Republic of Estonia
Land Board

EG2000 – new gravity reference frame of Estonia

Tõnis Oja
Maa-amet / Estonian Land Board (tonis.oja@maaamet.ee)

EUREF Symposium 2019, Tallinn, Estonia

Topics

Definitions, conventions

EME 2017 (Estonian Ministry of Environment, 2017. Geodeetiline Süsteem [Geodetic system]. In Legal Acts of Estonia, Decree No. 64)

Gravimetric system:

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Gravimetric system:

- IAGBN standards* for AG Observations Data Processing
  - **Zero-tide system** for the permanent tide (ampl.factor 1.0 for $M_0 S_0$)
  - DIN5450 (ISO 2533:1975) Standard Atmosphere with admittance factor -3 nms^{-2}/hPa for atm.variations
  - IERS reference pole (with elastic grav.factor 1.164) for polar motion

*International Absolute Gravimeter Base Network (IAGBN) standards (Boedecker 1988, BGI Bull. Inf. 63, 1992)

Gravity units: 10 nms^{-2} $= 1\mu$Gal $=$ 0.001 mGal

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- **Epoch 2000.0**
- **Absolute gravity** values at 1st order (**I order**) points of gravity network realizes the **EG2000**
- I order network is densified by **II, III order** networks
- All other realizations in Estonia are based on the EG2000

Gravity units: 10 nms^{-2} = 1μGal = 0.001 mGal

Topics

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1. EG2000 definitions, conventions
2. EG2000 realization
   - I order gravity network
   - Absolute gravity data
   - II, III order gravity networks
   - Integrated geodetic frames
   - Scale change of relative gravimeters
   - Data processing
3. Summary

I order gravity network

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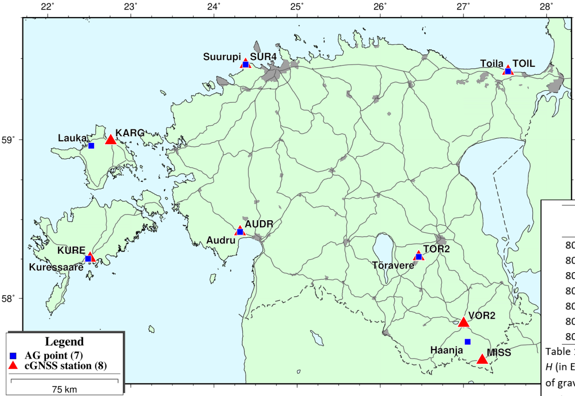
AG sites with nearest cGNSS stations:



Point ID	Point Name	Lat [°] (GRS80)	Lon [°] (GRS80)	H [m]	$\dot{h}_{\mathrm{gnss}} \pm u_{\dot{h}}$ [mm/yr]	$\dot{h}_{\mathrm{LU}} \pm u_{\dot{h}}$ [mm/yr]
80001	Kuressaare	58.2519	22.4853	4.61	2.70 ± 0.26	2.61 ± 0.17
80002	Suurupi	59.4636	24.3803	43.55	3.95 ± 0.27	3.40 ± 0.19
80003	Tõravere	58.2643	26.4633	71.96	1.21 ± 0.30	1.33 ± 0.19
80701	Audru	58.4222	24.3136	10.04	2.42 ± 0.18	2.09 ± 0.18
80702	Haanja	57.7217	27.0508	245.47	0.72 ± 0.23	0.65 ± 0.23
80703	Lauka	58.9625	22.5234	6.15	3.10 ± 0.29	3.63 ± 0.18
80704	Toila	59.4223	27.5363	36.47	2.33 ± 0.20	2.16 ± 0.19

Table 1. The coordinates (in EUREF-EST97 on GRS80 ellipsoid) and normal height H (in EH2000) of Estonian I order gravity network points. The vertical velocities of gravity points in ITRF2008 are computed from nearby cGNSS stations ($\dot{h}_{\mathrm{gnss}}$) and NKG2016LU ($\dot{h}_{\mathrm{LU}}$). For Haanja site the weighted arithmetic mean from the velocities of two nearest cGNSS stations VOR2 ($\dot{h}$ = 0.85 ± 0.38 mm/yr) and MISS ($\dot{h}$ = 0.65 ± 0.28 mm/yr) were estimated.

