DATA MANAGEMENT OF DIFFERENT HEIGHT SYSTEMS WITHIN GPS/GIS INTEGRATED SPATIAL TECHNOLOGY

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ABSTRACT

The integration between both GPS and GIS technologies has proved to be precious in collecting, managing, analyzing, and presenting spatial data. A problematic aspect of dealing with GPS-based datasets is that their heights are ellipsoidal type in nature, while the traditional height type used in civil engineering and mapping activities is the orthometric height. A height conversion methodology is needed, through the so-called geoid modelling, in GPS/GIS data integration. This paper develops a conversion scheme, within a GIS environment, that transforms ellipsoidal into orthometric heights of collected GPS data survey utilizing the most-recent EGM2008 global geoid model. Results of testing the proposed technique, using 300 ground control stations along the Nile river in Egypt, reveals that the excepted accuracy is less than quarter a meter. Performing the height transformation process inside a GIS environment enables efficient and faster management of GPS data collected for GIS projects and assets in producing DEM and contour maps effectively, which in turns reduce the costs of spatial applications.

KEYWORDS

GPS, GIS, Height Systems, Geoid, Egypt

1 Introduction

Recently, the applications of the Geographic Information Systems (GIS) have covered a wide range of engineering disciplines particularly in the Arab countries. For example, Gaber et al. (2009) has utilized the GIS and remote sensing technologies to study the geological structures exist in Sinai, Egypt. Also, El-Mowafy et al. (2008) have developed a scheme for improving the pavement maintenance activities in Abu Dhabi based on GIS. Additionally, Aljenid and Mohamed (2007) has utilized GIS to assess the ecological characteristics of a region in Egypt. In Jordan, the GIS has been used to analyze the impact of modern practices and polices of urban planning (Al-Kheder et al. 2009). In Bahrain, the GIS was applied for documenting historical cities (Tolba 2007). Moreover, GIS has been applied for investigating agricultural development scenarios in the Egyptian deserts (Effat and Hegazy, 2009) and in sustainable development of coastal areas (El Raey et al. 2005).

The integration between the Global Positioning System (GPS) and the GIS technologies has become a major task for the surveying and mapping community in the last decade. GPS/GIS integrated technology has been utilized in a wide range of engineering applications. For example, Shalaby and Tateishi (2007) has used GPS/GIS for mapping and monitoring land cover and land-use changes in Egypt. Al-Musawa and El-Mowafy (2008) has applied GIS/GPS integration for machine automation in construction projects in Dubai. GPS/GIS can be a new tool for road traffic data collection (Owusu et al. 2006). A unique GIS was designed for manipulating various types of geodetic networks in Algeria (Derkaoui et al, 2008). Moreover, the integration of three technologies (namely GIS, GPS, and remote sensing) has been proposed for updating digital maps (Okuno and Shikada, 2004).

However, most GPS/GIS applications has focused only on the different horizontal coordinate systems, and how to convert features' coordinates from one geodetic datum to another. The problem of dealing with different height systems has not been addressed intensely, and hence, it is the main objective of the current study.

2 Height Systems and Geoid Models

Two main height systems are used in engineering and GIS applications: (1) the geodetic height, and (2) the orthometric height. The geodetic or the ellipsoidal height (h) is the height of a point above the surface of an ellipsoid. It worth mention that the GPS-based height is a geodetic height referenced to the World Geodetic System 1984 (WGS84) ellipsoid. On the other hand, the orthometric height (H) is the height of a point above the geoid (approximated by the Mean Sea Level; MSL). Most heights used in surveying and mapping applications are orthometric heights. The difference between the two height types is called the geoid undulation or geoidal height (N), which can be described by (Figure 1):

