Did the new geopotential models improve the fit of gravimetric quasigeoid in Poland to GPS/levelling data?

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Abstract

The choice of global geopotential model used in remove-restore technique for determination of regional quasigeoid from gravity data may affect the solution, in particular when the accuracy is supposed to reach a centimetre level. Global geopotential model plays also an important role in validating height anomalies at GPS/levelling sites that are used for the estimation of the external accuracy of quasigeoid models. The quality of the *quasi97b* quasigeoid model for Poland developed in 1997 with use of available terrestrial gravity data and EGM96 geopotential model was estimated at sub-decimetre level using GPS/levelling data at 360 stations of the POLREF network. Since then new data became available as well as new geopotential models were developed.

In the framework of the project on the determination of a centimetre geoid in Poland with the use of geodetic, astronomical, gravimetric, geological and satellite data, that became operational in 2003, a number of new quasigeoid models for Poland were developed with the use of six different global geopotential models: EGM96, EIGEN-CH03S, GGM01S, GGM02S, GGM02C and GGM02S/EGM96.

Three kinds of numerical tests with the use of terrestrial gravity data and GPS/levelling height anomalies at the POLREF and densified EUVN network stations were conducted. The first one concerned comparison of height anomalies at GPS/levelling sites in Poland with the corresponding ones computed from various global geopotential models. In the second one the terrestrial gravity anomalies in Poland and neighbouring countries were compared with the corresponding gravity anomalies computed from global geopotential models. Finally the quasigeoid models obtained from gravity data with use of different global geopotential models were verified against corresponding height anomalies at GPS/levelling sites in Poland.

Data quality was discussed and best fitting global geopotential model in Poland was specified. It was shown that the quality of the present solutions of POLREF and EUVN networks does not allow for quantifying the improvement of quasigeoid models due to the use of newly developed geopotential models.

1. Gravity data (47ºN-57ºN; 11ºE-26ºE) used

Gravity data available at the area of interest are not uniform both in terms of quality and coverage. Terrestrial gravity data used for quasigeoid modelling consists of 2 × 2 km grid of free-air gravity anomalies generated from inhomogeneous set of point and mean gravity anomalies of different spatial resolution, acquired within last 50 years (Fig. 1). They differ in geodetic datums, gravity systems, normal gravity formulae, atmospheric corrections.

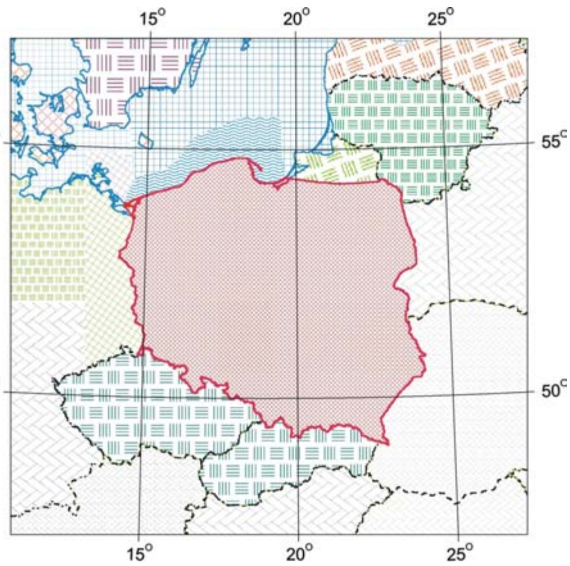

Fig. 1. Distribution of terrestrial and marine gravity data. Different data sets including those from different marine gravity surveys in Baltic Sea are distinguished with different colours and patterns

There is still a shortage of information needed for full unification of gravity data; complete information is only available for gravity data from Poland. It can be specified as follows

- over 800 000 point data, almost uniformly distributed, form gravity surveys conducted for geological prospecting since 1951,
- measurements with Ascania GS-11, Sharp or Worden gravimeters in two hours loops,
- drift eliminated by linear interpolation with respect to the time between the control stations,

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- no tidal correction applied; tide effect eliminated as a drift between the control stations,
- uncertainty of individual gravity value consists of the measuring error (±0.05 mGal) and uncertainty of gravity network (±0.10 mGal),
- σ of resulting point gravity equals to ±0.11 mGal,
- gravity in PIG-66 system (the system of gravity data in the Polish geological database) referred to Potsdam,
- heights of gravity stations in the Kronstadt1960 vertical datum (fixed to levelling benchmarks with accuracy of ±1.5 cm,
- horizontal coordinates taken from the topographic maps in scale of 1:50 000 referred to Borowa Gora datum (Bessel ellipsoid: a = 6 356 079 m, f = 299.1, with main point at Borowa Gora); approximate shift between GRS80 and Borowa Gora datum: Δx = 571 m, Δy = 13 m, Δz = 514 m (geological database was transformed to Borowa Gora datum and Potsdam system with use of Helmert 1901 formula).

