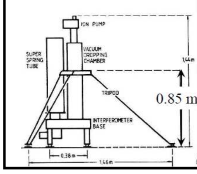
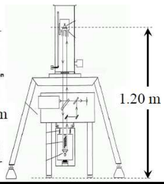
Evaluation of vertical gravity gradient (VGG) in Estonia

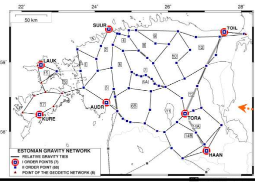
T. Oja

Intro1

- Since 1995 absolute gravity have been determined 3 times in Estonia:
  - 1995 JILAg-5 (~0.85m) FGI (3 points)
  - 2007 FG5-220 (1.2m) IfE (2p)
  - 2008 FG5-221 (1.2m) FGI (7p)







Intro2

Important outputs of these absolute measurements:

- the realization of the national gravity system (*g* at BM level)
- the constraints for gravity change due to GIA (*g* at the same height)

Evaluation of VGG

- Common practice: carry out observations along the vertical *z* (tangent to a plumbline) with relative gravimeter(s) and compute constant VGG (linear function for W_z, const. for $W_{zz} = \partial^2 W/\partial z^2 = \partial W_z/\partial z$)
- But…

Evaluation of VGG

- In Suurupi (SUUR)

  collected data: fitting (*dg*=VGG**z*):

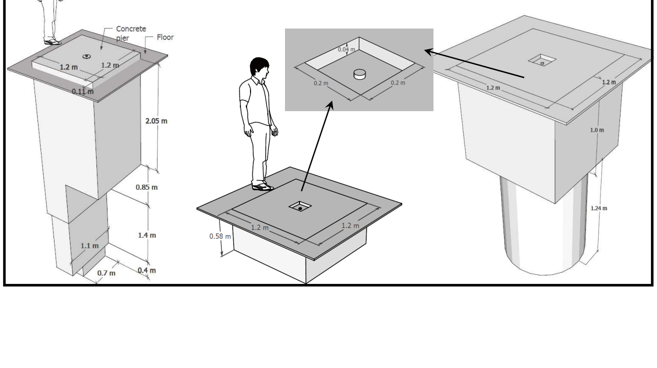
No	Institution	Observer	Gravimeter	Date	Obs.height h1 (mm)	Obs.height h2 (mm)	Sensor height sh1 (mm)	Sensor height sh2 (mm)	Height diff. dh (mm)	Gravity diff. dg (μGal)	stdev dg_err (μGal)
1	FGI	JM	LCR-G600	1995-09-30	201	938	42	779	737	258.7	1.0
2	FGI	JM	LCR-G600	1995-10-01	201	938	42	779	737	258.3	0.9
3	ELB	TO	CG5-36	2004-11-12	313	1323	102	1112	1010	341.3	1.0
4	ELB	TO	CG5-36	2004-12-17	317	1307	106	1096	990	337.9	0.4
5	ELB	TO	CG5-10092	2004-12-17	322	1311	111	1100	989	338.8	0.6
6	IfE	LT	CG3-4492	2007-07-09	427	1483	229	1285	1056	357.9	0.7
7	ELB	TO	CG5-36	2007-09-26	312	1048	101	837	736	254.6	0.6
8	ELB	TO	CG5-36	2007-09-26	312	1523	101	1312	1211	413.7	0.6
9	ELB	TO	CG5-10092	2007-09-26	313	1046	102	835	733	255.1	0.5
10	ELB	TO	CG5-10092	2007-09-26	313	1522	102	1311	1209	411.7	0.5
11	ELB	TO	CG5-36	2007-11-15	313	1065	102	854	752	261.1	0.4
12	ELB	TO	CG5-36	2007-11-15	313	1459	102	1248	1146	391.6	0.5
13	ELB	TO	CG5-10092	2007-11-15	312	1064	101	853	752	258.6	0.3
14	ELB	TO	CG5-10092	2007-11-15	312	1458	101	1247	1146	391.6	0.4
15	ELB	TO	CG5-10092	2008-02-05	314	1024	103	813	711	246.8	0.4
16	ELB	TO	CG5-10092	2008-02-05	314	1539	103	1328	1225	417.6	0.4
17	ELB	TO	CG5-36	2008-02-21	309	1047	98	836	738	256.2	0.4
18	ELB	TO	CG5-36	2008-02-21	309	1563	98	1352	1254	427.9	0.4
19	ELB	TO	CG5-10092	2008-02-21	310	1049	99	838	739	256.0	0.4
20	ELB	TO	CG5-10092	2008-02-21	310	1565	99	1354	1255	428.2	0.5
21	FGI	MBK	CG5-10052	2008-07-17	332	1499	121	1288	1167	396.9	0.9
22	FGI	MBK	CG5-10052	2008-07-17	332	1000	121	789	668	231.8	1.0

