Detailed Geoid Model for Africa

Final Report

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1. Over View

This report summaries the main activities and achievements of the IUGG grant entitled "Detailed Geoid Model for Africa". The grant ran in the period 2012–2014. The lead applicant is IAG, represented by the IAG Secretary General, Hermann Drewes, DGFI, Munich, Germany. The Project Principal Participant of the IAG lead applicant is Hussein Abd-Elmotaal, Minia University, Egypt. The supporting applicant is IASPEI represented by the IASPEI Secretary General, Peter Suhadolc, University of Trieste, Italy. The Project Principal Participant of the IASPEI supporting applicant is Rashad Kebeasy, National Research Institute of Astronomy and Geophysics, Egypt.

2. Activities and Achievements

A number of very important activities and tasks of the project have been achieved during the course of the IUGG grant. They are summarized in the following sections.

2.1 Collecting Gravity Data

This task represents the core of the project. It is a very hard task, since most institutions don't like to release the gravity data they have. A very laborious work has been done by the IAG PPP, Hussein Abd-Elmotaal, to collect the gravity data along the life time of the project (even before starting the IUGG grant).

Figures 1 to 4 show the development achieved in collecting the land and ocean gravity data for Africa in the course of the project. The currently available data consist of land, shipborne and altimetry derived gravity anomalies data (cf. Fig. 4).

It should be mentioned that collecting the gravity data is a dynamic process, and additional data are seeked for and hopefully it will become available in the second phase of the project.

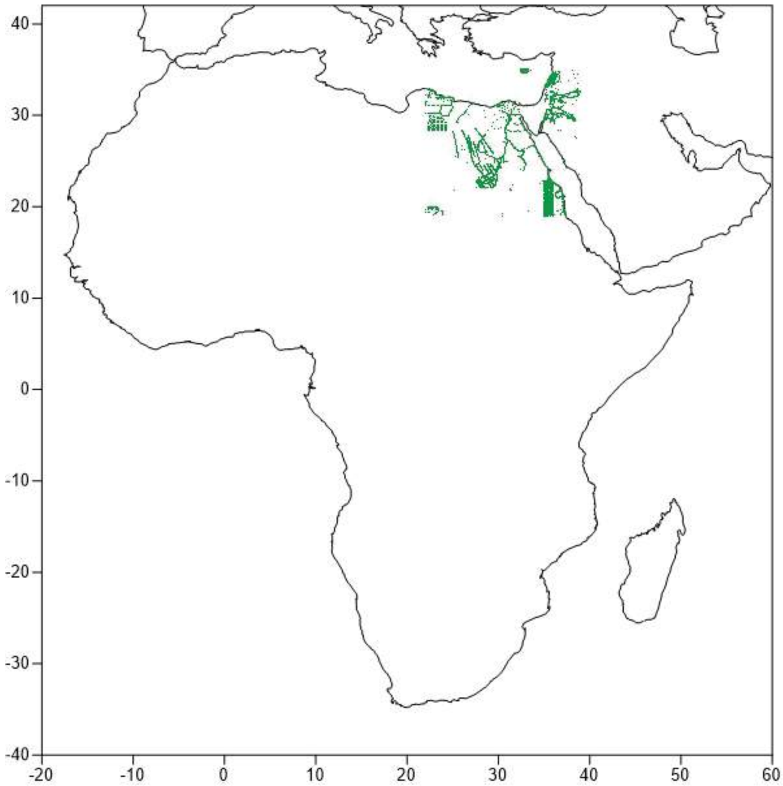

Fig. 1: The available gravity data for Africa as of August 2012.

