IMPACT OF GOCE ON REGIONAL GEOID MODELLING: FINNISH TERRITORY

Timo Saari and Mirjam Bilker-Koivula

Finnish Geospatial Research Institute (FGI), National Land Survey of Finland (http://www.fgi.fi)
Geodeetinrinne 2, FI-02430 Masala, Finland
Email: timo.saari@nls.fi, mirjam.bilker-koivula@nls.fi

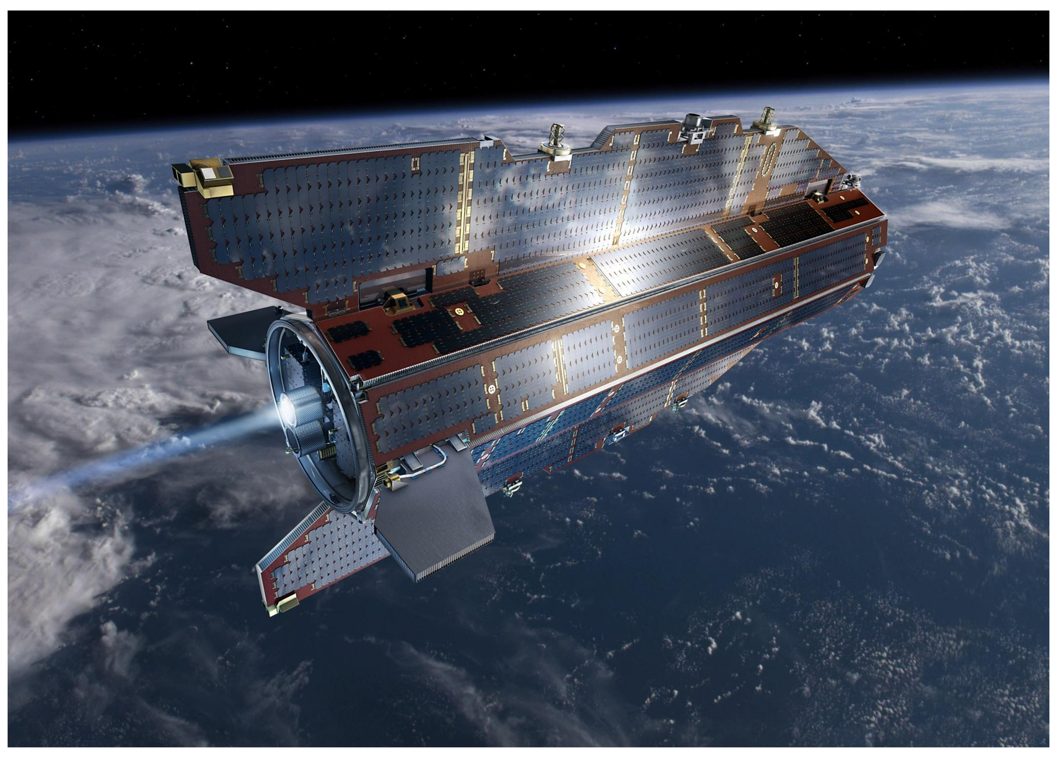

Figure 1. (GOCE) (image credit: European Space Agency).

INTRODUCTION & OBJECTIVE

The gravity satellite mission "Gravity field and steady-state Ocean Circulation Explorer" (GOCE, Fig. 1) made its final observations in the fall of 2013. By then it had exceeded its expected lifespan of 20 months with additional 35 months and observed the Earth's gravitational field from a lower orbit as originally planned during the last 6 months of its mission lifetime. Thus, the mission collected more data from the Earth's gravitational field than expected, and more comprehensive global geoid models have been derived ever since.

We've combined the latest GOCE global gravity field models with the terrestrial gravity data of Finland and surrounding areas for calculating a new enhanced quasi-geoid model for Finland. Additionally the high resolution global gravity field model EIGEN-6C4 (which includes the full cycle of GOCE data) was used for modelling the higher degrees and orders. Altogether 249 geoid models with different modifications were calculated using the GOCE DIR5 models up to spherical harmonic degree and order 240 and 300 and the EIGEN-6C4 up to degree and order 1000 and 2190.

