# Testing EGM2008 on Leveling Data from Scandinavia, adjacent Baltic areas, and Greenland

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**Abstract.** We tested EGM2008 on GPS/leveling data from Scandinavia and adjacent areas. EGM2008 performs at the same level as the best regional geoid model, NKG2004. However, the direct evaluation of EGM2008 is difficult in Greenland because no leveling data are available. Nevertheless, we show on 78 GPS-MSS data that EGM2008 also performs at the same level as the best regional geoid model GOCINA04.

**Keywords.** Geopotential models, EGM2008, leveling

## 1 Introduction

Prior to the official release of the new global geopotential model EGM2008 (Pavlis et al., 2008), complete to the degree and order 2160, the authors contributed to the "EGM2007 Evaluation Project" by testing the preliminary model PGM2007A on leveling data from northern Europe (Scandinavia, the Baltic countries and the adjacent areas around the Baltic Sea) as well as from Greenland. The final report "PGM2007A evaluation on GPS-leveling data in Greenland and Scandinavia and adjacent areas" was submitted to the Joint IGFS/IAG Comission-2 Working Group and included as a "feed back"-contribution to improve the global model. The present work is a repetition of this exercise for the newly released EGM2008.

## 2 Scandinavia and adjacent areas

Scandinavia and adjacent Baltic areas is a sector covering Norway, Sweden, Finland, Denmark, Estonia, Latvia, Lithuania and a section of Poland. The sector is bounded by the following parallels and meridians: 53°N - 73°N and 1°E - 33°E.

The GPS/leveling data from Scandinavia and adjacent Baltic areas used for the evaluation of the PGM2007A model are the same as those used in the past for the evaluation of the regional Nordic geoid models. In fact, these formerly used GPS/leveling data sets were enhanced by the inclusion of additional leveling data from Norway, Sweden and Finland. Basically, the new data are more consistent (and recent) with respect to the epoch of the GPS campaigns and leveling. Because of the substantial land uplift in the area, this consistency is important.

The leveling data from the different countries consist usually of heights in their national height system, which can differ from country to country (orthometric heights, normal heights), but also in the way they are linked to the Mean Sea Level via a tide gauge (a vertical datum). In assessing the quality of the Nordic geoid model these national data sets are usually used separately (i.e. country wise). The main parameter for the "goodness-of-fit" in a given country is the standard deviation of the misfit between the gravimetric geoid/quasi-geoid model and the "geoid" derived from GPS and leveling measurements: $N = h - H$.

For the purpose of the regional comparison the GPS/leveling data from individual countries were corrected for relative vertical offset with respect to each other. The biases used were the assessed offset of each countries height datum with respect to the common European Vertical Datum.

We compared the GPS/leveling data to the quasi-geoid models in Table 1.:

**Table 1.** The quasi-geoid models used in the comparison.

| Model | comments |
|---|---|
| EGM96 | (Lemoine et al., 1996) |
| EGM96+GRACE2S | |
| NKG96 | 1996 regional geoid model for the Baltic and Nordic area |
| NKG2004 | 2004 regional geoid model for the Baltic and Nordic area |
| PGM2007A Zero Tide | Preliminary model released by NGA in 2007 |
| EGM2008 Zero Tide | (Pavlis et al., 2008) |

The statistics of the comparison for the whole area are shown in Table 2.

**Table 2.** Scandinavia and adjacent Baltic areas. Statistics of the comparison of GPS/leveling to different quasi-geoid models. (Unit: m).

| model | Mean | std. dev. | rms | min | max |
|---|---|---|---|---|---|
| EGM96 | 0.38 | 0.26 | 0.46 | -0.51 | 1.80 |
| EGM96 + GRACE2S | 0.35 | 0.20 | 0.41 | -0.66 | 1.18 |
| NKG96 | 0.01 | 0.14 | 0.14 | -0.61 | 0.51 |
| NKG2004 | 0.03 | 0.11 | 0.11 | -0.48 | 0.39 |
| PGM2007A ZeroTide | -0.59 | 0.11 | 0.60 | -0.96 | -0.18 |
| EGM2008 ZeroTide | -0.55 | 0.11 | 0.56 | -0.91 | -0.13 |

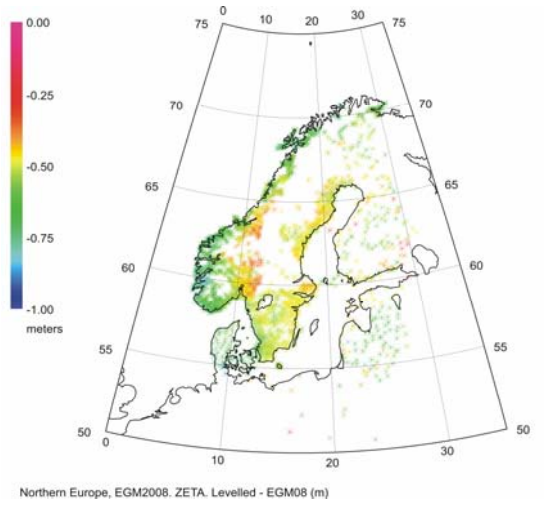


**Fig. 1** $\varepsilon=(h-H^{lev})-N_{EGM2008}$ Comparison of the geoid heights from the joint GPS/leveling data set (3144 points) for Scandinavia and adjacent Baltic areas to the EGM2008 model.