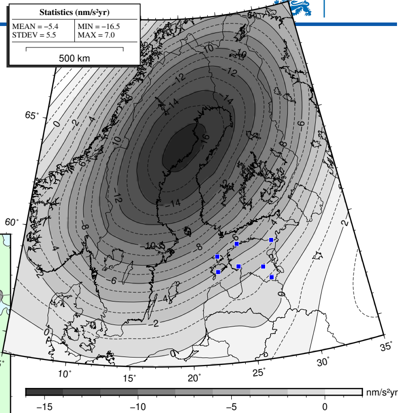
I order network information:

I order gravity network

NKG2016LU_gdot:

$$\dot{g} = C\dot{h}$$

where $C = -1.63\ \text{nms}^{-2}/\text{mm}$



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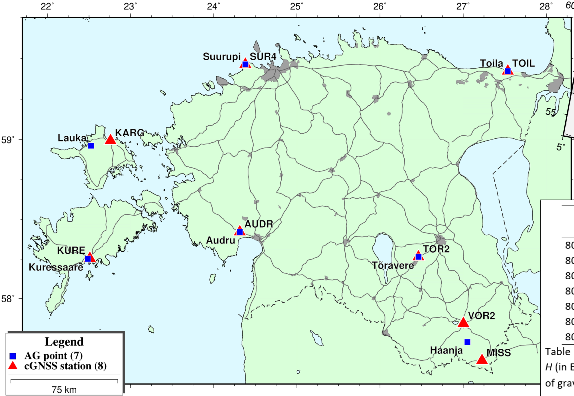

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AG measurements 1995-2017

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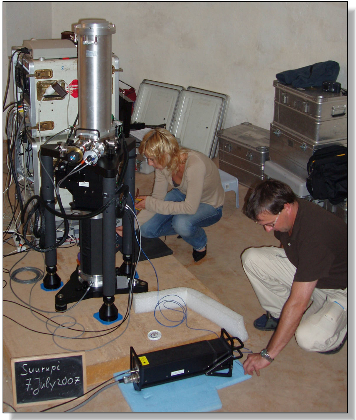
Free-fall absolute gravimeters in Estonia



Olga Gitlein, Ludger Timmen (LUH)

with FG5-220 in Suurupi in 2007

LUH - Institute of Geodesy, Leibniz Universität

Hannover

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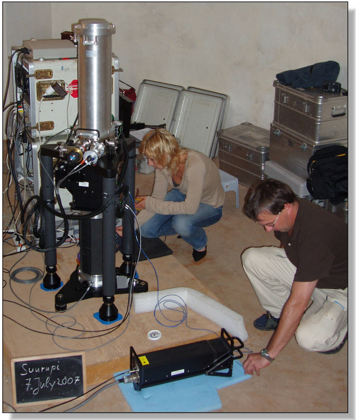

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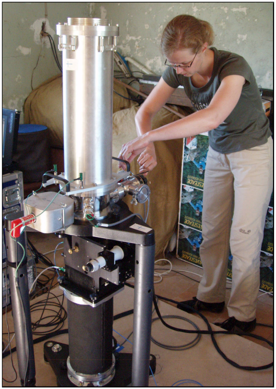

Mirjam Bilker-Koivula (FGI) with FG5-221 in Tõravere in 2008

FGI - Finnish Geospatial Research Institute

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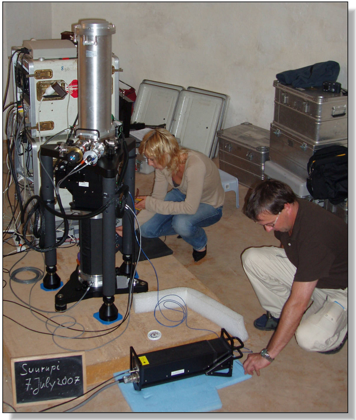

