Status of the European Gravity and Geoid Project EGGP

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Abstract. The European Gravity and Geoid Project (EGGP) is a project within IAG Commission 2, reporting to Sub-commission 2.4. The main goal of the project is to compute an improved European geoid and quasigeoid model. This appears to be possible now because significant new and improved data sets have become available since the last computation in 1997 (EGG97). These improvements include better global geopotential models from the CHAMP and GRACE missions, better digital elevation models (DEMs) in some regions (e.g., new national DEMs, SRTM3, GTOPO30), updated gravity data sets for selected regions, updated ship and altimetric gravity data including improved merging procedures, the use of GPS/levelling data, as well as improved modelling and computation techniques.

An overview is given on the project structure, the computation strategy, the available data sets, the expected accuracies, the time schedule, and the work done so far. The primary input data sets are high-resolution gravity and terrain data supplemented by a state-of-the-art global geopotential model. The general computation strategy is the remove-restore procedure. The initial computations are based on the spectral combination approach with integral formulas evaluated by 1D FFT. First results based on an updated terrestrial gravity data set and GRACE geopotential models show significant improvements (up to 60 %) as compared to GPS/-levelling. Moreover, also the tilts, existing in previous solutions, have been reduced to typically below 0.1 ppm.

Keywords. Geoid, quasigeoid, gravity field modelling, GPS/levelling, EGGP, CHAMP, GRACE

1 Introduction

The latest high-resolution European geoid and quasigeoid models (EGG97) were computed at the Institut für Erdmessung (IfE), University of Hannover, acting since 1990 as the computing center of the International Association of Geodesy (IAG) Sub-commission for the European Geoid (predecessor of the EGGP), for details cf. Denker and Torge (1998). EGG97 is based on high-resolution gravity and terrain data in connection with the global geopotential model EGM96. The evaluation of EGG97 by GPS/levelling data revealed the existence of long wavelength errors at the level of 0.1 to 1 ppm, while the agreement over distances up to about 100 km is at the level of 0.01 m in many areas with a good quality and coverage of the input data (Denker and Torge, 1998; Denker, 1998).

Since the development of EGG97, significant new or improved data sets have become available, including strongly improved global geopotential models from CHAMP and GRACE, new national and global terrain data sets, new or updated gravity data sets, improved altimetric results, as well as new GPS/levelling campaigns. Furthermore, also the combination of ship and altimetric data has been refined, and new gravity field modelling techniques, e.g., wavelet techniques, fast collocation, etc., have become operational.

Considering all these advancements, a complete re-computation of the European geoid/quasigeoid is appropriate and promises significantly improved accuracies, especially at long wavelengths. Therefore, after the IUGG General Assembly in Sapporo in 2003, it was decided to support this task in the form of an IAG Commission 2 Project, named CP2.1 and entitled "European Gravity and Geoid Project EGGP". The project is reporting to Sub-commission 2.4 and has strong connections to the International Gravity Field Service (IGFS), with its centers Bureau Gravimétrique International (BGI), International Geoid Service (IGeS), National Geospatial-Intelligence Agency (NGA), and GeoForschungsZentrum Potsdam (GFZ), as well as to several other IAG bodies, e.g., EUREF. The EGGP is running within the 4-year period from 2003 to 2007 until the next IUGG General Assembly. The project is organised by a steering committee (H. Denker (Chair), J.-P. Barriot, R. Barzaghi, R. Forsberg, J. Ihde, A. Kenyeres, U. Marti, I.N. Tziavos) and has about 50 national delegates (project members) from most of the countries in Europe. The EGGP terms of reference can be found in EGGP (2003).

This contribution gives an overview on the general computation strategy and on the progress in the collection of gravity data, terrain data, and global geopotential models from the new space missions CHAMP and GRACE. First updated geoid/quasigeoid solutions are presented based on the new global geopotential models from CHAMP and GRACE. Moreover, results from an improved terrestrial gravity data set, including reprocessed ship gravity and new altimetric anomalies, are presented.