981823642.7	0.000	0.821	981823645.5	2.8
981823517.0	0.000	1.200	981823515.6	-1.4
981823516.9	0.000	1.200	981823515.6	-1.3
-258.7	0.042	0.779	-252.6	6.1 ←
-258.3	0.042	0.779	-252.6	5.7 ←
-338.8	0.111	1.100	-339.0	-0.2
-358.0	0.229	1.285	-362.0	-4.0 ←
-254.6	0.101	0.837	-252.3	2.3
-413.7	0.101	1.312	-415.1	-1.4
-255.1	0.102	0.835	-251.2	3.9
-411.7	0.102	1.311	-414.4	-2.7
-261.1	0.102	0.854	-257.8	3.3
-391.6	0.102	1.248	-392.8	-1.2
-391.6	0.101	1.247	-392.8	-1.2
-246.8	0.102	0.813	-243.5	3.3
-417.6	0.102	1.327	-419.9	-2.3
-256.2	0.098	0.836	-253.0	3.2
-427.9	0.098	1.352	-429.8	-1.9
-256.0	0.099	0.838	-253.3	2.7
-428.2	0.099	1.354	-430.2	-2.0
-396.9	0.121	1.288	-400.0	-3.1
-231.8	0.121	0.789	-229.0	2.8

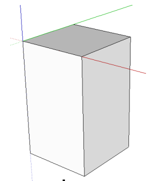
Systematically biased residuals from the fitting!

VGG not constant!

- There is deep underground concrete pier in every 1st order point:
- SUUR TOIL HAAN



Solution1

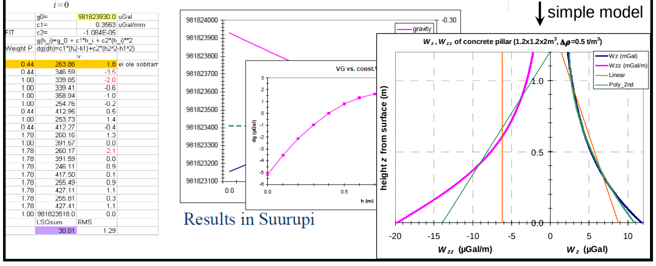


- Polynomial approximation

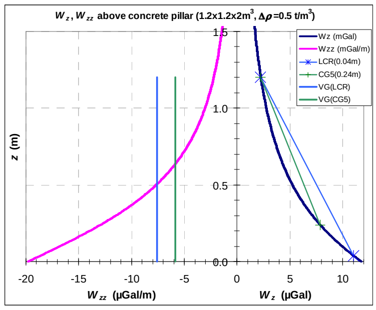
- Fitting the function (by WLSQ)

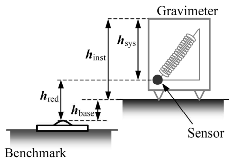
$$g(h)=\sum_{i=0}^{m} c_i h^i \approx g_0 + c_1 h + c_2 h^2 \Rightarrow g(h_2)-g(h_1)=c_1(h_2-h_1)+c_2(h_2^2-h_1^2)$$

↓simple model



Sensor height dependence when linear approximation!





GGEO2008 in Crete

Abstract:

- "Gravity gradients above piers in absolute gravimetry: use remove-restore for the pier attraction!"

Gravity gradients above piers in absolute gravimetry: use remove-restore for the pier attraction!

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Much absolute gravimetry especially at laboratory-type reference sites is conducted on massive concrete piers constructed expressly for the purpose. Since the attraction of the pier diminishes rapidly with height, the vertical gradient of gravity is then not constant, i.e. the dependence of gravity on height above the pier is not linear. This will cause extra work when

Jaakko explained:

"Actually its very simple":

- remove the theoretical influence of local masses (massive pier)
- fit the constant VG or polynomial function
- restore the theoretically calculated attraction

- so called "remove-restore" (rmr) method (or remove-fit-restore(rfr)?)

Implementation1

- Functional model

The functional model for remove-restore method is following:

$$dg-\sum_{i=1}^{k}\left[M_i(h_2)-M_i(h_1)\right]=\sum_{i=1}^{n}c_i\left(h_2^i-h_1^i\right),\ (1)$$

where dg is observed gravity difference between heights h_1, h_2 and $M_i(h)$ is the modeled attr
of i-th (i = 1:k) local mass (e.g. a part of pier) at height h (along the vertical).

- we know well the dimensions of pier in every 1st order station but not the densities (or density contrasts)!

Implementation2

- Functional model

The model (1) can now be written:

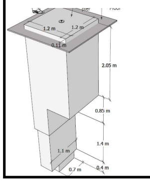
$$dg=\sum_{i=1}^{n}c_i\left(h_2^i-h_1^i\right)+\sum_{i=1}^{k}\Delta\rho_i\left[M_i'(h_2)-M_i'(h_1)\right],\ (2)$$

where $M'(h)$ is the attraction of the i-th body with unit density contrast ($\Delta\rho'$ = 1 [Mg/m³

- Software WZZ (f77, LS method, multiple bodies: rectangular prisms and/or cylinders)

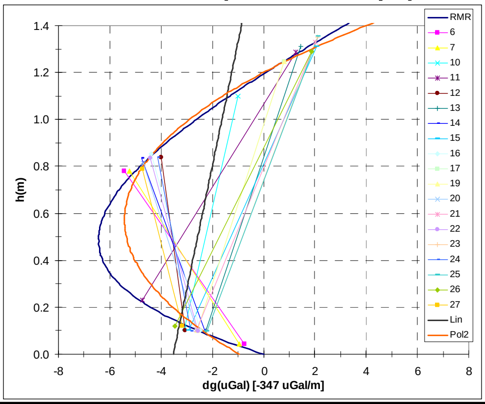
Results (in Suurupi)