STUDY AREA & DATASETS

Terrestrial gravity datasets (the area between 15° and 36° longitude and 56.8° and 72.2° latitude):

- FGI's dataset within the territory of Finland, a Russian dataset for most of Russia, NKG's (Nordic Geodetic Commission) dataset for all the other surrounding areas

Global gravity field models (as a background model in the regional quasi-geoid modelling):

- The direct approach (DIR5) (Bruinsma et al., 2013) published by the GOCE High-level Processing Facility (HPF) by ESA
- The high resolution model EIGEN-6C4 (Förste et al., 2015)

GPS-levelling datasets (for the evaluation of the calculated quasi-geoid models):

- The EUVN-DA dataset containing 50 GPS–levelling points (class 1) in Finland
- The NLS-FIN dataset by the National Land Survey of Finland containing 1538 GPS–levelling points (classes 1 to 3)

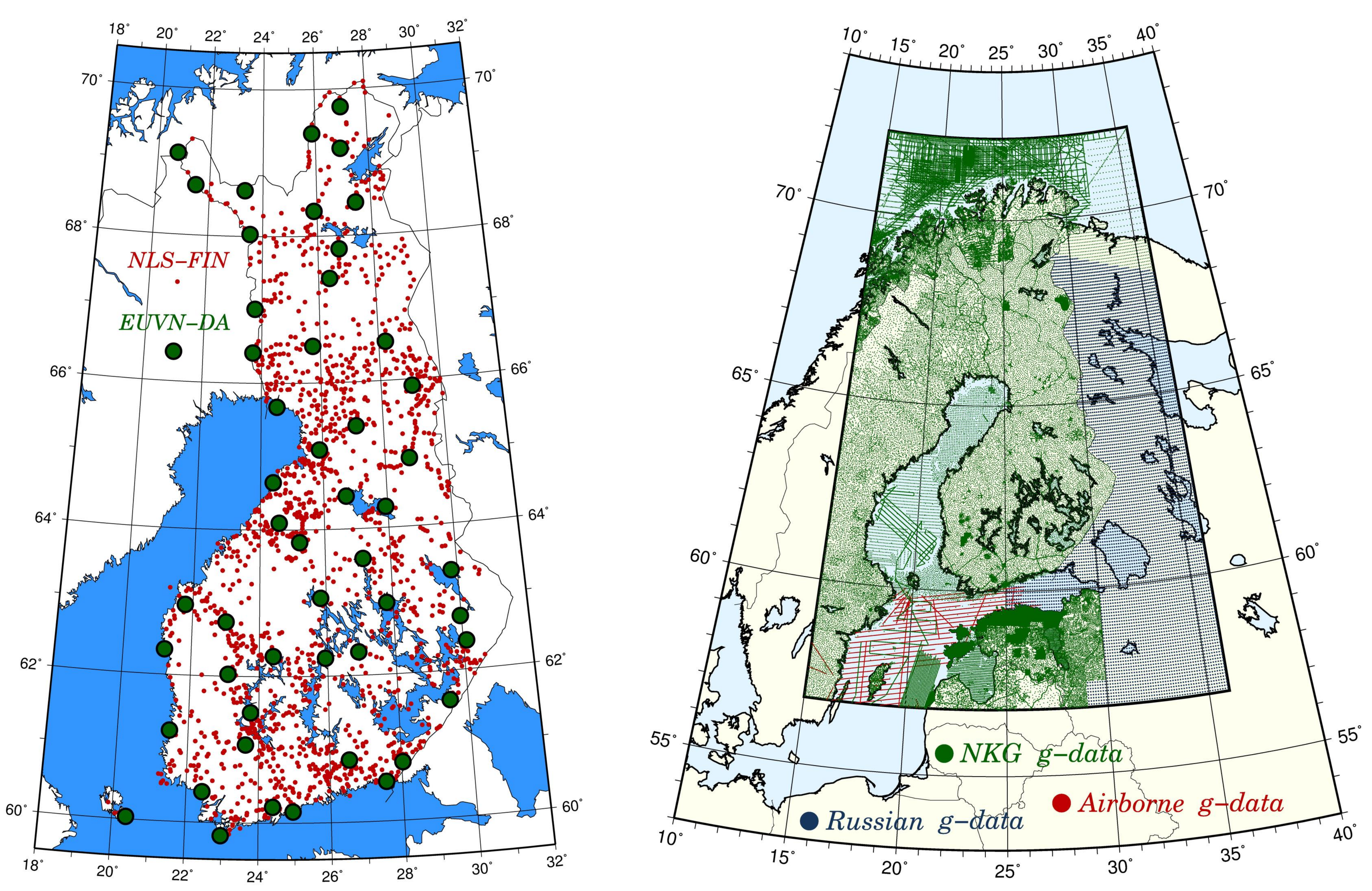

Figure 2. Left: the coverage of the GPS-levelling datasets over Finland: EUVN-DA (large green dots) and NLS-FIN (small red dots) Right: Gravity data (green NKG database, red Airborne Baltic data, blue Russian database)

QUASI-GEOID MODELLING OF FINLAND

The remove-compute-restore technique was applied - pyGravsoft-software (Forsberg and Tscherning, 2008)