Besides terrestrial gravity data some marine gravity data were available. They consist of ship-borne data from the southern part of Baltic Sea, up to 100 km from the coastal line, acquired in 1978-1980 by former USSR research team, of the following characteristics
- survey with Russian gravimeters every 4 km along the profiles mutually distant by 10 km (one point per 4 km^2),
- gravity control points surveyed with underwater GAK gravimeters,
- originally gravity in IGSN71 (before taken to geological database data was transformed to Borowa Gora datum and Potsdam system with use of Helmert 1901 formula),
- σ of gravity anomalies estimated by surveying team equals to ±0.57 mGal,
- positions determined in "Pulkowo 1942" datum with "Poisk" system with an accuracy of 80 m,
- water depth determined by "Paltus" and "Atlas Electronic" devices with an accuracy of 1.4 m.

Newly available marine gravity data acquired in coastal zone of Poland during the geophysical missions of Zaria and Turlejski vessels in 1971 and 1972 were also considered. Their specification is as follows
- gravity measured 1 m below sea surface is referred to the Potsdam system,
- σ of gravity equals to ±2 mGal,
- positions determined using radio-navigation technique with accuracy of ±100 m,

Finally, marine gravity data from the Swedish coastal area of southern Baltic Sea, acquired in 1999 by the Norwegian Hakoon Mosby vessel (provided by KMS) were also used.

All terrestrial and marine gravity data, including that from neighbouring countries has been transformed to ETRF89 and to POGK-99 gravity system (an official gravity system in Poland) (Krynski and Lyszkowicz, 2004). The 2 × 2 km grid obtained from that data was further used in numerical tests.

2. GPS/levelling data used

Height anomalies precisely determined at the sites of the POLREF and EUVN networks were used in the analysis.

The POLREF network (Fig. 2) that is a densification of EUREF-POL92 network (11 Polish stations linked in 1993 to ETRF89) consists of 360 sites surveyed (2×4h) in three campaigns from July 1994 to May 1995. It was adjusted in 1995. The accuracy of the POLREF meets the demands of the EUREF densification network. It has been specified as follows
- σ of a single observation equals to 0.39 cm,
- σ of calculated station coordinates: σ_φ (0.5-1.0 cm), σ_λ (0.5-1.0 cm), σ_h (1.0-1.5 cm) (Zielinski et al., 1997).

Those numbers reflect the level of data consistency and internal accuracy only; they are too optimistic as the estimate of real positioning accuracy (Krynski and Zanimonskiy, 2003).

POLREF stations were linked to the national vertical control by spirit levelling (Kronstadt86 datum),
- σ of normal height equals to 1.0-1.5 cm,
- σ of ellipsoidal height (GRS80 ellipsoid) 1.0-1.5 cm
- σ of height anomaly equals to 2 cm (optimistic estimate).