$$N = h - H \qquad (1)$$

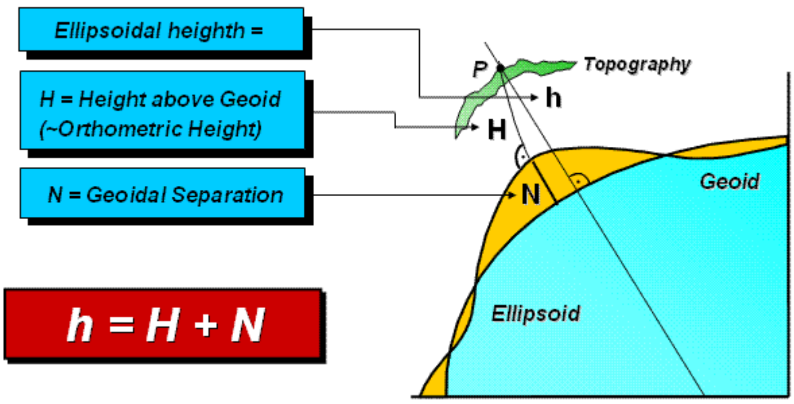

Figure 1: Height Systems

This equation implies that in order to convert the GPS-based geodetic height (h) into the map-based orthometric height (H), the undulation term (N) should be known at every point, in other words, a geoid model is needed. Geoid modelling is an old task of geodesy, which has become a crucial need in all countries since the spread of GPS utilization. Geoid may be developed locally (called local geoid models) or globally (global geoid models). An example of a local geoid model for Egypt is the SRI2002 developed by Saad and Dawod (2002). Regarding global geoids, it worth to mention that the International Center for Global Gravity Field Models (ICGEM) makes available a number of global geoid models, in the form of fully-normalized spherical harmonic coefficients, that can be used to compute geodetic and gravitational quantities (http://icgem.gfz-potsdam.de/ICGEM/ICGEM.html). The most-recent released global geoid model is the Earth Gravitational Model 2008 (EGM2008) published by the U.S. National Geospatial-Intelligence Agency (NGA) in mid 2008 ((Pavlis et al. 2008). The EGM2008 has been utilized for height conversion in several countries and was found to be superior, in terms of accuracy, to all preceded global geoid models (e.g. Femandes 2009, Sadiq and Ahmad, 2009, and Claessens et al. 2009). Comparable investigations have been carried out in Arabic countries. For example, Daho (2009) has evaluate the performance of EGM2008 in Algeria, and has found that its standard deviation equals 0.21 meter over known GPS/levelling points. In Egypt, the overall accuracy of EGM2008 in Egypt was found to be 0.23 meter, and could be decreased to 0.17 meter (Dawod et al, 2009).

3 Data Utilized

In order to assess the GIS-Based height conversion process, utilizing EGM2008 in Egypt, a local geodetic dataset has been utilized. This recent database consists of 300 GPS/levelling points (Figure 2), where geoid undulations have been directly computed. The majority of this data set comes from GPS campaigns carried out by the Nile Research Institute (NRI) for updating the hydro-topographic maps of the Nile. Regarding this geodetic dataset, both the GPS and the spirit levelling networks have been observed, through sub-sections, applying the first-order standards and specifications, and have adjusted using the least-square adjustment techniques. 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 MSL at Alexandria tide gauge of 1906. The accuracy of the derived geoid undulations has been estimated to be ± 5 centimeters (Dawod 2008).

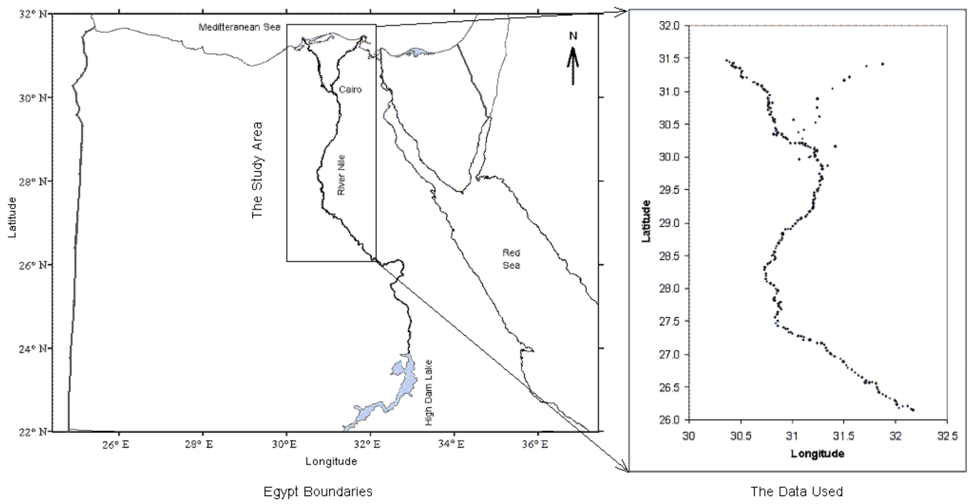

Figure 2: GPS/Levelling Known Stations

4 Methodology

The EGM2008 global geoid model constitutes the chief tool, in the current research study, to convert the GPS-based geodetic heights into the MSL-based orthometric heights. The EGM2008 is available, free of charge, at: http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/. Three methods have been investigated in such process.

4.1 Point-by-point conversion

The original version of the EGM2008, released in April 2008, was in the format of fully-normalized harmonic coefficients' file along with a program that computes the undulation values for some points knowing their geodetic coordinates (latitude and longitude).