2 Computation Strategy

The basic computation strategy is based on the remove-restore technique, considering high-resolution terrestrial gravity and terrain data in combination with a state-of-the-art global geopotential model (probably based on the GRACE mission). Terrain reductions will be applied to smooth the data and to avoid aliasing effects. At present, the residual terrain model (RTM) technique according to Forsberg and Tscherning (1981) is favoured. Bathymetry and density data may be considered in special test areas. Moreover, GPS/levelling data will be used for control purposes, and may also be used for a combined solution (e.g., Denker et al., 2000), depending on the quality and availability of data. All data sets will be referred to uniform horizontal, vertical, and gravity reference systems. The collection of the relevant data sets is pursued by the steering committee and the members of the project.

A significant problem with high-resolution gravity and terrain data is the confidentiality of data, which must be assured to most of the data owners. For this reason, it was decided to have only one data and computation center at the Institut für Erdmessung (IfE), University of Hannover. In addition, a second confidential gravity data center is setup at Bureau Gravimétrique International (BGI) to use the expertise of BGI in the validation and cleaning of large gravity data sets. The inclusion of data in the confidential BGI project database requires separate agreements between the data owners and BGI, and there will be no connection to the BGI public database.

The primary gravity field quantity to be computed will be the height anomaly or the quasigeoid undulation, with the advantage that only gravity field observations at the Earth's surface and in its exterior enter into the calculation, avoiding assumptions about the Earth's interior gravity field. A geoid model is then derived by introducing a density hypothesis, which should be identical to the one used for the computation of corresponding orthometric heights.

Initially, the gravity modelling at IfE will be based on the spectral combination technique with integral formulas (e.g., Wenzel, 1982). In this method, the combination of terrestrial gravity data and a global geopotential model is done by means of spectral weights, which depend on the accuracy of the input data sets. Due to the high accuracy of the global models at long wavelengths, the terrestrial data mainly contribute the shorter wavelength components. Lateron, IfE may also test other modelling techniques, e.g., least squares collocation or wavelets. Moreover, it is planned to use the fast collocation approach developed by the Milan group (e.g., Sansò and Tscherning, 2003). Regarding the time frame, it is planned to have the final geoid/quasigeoid models in 2007 and preliminary solutions in 2005 and 2006.

The final goal is to strive for an accuracy of 0.01 m for the computed geoid/quasigeoid models (for distances up to some 100 km). Obviously, this is only possible in areas with a good coverage and quality of the input gravity and terrain data. The data requirements can be derived from theoretical and numerical studies including spectral analysis. With respect to the gravity data, a spacing of 2 to 5 km and an accuracy at the level of 1 mgal (white noise) is sufficient (Denker, 1988; Forsberg, 1993; Grote, 1996), but on the other hand even small systematic gravity errors affecting large regions may integrate up to significant geoid errors. For the elevation models, a resolution of roughly 100 m to 1000 m is adequate for alpine to low relief, respectively, with an accuracy at the level of some ten meters.

3 Recent Progress in Data Collection

3.1 Gravity Data

Since the start of the project, significant improvements of the gravity database have been made, including new data sets for several countries, e.g., Belgium, Luxemburg, Germany, Slovenia, Switzerland, and Netherlands. Moreover, positive responses, indicating a data update in the near future, were received from Austria, the Baltic States, Croatia, France, Greece, Poland, Serbia, Russia, the Scandinavian countries, etc. In addition to this, also the public domain data set from the Arctic Gravity Project became available (Forsberg and Kenyon,