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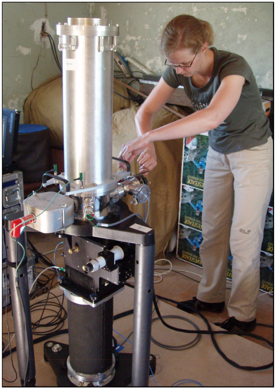

Mirjam Bilker-Koivula (FGI) with FG5-221 in Tõravere in 2008

FGI - Finnish Geospatial Research Institute

Jaakko Mäkinen (FGI) with FG5X-221 in Suurupi in 2013

Gravimeters and vertical gradient

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International Comparisons of AG for long term stability, repeatability and traceability to the SI of JILAg#5, FG5#220, FG5#221 (FG5X#221)

Comparison	Epoch	DoE [nm/s²]				SD of DoE [nm/s²]	Reference
		JILAg#5	FG5#220	FG5#221	FG5X#221		
ICAG1994	1994.4	−39 ± 80				± 33	Marson et al. (1995)
ICAG1997	1997.9	5 ± 72				± 28	Robertsson et al. (2001)
ECAG2007	2007.9		25 ± 22	1 ± 22		± 21	Francis et al. (2010)
ICAG2009	2009.8		17 ± 28	16 ± 32		± 42	Jiang et al. (2012)
ICAG2013	2013.9				15 ± 33	± 38	Francis et al. (2015)
EURAMET.M.G-K2 in 2015	2015.8				−21 ± 33	± 51	Palinkas et al. (2017)

Table 3. Degrees of Equivalence (DoE) values with uncertainties (at ≈ 95% confidence level, 2σ) relevant for this work. SD of DoE describes the standard deviation (1σ) of all DoE values estimated in the comparison.

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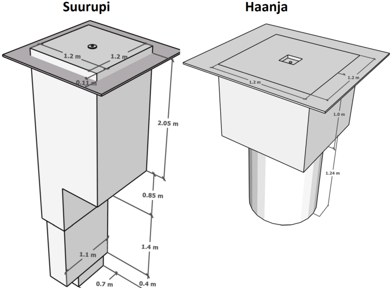
Piers at I order stations:



Vertical gradient evaluation:

$$dg = g(h) - g(0) = ah + bh^2$$
$$VG(h) = W_{zz} = a + 2bh$$

$$u_{dg} = \sqrt{hu_a^2 + (h^2 u_b)^2 + 2h^3 u_a u_b \mathrm{Corr}[a, b]}$$
$$u_{VG} = \sqrt{u_a^2 + (2hu_b)^2 + 4hu_a u_b \mathrm{Corr}[a, b]}$$

Coefficient Unit	$a \pm u_a$ nm/s²	$b \pm u_b$ nm/(s²m²)	Corr(a,b)	Obs. n
SUUR	-3580 ± 14	119 ± 10	-0.992	36
TORA	-3265 ± 16	68 ± 12	-0.994	18
KURE	-2751 ± 34	45 ± 25	-0.987	6
HAAN	-2961 ± 57	49 ± 41	-0.996	11
TOIL	-2885 ± 30	64 ± 21	-0.995	14
AUDR	-2973 ± 19	-40 ± 14	-0.995	5
LAUK	-2928 ± 53	-20 ± 37	-0.998	5

Table 2. Approximation of gravity above the station BM using a second-degree polynomial (eq. 3-5). The coefficients a and b, their uncertainties u_a, u_b and correlation Corr(a, b) have been estimated by applying the weighted least squares to the n observations (gravity differences dg).

