EGM2008 EVALUATION FOR AFRICA

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1 Introduction

The Earth Geopotential Model 2008 (EGM2008) is the latest version of a series of geopotential models developed under the leadership of the National Geospatial-Intelligence Agency (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. It is likely to become the standard geopotential model used for many applications including orbit modelling and geoid modelling. As such, it is important that it be assessed by means of comparisons with independent or quasi-independent data sets. This paper focusses the assessment on the continent of Africa, probably the continent for which the details of the Earth's geopotential are least well known. This evaluation has been carried out using three data sets:

- African Geoid Project 2007 geoid model (5' by 5' grid)
- Point gravity anomalies for southern Africa
- GPS/levelling data for 79 points in South Africa

The first two data sets are not truly independent of the EGM2008. Most of the point gravity anomalies in the second data set also formed part of the terrestrial data used in EGM2008. The AGP2007 geoid model (Merry, 2007) used gravity anomalies which were also used in EGM2008, and it also used harmonic coefficients derived from GRACE tracking data. Nevertheless, there are sufficient differences in the way the data were used for the two data sets to provide a meaningful comparison.

2 Geoidal Heights

The AGP2007 geoidal height model uses the following data in a remove-restore model:

- Eigen GL04C geopotential model, truncated at degree 120, tide-free system, referenced to the WGS84 ellipsoid, a=6378137m.
- A gridded set of 5' free-air gravity anomalies, derived from three major data sets – the holdings of the University of Cape Town (UCT) for Africa south of 8° S; the holdings of the University of Leeds for the rest of Africa (Fairhead et al. 1988); and the KMS02 marine gravity anomaly data set from the Danish National Survey and Cadastre (Andersen et al., 2005). Where

insufficient measured values existed, the Eigen GL04C field was used to generate grid values.

- The Molodensky G_1 correction term and the correction $N-\zeta$ to convert from height anomalies to geoidal heights were computed using the gridded anomalies and the SRTM 30" DEM (Farr and Kobrick, 2000).

EGM2008 geoidal heights for Africa, referred to the WGS84 ellipsoid in the tide-free system, were extracted from a data set available on the NGA EGM2008 web page (Pavlis et al., 2008). These data are on a 2.5' grid - this set was decimated to a 5' grid to enable a direct comparison with the AGP2007 model. The results are summarised in Table 1 and Figures 1 and 2.

Difference	# of points	Minimum	Maximum	Mean	Std. Dev.
EGM2008 minus AGP2007	593832	-4.58m	+6.31m	+0.02m	0.73m

