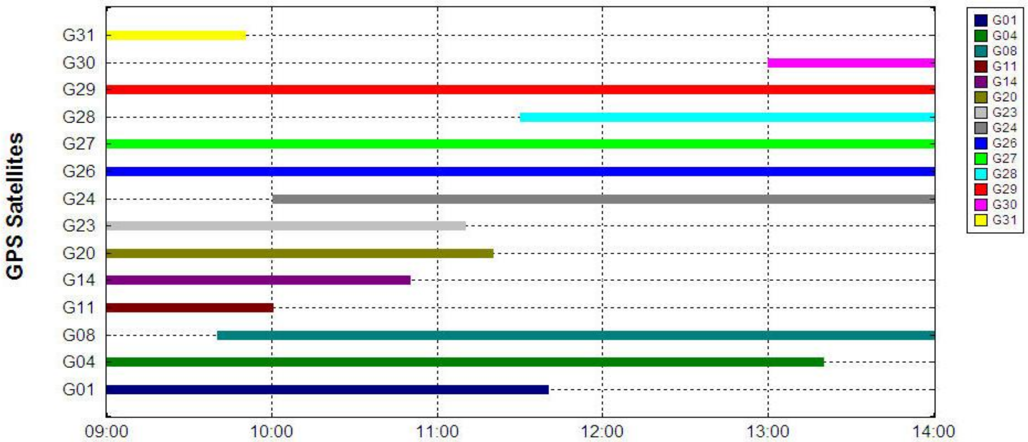

Figure 3. Number of satellite covered in site fieldwork

Table 1. Observed DGPS/Precise Levelling data for all survey stations

		Geodetic coordinates		Reference point Elevation (m)	
Point no.	Reference point name	Geographic cords. (WGS 1984) (Degree)		Ellipsoidal Height (h)	Elevations above M.S.L.
L01	Eastern Hasheesh	Ø =31°20'06.26"	λ=27°20'58.98"	18.086	1.883
L02	Western Hasheesh	Ø =31°21'20.32"	λ =27°21'11.74"	19.988	3.890
L03	Andloseya	Ø =31°22'05.06"	λ =27°17'18.28"	19.086	2.867
L04	Assala	Ø =31°22'00.70"	λ =27°16'34.26"	25.544	9.303
L05	Rumel	Ø =31°21'46.73"	λ =27°15'15.81"	21.031	4.605
L06	Rumel Beach	Ø =31°21'56.40"	λ =27°14'52.82"	18.323	1.970
L07	Matrouh1	Ø =31°21'39.58"	λ =27°14'43.05"	18.182	1.795
L08	Matrouh2	Ø =31°21'27.75"	λ =27°14'26.59"	19.782	3.352
L09	Matrouh3	Ø =31°21'26.00"	λ =27°13'57.88"	25.756	9.283
L10	Matrouh4	Ø =31°21'33.41"	λ =27°13'29.61"	19.592	3.137
L11	Masiaf	Ø =31°21'52.88"	λ =27°13'09.70"	18.304	1.781
L12	Cleopatra1	Ø =31°22'16.86"	λ =27°10'47.72"	21.189	4.605
L13	Cleopatra2	Ø =31°22'19.74"	λ =27°11'40.23"	23.245	6.762
L14	El-Mehata	Ø =31°22'16.07"	λ =27°12'25.56"	25.299	8.874
L15	El-Ghram	Ø =31°22'07.64"	λ =27°13'21.27"	19.156	2.753
L16	El-Hemaya	Ø =31°21'17.60"	λ =27°09'26.28"	33.620	--------
L17	El-Kasr	Ø =31°22'21.50"	λ =27°09'22.34"	26.076	9.465
L18	El-Aseel	Ø =31°22'32.24"	λ =27°06'49.56"	20.552	3.864
L19	El-Abyad	Ø =31°22'46.08"	λ =27°05'45.26"	21.450	4.770
L20	Blue Beach	Ø =31°23'14.21"	λ =27°04'06.35"	18.780	------
L21	Om El-Rakhm	Ø =31°24'17.56"	λ =27°03'16.14"	25.278	8.749
L22	Ageeba	Ø =31°24'43.25"	λ =27°00'36.63"	21.714	5.011
L23	El-Sowynat1	Ø =31°26'21.57"	λ =26°55'39.95"	21.734	5.056
L24	Abo Lahw	Ø =31°26'22.05"	λ =26°51'07.91"	29.571	12.677
L25	El-Sowynat2	Ø =31°28'04.55"	λ =26°44'50.60"	32.498	15.526
L26	El- Zoghyrat1	Ø =31°29'22.41"	λ =26°39'08.81"	21.503	4.409
L27	El- Zoghyrat2	Ø =31°29'14.95"	λ =26°36'18.81"	31.994	14.737
L28	Barany1	Ø =31°36'55.68"	λ =25°57'36.97"	22.289	4.264
L29	Barany2	Ø =31°37'07.33"	λ =25°55'09.61"	32.400	14.313
L30	ElSaloum1	Ø =31°32'38.63"	λ =25°09'55.02"	23.916	3.963
L31	ElSaloum2	Ø =31°33'46.44"	λ =25°09'45.78"	23.980	3.193
L32	Meyami	Ø =31°16'22.11"	λ =27°22'53.23"	19.841	3.196
L33	Alealamieen	Ø =31°15'39.98"	λ =27°23'07.32"	19.559	2.802
L34	Al-Noran	Ø =31°15'18.49"	λ =27°23'26.19"	19.540	2.704
L35	Kasr El-Shouk	Ø =31°12'23.00"	λ =27°30'06.82"	19.055	2.352
L36	Almaza	Ø =31°11'54.04"	λ =27°33'27.83"	20.071	3.507
L37	Sidi Henish	Ø =31°10'50.23"	λ =27°38'25.23"	21.928	5.525
L38	Yagosh	Ø =31°10'33.14"	λ =27°40'10.45"	21.034	4.684
L39	Ras El-Hekma	Ø =31°12'27.37"	λ =27°51'51.91"	26.498	10.873
L40	Etai	Ø =31°05'42.51"	λ =27°54'31.43"	26.630	10.570
L41	Royal Beach	Ø =31°04'57.07"	λ =27°58'33.72"	49.666	33.756