Trial	rho (adj. Yes/No)	Poly-nomial degree	RMS of residuals	g0 (at mark height)	stdev of g0	rho1 (adjusted or fixed)	stdev of rho1	rho2 (adjusted or fixed)	stdev of rho2	Method
1	N	1	3.01	981823926.9	2.0	0.0	0.0	0.0	0.0	Pol.fit
2	N	2	0.72	981823929.5	0.5	0.0	0.0	0.0	0.0	Pol.fit
3	N	1	1.40	981823928.76	0.92	2400	0.0	300	0.0	RMR
4	N	2	0.59	981823929.89	0.42	2400	0.0	300	0.0	RMR
5	Y	1	0.50	981823930.4	0.33	2400	0	1032	65	RMR
6	Y	2	0.44	981823931.2	0.31	2400	0	2179	485	RMR
7	Y	1	0.51	981823930.38	0.33	2779	0	932	65	RMR
8	Y	1	0.51	981823930.32	0.34	3348	249	779	0	RMR
9	N	1	0.57	981823930.03	0.38	2779	0	779	0	RMR

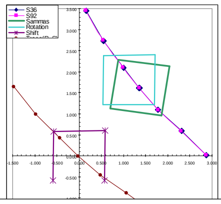


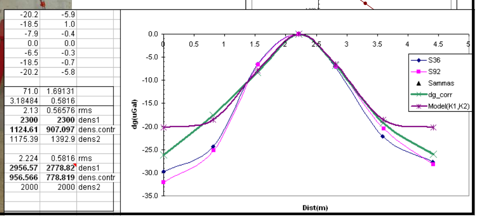
NB! Pier divided into two: upper body (above the floor, with rho1) and lower body (below floor, rho2)

Results (in Suurupi)



Horiz.profile over the pier to find rho1 or rho2





Results

- Small empty rectangle around BM complicates situaton (e.g. in TOIL):

TOIL

0.88	1.05	981848755.04	1.16	Wzz1_d1_rho-0(r1).out	order=1, 1 lug.eemal.
0.26	0.34	981848756.19	0.42	Wzz1_d2_rho-0(r1).out	order=2, 1 lug.eemal.
0.78	0.99	981848756.57	1.19	Wzz1_d2_rho-0.out	order=2
0.81	1.03	981848757.28	1.43	Wzz1_d1_rho-adj1.out	RMR (dens1(adj)=764, order=1
0.27	**0.32**	**981848756.95**	**0.36**	**Wzz1_d1_rho-fix(r1).out**	**RMR (dens1=797), order=1**
0.28	**0.33**	**981848754.45**	**0.36**	**Wzz1_d1_rho-fix2(r1).out**	**RMR (dens1=863, dens2=-1954(small box)), ord**
0.81	1.03	981848754.78	1.41	Wzz1_d1_rho-adj3(r0).out	RMR (dens1(adj)=832, dens2=-1954(small box)),

g values at the BM height: small box first exluded then included

Conclusions

- Absolute gravity value at BM level may differ several uGal and depends on how to model local gravity field
- Test nonlinearity of VG. Avoid to use constant VG!
- RMS values show better performance with „rmr" (not always)
- Overfit danger: unrealistic results (*rho*)
- Publication is under preparation

Software package GRAVS2 for advanced process of relative gravity data.

T. Oja

Intro

- Since 2001 renovation of 2nd order gravity network in Estonia. Two important issues:
  - Observations
  - Data processing
- What software to use? Develop its own soft to solve:
  - addition of corrections
  - calibration
  - adjustment, drift, tares(jumps), statistical tests

Choices, tested soft in 2001-2003

- *KMS* (Kort & Matrikelstyrelsen, Denmark) tarkvarapaketti *GRAVSOFT* kuuluvad ***GRREDU*** ja ***GRADJ*** (ANSI fortran 77)
- Saksamaal (University of the Federal Armed Forces Munich, *IfEN*) välja arendatud ***GravAP*** (Gravimetric Adjustment Package Software) (piiratud kasutus, kirjutatud C-s)
- Soome Geodeesia Instituudi (*FGI*) programmid ***GRED*** ja ***GADJD*** (MS fortran 77)
- Taiwani Rahvuslikus Chiao Tung Ülikoolis välja töötatud programmi ***GRAVNET*** **(**FORTRAN90) (Hwang jt., 2002)
- ***CG3TOOL*** - interactive computer program to process Scintrex CG-3/3M gravity data (freeware, Sun Solaris, C)

In 2003

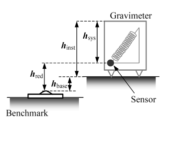
- In 2003 it was decided to continue with GRREDU, GRADJ
- GRREDU:
  - LGR calibration table (in source code)
  - scale factor
  - tidal correction (Longman's algorithm, δ=1.16)
- GRADJ:
  - Functional model: $sy = g + a + Dt$
- Rene: "It is OK to use and modify programs." (e-mail 2000)

In 2010

- GRAVS2:
  - Preprocessing: sform2 (CG5 *.txt -> GRREDU2 *.obs), tform (GRREDU-> GRREDU2 *.obs) etc
  - Corrections, calibr.info: GRREDU2
  - Network adjustment, drift and calibration computation: GRADJ2
  - Postprocessing: GRLOOP2(misclosures), histogram, WZZ (vert.gradient), anomaly

GRREDU2 (corrections):