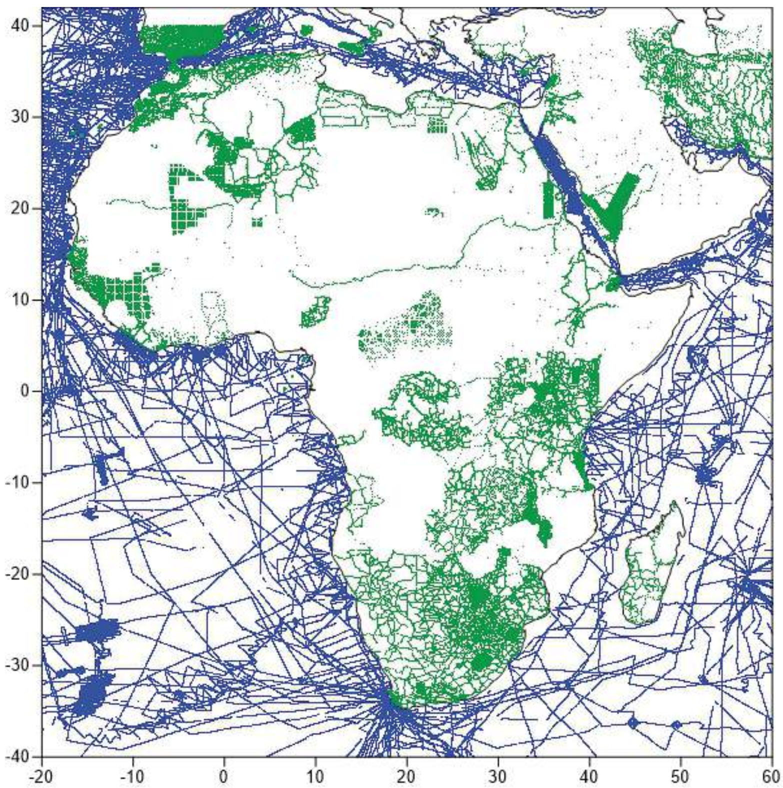

Fig. 2 The available gravity data for Africa as of April 2013.

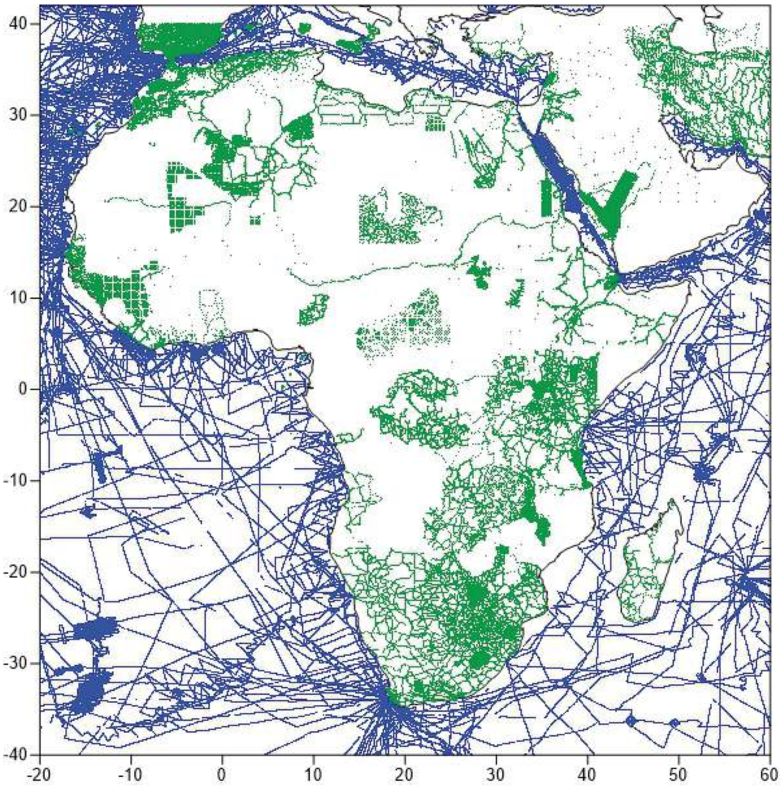

Fig. 3: The available gravity data for Africa as of June 2013.