AG measurements 1995-2017

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Summary of all AG campaigns:

Tabel 6: Raskuskiirenduse väärtused gravivõrgu I klassi punktidel efektiivsel (h_{eff}) ja referentskorgusel ($h_{\text{ref}} = 120$ cm) ajavahemikust 1995-2017, mis on täpsustatud peale uute vertikaalgradiendi, korgusparandi dg (valemid 2, 8), DC ja SAC parandite arvutust ning lisamist. Raskuskiirenduse määramatust kirjeldab osaliselt seeria hajuvus e SD väärtus (set scatter) u_{set} ja täielikult standard(liit)määramatus u_{st}. Kõigi kampaaniate peale kokku on langatuseksperimente tehtud $\sum n = 62864$.

Punkti nimi	Mõõtmisepohh [aaaa-kk-pp]	Mõõtmisepohh [aaaa.aa]	h_{eff} [cm]	$g_{\text{eff}} \pm u_{\text{set}}$ [μGal]	d$g \pm u_{\text{dg}}$ [μGal]	$g_{120} \pm u_{\text{st}}$ [μGal]	Lang. n	Gravi-meeter	Mõõtja (asutus)
SUUR	1995-09-29	1995.74	82.1	981 823 653.8 ±4.7	−126.54 ± 0.27	981 823 527.3 ±5.1	4225	JILAg-5	JM(FGI)
	2007-07-08	2007.52	117.8	981 823 525.2 ±1.9	−7.25 ± 0.02	981 823 518.0 ±2.5	1999	FG5-220	LT,OG(IfE)
	2008-07-16	2008.54	118.2	981 823 522.7 ±1.2	−5.93 ± 0.02	981 823 516.8 ±2.5	3093	FG5-221	MBK(FGI)
	2013-12-03	2013.92	124.3	981 823 507.3 ±4.3	14.14 ± 0.05	981 823 521.5 ±2.3	4496	FG5X-221	JM(FGI)
	2017-06-22	2017.47	124.2	981 823 503.8 ±1.1	13.81 ± 0.05	981 823 517.6 ±2.3	3893	FG5X-221	MBK(FGI)
TORA	1995-10-10	1995.77	82.7	981 759 408.8 ±7.6	−116.63 ± 0.33	981 759 292.2 ±5.6	3525	JILAg-5	JM(FGI)
	2007-07-12	2007.53	118.5	981 759 289.5 ±3.5	−4.65 ± 0.02	981 759 284.9 ±2.5	2474	FG5-220	LT,OG(IfE)
	2008-07-24	2008.56	118.9	981 759 287.1 ±1.1	−3.41 ± 0.01	981 759 283.7 ±2.5	3856	FG5-221	MBK(FGI)
	2017-06-28	2017.49	124.9	981 759 273.1 ±0.9	15.18 ± 0.07	981 759 288.3 ±2.3	3697	FG5X-221	MBK(FGI)
KURE	1995-10-04	1995.76	85.2	981 753 624.1 ±3.6	−92.56 ± 0.67	981 753 531.5 ±5.1	4025	JILAg-5	JM(FGI)
	2008-08-06	2008.60	122.2	981 753 517.4 ±1.7	5.82 ± 0.06	981 753 523.2 ±2.5	3457	FG5-221	JM(FGI)
HAAN	2008-07-28	2008.57	122.7	981 678 503.7 ±1.7	7.67 ± 0.12	981 678 511.4 ±2.5	3957	FG5-221	MBK(FGI)
	2017-07-01	2017.50	128.8	981 678 490.0 ±1.2	24.98 ± 0.41	981 678 515.0 ±2.3	4243	FG5X-221	MBK(FGI)
TOIL	2008-07-20	2008.55	123.1	981 848 410.8 ±1.8	8.46 ± 0.07	981 848 419.2 ±2.5	3824	FG5-221	MBK(FGI)
	2017-07-04	2017.50	129.0	981 848 394.6 ±0.9	24.54 ± 0.22	981 848 419.1 ±2.3	3840	FG5X-221	MBK(FGI)
AUDR	2008-08-02	2008.58	122.6	981 791 962.3 ±1.4	7.98 ± 0.04	981 791 970.3 ±2.5	3807	FG5-221	JM(FGI)
LAUK	2008-08-10	2008.61	123.0	981 833 311.8 ±1.7	8.93 ± 0.11	981 833 320.7 ±2.5	4453	FG5-221	JM(FGI)