1. First the known signals are removed from the free-air anomalies (Fig. 3 and 4) → **residual gravity anomalies:**

$$\Delta g_{residual} = \Delta g_{FA} - \Delta g_{EGM} - \Delta g_{RTM}$$

2. **Residual height anomalies** → Molodensky's integral using multi-banded spherical FFT (Forsberg and Sideris, 1993)

Stokes' integral kernel function with the Wong-Gore modification (Wong and Gore, 1969), tapered over an interval (Fig. 5):

$$S_{\mathrm{mod}}(\psi) = S(\psi) - \sum_{n=2}^{N_2} \alpha(n) \frac{2n+1}{n-1} P_n \cos\psi \qquad \alpha(n) = \begin{cases} 1 & for \quad 2 \le n \le N_1 \\ \frac{N_2 - n}{N_2 - N_1} & for \quad N_1 \le n \le N_2, \quad n = 2, \dots, N \\ 0 & for \quad N_2 \le n \le N \end{cases}$$

3. **The quasi-geoid heights** (Fig. 6) are obtained by adding the height anomaly effect of the residual terrain corrections and the global geoid model to the residual height anomalies:

$$\zeta = \zeta_{residual} + \zeta_{RTM} + \zeta_{EGM}$$

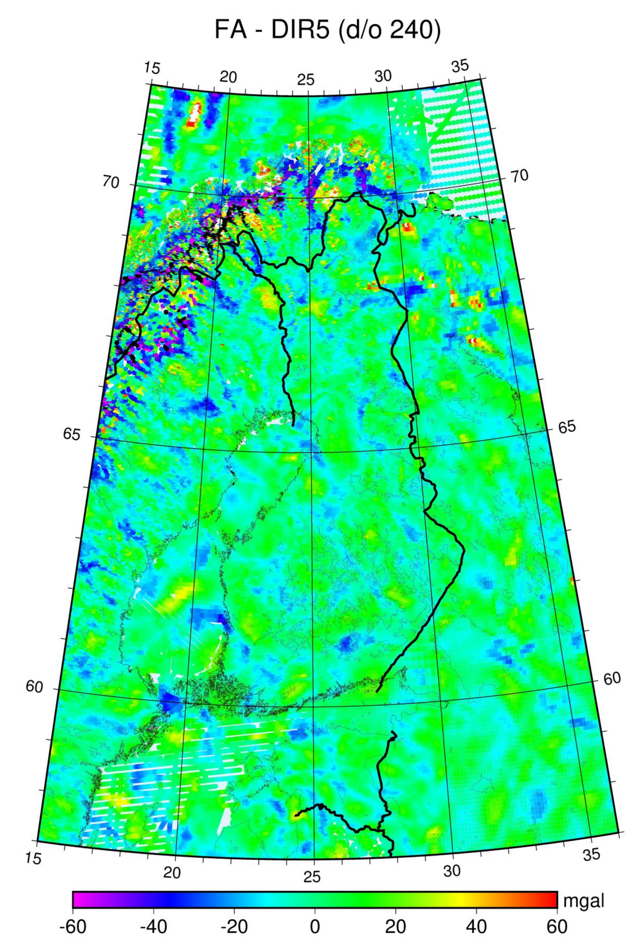

Figure 3. Gravity variations over Finnish borders after the removal of the global gravity field model (DIR5 d/o 240) from the free-air gravity data