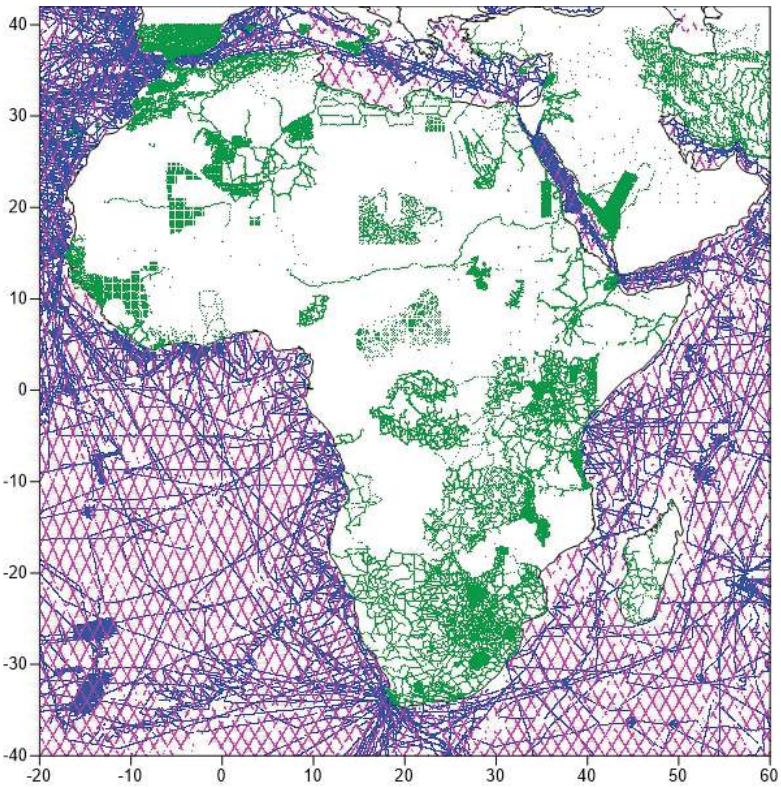

Fig. 4: The available gravity data for Africa as of April 2014.

2.2 Create and Maintain a Webpage of the Project

A webpage of the project (mn.minia.edu.eg/Geodesy/AFRgeo/index.htm) has been created and maintained. It is hosted at Minia University (where Hussein Abd-Elmotaal comes from). It contains a lot of useful information about the project, its data and obtained results and achievement. It also hosts a number of important publications and reports related to the project.

2.3 Gross-Error Detection and Validation

The gross-error detection within each type of the collected gravity data sets took place in somewhat different way, depending on the available number of data points. These approaches for each data set, as well as for combing the ocean data sets, are described in the following sections.

2.3.1 *Land data*

A number of 96,472 gravity data points on land are collected so far. Figure 4 shows their distribution. It shows very large data gaps. A gross-error detection has been implemented on the land data set using a smart gross-error detection technique (Abd-Elmotaal and Kühtreiber, 2014b). It is based on the least-squares prediction algorithm. The technique works first to estimate the gravity anomaly value at the data station using other values than the current data point. It thus compares the estimated value to the data value for possible blunder detection. Hence the technique measures the influence of removing the data value of a current point on the neighbourhood stations. Only if the value of a certain station proves to be blunder, it is then removed from the data base. This approach saves as much data as possible. Using that approach, only 0.5% are found to be blunders in the land gravity data set. More details are found in (Abd-Elmotaal and Kühtreiber, 2014b).

2.3.2 *Shipborne data*

A large number of 971,945 shipborne gravity data points are collected. Figure 4 shows their distribution. It shows better distribution than that of the land data. Still some data gaps exist, which are mostly filled by altimetry-derived gravity anomalies. A gross-error detection has been implemented on the shipborne data set using a gross-error detection technique described in (Abd-Elmotaal and Makhloof, 2013). It is based on the least-squares prediction algorithm, which estimates the gravity anomaly value at the data station using other points than the current data point and then compares the estimated value to the data value for possible blunder detection. The technique works in an iterative scheme till the standard deviation of the residuals (data minus estimated) becomes less than 1.5 mgal. More details are found in (Abd-Elmotaal and Makhloof, 2013).

2.3.3 *Altimetry data*

119,249 altimetry-derived gravity anomalies are collected. Figure 4 shows their distribution. It shows rather a normal distribution. A gross-error detection technique, similar to that implemented on the shipborne data, took place (cf. Abd-Elmotaal and Makhloof, 2014b).

A study on the proper combination of the shipborne and altimetry data has taken place. Altimetry data were removed (basically near the coast) when they have discrepancies to the shipbornge data larger than 20 mgal. More details on that combination between shipborne and altimetry-derived gravity anomalies can be found in (Abd-Elmotaal and Makhloof, 2014b).

2.4 Establishing Topo/Bathymetry DHM for Africa

For the terrain reduction computation, a set of fine and coarse Digital Height Models (DHMs) is needed. A set of 30" × 30" and 3' × 3' DHMs based on SRTM are created. Figure 5 illustrates the 30" × 30" fine DHM for Africa.