- Tides: Tamura1200 (1987) development, local parameters (δ, $\Delta\varphi$) for the wavegroups from the global grid (Wenzel,Timmen 1994), for M_0S_0 δ=1.0, $\Delta\varphi$ = 0.0
- Atmosphere: observed, normal air pressure (DIN 5450) and the coefficient –0.3 µGal/hPa
- Sensor height (linear func): observed VGG*h_{red} (for LGR-G h_{red} ~ 5-10 cm, for CG5 h_{red} ~ 10…25 cm)
- GIA: $\dot{g}(t) = \dot{g}(t - T_0)$
- Calibration: polynomial, periodic
- Polar motion: IERS EOP-PC timeseries



GRREDU2 (corrections):

- Tides: Tamura1200 (1987) development, local parameters (δ, $\Delta\varphi$) for the wavegroups from the global grid (Wenzel,Timmen 1994), for M_0S_0 δ=1.0, $\Delta\varphi$ = 0.0
- Atmosphere: observed, normal air pressure (DIN 5450) and the coefficient –0.3 µGal/hPa
- Sensor height (linear func): observed VGG*h_{red} (for LGR-G h_{red} ~ 5-10 cm, for CG5 h_{red} ~ 10…25 cm)
- GIA: $\dot{g}(t) = \dot{g}(t - T_0)$
- Calibration: polynomial, periodic
- Polar motion: IERS EOP-PC timeseries

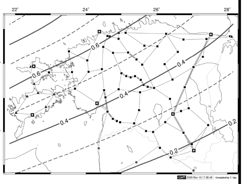


Figure 4. Contours represent $\dot{g}$ isolines (µGal/yr), derived from the NKG2005LU uplift map (Ågren, Svensson (2007)). The eustatic rise of mean sea level (+1.32 mm/yr), the uplift of the geoid (about 6 %) were added and then scaled by value 0.2 µGal/mm (see Ekman, Mäkinen (1996)).

GRADJ2

- Functional model:

$$y^t = g^{T_0} + \dot{g}^{T_0}(t - T_0) + a + \sum_{p=1}^{r} d_p (t - t_0)^p +$$

$$+ \sum_{k=1}^{m} c_k z^k + \sum_{l=1}^{n} E_l \sin(2\pi z / P_l + \varphi_l)$$

For more details, see my presentations during previous NKG Geodyn.WG meetings

GRADJ2

- x´ - a best linear unbiased estimator (BLUE):
  $A^T P A \boldsymbol{x}' = A^T P \boldsymbol{b}$ ➔ $\boldsymbol{x}' = (A^T P A)^{-1} A^T P \boldsymbol{b}$
- Covariance matrices:
  $\Sigma_{x'} = \sigma^{*2}_0 (A^T P A)^{-1} = \sigma^{*2}_0 / \sigma_0^2 (A^T \Sigma_b^{-1} A)^{-1}$
  $\Sigma_{r'} = \sigma^{*2}_0 (P^{-1} - A(A^T P A)^{-1} A^T)$
- Choleski decomposition: $(A^T P A)\boldsymbol{x} = A^T P \boldsymbol{b}$ ➔ $G\boldsymbol{y} = A^T P \boldsymbol{b}$ ➔ $G^T \boldsymbol{x} = \boldsymbol{y}$
- Statistical tests: Student's *t*-test, χ^2 statistic, Pope's *t*-test (at conf. level selected by user)

Usage of GRAVS2

- free GNU f77 compiler (or free Force2) to make exe files
- input: ASCII txt files (obs, parameter files)
- bat scripts (MS-DOS, could be modified for Linux shells)
- preprocessing: sform2, tform
- postprocessing: GRLOOP2, hist, WZZ, anomaly
- For some scripts GMT, gawk are needed (both open & free)

Example of bat script:

Lister - [c:\PROGS\redu27.bat]
File Edit Options Encoding Help

```
@echo off

set exe=Grredu274

echo SCRIPT FILE FOR %exe% by T.OJA Jan 2010

set tmpfile=in

echo *** INPUT PARAMETERS:
echo set timezone (..,-1,0,1,2,..), epoch (DDMMYY)
echo 0 2008-07-31> %tmpfile%

echo set ltide,lpres,lfair,lpmot,ltime
echo t t t f t >> %tmpfile%

echo set iprint,imodel,irigid
echo 0 2 0 >> %tmpfile%

echo set pcoef (uGal/hPa)
echo -0.3 >> %tmpfile%

echo *** INPUT FILE NAME:
echo %DATA%\coord_2010
REM
echo %DATA%\coord_2010 >> %tmpfile%
REM echo E:\data\grant7356\EMU2009\Tatjana_arvutused\minu_arvutus\coord.txt >> %tmpfile%

echo %DATA%\coord_2010.tide
REM
echo %DATA%\coord_2010.tide >> %tmpfile%
REM echo E:\data\CG5data\2009\2009-04-17_Vortsjarv_Peipsi_baas\adj_all\coord.tide >> %tmpfile%
REM echo C:\graviope\data\coord.tide >> %tmpfile%

echo %DATA%\ETCPOT.DAT
echo %DATA%\ETCPOT.DAT >> %tmpfile%
```

