EVALUATING THE CALIBRATION OF SCINTREX CG-5 SPRING GRAVIMETERS

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INTRODUCTION

Evaluating the accuracy of relative spring gravimeter by users is strongly recommended for obtaining reliable results from the terrestrial gravimetric surveys.

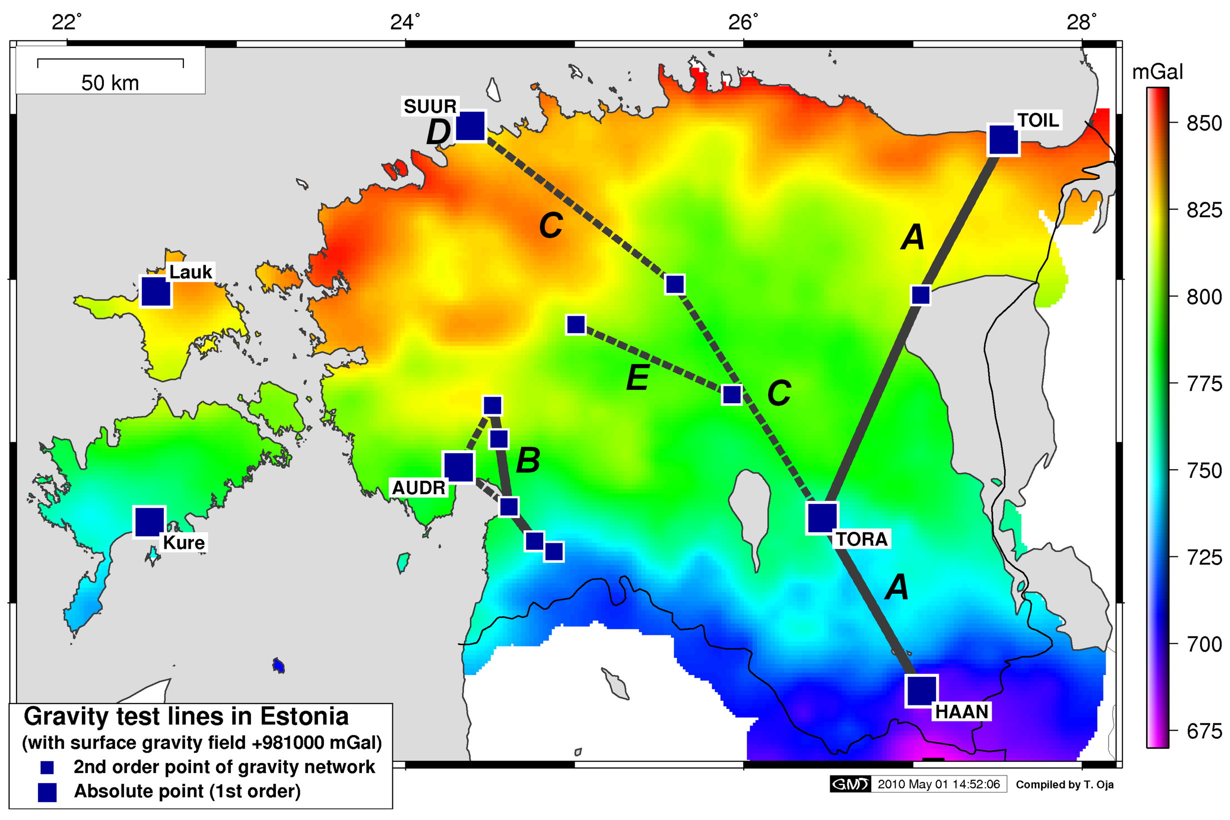
In this study the calibration (determined by the gravimeter's manufacturer) of three digital Scintrex CG-5 relative gravimeters (owned by ELB and EULS, see Fig. 1a) were tested on several specially designated calibration lines in Estonia (Fig. 1b, see also Table 1). The calibration function of CG-5 gravimeter is modeled by single scale factor *GCAL1* (see CG-5 manual) which simplifies such testing.

The spatial variability of surface gravity in Estonia is about 200 mGal ($200 \cdot 10^{-5}$ m/s^2, see Fig.1b). Thus the calibration accuracy of relative gravimeters used in Estonia should be:

- equal or better than $5 \cdot 10^{-5}$ (50 ppm) for gravity network measurements and geodynamical, hydrological etc studies (uncertainties $u \leq \pm 0.010$ µGal)
- about $25 \cdot 10^{-5}$ (250 ppm) for the network densification and geodetic, geological gravity surveys ($u \approx \pm 0.050$ µGal).