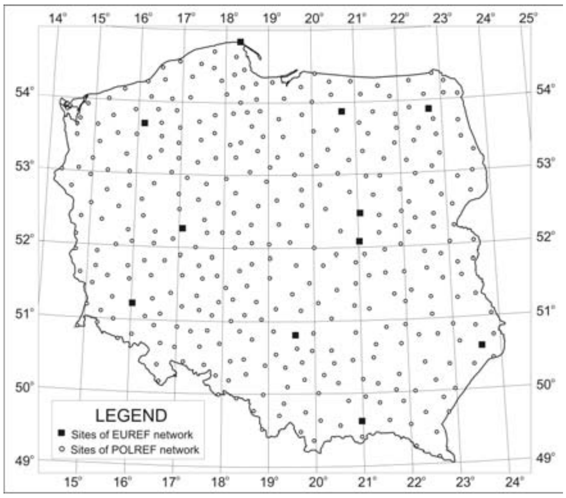

Fig. 2. Sites of EUREF-POL92 and POLREF networks

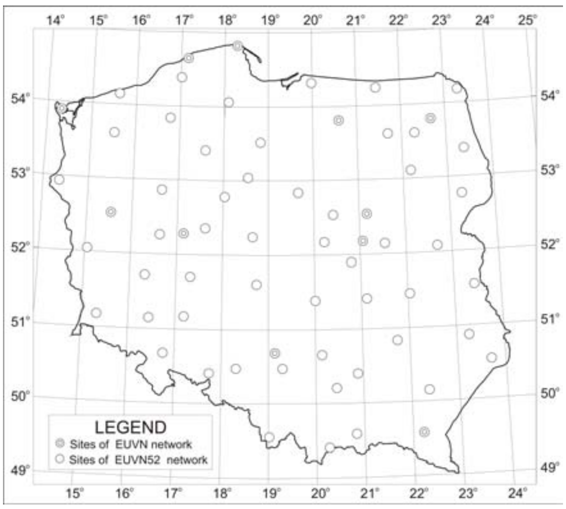

Fig. 3. Sites of the EUVN52 network in Poland and its densification

The EUVN52 network (Fig. 3) is a densification of the EUVN97 network (11 Polish EUVN sites established in 1997 to realize the European vertical datum). The whole network consists of 196 sites: 66 EUREF sites, 13 national permanent GPS stations, 54 UELN and UPLN stations and 63 tide gauges, surveyed in 1997 (7-9 days each site) (Pacus, 2002). Final solution of the EUVN (Ineichen et al., 1998) was constrained to ITRF96 (epoch 1997.4) of 37 stations with an a priori σ = 0.01 mm for each coordinate component. Estimated σ of the adjusted position equal to 1-2 mm (IGWiAG, 2000) reflects the internal accuracy.

52 sites of the EUVN52 (on benchmarks of 1 order vertical control) were surveyed (2×24h) in September 1999 (Baran et al., 2000; Pacus, 2002).

Coordinates of EUVN52 sites were computed in ITRF96 (epoch 1997.4). The accuracy estimate provided by the Bernese software was specified as follows

- σ of calculated station coordinates: σ_φ = 0.19 cm, σ_λ = 0.22 cm, σ_h = 0.28 cm (IGWiAG, 2000).

Those numbers reflect the level of data consistency and internal accuracy only; they are too optimistic as the estimate of real positioning accuracy (Krynski and Zanimonskiy, 2003).

3. Fit of global geopotential models to GPS/levelling data

Height anomalies computed from six global geopotential models at each POLREF and EUVN52 site were compared with the respective ones from GPS/levelling.

Statistics of the differences between height anomalies computed from global geopotential models and the respective ones derived from GPS/levelling at the POLREF sites and at the EUVN sites [m] are given in Tables 1 and 2, respectively.

Table 1.

Model	Mean	Std dev.	Min	Max
EGM96	-0.53	0.19	-1.03	0.08
EIGEN-CH03S	-0.33	0.76	-2.22	1.06
GGM01S	-0.36	0.46	-1.70	1.05
GGM02S (140)	-0.34	0.47	-1.53	1.23
GGM02C	-0.35	0.26	-1.09	0.49
GGM02S/EGM96	-0.37	0.13	-0.79	0.05

Table 2.

Model	Mean	Std dev.	Min	Max
EGM96	-0.57	0.22	-1.24	-0.16
EIGEN-CH03S	-0.42	0.76	-1.98	0.89
GGM01S	-0.44	0.42	-1.54	0.39
GGM02S (140)	-0.46	0.44	-1.47	0.31
GGM02C	-0.42	0.22	-0.90	0.02
GGM02S/EGM96	-0.40	0.13	-0.66	-0.10

Means and standard deviations of the differences between height anomalies computed from global geopotential models and the respective ones derived from GPS/levelling at the POLREF and EUVN52 sites are shown in Fig.4 and Fig. 5, respectively.