GRREDU vs GRREDU2

- Observation file:

```
# G-999    Pärnu baas 2007 EGK
80046 290507 08.14 1000
80014 290507 08.29 1000
80046 290507 08.43 1000
80014 290507 08.58 1000
80006 290507 09.31 1000
```

```
# G-191    TORA-Kanepi-HAAN 2009 EMU
   80003   2009-11-27   05:29:00   5295.9560  0.0100   249   -999.9  -99.9  -99.9  -99
   80003   2009-11-27   05:31:00   5295.9580  0.0100   249   -999.9  -99.9  -99.9  -99
   80003   2009-11-27   05:35:00   5295.9600  0.0100   249   -999.9  -99.9  -99.9  -99
   80003   2009-11-27   05:43:00   5295.9720  0.0100   249   -999.9  -99.9  -99.9  -99
   80003   2009-11-27   05:45:00   5295.9710  0.0100   249   -999.9  -99.9  -99.9  -99
   80003   2009-11-27   05:46:00   5295.9730  0.0100   249   -999.9  -99.9  -99.9  -99
```

- Coordinate file:

```
80046   59.163890      25.194440      63.16   Kose-Risti
80014   59.060367      25.431500      86.22   Mustla
```

```
80001   Kuressaare      58.251944       22.485278       4.40    2700    0.46
80002   Suurupi 59.463577       24.380255       43.32   3500    0.64
80003   Toravere        58.264367       26.463421       71.79   3200    0.28

80004   Haljala_I       59.431189       26.268144       73.33   3086    0.51
80005   Heimtali_I      58.321900       25.504333       79.07   3086    0.34
80006   Reiu    58.298780       24.610220       6.13    3238    0.37
```

- Input file:

```
gravi_EGK_2007_UT3
coord.txt
gravi_EGK_2007_UT3.red
2
3
59 25 50
```

```
0 2008-08-01
f f f f f
0 2 0
-0.3
E:\DATA\coord_2008
E:\DATA\coord_2008.tide
E:\DATA\ETCPOT.DAT
E:\DATA\eopc04.70-now
E:\DATA\meter_new.cal
E:\DATA\meter10.par
271109_G191.obs2
```

GRREDU vs GRREDU2

- Local parameters (δ, $\Delta\varphi$) for the wavegroups:

```
#     80001 Kuressaare     58.251944  22.485278       4.400
    1    1   M0S0  1.0000  0.0000
    2  285     MF  1.1730 -0.1854
  286  428     Q1  1.1469  0.0086
  429  537     O1  1.1483  0.1886
  538  555     P1  1.1474  0.0925
  556  593     K1  1.1327  0.0165
  594  634     J1  1.1600  0.0000
  635  739    OO1  1.1600  0.0000
  740  890     N2  1.1727  1.0596
  891  973     M2  1.1815  0.7985
  974 1004     S2  1.1760  0.0710
 1005 1121     K2  1.1696 -0.1345
 1122 1214     M3  1.0682  0.0000
```

- Calibration table for LCR

```
# G-65
4800    4968.700        1.038100
4900    5072.510        1.038100
5000    5176.320        1.038150
5100    5280.135        1.038200
5200    5383.955        1.038250
5300    5487.780        1.038350
5400    5591.615        1.038350
5500    5695.450        1.038400
# G-191
5000    5190.380        1.04170
5100    5294.550        1.04170
```

- Instrument's sensor height, calibration info:

```
# S-92
211
99
1.00000
# S-36
211
0
# G-191
159
99
0.9992333766
1
```

Result file

- GRREDU

```
# G-999   Pärnu baas 2007 EGK
   80046  290507,  8.14     1  1000.000    -0.003  1999.997  Kose-Risti
   80014  290507,  8.29     2  1000.000     0.004  2000.004  Mustla
   80046  290507,  8.43     3  1000.000     0.010  2000.010  Kose-Risti
   80014  290507,  8.58     4  1000.000     0.017  2000.017  Mustla
```

- GRREDU2

```
|                                      |-------C.U.-------|----------CORRECTIONS (uGal)----------|--------mGal--------|
 station      date,      time     nr        reading         tides  air-   free-   polar    gdot    calibr.  reduced   station
 number                  UT + 0                                    pres.  air     motion           error    reading   name
# G-191   TORA-Kanepi-HAAN 2009 EMU
   80003  2009-11-27, 05:29:00     1  5295.9560     10.0   -44.7   0.0   28.8    0.0   -0.4   -4.2650  5494.3941 Toravere
   80003  2009-11-27, 05:31:00     2  5295.9580     10.0   -44.7   0.0   28.8    0.0   -0.4   -4.2650  5494.3962 Toravere
   80003  2009-11-27, 05:35:00     3  5295.9600     10.0   -44.9   0.0   28.8    0.0   -0.4   -4.2650  5494.3981 Toravere
   80003  2009-11-27, 05:43:00     4  5295.9720     10.0   -45.1   0.0   28.8    0.0   -0.4   -4.2651  5494.4103 Toravere
   80003  2009-11-27, 05:45:00     5  5295.9710     10.0   -45.2   0.0   28.8    0.0   -0.4   -4.2651  5494.4092 Toravere
   80003  2009-11-27, 05:46:00     6  5295.9730     10.0   -45.2   0.0   28.8    0.0   -0.4   -4.2651  5494.4113 Toravere
   80911  2009-11-27, 06:49:00     7  5276.8690     10.0   -48.8   0.0   36.7    0.0   -0.3   -4.1686  5474.6120 Kanepi
   80911  2009-11-27, 06:50:00     8  5276.8700     10.0   -48.9   0.0   36.7    0.0   -0.3   -4.1686  5474.6129 Kanepi
   80911  2009-11-27, 06:51:00     9  5276.8700     10.0   -48.9   0.0   36.7    0.0   -0.3   -4.1686  5474.6128 Kanepi
   80911  2009-11-27, 06:56:00    10  5276.8710     10.0   -49.4   0.0   36.7    0.0   -0.3   -4.1686  5474.6134 Kanepi
   80911  2009-11-27, 06:58:00    11  5276.8710     10.0   -49.6   0.0   36.7    0.0   -0.3   -4.1686  5474.6132 Kanepi
   80911  2009-11-27, 06:59:00    12  5276.8720     10.0   -49.7   0.0   36.7    0.0   -0.3   -4.1686  5474.6141 Kanepi
   80702  2009-11-27, 07:50:00    13  5218.3450     10.0   -55.6   0.0   29.6    0.0   -0.2   -4.1802  5413.6231 HAAN
```