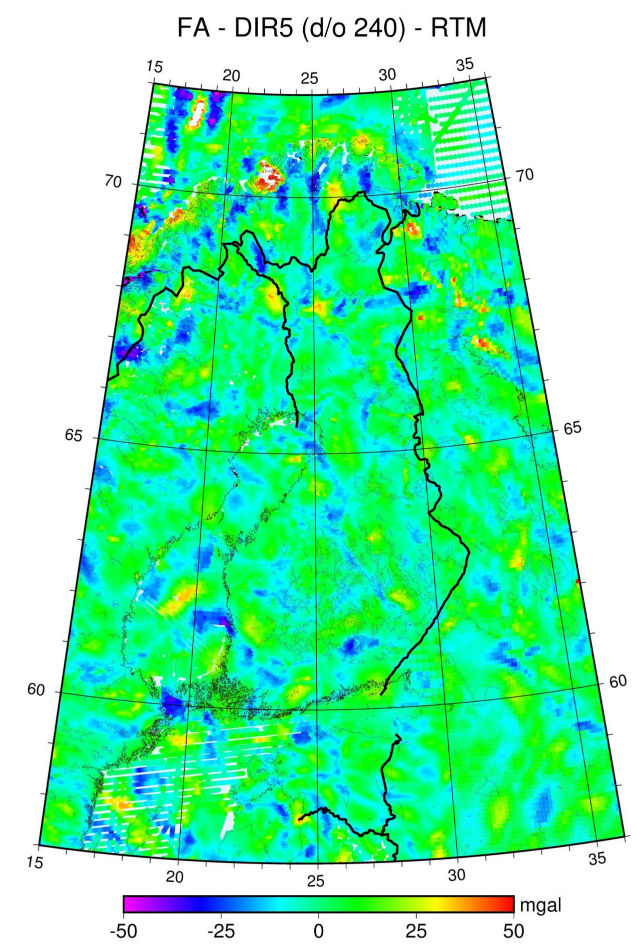

Figure 4. Gravity variations over Finnish borders after the removal of the global gravity field model and residual terrain corrections from the free-air gravity data