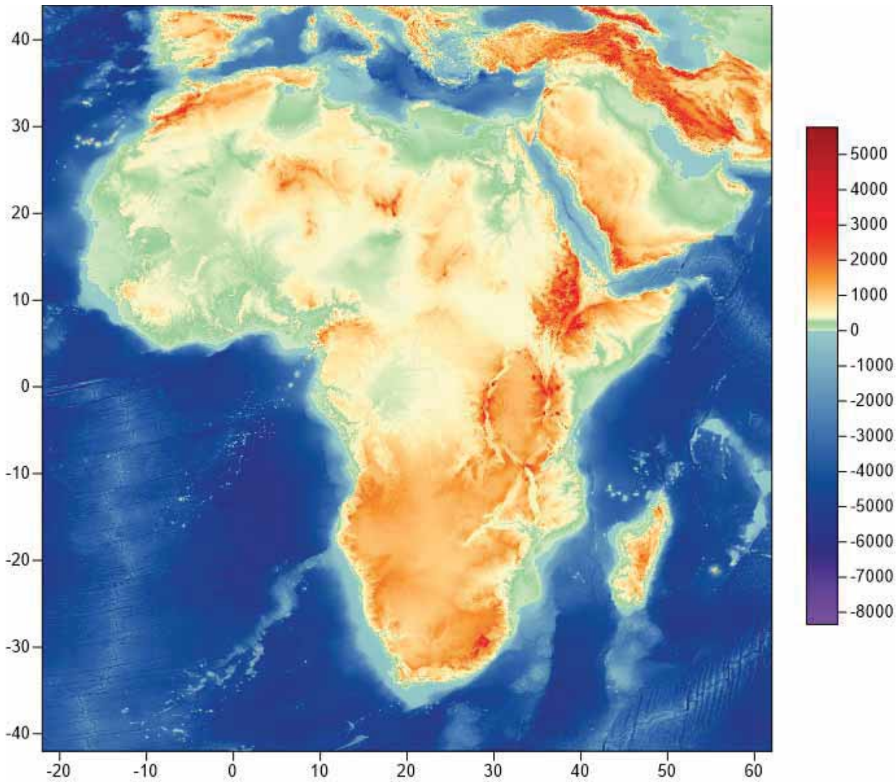

Fig. 5: The fine 30" × 30" DHM for Africa.

2.5 Establishing a Tailored Geopotential Model for Africa

A comparison study on the recovery of the gravity field in Africa using all available recent geopotential models have been carried out. It proved that none of the existing reference geopotential models fits the African gravity field better than ± 30 mgal standard deviation. More details can be found in (Abd-Elmotaal and Makhloof, 2014c). Hence, a tailored geopotential model for Africa, complete to degree and order 360, has been established (cf. Abd-Elmotaal et al., 2013b). This model represents the initial model used to fill-in the data gaps (see Sec. 2.6). Three harmonic analysis techniques are used to generate the tailored geopotential model for Africa; they are:

- FFT technique (Abd-Elmotaal, 2004),
- Least-squares technique (Heck and Seitz, 1991),
- Gauss-Legendre numerical integration technique (Abd-Elmotaal et al., 2013a).

The results show that using the tailored model created by Abd-Elmotaal et al. (2013b) gives smaller residual gravity anomalies for Africa (unbiased and have much less variance and range). The variance and the range decreased by about 50% compared to the original free-air anomalies. The FFT and the Gauss harmonic analysis techniques give quite similar results, which are very close to those derived by the least-squares harmonic analysis technique. The tailored geopotential models created within that investigation are more suitable than EGM2008 or recent GRACE-GOCE derived geopotential models for gravity interpolation considering the large data gaps appearing in the African gravity database. More details can be found in (Abd-Elmotaal et al., 2013b).

The created initial tailored geopotentail model for Africa, developed in 2013, has been used in an iterative process within the window remove-restore technique (Abd-Elmotaal and Kühtreiber, 2003) to generate a better ultra high-degree, complete to degree and order 2160, tailored geopotential model for Africa (Abd-Elmotaal et al., 2014). This ultra high-degree tailored geopotaential model has been then used to fill-in the data gaps. Figure 6 shows the lower harmonic coefficients (complete up to degree and order 360) of the tailored geopotential model of Africa compared to those of EGM2008. It shows significant changes in the lower harmonics to those of the EGM2008 to better fit the gravity field of Africa. It is worth mentioning that the ultra high-degree tailored geopotential model for Africa is complete to degree and order 2160 as it keeps the harmonic coefficients of the EGM2008 model from degree 361 till 2160 unchanged. More details on the technique used to create this ultra high-degree tailored geopotential model for Africa can be fund in (Abd-Elmotaal et al., 2014).