GRADJ2

- Input files:

2009-06-10_G191.par - Notepad

```
# G-191
!!d1-2
s11
t17
!!s17-19
!s20-21
!!t20
!s27
!s29
```

G191cal.proj - Notepad

```
6   T   99
0.003 0.95
5000  0.002
F  1995-10-01
80003  981759.666  0.004  TORA
80702  981678.859  0.004  HAAN
80006  981772.201  0.01   Reiu
80035  981737.796  0.01   Lodja
80046  981819.894  0.01   P-Jaagupi_I
80911  981739.895  0.02    Kanepi
```

GRADJ2 examples:

- Output files (*.resi):

G191cal.resi - Notepad

```
G191cal.proj
 ---------------------------------------------------------------
 Critical values for parameter and residual statistical tests:
 conf.level=  0.95, t-crit=  2.00, tau-crit=  2.06

 === Residuals of the readings with tare and drift info ===
 ----------------------------------------------------------------------------------------------------------
  station   date,     time      instr. seqno  obs      weight     drift    res  st.res  red.no  res.plot   station
  number                        number       (mGal)                       (uGal)   tau-test   ( 2 uGal/div)  name
 ----------------------------------------------------------------------------------------------------------
 DRIFT degree = 1
 DRIFT of  1 order:    -132.5 ±      9.1 uGal/day^1 (t-stat= 14.60)
 BIAS parameter:     -265084.6 ±  382.2 uGal
  80046  2009-06-10, 09:57:00  191     1  5559.0630   2.25      0.0    1.7    1.1      0.8      !*      P-Jaagupi_I
  80046  2009-06-10, 10:00:00  191     2  5559.0650   2.25     -0.3   -0.5    0.3      0.8      *       P-Jaagupi_I
  80046  2009-06-10, 10:02:00  191     3  5559.0656   2.25     -0.5   -1.3    0.8      0.8     *!       P-Jaagupi_I
  80046  2009-06-10, 10:09:00  191     4  5559.0645   2.25     -1.1   -0.9    0.5      0.8      *       P-Jaagupi_I
  80046  2009-06-10, 10:10:00  191     5  5559.0658   2.25     -1.2   -2.3    1.4      0.8     *!       P-Jaagupi_I
  80006  2009-06-10, 11:20:00  191     6  5511.3759   2.25     -7.6    0.0    0.0      0.8      *       Reiu
  80006  2009-06-10, 11:21:00  191     7  5511.3749   2.25     -7.7    0.9    0.6      0.8      *       Reiu
  80006  2009-06-10, 11:22:00  191     8  5511.3750   2.25     -7.8    0.7    0.5      0.8      *       Reiu
  80006  2009-06-10, 11:25:00  191     9  5511.3763   2.25     -8.1   -0.8    0.5      0.8      *       Reiu
  80006  2009-06-10, 11:26:00  191    10  5511.3763   2.25     -8.2   -0.9    0.6      0.8      *       Reiu
  80046  2009-06-10, 12:30:00  191    12  5559.0507   2.25    -14.1   -0.2    0.1      0.8      *       P-Jaagupi_I
  80046  2009-06-10, 12:31:00  191    13  5559.0495   2.25    -14.2    0.9    0.6      0.8      *       P-Jaagupi_I
  80046  2009-06-10, 12:32:00  191    14  5559.0494   2.25    -14.3    0.9    0.6      0.8      *       P-Jaagupi_I
  80046  2009-06-10, 12:59:00  191    15  5559.0476   2.25    -16.7    0.3    0.2      0.8      *       P-Jaagupi_I
  80046  2009-06-10, 13:00:00  191    16  5559.0463   2.25    -16.8    1.5    0.9      0.8      !*      P-Jaagupi_I
            TARE:       30.5 ±    1.7 uGal     (t-stat= 17.50)
  80006  2009-06-10, 14:01:00  191    17  5511.3882   2.25      0.0    3.3    2.1      0.8      ! *     Reiu
  80006  2009-06-10, 14:03:00  191    18  5511.3906   2.25     -0.2    0.7    0.5      0.8      *       Reiu
  80006  2009-06-10, 14:06:00  191    19  5511.3905   2.25     -0.5    0.6    0.3      0.8      *       Reiu
  80035  2009-06-10, 15:00:00  191    22  5476.8814   2.25     -5.4   -0.4    0.3      0.8      *       Lodja
```

GRADJ2 examples:

- Output files (*.resi2):