AG time series with WLSQ trend fit

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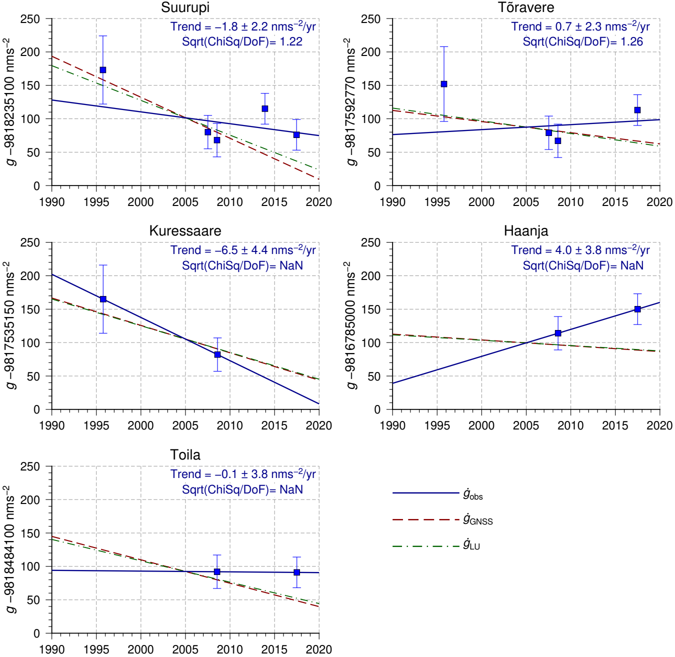

AG with HYDL from LSDM model (GFZ)