4.2 Grid-wise conversion

In July 2008, the NGA has released 2.5-minute world raster grids of the EGM2008 geoid (Fig. 3). Each grid covers an area extending 45 degrees in both latitude and longitude. An interpolation program has been released, too, in order to interpolate points' geoidal undulation values from the corresponding grid.

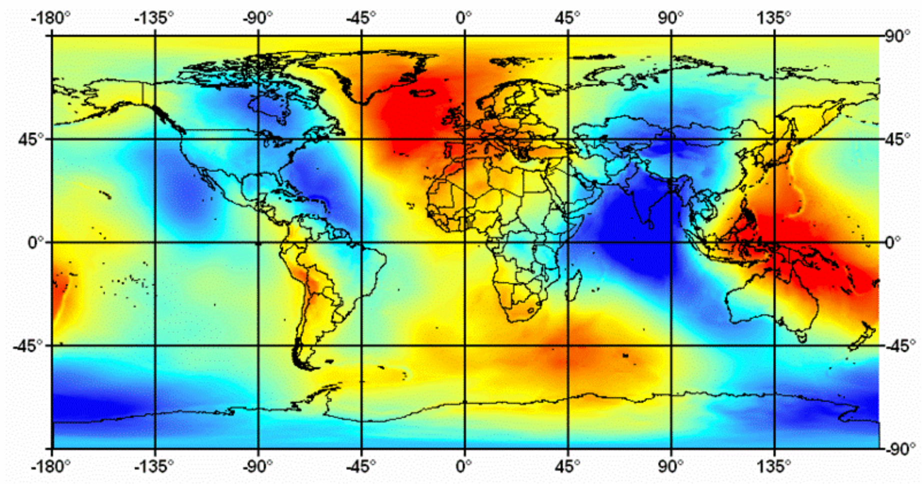

Figure 3: The World Raster Grids of the EGM2008

4.3 GIS-based grid conversion

More recently, in February 2009, the NGA has released a new 2.5-minute GIS-based geoid grid for the Middle East. This ESRI-format grid (Fig. 3) covers the area extending from 20°E to 90°E longitude and from 5° S to 60° N in latitude.

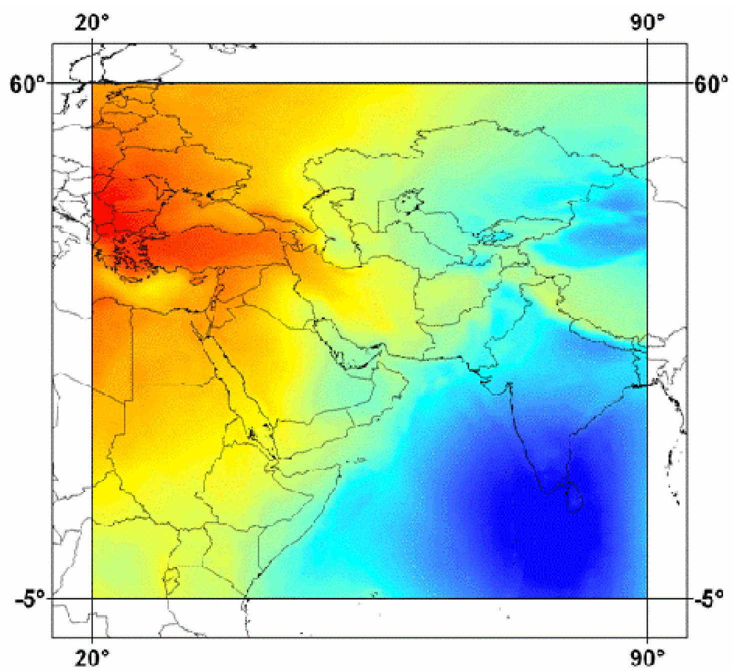

Figure 4: The Middle-East GIS Grid of the EGM2008

5 Processing and Results

In the first stage before starting the actual computations, a comparison has been carried out between the available three different representation means of the EGM2008 geoid. Such a comparison reveals the general characteristics of each method.

The point-wise technique may be considered the most-precise method since it compute the EGM2008 geoidal heights for each point based on the original EGM2008 harmonic coefficients. Hence, it may considered as the optimum mean for geoid computations in high-precision GPS surveying applications. However, it can expect that this method will be the slower one particularly for large geodetic datasets.

