ENHANCEMENT OF THE EGYPTIAN GRAVIMETRIC GEOID 1995 USING GPS OBSERVATIONS

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GPS precise three dimensional coordinates are helping in solving many geodetic problems. One of these problems is the geoid determination with good-enough accuracy. In one of the projects in the Egyptian Eastern Desert, the coordinates of 389 points were obtained by using GPS. Meanwhile, a gravimetric geoid for the same area has been developed in 1995. Geoid undulations from this geoid were interpolated at the same positions of the GPS stations, and compared with their corresponding values. Statistical parameters of the two geoids under investigation, namely GPS and gravimetric, have been compared and discussed, for the Eastern Desert area. The results showed that there is a disagreement between the two geoids. Consequently, a new geoid for the same area is calculated as a result of fixing the surface of the GPS geoid and modifying the gravimetric geoid to fit the GPS geoid. Finally, an enhanced and improved geoid, for the entire Egyptian territory, has been developed here, on the basis of considering the influence of modifying the gravimetric undulations to fit the GPS undulations.

1. INTRODUCTION

Many researches studied the use of GPS in computing, controlling and strengthening the local geoids in many areas, the following are some examples;

- (A. Mainville and Veronneau M., 1990) Obtained orthometric heights in Canada and analyzed the difference between GPS and gravimetric undulations. They discovered slope error, in the gravimetric geoid, of 1 meter at distance 400 to 700 km. This slope corresponds to the long wave-length in the used global geoid model. They showed also that the orthometric heights can be obtained by GPS and a geoid model with uncertainties ranging from 6 cm for short baselines (10 km) to 20 cm for very long baselines (few hundreds km).

- (A. Kenyeres, 1992) Used the GPS undulations as a reference instead of the geopotential models whom incorporating a significant long wave-length error into the results. The research showed that the significance of the long wave-length error of the global geoid models is clear in the neighborhood of input data gaps rather than the input data gaps areas themselves, i.e. the case in Egypt. He also used the GPS geoid to judge the gravimetric geoid and finally he lasted with GPS-gravimetric geoid.

- (L. Mervart, 1992) Studied the accuracy of GPS measurements in geoid computations. The results of this study showed that the GPS measurements, are very accurate global measuring technique and they overcome the problem of the compatibility of various kinds of data and are a powerful method for the determination of the geoid.

- (Hanafy and Eltokhey M., 1993) investigated the improvement of the geoid by adding GPS observations in a simulation study. They found that adding GPS undulations is better than adding gravity observations but adding both is the best.

The geoid in Egypt for the whole territory was computed in 1986 using the collocation technique based on the available heterogeneous data at that time (Alnagar, 1986). This geoid is related to WGS-72. Again in 1993, the geoid in Egypt was computed after adding some more data using also the collocation technique (Eltokhey, 1993). In 1995, the geoid was calculated using FFT technique and for the first time using DTM in calculating the terrain effect (El Sagheer, 1995). This time the short, medium and long wavelengths were taken into account. The last two geoids are related to WGS-84. In every case, the output was 15` by 15` grid values of the undulations and also a free-air gravity anomaly map was produced. The results of the three cases show that the precision of the geoid in Egypt is still not good enough for the different geodetic applications. The main reasons are the lack of data, the uneven distribution of the existed data. So every time we get more data, the geoid should be computed tell we get the geoid with enough precision for our applications.

2. GEOID UNDULATIONS FROM GPS AND ORTHOMETRIC HEIGHTS (GPS/LEVELLING GEOID)

GPS geodetic technique allow the determination of the separation between the ellipsoid and the geoid if the GPS- derived elevations are compared with heights derived from spirit leveling measurements; this approach may provide a contribution of the geoidal undulation on the test area under consideration.