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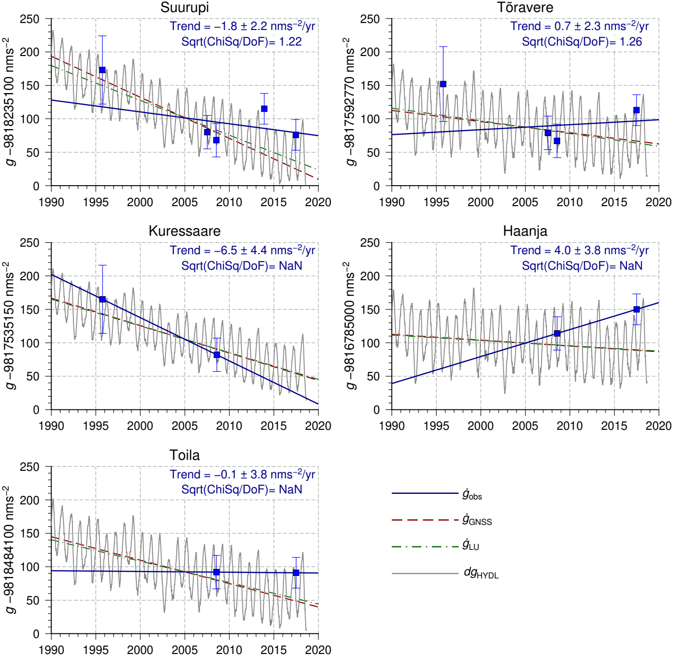
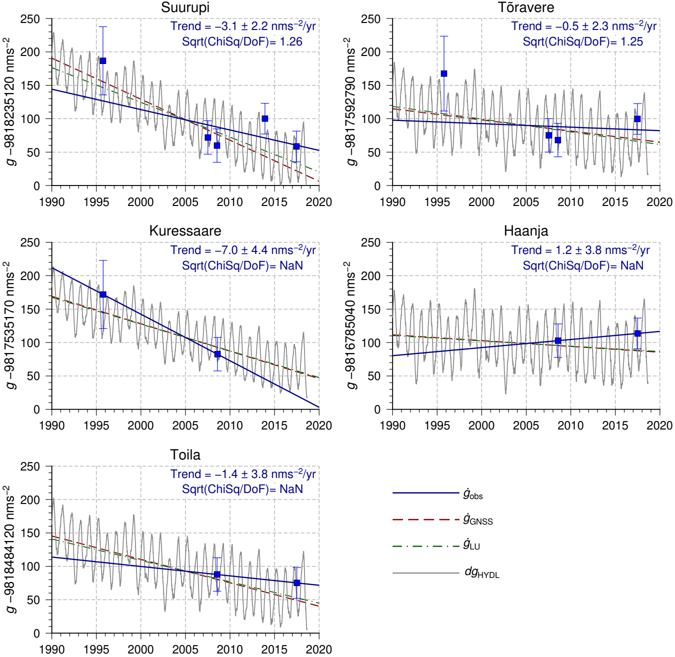
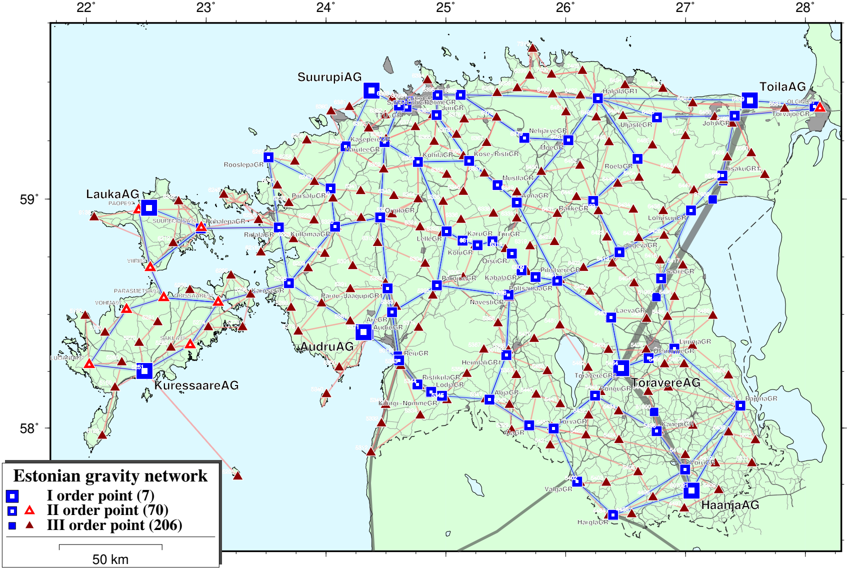