		Geodetic coordinates		Reference point Elevation (m)	
Point no.	Reference point name	Geographic cords. (WGS 1984) (Degree)		Ellipsoidal Height (h)	Elevations above M.S.L.
L42	Mountain View	∅ =31°05'08.28"	λ =28°01'48.15"	21.910	6.071
L43	Teba	∅ =31°04'57.20"	λ =28°05'57.53"	43.276	27.648
L44	El-Kanaria	∅ =31°03'28.53"	λ =28°14'54.36"	48.973	33.483
L45	La-Viesta	∅ =31°04'11.64"	λ =28°21'22.54"	30.221	15.021
L46	Palma de Mayorika	∅ =31°04'58.84"	λ =28°23'34.17"	18.232	3.034
L47	Kato	∅ =31°00'49.58"	λ =28°35'17.15"	24.397	9.325
L48	Ghazala	∅ =31°01'08.22"	λ =28°36'01.13"	18.778	3.701
L49	Marina	∅ =30°59'40.28"	λ =28°40'08.21"	41.168	26.203
L50	Orkidia	∅ =30°59'19.53"	λ =28°42'57.23"	18.368	3.409
L51	Heliopolis	∅ =30°57'18.77"	λ =28°47'55.43"	19.607	4.642
L52	La Zordi	∅ =30°57'10.52"	λ =28°49'37.16"	18.545	3.612

The GPS observations for the 52 stations were taken at different times. The mission was done through many sessions; each session consists of four stations to form good baseline geometry. Therefore, the stations have been observed through these sessions during June 2013.

5. Methods

The dual frequency Trimble 5700 DGPS geodetic receivers were used in relative static mode on base reference station for a 2-hour duration of each rover observation positions. This provided the geodetic coordinates data of latitudes, longitudes and ellipsoidal heights. Online post-processing TBC planning software was used to post-process the attained data.

