Evaluation of EGM08 in Uganda: Preliminary Results

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Abstract
This paper presents an overview of the preliminary evaluation results of the new Earth Gravitational Model (EGM08) in Uganda. The evaluation was based on a network of 12 GNSS/levelling points in Kampala and was performed in point wise (absolute) and relative (varying baselines) sense. For completeness the evaluation tests were also performed for EGM96. Our preliminary results were inconclusive as in the absolute tests, EGM96 was unexpectedly significantly better than EGM08. However, in the relative tests, EGM08 was consistently better than EGM96 for all baseline lengths considered. Subsequently further tests with much higher density and distribution than our test network should be carried out to conclusively determine the best global model for geodetic applications in Uganda

Keywords: EGM08, geoid, ellipsoidal and orthometric heights, GNSS/levelling.

1. Introduction

The Earth Gravitational Model EGM08 is the latest version of a series of geopotential models developed under the leadership of the US National Geospatial-Intelligence Agency (NGA) (Pavlis et al., 2008). It incorporates harmonic coefficients derived from the GRACE satellite mission, marine gravity anomalies derived from satellite altimetry, and a comprehensive set of terrestrial gravity anomalies. Complete to degree and order 2159, with additional spherical coefficients (SHCs) extending up to degree 2190 and order 2159, EGM08 offers an unprecedented level of spatial resolution (~9 km) for the recovery of any gravity field functional over the entire globe (Kotsakis et al.,2010). Since its release, EGM08 has become the standard geopotential model used for many applications including geoid modeling. It has been evaluated in a number of countries using a number of methods. The evaluation and quality assessment of the EGM08 is important for being used in various geodetic and other scientific applications at global and regional scales. The evaluation of the EGM08 is based on the comparisons with other external data. This data may include GNSS/leveling observations, airborne and surface gravity data, sea surface topography and deflections of the vertical.
This paper focuses on the evaluation of EGM08 in Uganda using GNSS/leveling over a network of 12 points in Kampala. In addition evaluation results for EGM96 will be presented for comparison purposes.

2. Data sets

All our evaluation results that are presented in the next sections refer to the network of 12 GPS points shown in Table 1. These points were established by a private surveying company SIG for the Department of Surveys & Mapping under the Greater Kampala Mapping project of 1993. They were observed using GPS (Wild GPS system 200). UTM coordinates were determined based on the Clarke 1880 Modified ellipsoid with a central meridian of 33.

2.1 Uganda's Vertical Height datum

Heights in Uganda were tied to two height datums ie Mombasa datum and the New Khartoum datum. Before the Second World War, the British Directorate of Overseas Surveys (DOS) carried out precise differential leveling from the Kenyan coast (Mombasa) to Uganda. As the reference sea level for this exercise was in Mombasa, the datum was called MSL Mombasa. Another precise differential leveling project was commissioned from Egypt to Uganda which passed through Sudan. In this case the reference sea level was obtained from the harbor of Alexandria, and new calculations for the heights of all the benchmarks were carried out in the New Khartoum datum (the fundamental point of which is given at 363.082 meters above MSL at Alexandria). By 1970 the First order network was completed and a block adjustment was carried out by the Surveys and Mapping Department in Uganda using the observation equation method producing values referring to MSL Alexandria with a standard error of 0.00115 feet per unit weight (IGN, 2003). Therefore the heights in Uganda are based on only one connection to the Egyptian Benchmark BM 9029 which is related to MSL Alexandria. However, check connections with Egyptian BM 927 have revealed a disagreement of -0.1497 feet(IGN, 2003). By 1972 a total of 3033 benchmarks consisting of 51 fundamental benchmarks and 1015 town benchmarks were listed in Uganda. Heights of the 12 GNSS/leveling points were subsequently obtained by precise differential levelling from nearby Benchmarks.However the actual accuracy of these heights and the correctons applied to the raw leveling data are largely unknown due to the absence of sufficient documentation.

2.2 Ellipsoidal heights

For evaluation tests, ellipsoidal heights for the GPS points in Table 1 were determined by making static GNSS observations. A GNSS campaign was undertaken in mid April 2011 using a pair of Trimble R7 GNSS receivers. The base was setup on 71Y151, this was continuously observing for a minimum of 10 hours on each of the observation days. The other points in the network were then observed for a minimum of two hours each. The RINEX data for the base (71Y151) were then submitted to the AUSPOS online GPS Processing Service (http: www.ga.gov.au). The data was computed using the Bernese GPS software version 5.0. All the computed coordinates were based on the IGS realization of the ITRF 2005 reference frame using the IGS Rapid orbit product precise ephemeris. Subsequently the computations for the remaining points in the network were determined using the Trimble Business Centre version 2.40.

Table 1: Final geodetic, GRS 80 ellipsoid, ITRF 2005 coordinates and known heights

station	Latitude (DMS)	Longitude (DMS)	Ellipsoidal Height (m)	Known height (m)
71Y65	0 21 28.545	32 32 43.656	1209.921	1222.122
71Y80	0 20 22.560	32 33 54.174	1253.079	1265.410
71Y97	0 20 17.733	32 33 53.313	1255.641	1267.942
71Y125	0 18 52.602	32 35 40.536	1137.505	1150.081
71Y141	0 16 25.747	32 37 12.317	1176.309	1188.934
71Y143	0 14 32.017	32 37 04.724	1152.722	1165.290
71Y149	0 19 11.331	32 37 29.541	1151.609	1164.099
71Y151	0 21 16.030	32 37 49.049	1237.155	1249.643
71Y152	0 21 46.374	32 37 30.282	1211.352	1223.836
71Y153	0 22 53.665	32 37 33.913	1193.261	1205.659
71Y154	0 24 07.490	32 37 13.163	1174.250	1186.604
71Y155	0 24 06.558	32 38 04.747	1171.592	1183.980

3. Evaluation procedure

The basic relationship between geoid, ellipsoidal and orthometric heights is given by the following simple equation

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

where *h, H* and *N* are ellipsoidal, orthometric and geoid heights respectively.
Based on the known heights and computed ellipsoidal heights, geoid heights were computed at the 12 GNSS/leveling points by re-arranging equation 1 into

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

The above values provided the dataset upon which the evaluation tests were performed.