From Table 2 and Fig. 1 we conclude, that EGM2008 model is excellent. It is at the same standard as the latest regional gravity model NKG2004. For the joint GPS/leveling data set (see above), this comparison is somehow misleading. On Figure 1, the large misfit in Norway is most certainly caused by problems related to leveling. A problem is the inconsistency between the fixed epoch of the leveling and the fact that, in practice, the leveling was done over many years in the presence of a substantial land uplift caused by the post glacial rebound (Dr. Ove Omang, Norwegian Mapping Authority, personal communication). This leveling and height system problem for Norway is discussed in some details by Lysaker et al. (2007). One can notice that the large misfits to EGM2008 in Norway on Fig. 1 co-locate with the pattern on Fig. 4 in (Lysaker et al., 2007) showing the vertical land uplift velocities. This indicates, as stated, that the misfit in Norway is not a problem with the gravimetric model, but (most probably) with the GPS/leveling. The GPS/leveling data for Finland and Sweden were corrected for the land uplift to a common epoch.

A similar comparison for the individual countries (standard deviation) and for four of the models is shown in Table 3.

**Table 3.** Scandinavia and its adjacent areas. Standard deviation of the misfit between the best available national GPS/leveling data sets and different quasi-geoid models. (Unit: m).

| | N | EGM 96 | NKG 2004 | PGM 07A Zero Tide | EGM 2008 Zero Tide |
|---|---|---|---|---|---|
| Denmark | 85 | 0.35 | 0.06 | 0.07 | 0.07 |
| Estonia | 31 | 0.25 | 0.07 | 0.06 | 0.07 |
| Finland | 154 | 0.14 | 0.04 | 0.07 | 0.07 |
| Latvia | 36 | 0.16 | 0.10 | 0.09 | 0.09 |
| Lithuania | 32 | 0.17 | 0.08 | 0.08 | 0.09 |
| Norway | 1693 | 0.31 | 0.12 | 0.12 | 0.11 |
| Poland | 6 | 0.23 | 0.05 | 0.11 | 0.11 |
| Sweden | 910 | 0.15 | 0.04 | 0.03 | 0.03 |

The conclusion from this comparison is that EGM2008 is an excellent model for Scandinavia and its adjacent areas. Its accuracy is similar to the current best regional geoid model (NKG2004).

From other reports, the new geopotential model EGM2008, performs also very well in other parts of the world when compared to GPS/leveling data. It renewed the discussion about the need for defining a global vertical datum. For this reason, it is of some interest to list the mean values of the deviation of the national geoid heights of the GPS/leveling data and the EGM2008 model. These values are listed in Table 4.

**Table 4** Mean deviation of the best available national GPS/leveling data from EGM2008 quasi-geoid.

| | Mean($N_{lev} - N_{EGM2008}$) (m) |
|---|---|
| Denmark | -0.63 |
| Estonia | -0.66 |
| Finland | -0.51 |
| Latvia | -0.60 |
| Lithuania | -0.60 |
| Norway | -0.57 |
| Poland | -0.53 |
| Sweden | -0.49 |

It should be emphasized, that the expression "the best available" GPS/leveling data does not mean "the best existing". The national mapping authorities in the involved countries have access to much better and denser GPS/leveling data, which also include a more thorough treatment of, especially, the regional land uplift, as well as a more consistent treatment of the difference in epochs between the GPS- and leveling campaigns. The GPS/leveling data used here are those used in the past under the auspices of the Nordic Geodetic Commission to model and to evaluate the regional geoid models (e.g. NKG96, NKG2004). In other words, there is much more to say about the quality of EGM2008 compared to the "best existing" national GPS/leveling data; especially in the neighboring countries like Poland, where the available data set is most probably not representative at all. In this context, the vertical offsets listed in Table 4 are only rough numbers and do not in any way claim to be an attempt to model the accurate vertical offsets between the national height systems and the global vertical datum.

In this report we are only trying to assess: How does EGM2008 perform compared to the best regional geoid models? The answer to this question is that, for Scandinavia and adjacent Baltic areas, the fit of the new global model is at the same level as the best regional gravimetric geoid model (NKG2004).

## 2 Greenland

No leveling data exist between settlements in Greenland. A GPS-mean sea-level height data set is selected from recent GPS campaigns. GPS points are all tied to ITRF, mainly through the REFGR Greenland fundamental GPS network. The height above mean sea level (MSL) of the GPS points are mostly based on older MSL determinations, usually from the 1960's, or more recent, often shorter-duration MSL and relative tide gauge campaigns. The GPS ellipsoidal heights and MSL-heights can be used for geoid validation through the following relation:

$$N^{GPS} = h^{GPS} - H_{MSL} - MDT\,, \qquad (1)$$

where MDT is the mean dynamic topography.