Using the Trimble TBC 3.2 GPS data processing package, ellipsoidal heights have been computed for each station at each session with a precision of ± 0.003 m. For each GPS station, the projected 2D coordinates (UTM east and north) have been computed at each session with a precision of ± 0.002 m.

The precise levelling data were collected by Leica NA2 precise level through tying the first-order levelling loops to the national vertical datum of Egypt. The allowable error of the precise levelling is $\pm 3\sqrt{L}$ mm where L is the distance between each two stations in kilometre. “AllTrans v.3.002” EGM08 geoid calculator software has been used for EGM08 geoid undulations; and the International Center for Global Earth Models (ICGEM) has also been used for EGM96 geoid undulations, by min1x1 Tidefree SEL 1' x 1' database.

An initial assessment of four different methods of EGM08 (Bi-Linear Interpolation, Bi-Quadratic Interpolation, Triangulation, Nearest Neighbour). These methods have been compared with accurate DGPS/precise leveling derived undulations over 52 station in the Northern-Coastal line of Mediterranean Sea, Egypt.

6. Results

The static DGPS provided better ellipsoidal heights. It is logical that better geoidal undulation would lead to better estimates of orthometric heights (Awka, et. Al., 2018).

The differences between gravimetric and DGPS/Precise levelling geoid undulations along the Mediterranean Western Coastal Line from El- Salloum to El- Alameen, have been calculated and shown in Table 2. Statistics of the differences between gravimetric and DGPS/Precise geoid undulations are given in Table 3.

The results from this study are highlighted below:

6.1. Geoid Undulation/Height (N)

The geoid height (N), is required for the most notable and primary use of the transformation between Global Positioning System (GPS)-derived ellipsoidal heights and orthometric heights. After post-processing of the DGPS data by TBC planning software, the geoid undulation is computed from both GGMs and DGPS/levelling observed heights.

6.1.1. From GGMs

From Table 2 below, the EGM08 geoid undulations have been determined for the four studied methods. EGM08-Bi-Linear Interpolation Method is noted to be nearly consistent. In addition, the EGM96 geoid undulations have been also computed.

The calculated geoid heights obtained from the EGM08 was computed as is referred by Equation (1) (Yazid, et Al., 2016):

$$\Delta N_{GGM} = \frac{GM}{r\lambda} \sum_{n=2}^{m} \left(\frac{a}{r}\right)^{n} \sum_{m=0}^{n} (C_{nm} \cos m\lambda + S_{nm} \sin m\lambda) P_{nm} (\cos \theta) \quad (1)$$

Where ΔN_{GGM} = the geoid heights derived from the global geopotential model *(GM).*

GM = the product of the Earth’s mass and the gravitational constant.

r = the radial distance to the computation point, a is the semi-major axis of the reference ellipsoid.

C_{nm} and S_{nm} = fully normalized harmonic coefficients.

P_{nm} = the fully normalized Legendre function.

$\emptyset$ & λ = the geodetic latitude and longitude of the computation point.

6.1.2. From DGPS/Levelling Observations

The measured ellipsoidal height (h) from DGPS is combined with observed orthometric (H) from precise levelling to compute geoid undulation (N), results are shown in Table 2.

The N is given by Heiskanen and Moritz (1967) and Eteje *et al* (2018) as:

$$N = h\text{-}H \qquad (2)$$

6.1.3. The Geoid Undulation Differences

From computations, the differences between both GGMs and DGPS/Precise levelling derived geoid undulations are also shown in Table 2.

The differences are calculated as follows:

$$\textit{Undulation Difference} = N^{GGMs} - N^{DGPS\text{-}Precise\ Levelling} \qquad (3)$$

Table 2. N^{Obs} & N^{GGMs} & Undulation Differences ($N^{GGMs} - N^{DGPS\text{-}Precise\ Levelling}$)