The grid-wise conversion method can be expected to be more faster than the point-wise technique, since the interpolation mathematical process will take less processor time than the harmonic expansion computations. That reason has encouraged many commercial GPS data processing software to include those world raster grids in order to perform the height conversion process. However, a main point need to be addressed about the precision of interpolating 2.5' grids, where a cell of 2.5'x2.5' (approximately 4.5x4.5 km) has the same unique geoid undulation.

The main advantage of the third EGM2008 representation technique is its compatibility with the GIS environment, where the height conversion process can take place within the GIS software. The question of interpolation' process is still applicable for this method too.

Secondly, the available geodetic dataset has been utilized to test the three methods of height conversion. In the point-wise scenario, the NGA's hsynth_wgs84.exe program has been run to compute the geoidal undulation for the 300 known geodetic stations. In order to judge the performance of the EGM2008 geoid, the computed undulations have been compared against the known corresponding values. This precision measure of the EGM2008, over Egypt, concludes that the EGM2008 is superior to earlier global geoids by a factor of 1.6 (Dawod et al. 2009).

The grid-wise method has been, then, performed using the NGA's interp_2p5min.exe program to interpolate the undulation at the known check points out of the raster 2.5' grid. The last step was to utilize the GIS-based middle-east ESRI grid, within the Arc GIS software, to interpolate the EGM2008 geoid undulations at the check points.

The attained results, of the three methods, are tabulated in Table 1. The first remark, from this table, is that the overall precision of the EGM2008 global geoid model is, in terms of standard deviation, is 0.23 m. This is an indication about the accuracy of utilizing global geoid models in converting the GPS-based geodetic heights into the MSL-based orthometric heights. In some high-precision GPS surveying, such an accuracy level may not be acceptable, and thus a local precise geoid model should be developed and applied in height transformation. However, that accuracy may be suitable for several GIS and mapping applications. Thus the global geoid models, particularly the EGM2008, provide an optimum free-of-charge candidate for height conversion. The second remark, drawn from Table 1, is that there are no significant differences between the point-wise and the grid-wise interpolation using the NGA's programs. Thus, the time-consumer point-wise method can be avoided in GIS applications, where the grid interpolation will be optimum. Surprisingly, significant differences have been found between the grid-wise interpolation using the NGA's program and the interpolation carried out within the Arc GIS software. The standard deviation of the undulation differences between both programs is about 0.05 m. The main reason may be due to the interpolation mathematical model utilized in each case. The NGA's interpolation program depends on a 6x6 spline interpolation method, while the ArcGIS interpolation (in the surface spot command) is based on the linear interpolation technique. But, the five-centimeter precision level is quite suitable for GIS and mapping projects. However, performing the height transformation within the GIS environment has extra merits.

Table 1: Known and EGM2008 Geoid Undulations over Check Points (m)

	Minimum	Maximum	Mean	Standard Deviation
Known undulations	9.92	18.36	14.22	2.23
EGM2008 point-wise undulations	10.25	18.44	14.33	2.20
Known minus point-wise undulation differences	-0.48	0.32	-0.11	0.23
EGM2008 grid-wise undulations	10.27	18.37	14.33	2.18
Known minus grid-wise undulation differences	-0.48	0.32	-0.11	0.23
Point-wise minus grid-wise undulation differences	-0.001	0.000	0.0001	0.0003
Grid-wise minus GIS-grid undulation differences	-0.08	0.09	-0.001	0.05

Performing the height transformation within the GIS environment not only convert geodetic to orthometric heights, but also produce other significant products. For example, a geoid surface map and a contour geoid map have been developed for Egypt (Figures 5 and 6). Moreover, all the GIS project's processing steps will be carried out within the same environment. If the project uses hand-held navigation GPS receivers, the data can be downloaded directly to the Arc GIS software. If geodetic GPS receivers were utilized, most GPS data processing software have the capability to export their final results in the shapefile format. For both cases, the transformation process is performed within the GIS package in order to convert the GPS-based geodetic heights into the MSL-based orthometric heights using the third discussed method. Furthermore, Digital Elevation Model (DEM), surface and contour maps can be developed for the study area. Even more, cut and fill computations can be also carried out within the GIS environment.