The scale factor *GCAL1* of CG-5 is determined with an accuracy about 85 ppm by Scintrex. After production, *GCAL1* may initially change 1...2 ppm per day (during few months period), due to the stress relaxation effects in the newly fused quartz spring. (CG-5 manual)

(a) CG-5 units No 36 and 10092 (S-36, S-92) owned by ELB, No 41156 (S-156) owned by EULS.



(b) Observed gravity field and calibration lines

Figure 1: **Digital relative gravimeters in use and calibration lines in Estonia.**

CALIBRATION LINES AND CAMPAIGNS

The first calibration line with permanent points (and subsurface concrete pillars as well as benchmarks) was established near Pärnu in 1982 (*line B* in Fig. 1a). Several GAG-2 relative gravimeters (produced in Soviet Union) were used to determine gravity differences between points of the line. Later GAG-2, LCR G, CG-5, ZLS Burris have been tested at the line (see Table 1). Today the main base for testing relative gravimeters is *line A* which connects 3 absolute stations (Haanja-Tõravere-Toila).

Instruments CG-5 S-36, S-92 (also LCR G-4, G-113, G-115) have also been tested several times at Masala-Vihti calibration line of Finnish Geodetic Institute (FGI) in 2002-2008.

Line	Dist. [km]	Gravity range [mGal]	Accu-racy [ppm]	Obs. Period	No of cam-paigns	Instruments tested
A	260	170	50	2008- -2014	10	CG-5 S-36, S-92, S-156 LCR G-191 (of TUT[1])
B	64	82	150	1983- -1989 2002- -2010	1 ? 8	GAG-2 No? (of NGF[2]) GAG-2 No 21, 26 LCR G-4,G-113,G-115 LCR G-65,G-191 (TUT) CG-5 No 40333, 9386 (LGIA[3]) ZLS (Burris) B-30 (GSE[4])
C	230	64	150	2001- -2008	5	LCR G-4,G-113,G-115 CG-5 S-36, S-92
D*	16	5	400	2002- -2009	8	LCR G-4,G-113,G-115 CG-5 S-36, S-92 LCR G-65 (TUT)
E	70	18	550	2001- -2007	7	LCR G-4,G-113,G-115 CG-5 S-36, S-92

Table 1: **Details about calibration lines in Estonia and instruments tested at these lines.** (*Vertical line at Suurupi lighthouse, distance in meters)

[1]TUT - Tallinn University of Technology, [2]NGF - Neftegeofizika (Soviet Union)

[3]LGIA - Latvian Geospatial Information Agency, [4]GSE - Geological Survey of Estonia

Measurements

Great care was taken during measurements along the calibration lines to minimize the errors due to transport, weather conditions etc. For instance, multilayer soft pads below gravimeters and smooth driving were used during car transport. In most cases temperature and air pressure were constantly monitored and recorded.

DATA PROCESSING

For data preprocessing, drift modeling and the adjustment of the readings the GRAVS2 software package was applied (for more info, see *GRAVS2 homepage*, Oja (2012)).

Preprocessing includes the computation of:

- tidal correction using Tamura's tidal potential development (Tamura 1987) with local amplitude factors and phase lags for main waves
- free air correction due to different sensor height of gravimeters using -0.3086 mGal/m or oberved value of gravity vertical gradient
- atmospheric correction using observed air pressure and coefficient -0.3 mGal/hPa
- GIA correction using the uplift model NKG2005LU (Agren and Svensson 2007) scaled by -0.16 µGal/mm

In a least-squares adjustment the daily drift of gravimeter's reading was modeled by using 1st or 2nd degree polynomial. After that the outliers were detected-removed by following residuals and statistical tests. Finally single coefficient for every CG-5 gravimeter was estimated to correct original calibration. The opposite value of coefficients can be seen in Fig. 2.

RESULTS

The calibration errors of CG-5 gravimeters from relative gravity campaigns at test lines in Estonia were found to be -300...600 ppm (see Fig. 2). The scale of CG-5 S-36, S-92 seems to increase systematically within study period 2004-2014.