For EGM08, the geoid height values of the 12 GNSS/leveling points with respect to WGS84 were determined using the FORTRAN harmonic synthesis program, hsynth_WGS84.f together with the EGM2008 Tide Free Spherical Harmonic Coefficients and its associated Correction Model. (http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/egm08_wgs84.html). To run this program an input file with the Latitudes and longitudes of the 12 points must be stored in the same folder as the executable file of the program. After running the program, an output file containing the geoid height values for all the points is automatically stored in the same folder as the program. The output file can then be opened using Notepad or Excel. For EGM96, the geoid height values were computed online using the NGA EGM96 Geoid Calculator found in the following website:

(http://earth-info.nga.mil/wgs84/gravitymod/egm96/intpt.html).This requires the manual input of the latitude and longitude of each individual point and then by clicking calculate the geoid height value is automatically computed and displayed.

Table 2: EGM08 and EGM96 geoid height values and N^{GPS} values for the 12 GNSS/leveling points

Station	N (EGM08)	N (EGM96)	N^{GPS}=h-H
71Y65	-12.953	-12.530	-12.201
71Y80	-12.959	-12.540	-12.331
71Y97	-12.959	-12.570	-12.301
71Y125	-12.996	-12.570	-12.576
71Y141	-13.074	-12.610	-12.625
71Y143	-13.115	-12.630	-12.568
71Y149	-13.037	-12.600	-12.490
71Y151	-13.023	-12.600	-12.488
71Y152	-13.013	-12.590	-12.484
71Y153	-13.008	-12.590	-12.398
71Y154	-12.999	-12.590	-12.354
71Y155	-13.011	-12.600	-12.388

4. Results

In this section we evaluate the absolute and relative differences of the geoid heights derived from EGM08 and EGM96 versus the geoid heights from GNSS/leveling. Table 4a shows the geoid height differences for the 12 GPS points and Table 4b the summary of statistics.

Unexpectedly, the results show that the EGM96 provides the most consistent agreement with the GNSS/leveling data over the test network. Disappointing are the EGM08 results which are substantially worse than those for EGM96, this was unexpected as studies in many other parts of the world have shown that EGM08 is a significant improvement on EGM96.

Table 3a: Geoid height differences for the 12 GNSS/leveling points (units in metres)

Station	$N^{GPS}-N^{EGM08}$	$N^{GPS}-N^{EGM96}$
71Y65	0.752	0.329
71Y80	0.628	0.209
71Y97	0.658	0.269
71Y125	0.420	-0.006
71Y141	0.449	-0.015
71Y143	0.547	0.062
71Y149	0.547	0.110
71Y151	0.535	0.112
71Y152	0.529	0.106
71Y153	0.610	0.192
71Y154	0.645	0.236
71Y155	0.623	0.212

Table 3b: statistics of the differences N^{GPS}-N at the 12 GPS points (units in metres)

	Minimum	Maximum	Mean	Standard deviation	RMS
EGM08	0.420	0.752	0.579	0.075	0.585
EGM96	-0.015	0.329	0.151	0.092	0.183

We continue our evaluation by presenting relative test results over five baselines of varying length. This is important as the absolute test above is less informative as far as the accuracy of the EGM is concerned because of a number of systematic errors that are inherent in both GPS and leveling observations. These include datum discrepancies in the GPS system, GPS observations errors especially the ionosphere and tropospheric biases and discrepancies in the leveling networks and gravimetric systems (Kiamehr and Sjöberg, 2005). Relative testing therefore offers an advantage in that errors that are common at either end of the baseline cancel out on differencing or are substantially minimized.

For all baselines formed, the relative geoid heights were determined according to equation 3 (Kotsakis, et al., 2010)

$$\Delta N_{ij}^{GPS} - \Delta N_{ij} = (h_j - H_j - h_i + H_i) - (N_j - N_i) \qquad (3)$$

Table 4: Relative EGM/GPS geoid height differences for different baselines (units in metres)

Stations	Baseline length	EGM08	EGM96
71Y151-71Y152	1000	-0.006	-0.006
71Y151-71Y153	3000	+0.075	+0.080
71Y151-71Y154	5000	+0.110	+0.124
71Y151-71Y125	6000	-0.115	-0.118
71Y151-71Y141	8000	-0.086	-0.127

The results in Table 4 show that unlike for the absolute test, the EGM08 performs much better than EGM96 from the shortest baseline to the longest baseline. The improvement is significantly better with increasing baseline length.

5. Conclusion and further work

The results obtained from our evaluation tests have not conclusively revealed which of the two models EGM08 and EGM96 is superior in the test area. Whereas the relative tests show that EGM08 is a superior model, the absolute results unexpectedly show that EGM96 is significantly better. This could be due to a number of reasons including; the small density and distribution of the GNSS/leveling points used for evaluation, the method adopted for removing systematic effects from GNSS/leveling observations and the fact that the accuracy of the known heights at the GNSS/leveling points is largely unknown. However, the relative results point to the potential for the future use of EGM08 for a number of geodetic applications in Uganda. Finally, the authors are working on a precise gravimetric geoid for Uganda hence more detailed tests will be carried out once GNSS/leveling observations have been performed in the rest of the country.

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