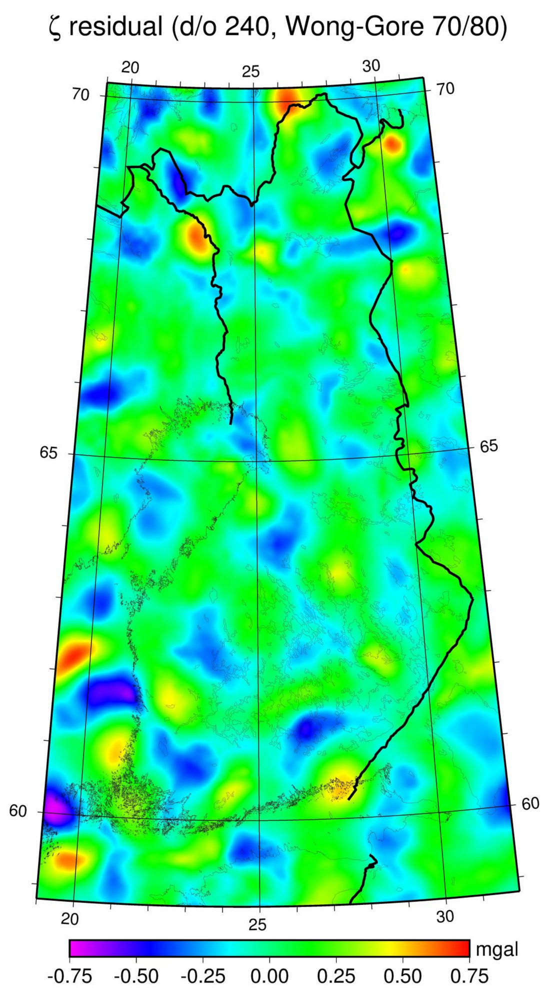

Figure 5. Residual height anomalies of the Finnish quasi-geoid

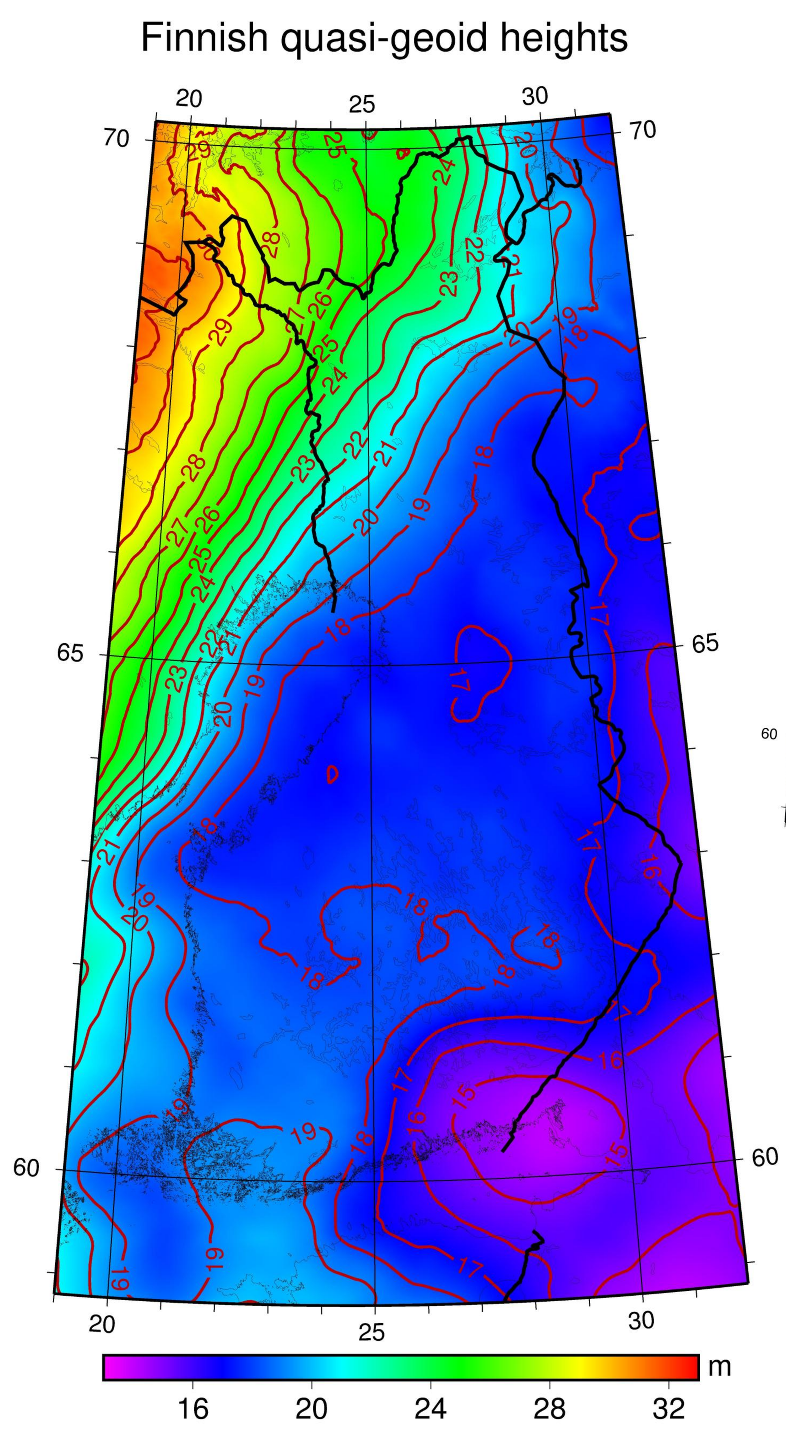

Figure 6. Finnish quasi-geoid heights (DIR5 d/o 240, Wong-Gore 70/80)