Figure 7 shows the validation in the space domain of the ultra high-degree tailored model for Africa. The residuals are perfectly unbiased with a standard deviation of about 6.5 mgal. Figure 7 shows that most of the area, especially on land, have residuals below 10 mgals (the white pattern). More details can be found in (Abd-Elmotaal et al., 2014).

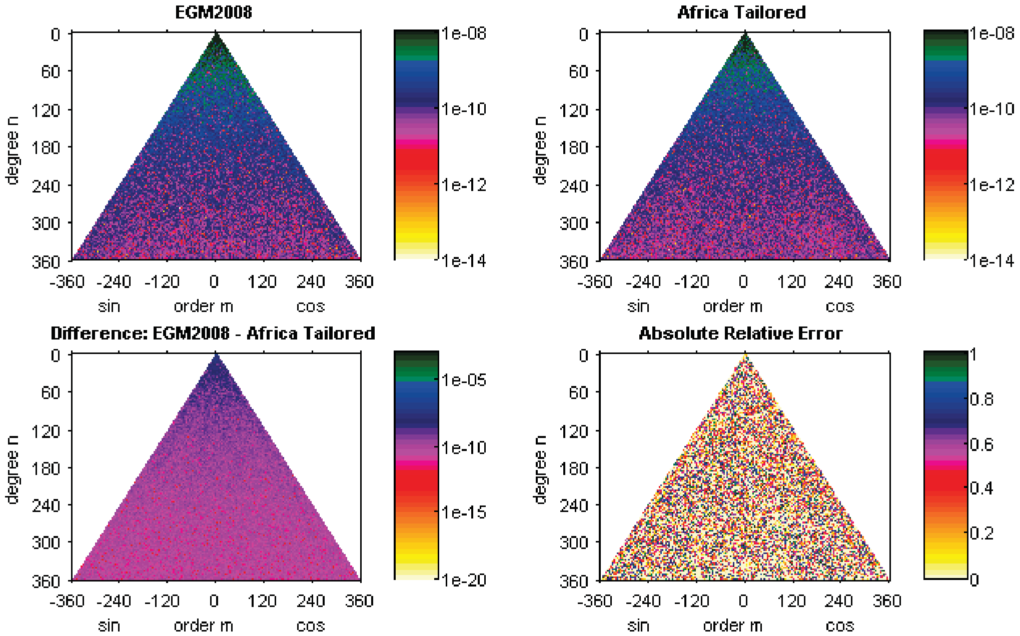

Fig. 6: The lower harmonic coefficients (complete up to degree and order 360) of the ultra high-degree tailored geopotential model of Africa (after Abd-Elmotaal et al., 2014).

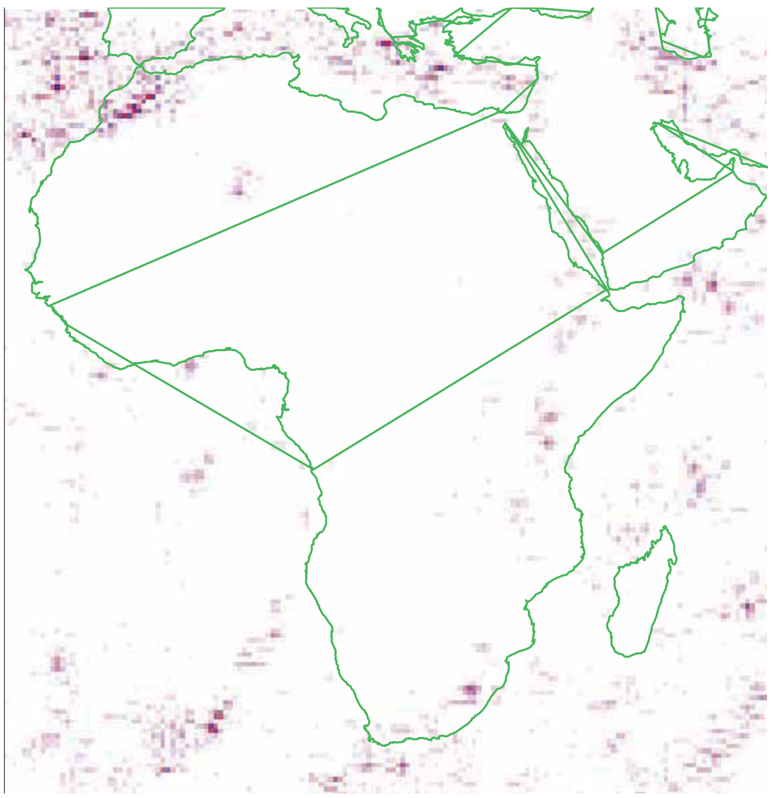

Fig. 7: Validation in the space domain of the ultra high-degree tailored geopotential model for Africa. Units in [mgal]. (After Abd-Elmotaal et al., 2014).