The data used for developing the GPS geoid in this study were obtained from the FINNMAP project . The area of the project covers two Belts, the Red Belt and the Blue Belt. The Red Belt area is subtended between longitude 29° E and longitude 33° E. The Blue Belt area is subtended between longitude 33° E and longitude 36° E . A total of 389 stations in the project area were established using the relative GPS technique. GPS observations were taken using six single frequency, 5 channels Trimple 4000SX receivers. Point positioning was done at the first order triangulation station E7 (Gebel Hamed) to position the network. This was done using pseudo ranging. Relative positioning was done using double differencing processing with fixed integer bias search. In the computations, satellites orbits were treated as fixed .

Observation sessions were classified into first and second order. The duration of the first order sessions was between 90 and 105 minutes with average PDOP equals 5. The duration of the second order sessions was 70 minutes and PDOP was 5 except in one session, it was 20. The cut-off angle was 18 degrees. In first order observations , the average length of a base line was 112 km and for the second order it was approximately 50 km, the number of first order stations is 31 and 340 for the second order stations. The distribution of these GPS data points is illustrated in Figure (1).

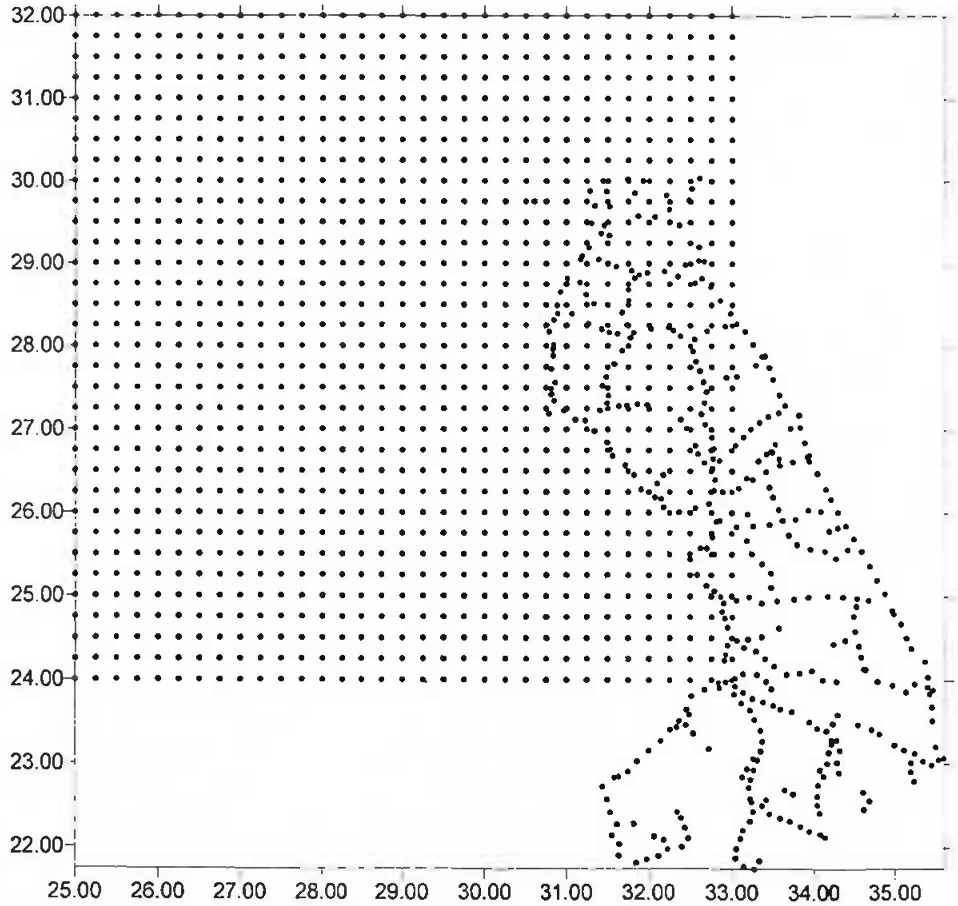

Figure 1: Data Distribution for the Available GPS and Gravimetric Geoidal Undulations in Egypt.