G191cal.resi2 - Notepad

```
G191cal.proj
 ---------------------------------------------------------------
 Critical values for parameter and residual statistical tests:
 conf.level=  0.95, t-crit=  2.00, tau-crit=  2.06

 === AVERAGED readings, residuals etc with tare and drift info ===
 ----------------------------------------------------------------------------------------------------------
  station   date,     time      instr. no  seqno  obs      weight    drift    res  st.res  red.no  res.plot   station
  number                        number     (init) (mGal)                     (uGal)   tau-test   ( 2 uGal/div)  name
 ----------------------------------------------------------------------------------------------------------
 DRIFT degree = 1
 DRIFT of  1 order:    -132.5 ±      9.1 uGal/day^1 (t-stat= 14.60)
 BIAS parameter:     -265084.6 ±  382.2 uGal
  80046  2009-06-10, 10:03:36  191     1     1  5559.0648   2.25     -0.6   -0.7    0.8     0.8     *      P-Jaagupi_I
  80006  2009-06-10, 11:22:48  191     2     6  5511.3757   2.25     -7.9    0.0    0.4     0.8     *      Reiu
  80046  2009-06-10, 12:42:24  191     3    12  5559.0487   2.25    -15.2    0.7    0.5     0.8     *      P-Jaagupi_I
            TARE:       30.5 ±    1.7 uGal       (t-stat= 17.50)
  80006  2009-06-10, 14:03:20  191     4    17  5511.3898   2.25     -0.2    1.5    1.0     0.8     !*     Reiu
  80035  2009-06-10, 15:04:24  191     5    22  5476.8806   2.25     -5.8   -0.1    0.6     0.8     *      Lodja
  80006  2009-06-10, 15:53:00  191     6    28  5511.3825   2.25    -10.3   -1.4    1.0     0.8    *!      Reiu
 DRIFT degree = 2
 DRIFT of  1 order:    -208.7 ±     20.6 uGal/day^1 (t-stat= 10.13)
 DRIFT of  2 order:     760.0 ±     49.6 uGal/day^2 (t-stat= 15.33)
            TARE:     -199.8 ±   13.5 uGal       (t-stat= 14.83)
  80003  2009-11-27, 05:44:40  191     7     4  5498.6754   2.25     -0.2    2.9    1.8     0.8     !*     Toravere
  80911  2009-11-27, 06:53:50  191     8     7  5478.7817   2.25     -8.4   -1.5    0.9     0.9    *!      Kanepi
            TARE:       30.3 ±    1.6 uGal       (t-stat= 19.39)
  80702  2009-11-27, 07:55:20  191     9    13  5417.8035   2.25     -0.3   -1.2    0.7     0.9    *!      HAAN
  80911  2009-11-27, 08:46:40  191    10    19  5478.8046   2.25     -1.8    0.3    0.6     0.9     *      Kanepi
  80003  2009-11-27, 09:44:30  191    11    25  5498.6960   2.25     -1.1   -0.7    1.1     0.9     *      Toravere
  80911  2009-11-27, 10:45:00  191    12    31  5478.8070   2.25      2.2    1.8    1.0     0.9     !*     Kanepi
  80702  2009-11-27, 11:45:20  191    13    37  5417.8096   2.25      8.1    1.2    0.9     0.9     !*     HAAN
  80911  2009-11-27, 12:38:10  191    14    43  5478.8227   2.25     15.5   -0.5    1.0     0.9     *      Kanepi
  80003  2009-11-27, 13:32:10  191    15    54  5498.7225   2.25     25.2   -0.8    0.6     0.9     *      Toravere
  RMS residuals:      1.7 uGal
 WRMS residuals:      1.7 uGal
 ---------------------------------------------------------------
```

GRADJ2 examples:

- Output files (*.grav):

G191cal.grav - Notepad

```
G191cal.proj
 # ===== Fixed stations and adjustment residuals (mGal) =====
 #      stat      fix g       sigma    weight       adj g         v     statname
  1     80003  981759.6660  0.0040   0.563    981759.6674  0.0014  Toravere
  2     80702  981678.8590  0.0040   0.563    981678.8585 -0.0005  HAAN
  3     80006  981772.2010  0.0100   0.090    981772.1966 -0.0044  Reiu
  4     80035  981737.7960  0.0100   0.090    981737.8031  0.0071  Lodja
  5     80046  981819.8940  0.0100   0.090    981819.8913 -0.0027  P-Jaagupi_I
  6     80911  981739.8950  0.0200   0.022    981739.8739 -0.0211  Kanepi

 # ===== Adjusted results with standard deviations (mGal) =====
 no   statno  gravity and stdev     statname

 === Calibration results of gravimeters ===

 Instrument no: 191
 == Terms of polynomial calibration function:
  deg.  coef. with std.dev      t-stat.
  1  0.9992333766  0.0000693414    11.1

 == Terms of periodical calibration function:
  Per.(CU),  x(cos) with st.dev, t-test, y(sin) with st.dev, t-test [UNIT=uGal]
   70.9412,    -7.2919 ± 12.5463,    0.6  -55.4745 ± 10.6092,     5.2 !
 ..and ampl.A(μGal) and phase for A*sin(2*pi*z/period+phase) with stdev-s
   70.9412,    55.9517,  187.4884, ±   11.8286, ±   11.6779

 === Statistics of adjustment ===
 Adjustment observations:    83
 Stations:                    6
 Total unknowns:             16
 Degrees of freedom:         67
 SIGMA1 (apriori standard dev. of unit weight)    :   0.0030
 SIGMA2 (aposteriori standard dev. of unit weight):   0.0027

 === Statistical tests ===
 Confidence level:      0.950

 == Critical t-value for statistical parameter testing: t-crit=  2.00
 NB! If t-stat > t-crit -> parameter significant, else with " ! " mark.

 == Chi-square test of the SIGMA1 (variance factor) ==
 Statistic (norm. with dof): X²= 0.82
                 X² lower value = 0.69
                 X² upper value = 1.37  ->  test PASSED!

Common epoch:  2009.442
```