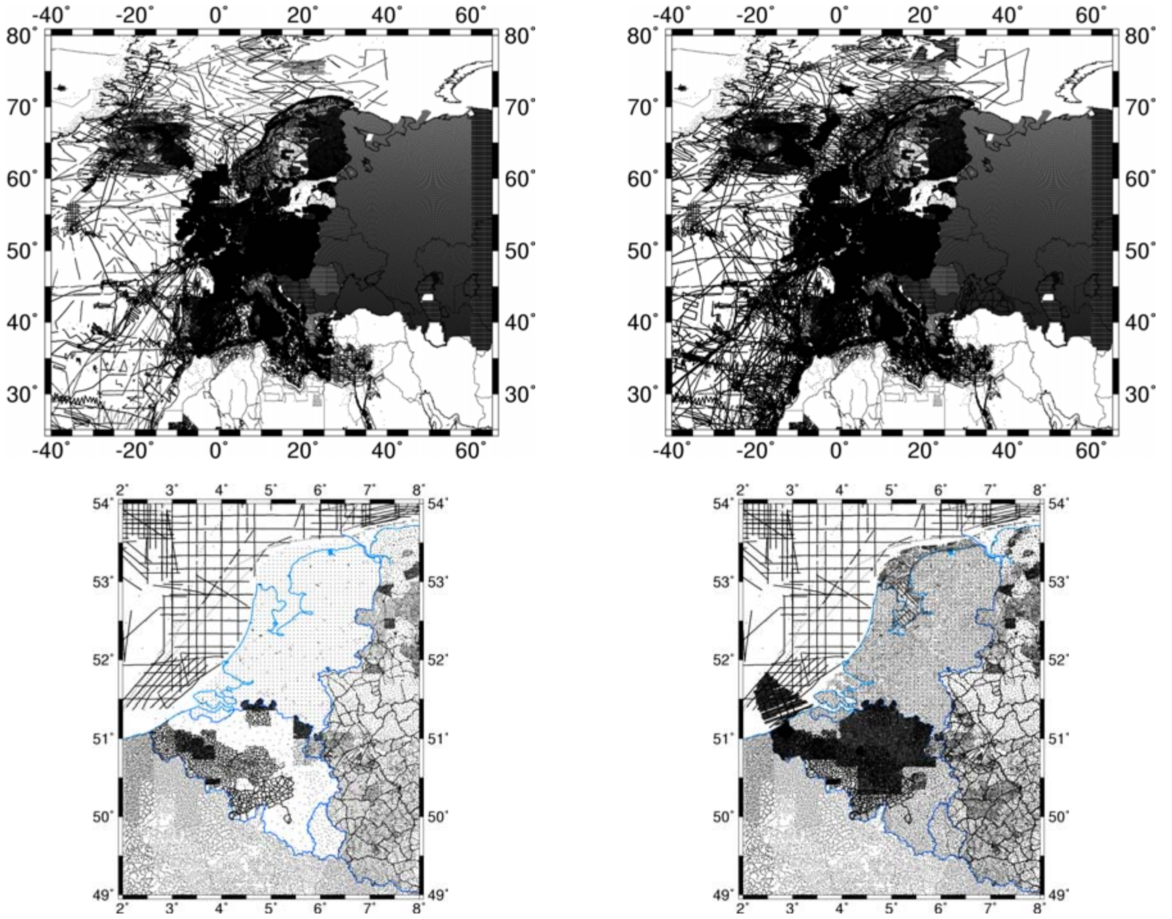

Fig. 1. Locations of terrestrial gravity data for entire Europe (top) and a sub-area (bottom). The left part shows the status for EGG97 and the right part shows the status of July 2004.

2004). As one example to document the progress in the collection of gravity data, Fig. 1 (bottom) depicts the old status (EGG97, Denker and Torge, 1998) and the new status in July 2004 for an area covering Belgium, Luxemburg, Netherlands, as well as parts of France and Germany.

In addition, the older gravity data sets were revised regarding the underlying reference systems, the target systems being ETRS (European Terrestrial Reference System), UELN (United European Levelling Network) and absolute gravity. Within the EGGP, only data which can be related without any doubts to the target reference systems will be included in the primary data base.

Significant progress was also made in the collection and reprocessing of ship gravity data (e.g., at IfE and other institutions). The ship gravity data, collected from several institutions for the European Seas, were crossover adjusted using a bias per track error model in order to reduce instrumental and navigational errors, incorrect ties to harbour stations, etc. (for details see Denker and Roland, 2003). An “original” and an “edited” data set were considered, where the edited data set excluded data affected by ship turns, data in the Red Sea, data from short tracks (< 3 points), and tracks with large crossover differences. Table 1 shows the crossover statistics for both data sets before and after the adjustment. The table clearly shows that the editing of some very bad observations resulted already in an improvement of the crossover differences by a factor of two, while the crossover adjustment again reduced the crossovers by a factor of two. Before the adjustment, the RMS crossover difference is 15.5 mgal for the original and 8.4 mgal for the edited data set; the corresponding values after the adjustment are 7.0 mgal and 4.7 mgal, respectively.