Table 1: Difference between EGM2008 and AGP2007 Geoid Models

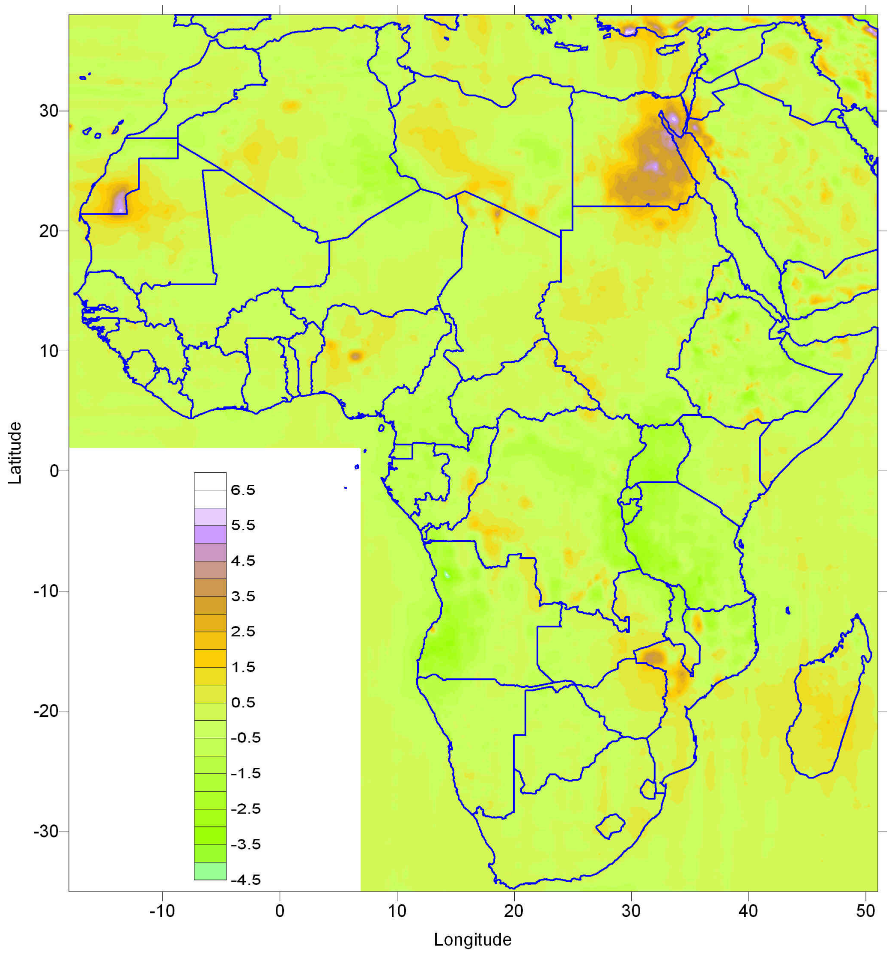

Figure 1: EGM2008 Geoid minus AGP2007 Geoid (metres)

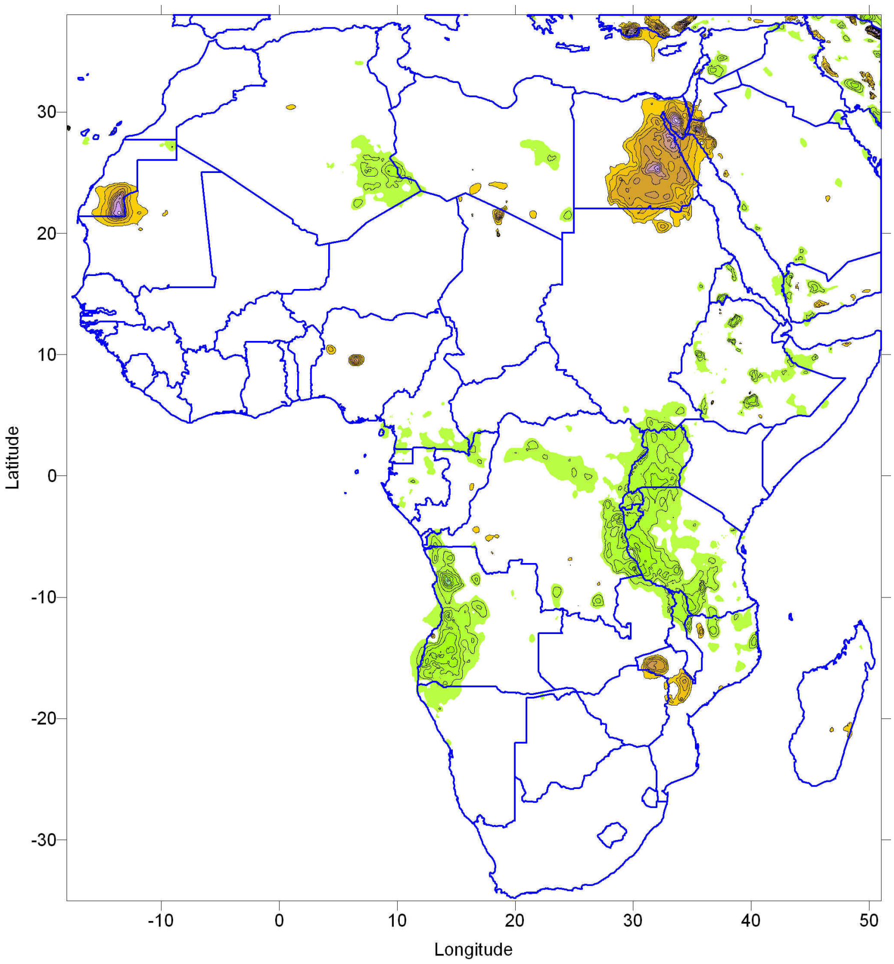

Figure 2: EGM2008 Geoid minus AGP2007 Geoid
(contour interval: 0.5m)
(showing differences where the magnitude exceeds one metre)