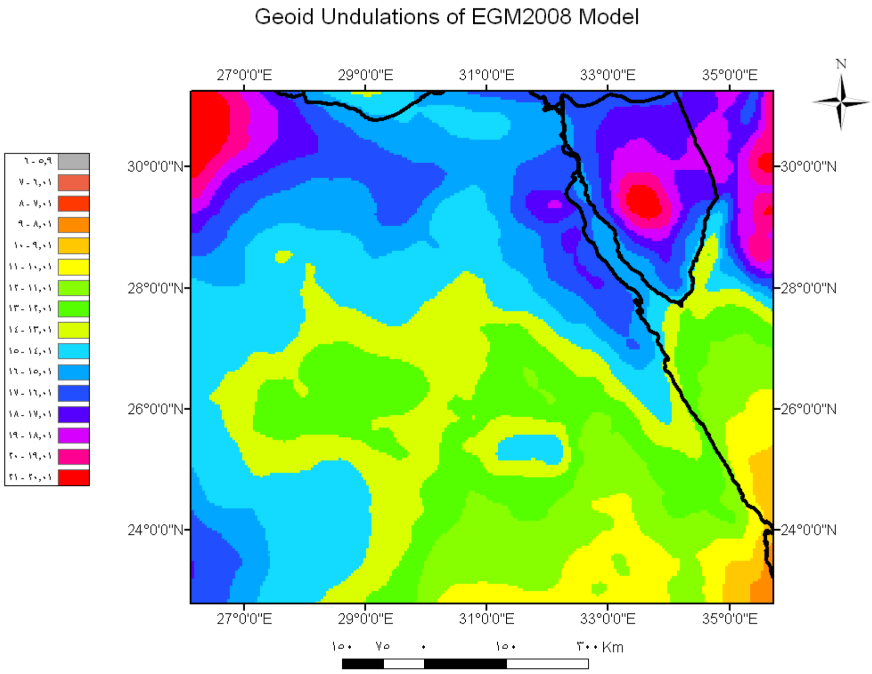

Figure 5: The EGM2008 Undulations over Egypt

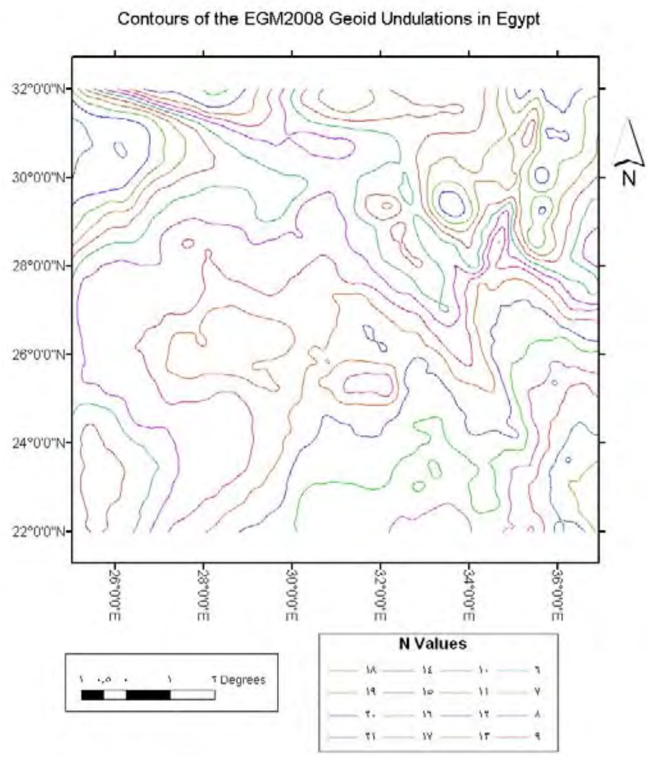

Figure 6: Contours of the EGM2008 Undulations over Egypt

6 Conclusions

The geodetic height obtained from GPS receivers must be converted to MSL-based orthometric height, which is the basic height type used for engineering, mapping, and GIS activities. Height transformation requires a local or a global geoid model. The most-recent and most-precise global geoid model is the EGM2008 released, by the US geospatial intelligence agency, in April 2008. In the current research study, three methods have been investigated for performing height conversion using the EGM2008 geoid. The point-wise height conversion technique is the most-precise but most-slower scenario, which might be suitable for high-precession GPS surveying. Both, the point-wise and the grid-wise methods are stand-alone and further procedures are required to convey the results into the GIS environment. The third conversion scenario, namely the EGM2008 ESRI grid, is the optimum one since it is completely carried out inside the ArcGIS software. But, it produces 0.05 precision differences compared with the previous two methods, which is not significant in many GIS applications. However, performing the height transformation within the GIS environment not only convert geodetic to orthometric heights, but also produce other significant products such as DEM, geoid surface maps, and contour geoid maps. Moreover, cut and fill computations can be also carried out in the GIS environment. Thus, all the processing steps of the GPS/GIS integrated spatial technology' applications will be carried out within the same environment. Furthermore, a cost reduction is anticipated for such projects.

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