Among the GPS stations, 56 precise leveling benchmarks were observed to get geoidal undulations over Eastern Desert. To connect GPS stations to the local vertical datum, geoidal undulations at these 56 benchmarks were obtained by subtracting their ellipsoidal from their corresponding orthometric heights. The geoidal undulations at the other stations are obtained by simple linear interpolation . The results concerned herein are the geoidal undulations at all the GPS stations in the project area. The resulted undulations are related to WGS -84 (Finnmap, 1989). The locations of these 389 stations are illustrated in Figure (1). Table (1) shows some statistics about the computed undulations in this area.

3. GEOID UNDULATIONS FROM THE GRAVITY DATA

The used gravimetric geoid in this research was developed by El Sagheer, in 1995, a brief discussion of the used data, the methodology of computations, and the obtained results are given in the following subsections.

3.1 The Used Data

The data used in developing this gravimetric geoid for Egypt were as follows:

1- A 5′ by 5′ grid of the gravity anomalies global trend as generated from the adopted OSU-81 Earth Geopotential Model. OSU-81 model expands to degree and order 180. This model has been found to be the best to fit Egypt among the other geopotential models (Nassar, et. al., 1993)
2- A 5′ by 5′ grid of the enhanced free-air gravity anomaly field for Egypt.
3- A 5′ by 5′ grid Digital Terrain Model (DTM) for Egypt.

3.2 The Methodology Used in Developing The 1995 Gravimetric Geoid

Satellite and terrestrial gravity measurements and heights from DTM are combined to produce the required geoidal model. The geoid undulation, N, at any point consists of three parts as represented in the following equation:

$$N = N(GM) + N(g) + N(h) \tag{1}$$

where:

N(GM) represents the contribution of the adopted geopotential model as a global trend (long wavelength feature of the geoid.

N(g) represents the contribution of the smoothed gravity anomalies as a regional trend (medium wavelength feature of the geoid.

N(h) represents the contribution of the topographic local irregularities of the terrain as a local residual trend (short wavelength feature of the geoid).

Satellite measurements provide the long-wavelength features of the gravity field through the analysis of satellite orbit perturbations and satellite altimeter data over the oceans. These measurements produce what is named a geopotential model. Geopotential models also include terrestrial gravity data. Geopotential models are a smooth representation of the actual gravity field. To achieve higher resolution, better accuracy, these models must be combined with regional and local terrestrial gravity measurements as gravity anomalies and heights information. The medium wavelengths are obtained by integrating the terrestrial gravity anomalies referenced to the geoid. The short wavelengths are calculated using the heights from DTM reflecting the effect of the irregularities of the terrain in the process of obtaining the gravity anomalies. So according to the above equation, the required undulations are obtained by combining the following; (Schwarz K.P. and M.G. Sideris, 1993):

1- A chosen geopotential model which provides the long wavelength feature of the geoid.
2- Dense terrestrial gravity data which provides the medium wavelength feature of the geoid.
3- A DTM to provide the short wavelength feature of the geoid. The used DTM here is a coarse one, so it does not show the details, i.e. low resolution, but it is suitable for terrain correction computations.

Three software program packages are used to calculate the above three parts. The first package evaluates the long-wave length feature of the geoid undulations (N(GM)) at the required points using the adopted model OSU-81. The second package calculates the medium-wave length feature of the geoid undulations at the required points using the FFT technique. The third package uses the DTM of Egypt to calculate the topographic terrain effect as the short-wave length feature of the geoid undulations. The statistical parameters for the developed gravimetric geoid for Egypt is given in Table 1. And the produced geoidal undulations in a regular grid are shown in Figure 1.

4. GEOID SOLUTIONS

In this section, existed and new geoid solutions in the project area will be shortly demonstrated. Firstly every solution will be defined as follows:

Sol.1: The gravimetric geoid as explained in section 3. The statistical parameters are shown in Table 1.

Sol.2: The GPS geoid computed by using the total number of the GPS points in the project. This project covers the Egyptian Eastern Desert. The statistical parameters are shown in Table 1.