Station No.	N^{Obs} (m)	Undulation [N^{GGM}] & Undulation Differences ($N^{GGM} - N^{Obs[DGPS\text{-}Precise\ Levelling]}$) (m)									
		EGM2008 (WGS84)								EGM96 (WGS84)	
		Bi-Linear Interpolation		Bi-Quadratic Interpolation		Triangulation		Nearest Neighbour			
		N (m)	Dif. (m)	N (m)	Dif. (m)	N (m)	Dif. (m)	N (m)	Dif. (m)	N (m)	Dif. (m)
L01	16.203	16.744	0.541	16.752	0.549	16.743	0.540	16.830	0.627	15.799	-0.404
L02	16.098	16.500	0.402	16.555	0.457	16.496	0.398	16.830	0.732	15.701	-0.397
L03	16.219	16.601	0.382	16.684	0.465	16.599	0.380	16.830	0.611	15.658	-0.561
L04	16.242	16.660	0.418	16.741	0.499	16.657	0.415	16.830	0.588	15.667	-0.574
L05	16.426	16.783	0.357	16.858	0.432	16.779	0.353	16.830	0.404	15.692	-0.734
L06	16.354	16.776	0.422	16.848	0.494	16.781	0.427	17.431	1.078	15.682	-0.672
L07	16.387	16.839	0.452	16.902	0.515	16.842	0.455	17.431	1.044	15.705	-0.682
L08	16.430	16.892	0.462	16.949	0.519	16.895	0.465	17.431	1.001	15.722	-0.708
L09	16.473	16.926	0.453	16.983	0.510	16.929	0.456	17.431	0.958	15.727	-0.746
L10	16.455	16.932	0.477	16.993	0.538	16.935	0.480	17.431	0.976	15.720	-0.736
L11	16.523	16.892	0.369	16.963	0.440	16.895	0.372	17.431	0.908	15.696	-0.827
L12	16.584	16.963	0.379	17.046	0.462	16.964	0.380	17.431	0.847	15.679	-0.905
L13	16.483	16.901	0.418	16.984	0.501	16.903	0.420	17.431	0.948	15.670	-0.813
L14	16.425	16.866	0.441	16.947	0.522	16.868	0.443	17.431	1.006	15.670	-0.756
L15	16.403	16.835	0.432	16.912	0.509	16.838	0.435	17.431	1.028	15.675	-0.728
L16	-	17.228	-	17.281	-	17.227	-	17.431	-	15.800	-
L17	16.611	17.037	0.426	17.122	0.511	17.036	0.425	17.431	0.820	15.683	-0.928
L18	16.688	17.164	0.476	17.253	0.565	17.156	0.468	17.431	0.743	15.687	-1.001
L19	16.680	17.191	0.511	17.284	0.604	17.179	0.499	17.431	0.751	15.678	-1.002
L20	-	17.211	-	17.313	-	17.224	-	18.035	-	15.700	-
L21	16.529	17.077	0.548	17.192	0.663	17.091	0.562	18.035	1.506	15.577	-0.952
L22	16.703	17.175	0.472	17.296	0.593	17.178	0.475	18.035	1.332	15.568	-1.135
L23	16.678	17.251	0.573	17.301	0.623	16.986	0.308	16.297	-0.381	15.489	-1.189
L24	16.894	17.585	0.691	17.670	0.776	17.578	0.684	17.105	0.211	15.545	-1.349
L25	16.972	17.729	0.757	17.809	0.837	17.718	0.746	17.760	0.788	15.497	-1.475
L26	17.094	17.887	0.793	17.914	0.820	17.860	0.766	17.760	0.666	15.486	-1.608
L27	17.257	18.028	0.771	18.074	0.817	17.998	0.741	17.760	0.503	15.548	-1.709
L28	18.025	18.168	0.143	18.214	0.189	18.070	0.045	17.743	-0.282	15.942	-2.083
L29	18.087	18.223	0.136	18.265	0.178	18.139	0.052	17.743	-0.344	16.010	-2.077
L30	19.953	20.109	0.156	20.120	0.167	20.108	0.155	20.283	0.330	18.199	-1.754
L31	20.787	20.040	-0.747	20.054	-0.733	20.038	-0.749	20.283	-0.504	18.128	-2.659
L32	16.645	16.992	0.347	17.097	0.452	16.977	0.332	16.830	0.185	16.078	-0.567
L33	16.757	17.046	0.289	17.156	0.399	17.028	0.271	16.830	0.073	16.130	-0.627