AG with HYDL corrected

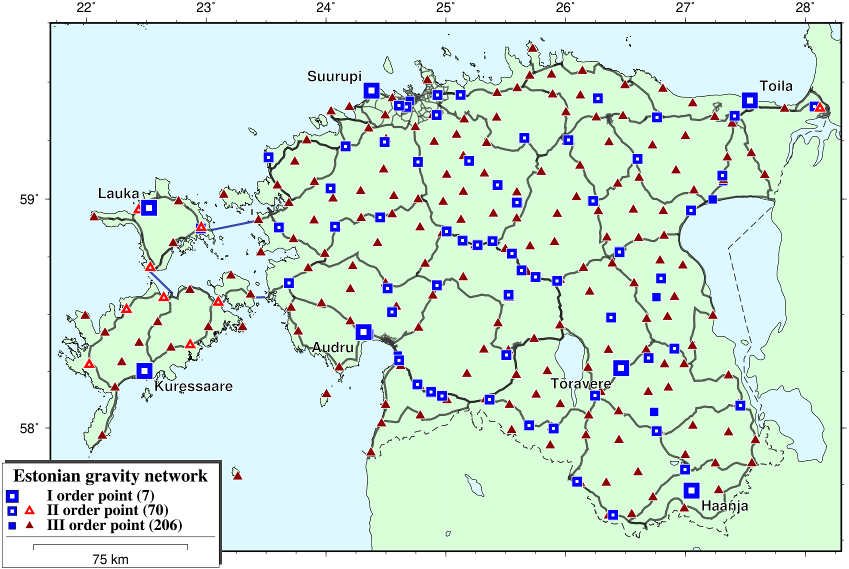


II, III order gravity networks



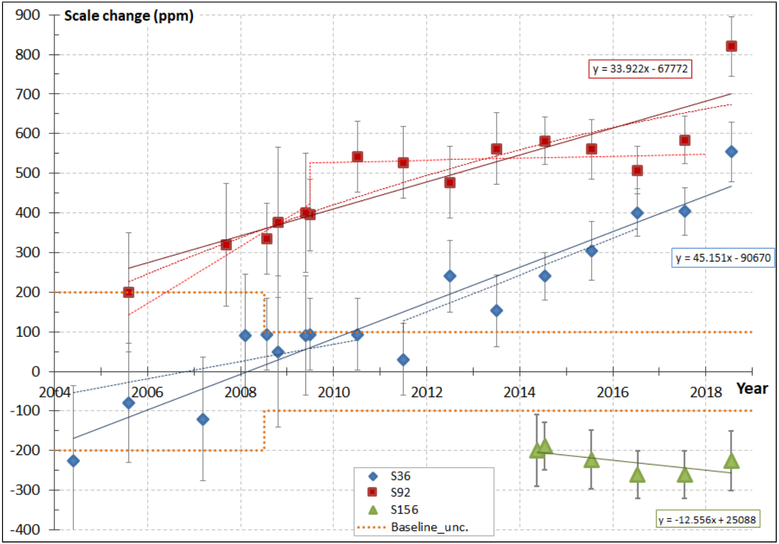
RG data by using LCR-G, CG5 in 1992-2018. Geodetic I, II order networks are integrated. Calibration line connecting 3 AG sites **to test the scale of RG meters**.

Integrated geodetic frames



Geodetic (131 p), gravity (43 p) networks with levelling lines.

Scale change of relative gravimeters



The scale check results of CG5 relative gravimeters in 2004-2018.

NB! Scale error 500 ppm with $dg = 100$ **mGal** $\Rightarrow$ **bias** 50μ**Gal.**

Data processing and network adjustment

Software **GRAVS2** (in-house, based on GRAVSOFT, script based fortran routines, Win/Linux):

- Conversion of raw data (e.g. CG5 txt files)

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- Corrections: tides*, atm.pressure*, height, calibration, GIA

*IAGBN standards are followed

Data processing and network adjustment

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- Conversion of raw data (e.g. CG5 txt files)
- Corrections: tides*, atm.pressure*, height, calibration, GIA
- Weighted least squares adjustment:

$$y_{obs}(t) = g_{adj}(T_0) + a + D(t) + F_{cal}(t) + v \quad (\boldsymbol{b} = A\boldsymbol{x} + \boldsymbol{v})$$

$$\min(\sum w \cdot v^2) \Rightarrow \hat{\boldsymbol{x}} = (A^{\mathrm{T}} W_b A)^{-1} A^{\mathrm{T}} W_b \boldsymbol{b}$$

Topics

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Summary

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  - ICAG, ECAG results $\Rightarrow$ traceability to the SI
  - Uncertainty ± 50 nms^{-2} or better (1σ)

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- II, III order gravity networks to densify EG2000
  - Scale of RG is regularly checked
  - Uncertainty $\pm 100 \ldots \pm 200$ nms^{-2} (1σ)

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References:

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