The striping that is a feature of many of the GRACE models, including Eigen GL04C used for AGP2007, is apparent in Figure 1. As mentioned in Pavlis et al. (2008) the GRACE data have been re-processed to remove this effect from EGM2008. Figure 2 highlights the larger discrepancies (magnitude larger than one metre). Negative values are blue/green, positive values are in yellow/brown/purple. The minimum discrepancy listed in Table 1 occurs in northwest Angola, in a region where no measured gravity values were available for AGP2007. The maximum discrepancy listed in Table 1 occurs in southern Turkey, outside the area of interest. Looking at some of the discrepancies within Africa:

- There are large positive discrepancies in Egypt, with the maximum (+5.7m) occurring in the Sinai region. No terrestrial data were available for AGP2007 in the Sinai region, and it could be that EGM2008 has made use of new data. Terrestrial data are available for AGP2007 in the remainder of Egypt, and the large positive discrepancies are unexplained.

- The large positive discrepancy in the southeast of Western Sahara is unexplained. Terrestrial gravity data are available in this region.
- The small regions of positive discrepancy in northern Chad and central Nigeria are in regions where there are no terrestrial data available for AGP2007. Presumably such data were available for EGM2008.
- The large (-4.6m) negative discrepancy in northwest Angola is in an area where no data were available to AGP2007. Further south, data are available, but a negative discrepancy persists.
- The positive discrepancies in central and northern Mozambique are in areas where no gravity data were available to AGP2007.

There are large gravity data gaps in Africa (Merry, 2007). For AGP2007 these data gaps were filled using the Eigen GL04C model only. For EGM2008 these gaps were filled using a combination of geopotential coefficients from GRACE and from gravity anomalies deduced from a 30" DEM using the Residual Terrain Model (RTM) approach (Pavlis et al., 2006). As is evident from the discussion above, the two different approaches have yielded substantially different results for geoidal heights in areas lacking observed terrestrial gravity data. Overall, the discrepancies are larger than expected. A more detailed investigation would need more detailed information regarding the terrestrial data used in EGM2008. Unfortunately there are no GPS/levelling data sets available in the areas of the major discrepancies which could be used to resolve these discrepancies.

3 Gravity Anomalies

The computation of AGP2007 used a 5' grid of free-air gravity anomalies. These were interpolated from point values. Only the point values in the University of Cape Town's holding are available for comparison (essentially south of 8° South). The EGM2008 harmonic coefficients were used to generate a 5' grid of gravity anomalies for southern Africa. In turn, these gridded data were used to interpolate gravity anomalies at the data points The comparison between the two sets is summarised in Table 2 and in Figure 3.

Difference	# of points	Minimum	Maximum	Mean	Std. Dev.
Measured Δg minus EGM2008	157495	-132.7mgal	+81.4mgal	-0.8mgal	9.3mgal

Table 2: Difference between Measured and EGM2008 Gravity Anomalies

There are some interesting discrepancies between the measured gravity anomalies and those deduced from the EGM2008 harmonic coefficients:

- With some exceptions the positive discrepancies are correlated with regions of high or rough topography. This is especially so in Lesotho, where elevations routinely exceed 2000m.