Station No.	N^{Obs} (m)	Undulation $[N^{GGM}]$ & Undulation Differences ($N^{GGM} - N^{Obs[DGPS\text{-}Precise\ Levelling]}$) (m)									
		EGM2008 (WGS84)								EGM96 (WGS84)	
		Bi-Linear Interpolation		Bi-Quadratic Interpolation		Triangulation		Nearest Neighbour			
		N (m)	Dif. (m)	N (m)	Dif. (m)	N (m)	Dif. (m)	N (m)	Dif. (m)	N (m)	Dif. (m)
L34	16.836	17.062	0.226	17.173	0.337	17.041	0.205	16.830	-0.006	16.155	-0.680
L35	16.703	16.970	0.267	17.009	0.306	16.970	0.267	17.232	0.529	16.355	-0.348
L36	16.564	16.869	0.305	16.892	0.328	16.880	0.316	17.232	0.668	16.387	-0.177
L37	16.403	16.773	0.370	16.794	0.391	16.771	0.368	16.808	0.405	16.464	0.061
L38	16.350	16.732	0.382	16.746	0.396	16.732	0.382	16.808	0.458	16.486	0.136
L39	15.625	15.935	0.310	16.007	0.382	15.934	0.309	16.369	0.744	16.383	0.758
L40	16.060	16.373	0.313	16.467	0.407	16.360	0.300	16.369	0.309	16.847	0.787
L41	15.910	16.180	0.270	16.207	0.297	16.176	0.266	16.450	0.540	16.912	1.002
L42	15.839	16.002	0.163	16.056	0.217	16.002	0.163	15.729	-0.110	16.915	1.076
L43	15.628	15.837	0.209	15.850	0.222	15.837	0.209	16.019	0.391	16.949	1.321
L44	15.490	15.625	0.135	15.633	0.143	15.611	0.121	16.019	0.529	17.092	1.602
L45	15.200	15.383	0.183	15.412	0.212	15.390	0.190	15.698	0.498	17.091	1.891
L46	15.198	15.254	0.056	15.291	0.093	15.275	0.077	15.698	0.500	17.058	1.860
L47	15.072	15.206	0.134	15.226	0.154	15.200	0.128	15.161	0.089	17.383	2.311
L48	15.077	15.161	0.084	15.185	0.108	15.154	0.077	15.161	0.084	17.370	2.293
L49	14.965	15.174	0.209	15.181	0.216	15.174	0.209	15.161	0.196	17.479	2.514
L50	14.959	15.109	0.150	15.127	0.168	15.107	0.148	15.161	0.202	17.517	2.558
L51	14.965	15.077	0.112	15.106	0.141	15.001	0.036	14.862	-0.103	17.654	2.689
L52	14.933	15.038	0.105	15.066	0.133	14.954	0.021	14.862	-0.071	17.672	2.739

7. Analysis and Discussion

Several steps have been used for comparing the geoid undulations from GGM and observations. 52 controls have been used for this study and the geoidal undulations from the two sources are shown in Table 2. This study has shown a range of differences in Table 3. were as follows; 1.540 for Bi-Linear Interpolation, 1.570m for Bi-Quadratic Interpolation, 1.515m for Triangulation, 2.010m for Nearest Neighbour and for 5.398m EGM96. The results from this study has shown a RMSE of these differences were as follows; ±0.239m for Bi-Linear Interpolation, ±0.254m for Bi-Quadratic Interpolation, ±0.241m for Triangulation, ±0.451m for Nearest Neighbour and ±1.393m for EGM96. There is a marked improvement in the overall RMSE from ±45cm (Nearest Neighbour) to ±24cm (Bi-Linear Interpolation). The smaller the range of values (between the lowest and highest $N^{GGMs} - N^{DGPS\text{-}Precise\ Levelling}$) the better orthometric heights obtained. In this instant, the EGM08-Bi-Linear Interpolation Model is more adequate source of orthometric height determination for topographical mapping, engineering and environmental studies and others along the Mediterranean Coastal Line.