Sol.3: It is excluded from the GPS geoid in the project area as explained in section 2. This solution covers the Red belt (Delta) area and expressed at the observation stations. The statistical parameters are shown in Table 1, and illustrated as a contour map in Figure (2).

Sol.4: It is excluded from the gravimetric geoid as explained in section 3. It covers the Red belt area (Delta), i.e. the same area covered in solution 3. The statistical parameters are shown in Table 1, and illustrated as a contour map in Figure (3).

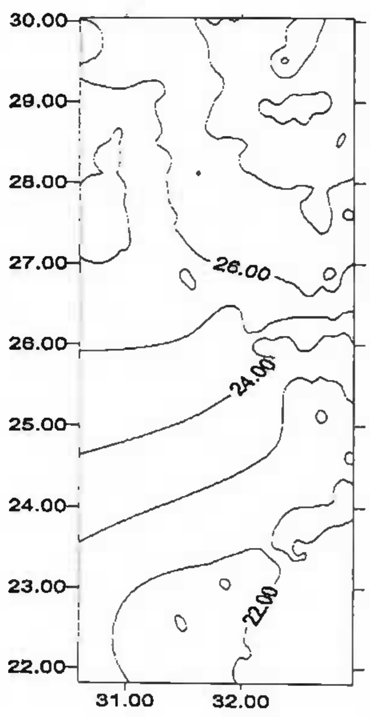

Figure 2: GPS Geoid for Red Belt Area (Test Area).

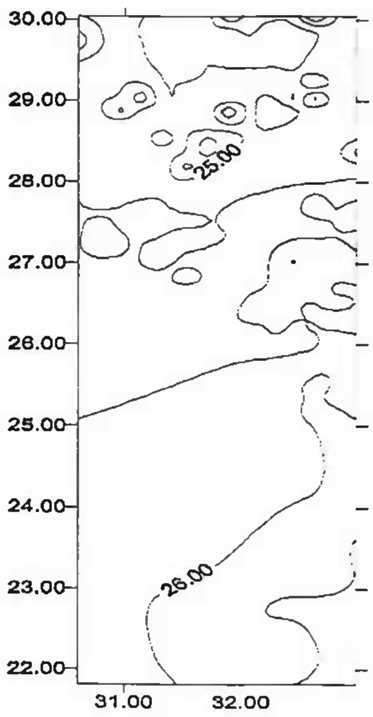

Figure 3: Gravimetric Geoid for Red Belt Area (Test Area).

The statistical parameters for every solution, will be given as number of points, the area covered, minimum, maximum and mean of the geoid undulations.

Table (1): Statistical Parameters for the Different Geoid Solutions.

Sol. No.	points	.φmin	φmax	λmin	λmax	Nmin	Nmax	Nmean
Sol.1*	1089	24 00 00	32 00 00	25 00 00	33 00 00	16.876	31.328	23.194
Sol.2**	389	21 44 21	30 02 08	30 36 04	35 36 19	20.500	29.670	24.141
Sol.3**	185	21 48 34	30 02 08	30 36 04	32 58 49	20.640	29.670	24.983
Sol. 4*	185	21 48 34	30 02 08	30 36 04	32 58 49	24.097	26.169	25.333

* The solution is obtained from gravimetric data.
** The solution is obtained from GPS data.