Table 1. Statistics of crossover differences from ship gravity observations. Units are mgal.

data set adjustment	original before	original after	edited before	edited after
#	89,328	89,328	78,929	78,929
Mean	0.20	-0.02	0.04	-0.01
RMS	15.48	7.01	8.37	4.69
Min	-258.43	-204.98	-109.91	-48.56
Max	+259.54	+198.37	+128.40	+49.16

The improvement of the ship data by editing and crossover adjustment was also illustrated by comparisons with altimetric anomalies from the KMS02 model (Andersen et al., 2003), giving a RMS difference of 18.0 mgal for the original data set and 10.2 mgal for the edited data set, both before the adjustment. The crossover adjustment further reduced the RMS difference to 7.8 mgal for the edited data set, proving the effectiveness of the entire procedure. In sub-areas, e.g., around Iceland, the RMS difference between the ship and KMS02 data is only 4.2 mgal.

Fig. 1 (top) depicts the locations of gravity data for entire Europe; the left part shows the status for EGG97, and the right part shows the status for July 2004 including the reprocessed ship gravity data.

3.2 Digital Elevation Models (DEMs)

For the EGG97 model, digital elevation models (DEMs) were available with a resolution of about 200 m for most countries in Central and Western Europe, while coarser grids with a resolution of 0.5 km to 10 km had to be used for the remaining parts of Europe. For EGG97, only in Germany a DEM with a very high resolution of 1" × 1" (approx. 30 m) was available. Meanwhile, also Switzerland has released a 1" × 1" DEM, and Austria has indicated the release of a corresponding model. However, especially in Eastern Europe and some other areas, fill-ins from global public domain databases have to be used, either because high-resolution DEMs do not exist or are not released for confidentiality reasons. For this purpose, the SRTM3 model with a resolution of 3" × 3" (JPL, 2004) and the public domain global model GTOPO30 with a resolution of 30" × 30" (LP DAAC, 2004) can be used. The SRTM3 model has been released recently from the analysis of the Shuttle Radar Topography Mission as a preliminary and “research-grade” model, covering the latitudes between 60°N and 54°S. On the other hand, the GTOPO30 model has global coverage and was derived already in 1996 from several raster and vector sources of topographic information (LP DAAC, 2004).

The SRTM3 and GTOPO30 DEMs were evaluated at IfE by comparisons with national DEMs for Germany, based on 1" × 1" data (Denker, 2004a). The comparisons of the national and SRTM3 models revealed that one of the national models contained less accurate fill-ins in some areas outside of Germany. After excluding these areas, the differences between the best national model and the SRTM3 DEM show a standard deviation of 7.9 m with maximum differences up to about 300 m. The largest differences are located in opencast mining areas and result from the different epochs of the data. Histograms of the differences show a clear deviation from the normal distribution with a long tail towards too high SRTM3 elevations. Moreover, the presently available SRTM3 “research-grade” models contain numerous data voids (undefined elevations), which cause significant problems. The filling of these data gaps by interpolation must be handled with care, especially for larger gaps in mountainous areas (Denker, 2004a).

The evaluation of the GTOPO30 model by national and SRTM3 DEMs demonstrated that in Germany the longitudes of GTOPO30 should be increased by 30" (one block). The longitude shift reduced the standard deviation of the differences to the national and SRTM3 models by roughly 75 %, yielding final values of about 6.8 m and 11.5 m for the national and SRTM3 models, respectively.

Thus, the national DEMs, augmented by the SRTM3 and GTOPO30 data will allow the creation of DEMs for entire Europe with a resolution of at least 30" × 30", which is a significant improvement compared to the previous EGG97 computation.