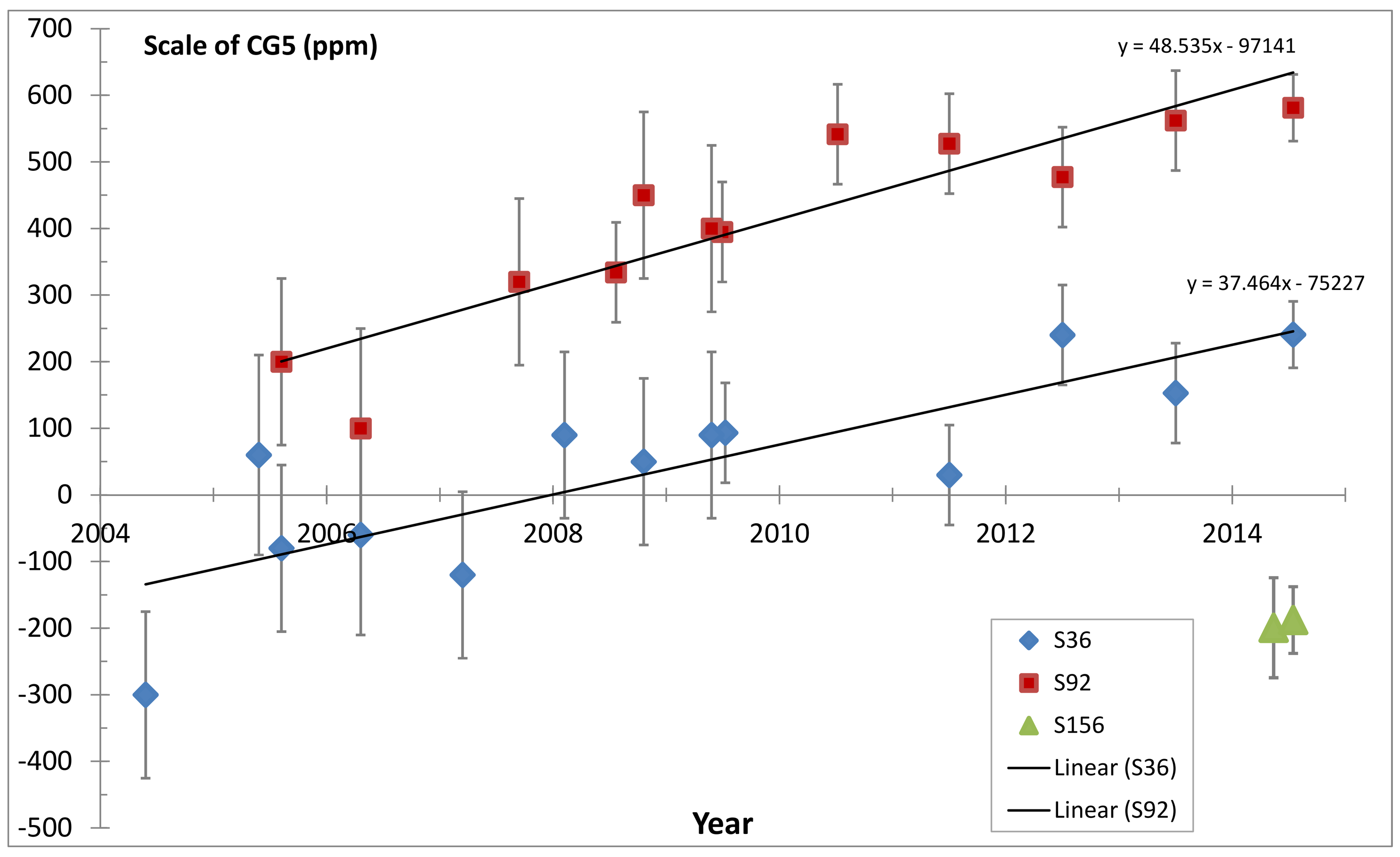


Figure 2: **The calibration errors of CG-5 gravimeters from relative gravity campaigns along the dedicated testing lines in Estonia.**

To evaluate uncertainty of the results the precision of measurements and the accuracy of calibration lines were taken into account. However, the uncertainty estimates could be still too optimistic.

The uncertainties could be higher due to the moving masses and loading effects. To model the effect of changing level of sea, lakes as well as groundwater level and soil moisture variations on gravity is complicated and would need high resolution data (both spatially and temporally) from different type of sensors. No such sensors close enough to the points of calibration lines are available in Estonia.

CONCLUSION

- CG-5 gravimeters S-36, S-92, S-156 are not suitable for accurate measurements (e.g. on gravity network) due to the calibration errors higher than 50 ppm. CG-5 S92 with scale error over 500 ppm cannot be used even for less accurate works.
- The scale of CG-5 gravimeter seems to change over a period of time. However, neglecting the effects of mass changes and loading on test measurements could be the reason of too optimistic uncertainty values and biased results.
- The coefficient to correct original calibration of these CG-5s should be used in data preprocessing (automatically done in GRAVS2). Should it be necessary to implement also time dependent calibration change in preprocessing?

ACKNOWLEDGMENTS

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