To compare and analyze the results between the two geoids; the gravimetric geoid as explained in solution 4, and the GPS geoid as explained in solution 3 in the common test area, the differences between the gravimetric undulations and the corresponding GPS values were computed at 185 GPS stations. The results of this case are illustrated and shown in Table (2) and the contour lines in Figure (4) as follows:

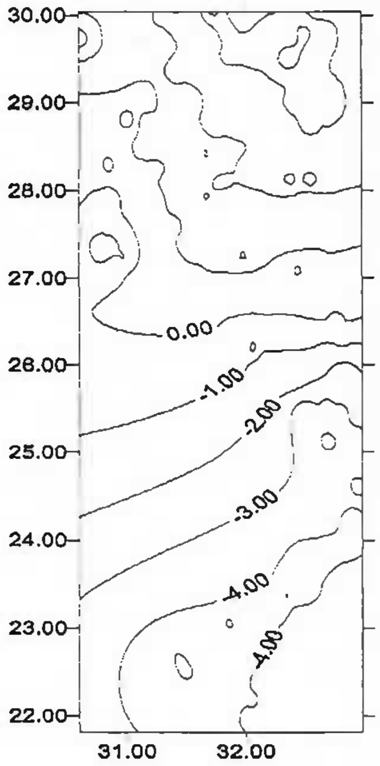

Figure 4: The Differences between the Gravimetric and GPS Undulations for the Red Belt Area (Test Area).

Table (2) : Statistical parameters for the differences between the gravimetric and GPS undulations for the test area

points	φ min	φ max	λ min	λ max	V min	V max	V mean	RMS
185	21 48 34	30 02 08	30 36 04	32 58 48	-5.418	5.480	-0.349	2.879

5. IMPROVING THE EGYPTIAN GRAVIMETRIC GEOID FITS

The statistics of the undulation differences from GPS and gravimetric geoids, illustrated in Table (2) and Figure (4), show that the gravimetric geoid does not agree with the GPS/leveling geoid in the same area. The differences range from -5.418 to 5.480 meters showing slope, rotation, and shift between the two geoids. The reasons of this could be as follows:

1- The used geopotential model does not represent Egypt well specially that the model does not involve data from Egypt. This will introduce the main part of the error in the long wavelength part of N which is N(GM).
2- The bad coverage of the gravity data in Egypt affects the medium wavelength part of the computed undulations N(g).
3- The error in defining the vertical datum, the difference between the wanted geoid and the used MSL.
4- Systematic and random errors in the differential leveling.
5- Errors of the GPS observations.
6- Using only 56 benchmarks to predict undulation values at the rest of the GPS stations.

Depending on the GPS/leveling undulations, fixing their values, The gravimetric geoid can be modified to fit the GPS/leveling one. A surface fitting is used in this purpose representing a slope, rotation and shift between the two geoid surfaces as follows (Heiskanen and Moritz 1967, p. 213):

$$N(GPS)=N(Grav.) + a_1 + a_2 \cos\varphi \cos\lambda + a_3 \cos\varphi \sin\lambda + a_4 \sin\varphi \qquad (2)$$

where a_1 to a_4 are constants. Using the values of the undulations at the common points, the four constants are calculated. Then the last equation is applied directly to all the values of the gravimetric geoid to make them fit the GPS/leveling geoid. Using the last equation and the same parameters, the gravimetric geoid of the whole territory of Egypt which mentioned in solution 1 is treated for these errors to fit the GPS/leveling geoid. The results indicated a geoid undulation varied between 12.357m and 34.229m as illustrated in Table 3 and Figure 5. So, as a main aim of this research, the gravimetric geoid 1995 of Egypt is enhanced and improved using GPS observations.