2.6 Establishment of the Gravity Database of Africa (AFRGDB_V1.0)

The geoid for Africa is going to be computed using Stokes' integral in the frequency domain by 1-D FFT technique. This needs the gravity data to be known (interpolated) on a regular grid. Hence, the establishment of a 5' × 5' African free-air gravity anomaly database has been successfully carried out in the framework of the window remove-restore technique using the developed ultra high-degree geopotential model of Africa employing an unequal least-squares prediction technique (Abd-Elmotaal et al., 2014). Figure 8 shows the 5' × 5' African free-air gravity anomaly database, ver. 1.0 (AFRGDB_V1.0). The free-air gravity anomalies range between -325.3 mgal and 771.6 mgal with an average of 1.1 mgal and a standard deviation of 35.3 mgal.

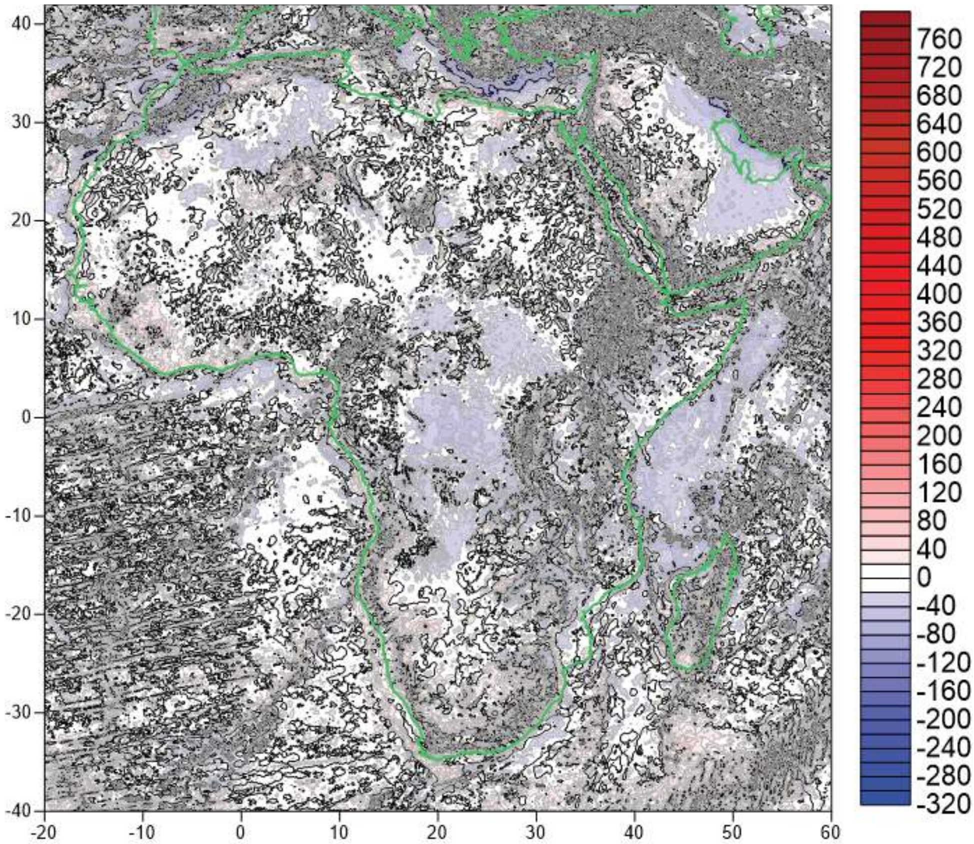

Fig. 8: The 5' × 5' African free-air gravity anomaly database AFRGDB_V1.0. Contour interval: 20 mgal. (After Abd-Elmotaal et al., 2014).

As an estimation of the quality of the established free-air gravity anomaly database of Africa AFRGDB_V1.0, Fig. 9 shows the residuals between the measured and the database values at the data points. These residuals range between -357.1 mgal and 89.2 mgal with an average of -1.2 mgal and a standard deviation of 12.2 mgal. Figure 9 shows that most of the area have residuals below 10 mgal (the white pattern).