- The "peak" on the coast of Namibia correlates with the Brandberg mountain, which EGM2008 has failed to model (no doubt due to the short wavelength nature of the feature).
- The "peak" to the west of Lesotho corresponds to the position of the Trompsburg gravity anomaly – like the Brandberg a short-wavelength feature.
- The linear feature on the border between South Africa and Mozambique corresponds with a known steep gradient in the observed anomalies.
- The extensive area of positive discrepancies in Angola corresponds to a similar discrepancy between the EGM2008 and AGP2007 geoid models. As the discrepancy is of the order of 14mgal, the possibility exists that measured data have not been converted from the Potsdam gravity datum to the IGSN71 gravity datum.
- There is a further positive discrepancy in the Caprivi region of northeast Namibia. This area is virtually flat and the cause of the discrepancy has not been identified.

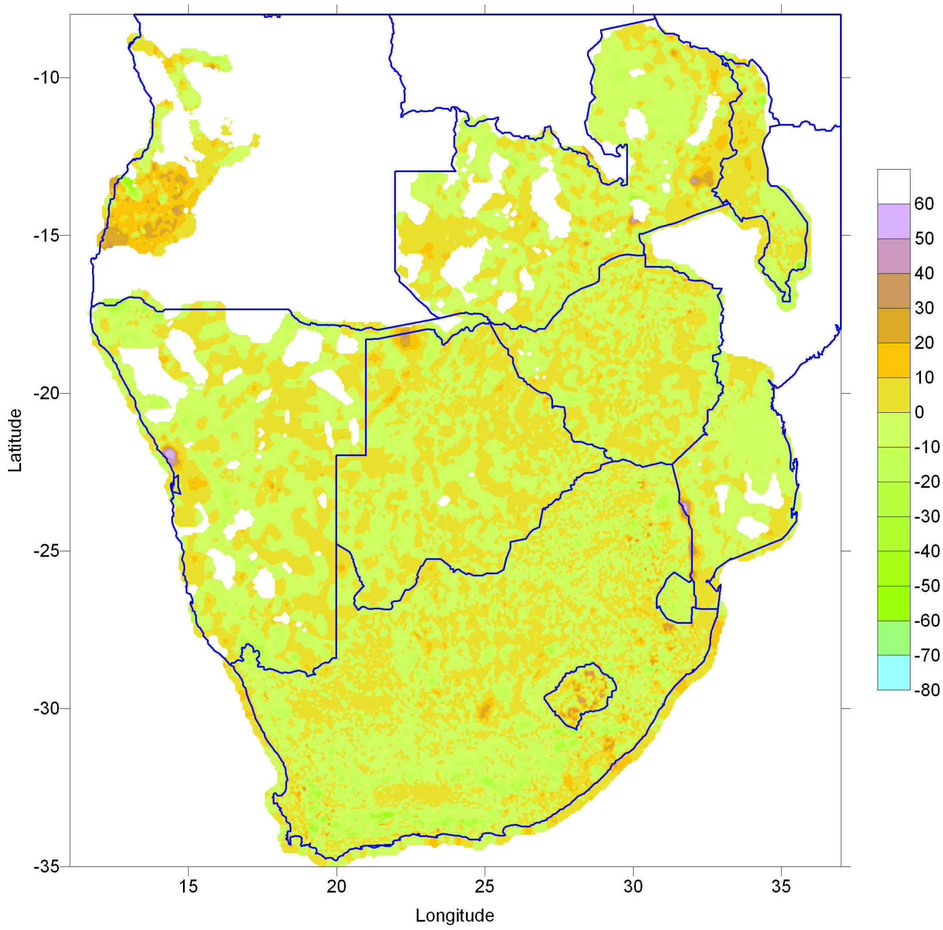

Figure 3: Measured minus EGM2008 Gravity Anomalies (mgals)

Generally, within South Africa, where there is good gravity coverage, the agreement is good. As with the geoidal heights, it is difficult to comment further upon the discrepancies without knowing in detail what observed gravity data were used in forming the EGM2008 model.