We obtained the MDT from the OCCAM oceanographic model. This model does not include the local effects of fjords etc., so "GPS/leveling" data of this type might have significant errors due to local MDT effects, land uplift, and other errors. Fig. 2 shows the locations of the GPS-MSS data.

For the evaluation of PGM2007A model the tide-free model was used. However, since the physical Earth is permanently deformed by tidal forces we are now using the zero tide model for the evaluation of EGM2008. Table 5 shows the effect of the MDT corrections for PGM2007A model. It is seen, that the mean value of the differences is reduced, whereas the standard deviation is only reduced slightly. This indicates that the used MDT model is not adequate for this local application.

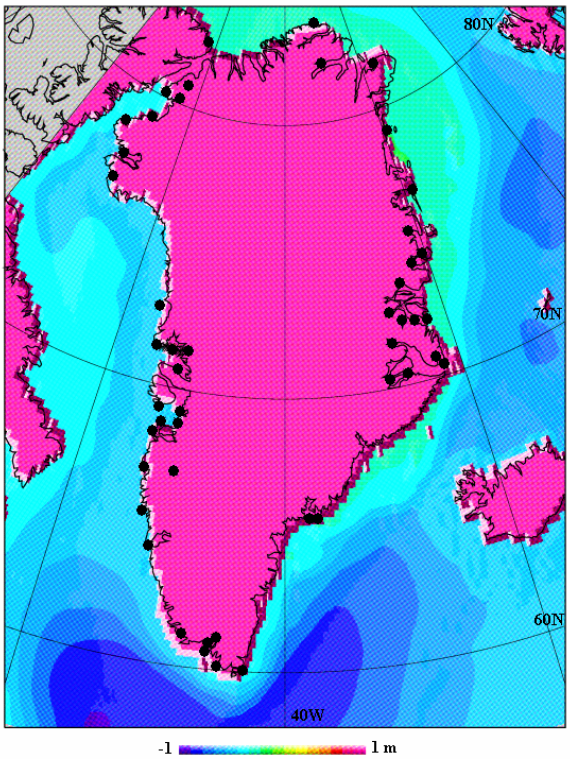


**Figure 2.** Location of Greenland GPS stations (black dots) and MDT from OCCAM model (color contour)

Table 5 also shows the comparison of the GPS-MSS data (reduced for MDT) to other geoid models: EGM96, GEOID96A and GOCINA04. The latter two are local gravimetric geoid models, derived by somewhat different methods. GEOID96A uses EGM96 as reference, and utilizes least squares collocation to merge high-elevation airborne gravity data (Brozena et al, 1993) and surface data in the ice-free coastal regions; the GOCINA04 model uses a JPL GRACE model as reference, and uses only surface gravity data in the coastal region. Both models use ice thickness information and terrain reductions, and are based on spherical FFT methods.

**Table 5.** Comparison of EGM2008 and PGM2007A and other models to GPS-MSS data in Greenland (78 points).
MDT – corrected for mean dynamic topography;
no MDT – not corrected for mean dynamic topography.

| Unit: m | Mean | Std.dev. | Min | Max |
|---|---|---|---|---|
| N =GPS-MSS-MDT | 35.04 | 12.66 | 8.94 | 57.01 |
| EGM2008, MDT | -0.19 | 0.40 | -0.43 | 1.60 |
| PGM2007A, no MDT | -0.63 | 0.45 | -1.66 | 1.08 |
| PGM2007A, MDT | -0.26 | 0.43 | -1.20 | 1.45 |
| EGM96, MDT | 0.71 | 0.52 | -0.52 | 2.62 |
| GEOID96A, MDT | -1.09 | 0.83 | -2.50 | 1.76 |
| GOCINA04, MDT | -0.16 | 0.37 | -0.98 | 1.44 |

Results in Table 5 indicate that PGM2007A and, especially, EGM2008 perform nearly at the same level as the "best" local geoid model – GOCINA04. The difference might be caused by the different weighting used for the high-altitude airborne gravity data, which might have long-wavelength errors not consistent with GRACE. However, other avenues for systematic errors are the use of terrain and ice reductions since large parts of the ice sheet do not have sufficiently accurate radar echo sounding depth data, especially near the margins of the ice sheet. It is also seen that the earlier geoid models have much larger errors, likely due to the absence of GRACE data. This is as expected.

## Conclusions

For Scandinavia and adjacent Baltic areas the new global model EGM2008 is a net improvement over the latest global reference model EGM96 and almost as good as (and sometimes better than) the latest regional quasi-geoid model NKG2004. For Greenland, EGM2008 performs with an accuracy which is comparable to the best local geoid model GOCINA04.


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