3.3 Global Geopotential Models

The CHAMP and GRACE missions have led to significant improvements in the modelling of long wavelength gravity signals. This is documented, e.g., by the accumulated formal geoid error, which does not exceed 0.01 m for spherical harmonic degrees up to about 25 for the CHAMP models (e.g., Reigber et al., 2004a) and 75 for the GRACE models (e.g., Reigber et al., 2004b). On the other hand, the limit of 0.01 m is already exceeded at degree 8 for the EGM96 model. Correspondingly, the limit of 0.05 m is exceeded at about degree 20 for EGM96, 40 for the CHAMP models, and 90 for the GRACE models.

The new geopotential models from the CHAMP and GRACE missions, in combination with terrestrial gravity data of good quality (±1 mgal) and coverage, allow the computation of significantly improved continental-scale geoid and quasigeoid models. Error estimates based on the degree variance approach result in standard deviations of about 0.02 m to 0.03 m for solutions based on the GRACE models, with the largest contribution (about 0.02 m) coming from the degree range 90 to 360. The corresponding values for geoid solutions based on the CHAMP models and EGM96 are about 0.04 m and 0.06 m, respectively.

4 First Results

Updated European geoid/quasigeoid models were computed based on the new CHAMP and GRACE geopotential models. The computations were done using the EGG97 terrestrial gravity data set as well as an updated data set (section 3.1). The computations were done using the remove-restore technique in connection with the least squares spectral combination method. The spectral weights were derived from the error estimates of the global models and the terrestrial data. Terrain reductions were done using the RTM method. The computation area is 25°N – 77°N and 35°W – 67.4°E. The grid spacing is 1' × 1.5', yielding 3,120 × 4,096 grid points. The GRS80 constants, the zero degree undulation terms, and the zero-tide system were used throughout all computations (for details see Denker, 2004b).

All computed quasigeoid models were evaluated by GPS/levelling data from the European EUVN data set (Ihde et al., 2000) and by national campaigns. Fig. 2 shows the differences (after subtracting a common bias) between 166 stations of the EUVN GPS/levelling data set (only stations with UELN normal heights were used) and the EGG97 gravimetric quasigeoid based on EGM96 (left part), as well as a new solution (right part) based on the EIGEN-GRACE02S geopotential model (Reigber et al., 2004b); the terrestrial gravity data are identical in both solutions (status of EGG97). Fig. 2 shows clearly that the long wavelength discrepancy over Central Europe almost disappears for the GRACE solution; the largest discrepancies remain at coastal stations, especially around the Mediterranean Sea where the gravity data quality is weak. The RMS difference is 0.262 m for EGG97 and reduces to 0.230 m for the EIGEN-GRACE02S solution (12 % improvement). Correspondingly, a solution based on the CHAMP EIGEN-3 model (Reigber et al., 2004a) gives a RMS difference of 0.238 m (9 % improvement). When using the updated terrestrial gravity data set from 2004 in combination with the EIGEN-GRACE02S model, the RMS difference reduces to 0.203 m (23 % improvement compared to EGG97). Furthermore, when transforming the GPS results (according to Poutanen et al., 1996) from the non-tidal to the zero-tide system, which is used for the quasigeoid solutions, another slight reduction of the RMS difference to 0.197 m can be observed (25 % total improvement versus EGG97). Tilt parameters were also computed, but not considered any further as they were less than 0.1 ppm in all cases.

Table 2. RMS differences from comparisons of GPS/levelling with EGG97 and a new quasigeoid based on EIGEN-GRACE02S. A constant bias is subtracted. Units are m.

Country	# pts.	EGG97/ EGM96	EGG04/ EIGEN-GRACE02S	Improvement
Belgium	31	0.061	0.046	25 %
France	965	0.128	0.084	34 %
Germany	678	0.107	0.041	62 %
Hungary	299	0.089	0.057	36 %
Netherlands	84	0.035	0.031	11 %
Switzerland	147	0.084	0.063	24 %
EUVN	166	0.262	0.230	12 %

Additional comparisons of EGG97 and the new quasigeoid solution based on EIGEN-GRACE02S