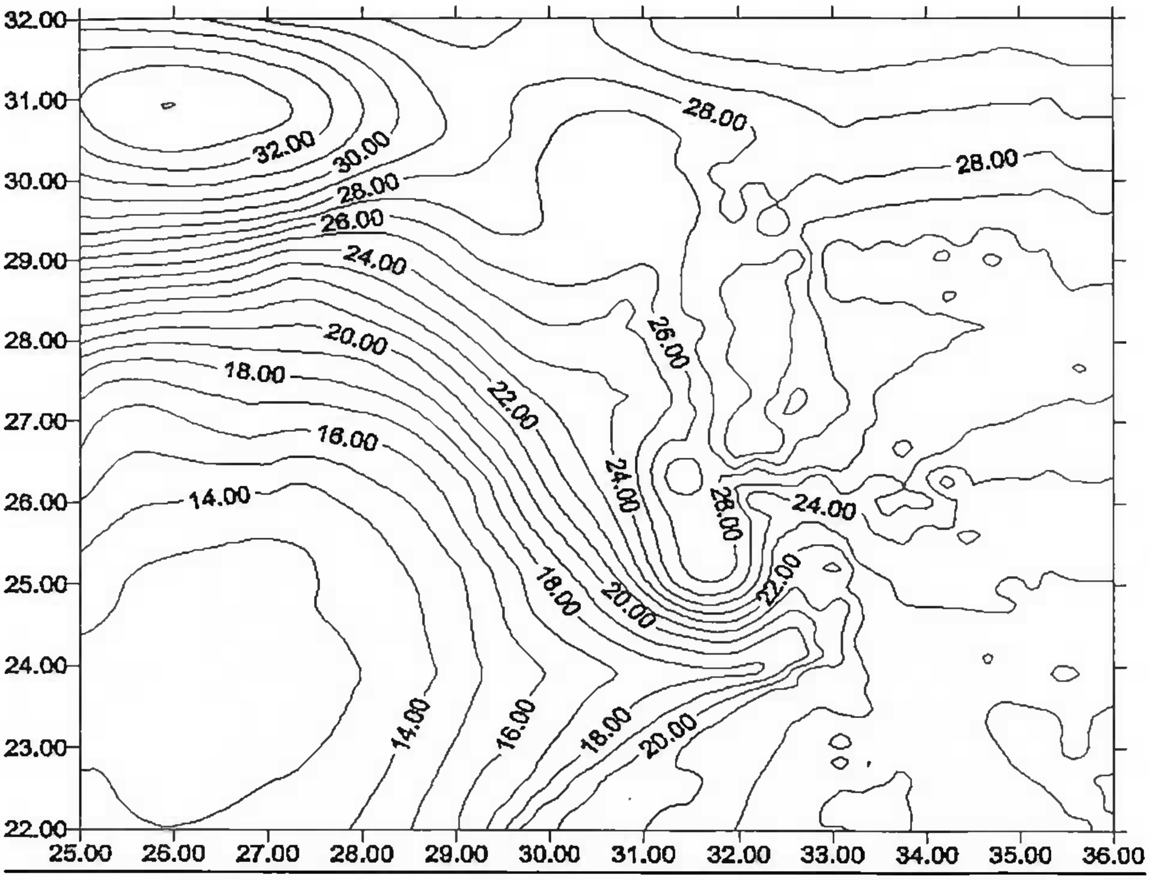

Figure 5: The Improved Egyptian Gravimetric Geoid 1997.

Table (3) : Statistical Parameters for the Improved Egyptian Gravimetric Geoid Using GPS Observations.

points	φ min	φ max	λ min	λ max	N min	N max	N mean	RMS
1476	21 48 34	32 00 00	25 00 00	36 00 00	12.357	34.229	23.474	4.473

6. CONCLUSION

GPS survey of 185 station in the test area (Red Belt) is used as control for inter-comparison of geoid solutions in Egypt from various GPS and gravimetric techniques. Looking at the tabulated and illustrated results , the following can be concluded:

1) Using global geopotential models which do not contain data from Egypt, is introducing a non acceptable errors in the geoid of Egypt.
2) GPS/leveling undulations can be used as fixed values in calculating the geoid from the gravimetric data. They can be also be used to correct the existed gravimetric geoids as it is the case of this research.
3) GPS/leveling undulations should be well distributed in the required area. The quality of the leveling and GPS observations should be high.
4) Still there are areas in Egypt free from the gravimetric and GPS observations which affects the geoid in Egypt.

5) Appropriate planning of the GPS survey and careful use of control stations of high quality is however required.
6) Research and quality control of the data to improve the geopotential models and ascertain geoid undulation throughout region is continuing.
7) Using additional local gravity and GPS information to evaluate the improvement in local geoid solutions in Egypt.

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