GRADJ2 examples:

- Output files (*.ties):

```
G191cal.ties - Notepad
File  Edit  Format  View  Help
   from    /   to         inst.no  date         time      dt(hr) dg(mGal) dD(µGal) dg+dD     dv    dg+dD+dv
Reiu          P-Jaagupi_I    191  2009-06-10, 10:03:36  1.320   47.6891   -7.3   47.6818  -0.6   47.6812
Reiu          P-Jaagupi_I    191  2009-06-10, 11:22:48  1.327   47.6730    7.3   47.6803   0.7   47.6810
Reiu          Lodja          191  2009-06-10, 14:03:20  1.018  -34.5091    5.6  -34.5035  -1.6  -34.5051
Reiu          Lodja          191  2009-06-10, 15:04:24  0.810  -34.5019   -4.5  -34.5064   1.4  -34.5050
Toravere      Kanepi         191  2009-11-27, 05:44:40  1.153  -19.8937    8.2  -19.8855  -4.4  -19.8899
HAAN          Kanepi         191  2009-11-27, 07:55:20  0.856   61.0011    1.5   61.0026   1.4   61.0040
Toravere      Kanepi         191  2009-11-27, 08:46:40  0.964  -19.8915    0.6  -19.8909   1.0  -19.8899
Toravere      Kanepi         191  2009-11-27, 09:44:30  1.008  -19.8890   -3.3  -19.8923   2.5  -19.8898
HAAN          Kanepi         191  2009-11-27, 10:45:00  1.006   60.9974    5.9   61.0033   0.6   61.0039
HAAN          Kanepi         191  2009-11-27, 11:45:20  0.881   61.0131   -7.4   61.0057  -1.7   61.0040
Toravere      Kanepi         191  2009-11-27, 12:38:10  0.900  -19.8998    9.7  -19.8901   0.3  -19.8898
   11 ties
```

GRADJ2 examples:

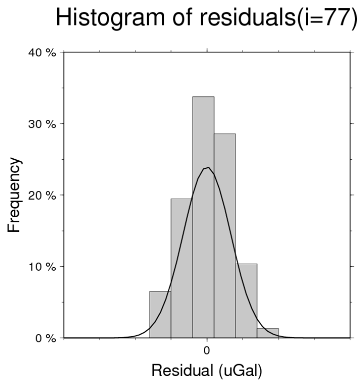
- Output files (*.cov):

```
G191cal.cov - Notepad
File  Edit  Format  View  Help
Lower triangular of symmetric covariance matrix (Cx) of adjusted parameters with dim(  16,  16):
         10.051823
         -0.909049      10.291915
          1.968337       1.728245       7.414530
          0.362599       0.319613      -0.682212       1.651830
         -4.255461      -3.843289       8.098750       1.498184      26.405800
         -0.192380      -0.165881       0.358262       0.066021      -0.776638
```

...

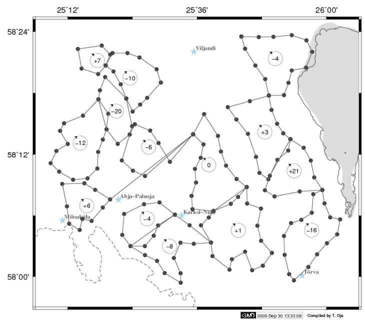
```
  from    /     to          adj.dg(mGal)   stdev (µGal)
Toravere     --> HAAN          -80.8089 ±    4.9
Toravere     --> Reiu           12.5292 ±    7.9
Toravere     --> Lodja         -21.8643 ±    7.8
Toravere     --> P-Jaagupi_I    60.2240 ±    7.6
Toravere     --> Kanepi        -19.7934 ±   13.6

HAAN         --> Reiu           93.3381 ±    9.1
HAAN         --> Lodja          58.9446 ±    8.8
HAAN         --> P-Jaagupi_I   141.0329 ±   -1.$
HAAN         --> Kanepi         61.0155 ±   14.5

Reiu         --> Lodja         -34.3934 ±   10.2
Reiu         --> P-Jaagupi_I    47.6948 ±   12.8
Reiu         --> Kanepi        -32.3226 ±   18.1

Lodja        --> P-Jaagupi_I    82.0882 ±   -1.$
Lodja        --> Kanepi          2.0708 ±   11.4

P-Jaagupi_I  --> Kanepi        -80.0174 ±   18.2
```

hist4



GRLOOP2(+GMT) example:

- Closing errors in S-Estonia:



GRAVS2 training days in Feb. 2010 at ELB

GRAVS2

- Under preparation:
  – manuals (EST, hopefully also ENG)
  – simple homepage (links to source codes, binaries, upgrades, FAQ, manuals etc)
  – not bug-free
- Free for everyone to try, use and modify!