4 GPS/Levelling

Precise GPS/levelling geoidal heights are few and far between in Africa. Not all data sets are freely available, and where there are such data, there is often no information on the quality of the data. Recently, a new GPS/levelling data set became available for South Africa (S. Koch, personal communication, 2008). The GPS measurements have been made at 79 benchmarks of the precise levelling network of South Africa by staff of the Chief Directorate: Surveys & Mapping (Figure 4). The GPS co-ordinates are in the ITRF2005 reference frame, and ellipsoidal heights refer to the WGS84 ellipsoid. The South African height system is essentially a modified normal height system, so for the purposes of comparison EGM2008 height anomalies were computed at these 79 points. The results are summarised in Table 3, which includes results for AGP2007 and EGM96 height anomalies.

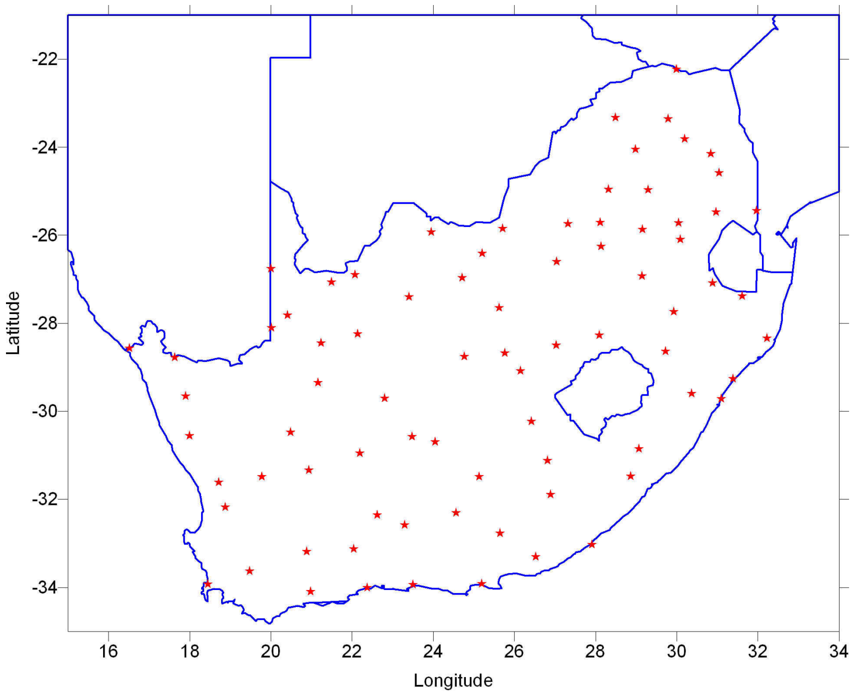

Figure 4: GPS/Levelling Data Points – South Africa

Difference	Minimum	Maximum	Mean	Std. Dev.
GPS/levelling – EGM2008	-0.84m	+0.02m	-0.42m	0.17m
GPS/levelling – AGP2007	-0.92m	+0.36m	-0.44m	0.24m
GPS/levelling – EGM96	-0.95m	+0.68m	-0.24m	0.35m

Table 3: Difference between GPS/Levelling and EGM2008 Height Anomalies

EGM2008 provides the most consistent agreement with the GPS/levelling data and is a substantial (two-fold) improvement over EGM96. The AGP2007 result is disappointing considering that (at least within South Africa) EGM2008 and AGP2007 used essentially the same terrestrial gravity data. It is possible that the "striping" inherent in the underlying GL04C model used for AGP2007 may have contributed to this comparatively poor result.

5 Conclusions

EGM2008 is a significant improvement over EGM96. Within South Africa there is a two-fold improvement in the agreement with GPS/levelling. EGM2008 appears to be free of the striping effect evident in geoidal heights computed from other models based upon the GRACE mission.

There are significant small scale discrepancies with the AGP2007 geoid model, and with the free-air gravity anomaly data in southern Africa. These discrepancies could be due to:

- differences in the available terrestrial gravity data sets.
- differences in the way in which data gaps have been filled.

Further investigation into the sources of these discrepancies is warranted.

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