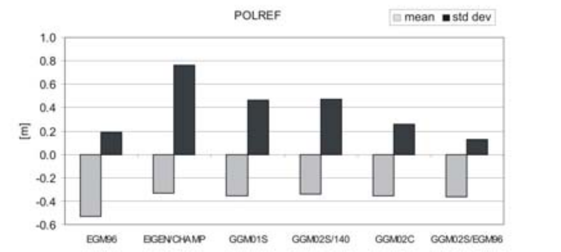

Fig. 4. Means and standard deviations of the differences between height anomalies computed from global geopotential models and the respective ones derived from GPS/levelling at the POLREF sites

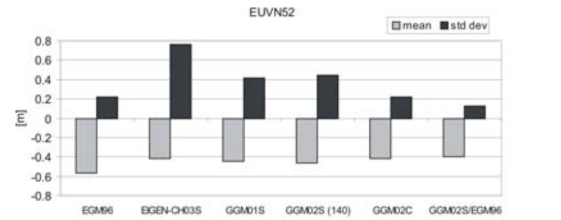

Fig. 5. Means and standard deviations of the differences between height anomalies computed from global geopotential models and the respective ones derived from GPS/levelling at the EUVN52 sites

4. Fit of global geopotential models to gravity data

Gravity anomalies derived from six global geopotential models were compared with the respective terrestrial and marine free-air gravity anomalies in Poland and in surrounding area, derived from more than 130 000 point and mean anomalies.

Statistics of the differences between gravity anomalies computed from global geopotential models and the respective ones derived from terrestrial and marine gravity survey [mGal] are given in Table 3.

Table 3.

Model	Mean	Std dev.	Min	Max
EGM96	-0.18	9.39	-112.01	137.34
EIGEN-CH03S	0.00	17.30	-111.42	182.54
GGM01S	0.26	15.37	-109.94	166.07
GGM02S (140)	-0.14	14.81	-111.89	157.57
GGM02C	-0.20	12.44	-115.57	153.86
GGM02S/EGM96	-0.30	9.31	-115.56	135.44

Means and standard deviations of the differences between gravity anomalies computed from global geopotential models and the respective ones derived from terrestrial and marine gravity are shown in Fig. 6.

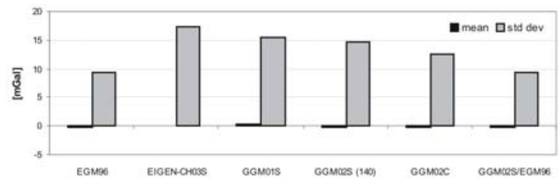

Fig. 6. Means and standard deviations of the differences between gravity anomalies computed from global geopotential models and the respective ones derived from terrestrial and marine gravity data

The higher is the resolution of global geopotential model the better is its fit to the terrestrial gravity data. Two GM models, i.e. EGM96 and GGM02S/EGM96 fit almost equally well to the terrestrial gravity data (Fig. 6) although height anomalies computed from GGM02S/EGM96 give substantially better fit to GPS/levelling heights (Fig. 4 and Fig. 5). The fit of the GGM02S/EGM96 model to terrestrial gravity data is, however, slightly better.

5. Fit of gravimetric quasigeoid to GPS/levelling data

Five gravimetric quasigeoid models were investigated:
- *quasi97b* - non uniformed gravity data + EGM96 (Łyszkowicz, 1998),
- *quasi04a* - uniformed gravity data + EGM96,
- *quasi04b* - uniformed gravity data + GGM02S,
- *quasi04c* - uniformed gravity data + GGM02S/EGM96,
- *quasi04d* - uniformed gravity data + GGM02C.

Statistics of the differences between height anomalies from quasigeoid models and the respective ones from GPS/levelling at the POLREF and EUVN52 sites [m] are given in Table 4.

Table 4.

Network	Quasigeoid model	Mean	Std dev.	Min	Max
POLREF	*quasi97b*	0.300	0.034	0.392	0.176
	quasi04a	0.304	0.032	0.388	0.203
	quasi04b	0.296	0.041	0.416	0.188
	quasi04c	0.313	0.039	0.415	0.199
	quasi04d	0.324	0.036	0.429	0.215
EUVN	*quasi97b*	0.322	0.033	0.388	0.225
	quasi04a	0.323	0.034	0.393	0.213
	quasi04b	0.317	0.032	0.384	0.223
	quasi04c	0.338	0.040	0.414	0.179
	quasi04d	0.348	0.037	0.424	0.234