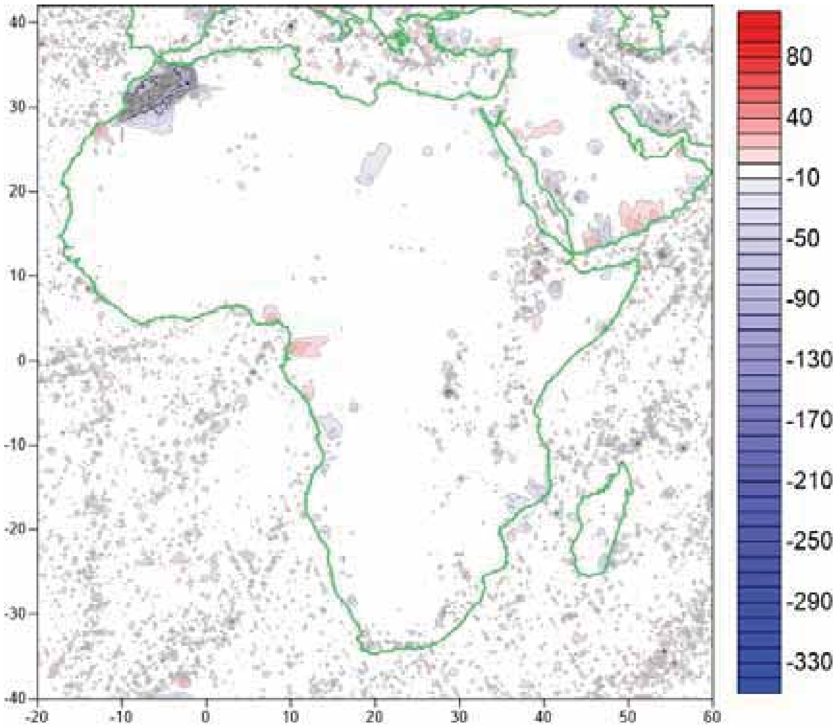

Fig. 9: Residuals at the data points between measured values and the 5' × 5' African free-air gravity anomaly database AFRGDB_V1.0. Contour interval: 10mgal. (After Abd-Elmotaal et al., 2014).

Figure 10 shows a histogram of comparing the established free-air gravity anomaly database of Africa AFRGDB_V1.0 with the real data. Figure 10 shows perfect Gaussian normal distribution with high precision index, which indicates a high precision of the established gravity database.

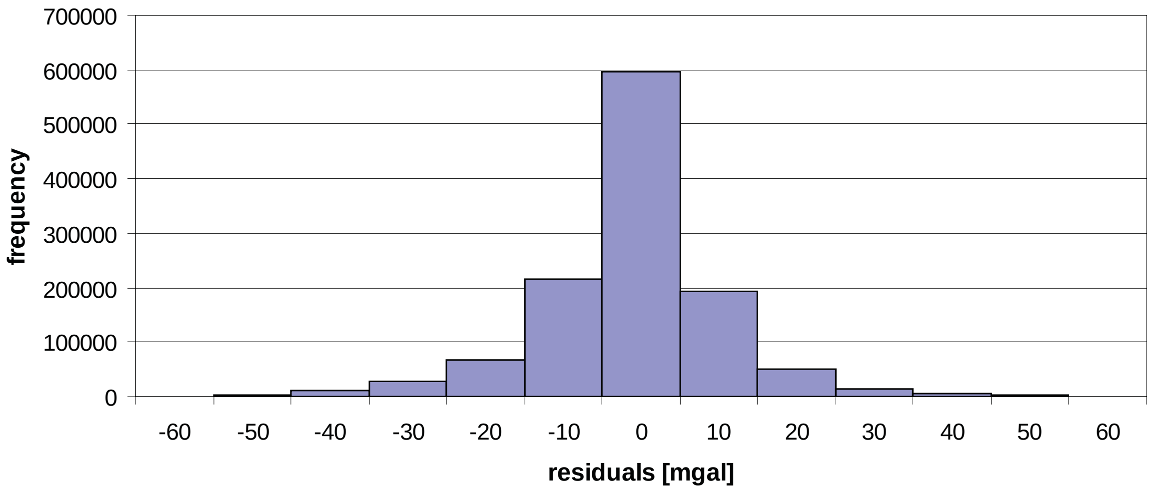

Fig. 10: Histogram of comparing the 5' × 5' African free-air gravity anomaly database AFRGDB_V1.0 with real data. (After Abd-Elmotaal et al., 2014).