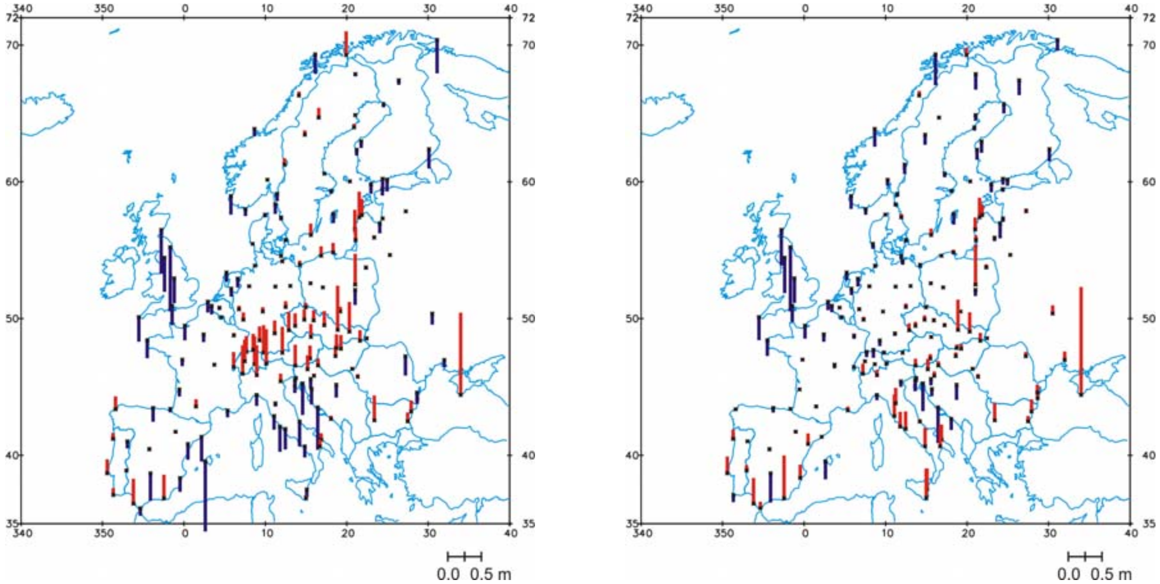

Fig. 2. Comparison of EGG97 quasigeoid solution (left) and a new solution based on the EIGEN-GRACE02S global model (right) with GPS/levelling data from the EUVN campaign. A constant bias is subtracted.

with several national GPS/levelling data sets are shown in Table 2. Again, both solutions use identical terrestrial gravity data (status EGG97). The table provides the RMS differences for both solutions after subtracting a common bias. The table clearly shows that in all cases the use of the new GRACE model improves the geoid/quasigeoid modelling significantly. The maximum improvement is more than 60 % for the German data set. A more detailed analysis shows that the tilts, existing in EGG97, are reduced to typically below 0.1 ppm, i.e. by one order of magnitude in some cases.

Furthermore, with the updated solutions based on the GRACE models, accurate determinations of W_0 (reference geopotential of the vertical datum) and vertical datum unifications become possible. When considering the 2004 terrestrial gravity data set, the EIGEN-GRACE02S model, the EUVN GPS/levelling data, and a transformation of the GPS heights to the zero-tide system, an estimate of W_0 (Europe) of 62,636,857.02 ±0.15 m^2s^{-2} is obtained. The corresponding value from the German GPS/-levelling data is 62,636,856.91 ±0.02 m^2s^{-2}. Both values are in good agreement with the value 62,636,857.25 m^2s^{-2} published for Europe by Burša et al. (2002). However, the European values deviate by about 1.0 m^2s^{-2} from the global best estimates (e.g., Burša et al., 2002).

5 Conclusions

Significant progress was made within the framework of the European Gravity and Geoid Project EGGP regarding the collection and homogenization of high-resolution gravity and terrain data. Several new data sets became available, and especially the new geopotential models from the CHAMP and GRACE missions improved the geoid/quasigeoid modelling very much. In the GPS/levelling comparisons, the RMS differences reduced up to about 60 % when using the GRACE models and up to 30 % for the solutions based on CHAMP, as compared to the previous EGG97 model relying on EGM96. In addition, the tilts, existing in EGG97, were also reduced to typically below 0.1 ppm. Due to the support with data by numerous people and agencies, further improvements are to be expected in the future.

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