No significant contribution of replacing EGM96 with GGM02S, GGM02S/EGM96 or GGM02C geopotential models to improvement of the fit of quasigeoid in Poland to GPS/levelling data has been observed.
The main reason might be a level of uncertainty of terrestrial gravity data used as well as uncertainty of height anomalies at GPS/levelling points.
Few important practical implications of the numerical tests, e.g. gravimetric quasigeoid, or in general high-resolution terrestrial gravity data are powerful tools for verification of consistency of GPS/levelling height anomalies and for more realistic estimation of their accuracy.
All developed quasigeoid models were then fitted to height anomalies at GPS/levelling sites. Differences between height anomalies from *quasi04c* quasi-geoid model and the respective height anomalies of GPS/levelling sites of the POLREF and EUVN52 networks are presented in Fig. 7, and Fig. 8, respectively.

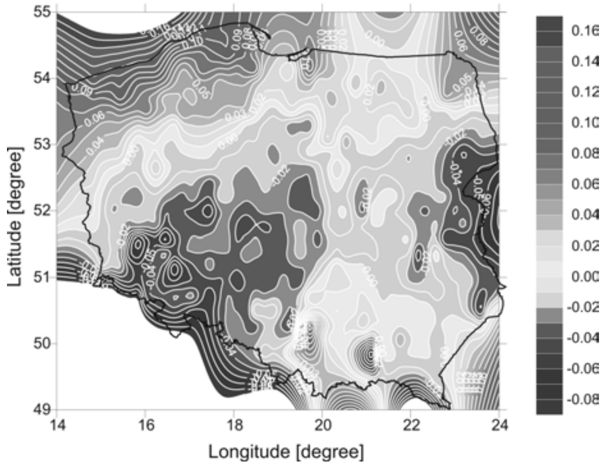

Fig. 7. Differences between height anomalies from *quasi04c* quasi-geoid model and the respective ones derived from GPS/levelling at POLREF sites

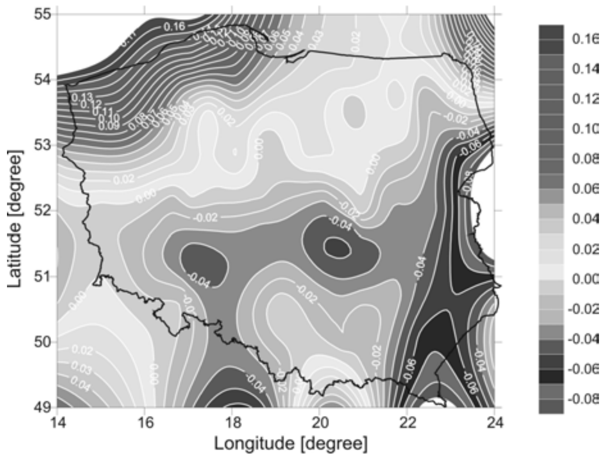

Fig. 8. Differences between height anomalies from *quasi04c* quasi-geoid model and the respective ones derived from GPS/levelling at EUVN52 sites

Conclusions

GGM02S/EGM96 fits best to height anomalies at POLREF and EUVN52 GPS/levelling sites.
GGM02S/EGM96 fits best to terrestrial gravity data in Poland, although the fit of EGM96 is almost equally good.
Replacements of EGM96 with new GMs do not significantly contribute to the improvement of the fit of quasigeoid in Poland to GPS/levelling data. The main reason might be a level of uncertainty of terrestrial gravity data used as well as uncertainty of height anomalies at GPS/levelling sites. Also long wavelengths bias in the c_{20} coefficient in GGM02S due to an incomplete sampling of the seasonal cycle affect but less significantly the fit quality.
Gravimetric quasigeoid is a powerful tool for verification of consistency of GPS/levelling height anomalies and for more realistic estimation of their accuracy.
Differences between height anomalies from quasi04a and the respective ones derived from GPS/levelling at GPS/levelling sites in Poland show mutual consistency of heights provided by POLREF and EUVN52 networks.

Comparison of GPS/levelling-derived height anomalies with the respective ones obtained from terrestrial gravity data allow for detection of outliers in GPS/levelling heights and for indication sites where data verification is needed and that should eventually be resurveyed.

Acknowledgements

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