Table 3. Statistics of N^{Obs} & N^{GGMs} & Undulation Differences ($N^{GGM} - N^{DGPS/Precise\ Levelling}$)

		Min (m)	Max (m)	Mean (m)	**RMSE** (m)
Observed Undulations		14.933	20.787	16.437	1.085
EGM2008 Undulations & Undulation differences	Bi-Linear Interpolation	15.038	20.120	16.789	1.053
	Undulation Differences	-0.747	0.793	0.335	0.239
	Bi-Quadratic Interpolation	15.066	20.120	16.845	1.059
	Undulation Differences	-0.733	0.837	0.390	0.254
	Triangulation	14.954	20.108	16.775	1.050
	Undulation Differences	-0.749	0.766	0.320	0.241
	Nearest Neighbour	14.862	20.283	16.968	1.100
	Undulation Differences	-0.504	1.506	0.500	0.451
EGM96		15.486	18.199	16.257	0.777
Undulation Differences		-2.659	2.739	-0.159	1.393

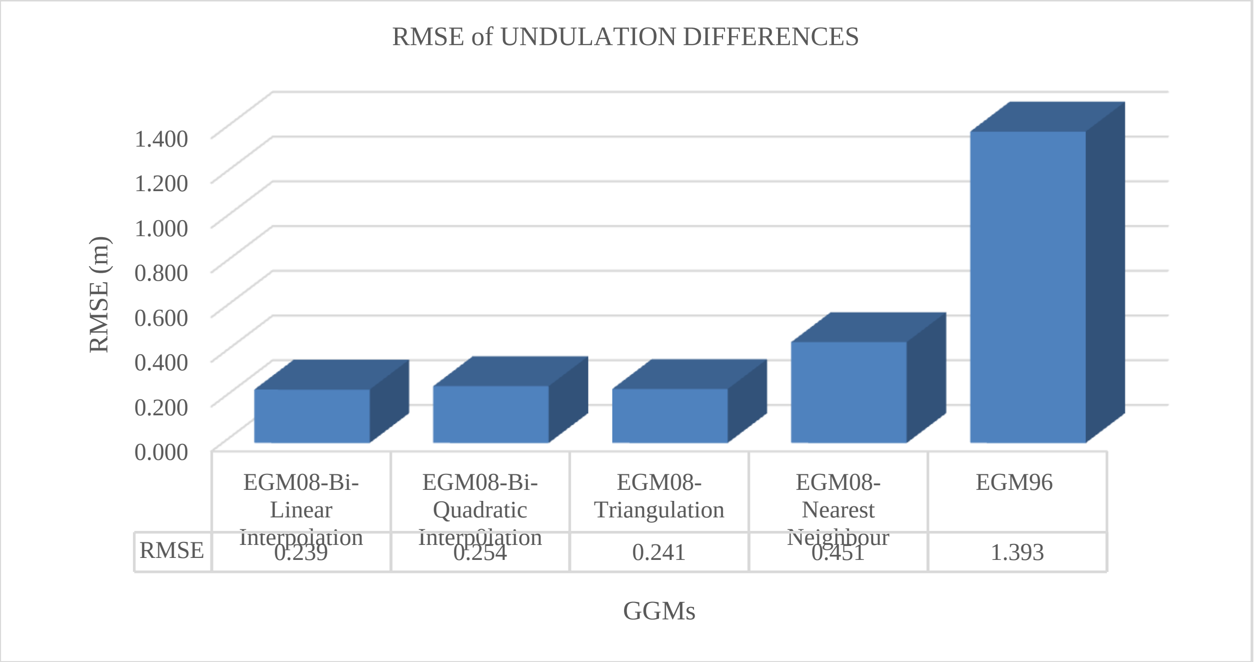

Figure 4. RMSE for GGMs different Models

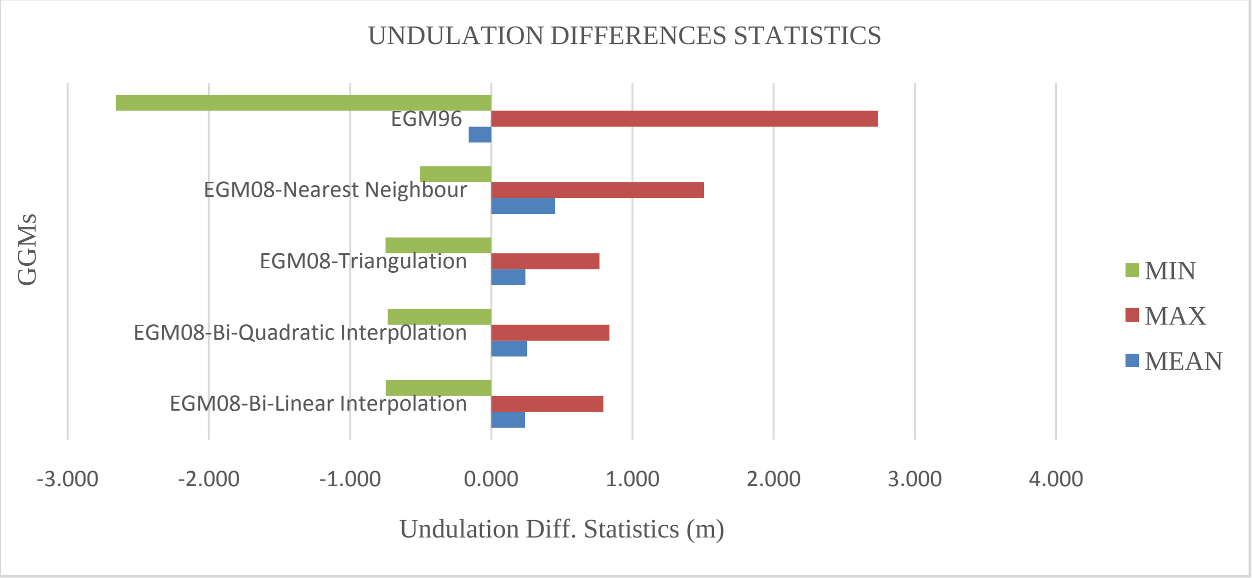

Figure 5. Statistics of GGMs different Models

Table 4. ASPRS Topographic Elevation Accuracy Requirement for Well-Defined Points

Contour Interval (m)	Class I(M) High Accuracy/ Standard Deviation Accuracy	Class II(M) Lower Than Class I Accuracy Standard Deviation	Class III(M) Lower Than Class II Accuracy Standard Deviation
0.5	0.08	0.16	0.25
1.0	0.17	0.33	0.50
2.0	0.33	0.67	1.00
4.0	0.67	1.33	2.00
5.0	0.83	1.67	2.50

Source: American Society of Photogrammetry and Remote Sensing (ASPRS 1993).

8. Specifications for Topographical Survey

The accuracy limits for contours can be obtained from, the standard deviation of the differences compared against the specifications given by American Society of Photogrammetry and Remote Sensing (ASPRS 1993) as shown in Table 4.

From Table 4, it is seen that the EGM08-Bi-Linear Interpolation with σ=±0.239m, checked against the specification above, can be used to produce topographical map with 2m contour interval for intermediate accurate survey, but still inadequate for survey applications where a high accuracy is required.

9. Conclusions

The release of the EGM08 GGM is a millstone step in improving geoidal modeling on a global scale. Based on several comparisons against DGPS/levelling data sets, the precision level of the EGM08 models is estimated to be ±0.239m for Bi-Linear Interpolation, ±0.254m for Bi-Quadratic Interpolation, ±0.241m for Triangulation and ±0.451m for Nearest Neighbour against ±1.393m for EGM96. There is a marked improvement in the overall RMSE of EGM08 models from ±45cm (Nearest Neighbour) to ±24cm (Bi-Linear Interpolation).

This study has also implied that use of EGM08-Bi-Linear Interpolation & EGM08-Triangulation methods is preferable to use for orthometric height determination.

It is also seen that EGM08-Bi-Linear Interpolation Model can be used to produce topographical mapping of 2m contour interval for intermediate accurate survey, but still inadequate for survey applications where a high accuracy is required. It may be encouraged to develop a geometric geoid model for local applications instead of adopting a model that is inadequate for accurate geo-data acquisitions.

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