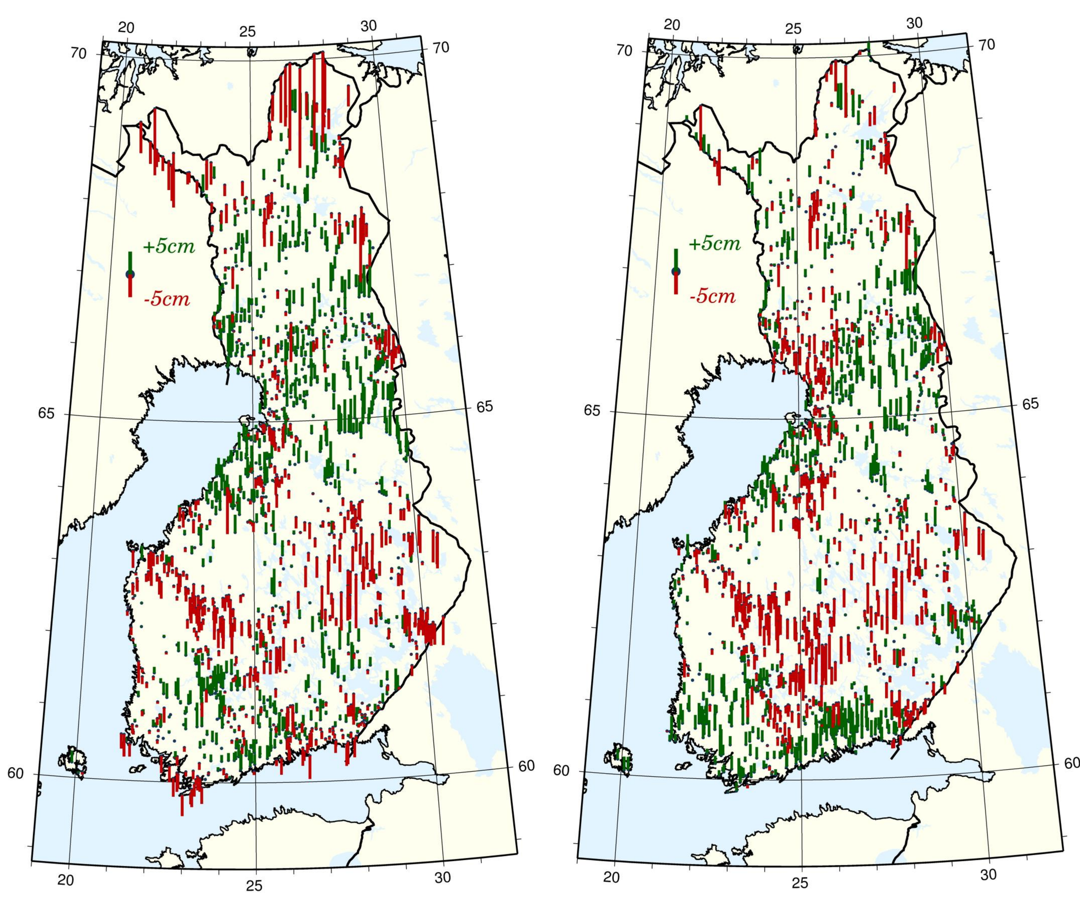

Figure 7. Differences between Finnish quasi-geoid (Left: d/o 240, Wong-Gore 70/80) (Right: d/o 2190, Wong-Gore 70/240) and NLS-FIN GPS-levelling dataset. Red columns are negative values, whereas green columns are positive