It should be noted that both the developed ultra high-degree tailored model for Africa (complete to degree and order 2160) and the gravity database of Africa AFRGDB_V1.0 will be available from the African Geoid Project webpage (mn.minia.edu.eg/Geodesy/AFRgeo).

3. Upcoming Phase of the Project

In order to achieve the continental geoid for Africa with an acceptable precision, an upcoming phase of the project is seeked by the applicants of the current project, and the IUGG is kindly requested to fund it. The enhancements of the upcoming phase include, but not limited to, the followings:

1- Collect more gravity data, especially on land areas.

2- Fill-in the large data gaps using innovative technique.

3- Establish a more precise gravity database for the African geoid project (AFRGDB_V2.x).

4- Validate the established gravity database with the global gravity database institutions, e.g., BGI and NGA.

5- Establish a detailed Digital Height Model (DHM) for the continent (both topography and bathymetry).

6- Develop an enhanced approach for combining different wavelengths of the gravity field in the geoid computation process.

7- Apply improved gravity reduction techniques in the framework of the geoid determination technique.

8- Employ high efficient harmonic analysis techniques for better approximating the gravity field using ultra high-degree geopotential models.

9- Compute a precise geoid model for Africa using 1D-FFT technique.

4. Publications

A number of papers are published within the course of the project. Here follows a list of these publications.

1. Abd-Elmotaal, H. and Kühtreiber, N. (2014a) The Effect of DHM Resolution in Computing the Topographic-Isostatic Harmonic Coefficients within the Window Technique. Studia Geophysica et Geodaetica, Vol. 58, 41–55, DOI: 10.1007/s11200-012-0231-6.

2. Abd-Elmotaal, H. and Kühtreiber, N. (2014b) Automated Gross Error Detection Technique Applied to the Gravity Database of Africa. General Assembly of the European Geosciences Union (EGU), Vienna, Austria, April 27 – May 2, 2014.

3. Abd-Elmotaal, H. and Makhloof, A. (2013) Gross-Errors Detection in the Shipborne Gravity Data Set for Africa. Geodetic Week, Essen, Germany, October 8–10, 2013.

4. Abd-Elmotaal, H. and Makhloof, A. (2014a) Optimum Geoid Fitting Technique for Egypt. General Assembly of the European Geosciences Union (EGU), Vienna, Austria, April 27 – May 2, 2014.

5. Abd-Elmotaal, H. and Makhloof, A. (2014b) Combination between Altimetry and Shipborne Gravity Data for Africa. 3rd International Gravity Field Service (IGFS) General Assembly, Shanghai, China, June 30 – July 6, 2014.

6. Abd-Elmotaal, H. and Makhloof, A. (2014c) Comparison of Recent Geopotential Models for the Recovery of the Gravity Field in Africa. Journal of Applied Geophysics, in press.

7. Abd-Elmotaal, H., Makhloof, A. and Ashry, M. (2014) Experiments with Different Techniques for Combination of Gravity Field Wavelength Components for Geoid Determination in Egypt. General Assembly of the European Geosciences Union (EGU), Vienna, Austria, April 27 – May 2, 2014.

8. Abd-Elmotaal, H., Seitz, K., Abd-Elbaky, M. and Heck, B. (2013a) Comparison among Three Harmonic Analysis Techniques on the Sphere and the Ellipsoid. Journal of Applied Geodesy, 1–18, DOI: 10.1515/jag-2013-0008.

9. Abd-Elmotaal, H., Seitz, K., Abd-Elbaky, M. and Heck, B. (2013b) Tailored Reference Geopotential Model for Africa. Scientific Assembly of the International Association of Geodesy, Potsdam, Germany, September 1–6, 2013 (Also accepted for publication in the International Association of Geodesy Symposia, **143**).

10. Abd-Elmotaal, H., Seitz, K, Kühtreiber, N. and Heck, B. (2014) Establishment of the Gravity Database for the African Geoid. 3rd International Gravity Field Service (IGFS) General Assembly, Shanghai, China, June 30 – July 6, 2014.

5. Financial Report

Item	Receipts	Expenditures
IUGG grant	14,000 $	
Travel		9,042 $
Research		3,000 $
Teaching		2,000 $
Planning/Coordination		1000 $
Sum	**14,000 $**	**15,042 $**