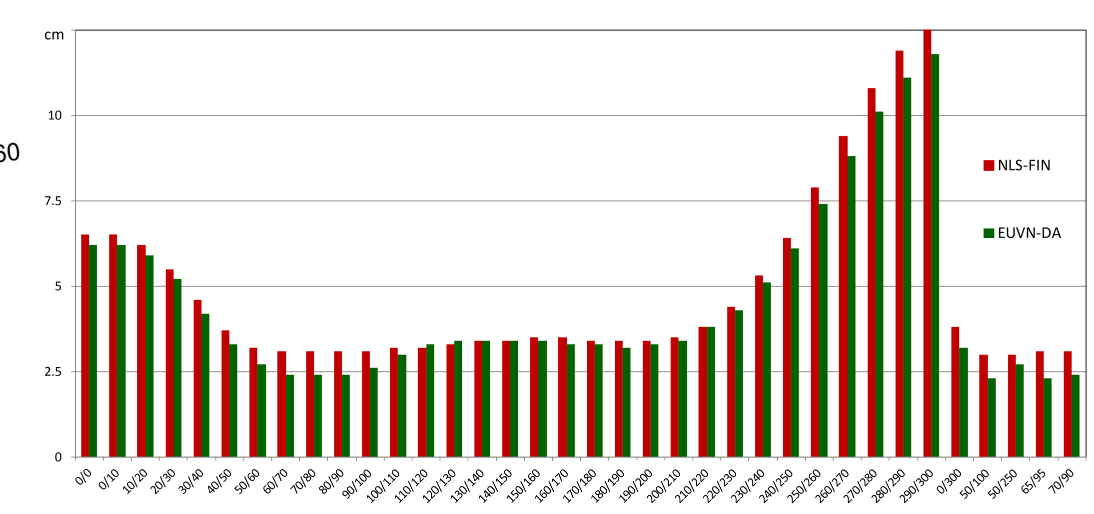

Figure 8. Finnish quasi-geoid modelling (DIR5 d/o 300) with multiple Wong-Gore combinations compared to the GPS-levelling datasets

RESULTS & CONCLUSIONS

- Fig. 7 presents the differences between Finnish quasi-geoids calculated with spherical harmonic degree and order 240 (left) and 2190 (right) – quite similar, most differences in northern Lapland
- Fig. 8 presents the solutions for degree and order 300 with different Wong-Gore boundaries
  - Gets better > 0 degrees – quite stable after 40 degrees – best at 70/80 – gets bad after 190 degrees.
  - Best results were achieved with larger and atypical intervals (e.g. 50/100) – especially for the EIGEN-6C4

GOCE DIR5 d/o 240, Wong-Gore 70/80 = **2.8 cm** (NLS-FIN) & **2.6 cm** (EUVN-DA)

GOCE DIR5 d/o 300, Wong-Gore 70/80 = **2.7 cm** (NLS-FIN) & **2.3 cm** (EUVN-DA)

EIGEN-6C4 d/o 1000, Wong-Gore 50/250 = **2.4** cm (NLS-FIN) & **1.8** (EUVN-DA)

EIGEN-6C4 d/o 2190, Wong-Gore 70/240 = **2.5** cm (NLS-FIN) & **1.7** (EUVN-DA)

The sub-2-centimetre (and near 2 cm with the GOCE-only) accuracy is an improvement over the previous and current Finnish geoid models, thus confirming the great impact of the GOCE-mission on regional geoid modelling!

MAJOR REFERENCES

Bruinsma, S.L., Foerste, C., Abrikosov, O., Marty, J.C., Rio, M.H., Mulet, S. & Bonvalot, S. (2013). The new ESA satellite-only gravity field model via the direct approach. Geophysical Research Letters. 40(14), 3607–3612. doi:10.1002/grl.50716

Forsberg, R. & Sideris, M.G. (1993). Geoid computations by the multi-band spherical FFT approach. Manuscripta Geodaetica. 18(2), 82–90.

Forsberg, R. & Tscherning, C.C. (2008). An overview manual for the GRAVSOFT Geodetic Gravity Field Modelling Programs. 2nd. Edition, August 2008. http://www.researchgate.net/publication/258889946_An_overview_manual_for_the_GRAVSOFT_Geodetic_Gravity_Field_Modelling_Programs

Förste, C., Bruinsma, S.L., Abrikosov, O., Lemoine, J.-M., Marty, J.C., Flechtner, F., Balmino, G., Barthelmes, F. & Biancale, R. (2015). EIGEN-6C4 The latest combined global gravity field model including GOCE data up to degree and order 2190 of GFZ Potsdam and GRGS Toulouse. GFZ Data Services. doi:10.5880/icgem.2015.1

Wong, L. & Gore, R. (1969). Accuracy of geoid heights from modified Stokes kernels. Geophysical Journal of the Royal Astronomical Society. 18(1), 81–91. doi:10.1111/j.1365-246X.1969.tb00264.x

ACKNOWLEDGEMENTS

This research has been funded by a grant of Vilho, Yrjö and Kalle Väisälä Foundation, and the ESA-MOST Dragon 3 contract No. 4000110315/14/I-BG.