Comparison between measurements with the superconducting gravimeter T020 and the absolute gravimeter FG5-221 at Metsähovi, Finland in 2003-2012

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The superconducting gravimeter (SG) T020 is recording at Metsähovi gravity laboratory since 1994. Regular absolute gravimeter (AG) measurements have taken place between 1988 and 2002 with the JILAg-5 gravimeter and from 2003 onwards with the FG5-221. We have compared results of the SG and the AG between 2003 and 2012.
The SG is a relative instrument, which should regularly be compared with an AG for determination of drift, to connect SG data after longer gaps, and to remove big offsets. Additionally, the scale factor of the SG needs to be determined using simultaneous observations with an AG. Conversely, comparison of SG and AG time series can support AG observations by detecting possible instrument problems in the AG.

For calibration we have used the time series of both instruments without any corrections. For drift comparison we have corrected the time series of both instruments in a similar way for three effects: tides, polar motion and influence of the atmosphere.

When a discrepancy appears between the SG and the AG time series, it may indicate a problem with one of the instruments. For determining which instrument is producing the more plausible result we can compare their data with models of environmental effects in gravity, not included in the above-mentioned three standard corrections. In Metsähovi, the hydrological variation (local-regional-global) is the largest effect. Seasonal variation can be up to 8 μgal peak-to-peak. In addition, loading by the Baltic Sea causes effects up to 3 μgal. The hydrological signal is seen in both the SG and AG data. More generally, most of the variation in AG time series is also seen in the SG data and can therefore be attributed to the same environmental effects.
Finally, correcting the AG record on the basis of models confirmed by the SG can improve the precision of determination of the gravity trend due to postglacial rebound.

Introduction

The superconducting gravimeter (SG) is a relative instrument, and as such should regularly be compared with an absolute gravimeter (AG) for determination of drift, to connect SG data after longer gaps, and to remove big offsets. Additionally, the scale factor of the SG needs to be determined using simultaneous observations with an AG. Conversely, comparison of SG and AG time series can support AG observations by detecting possible instrument problems in the AG. The SG T020 has been recording at Metsähovi (Finland) gravity laboratory since August 1994. Regular AG measurements have taken place between 1988 and 2002 with the JILAg-5 gravimeter and from 2003 onwards with the FG5-221. Determination of the gravity trend due to postglacial rebound has also been carried out.
Here we present results from comparisons of SG data and specific AG measurements campaigns aimed at calibrating the SG.

SG calibration

The scale factor for SG (T020) was first calibrated using simultaneous observations with the absolute gravimeter JILAg-5 in 1995. From that calibration we adopted the value **110.7±0.30** (µGal/V). Thereafter calibration has been checked occasionally. Some comparisons with ocean loading models seem to indicate that the value above is too high by 0.3 % (Baker and Bos, 2001; 2003). To obtain a large tidal amplitude, the AG-based calibrations were carried out near new or full moon. Typically, 2400 drops in the absolute gravimeter per day were carried out, the whole calibration lasting 2-7 days (mean 3.5 days).

We have about 130 common datasets at Metsähovi, most of them are short (1 day) and used for checking FG5-221 and for geodynamics studies. We have selected to this study 24 datasets, with durations of 2-7 days. For calibration we have used the time series of both instruments without any corrections. Data of SG was 1-second records in Volts. The data of AG consist of 50 drops in sets of 30 minute intervals. Duration of a set was 500 seconds (50 drops, every 10 second). We have regressed the gravity value (mean time of 50 drops) and SG data of ±250 seconds. We have tested several methods for determining the best mean of 500 SG gravity value e.g. mean, median and filtering to 1-minute. Results were practically the same. For AG observations g7 software was used. As weights in regression we have used the drop scatter error (g7). There was no significant difference in the results, regardless of either precision or uncertainty errors were applied or not. Used datasets are presented in the **Table 1**. An example of one dataset is shown in the **Fig 1**. Results from the comparisons are presented in **Fig 2**, showing both calibration factor and the linear drift of the SG. The drift of the SG includes also the trend of the Fennoscandian postglacial rebound (2 mm/year). The new calibration factor for SG T020 is 110.43±0.12 µGal/V.

Table 1. Calibration data sets and results. Numbers 1-20 were measured at pillar AB and numbers 21 – 24 at pillar AC. Total of 4033 sets including 201650 drops. Dur= Duration in days, Amp= max amplitude in µgals. In calculation a constant value (98191000) were subtracted. Cal=calculated calibration factor and standard error of result. Nset=number of dropping sets used.

Number	Date	Dur	Ampl	Constant	Cal	Err	Nset
1	2003 11 15 22 4	2	140	6698.518	-109.891	0.601	96
2	2003 11 25 13 19	2	208	6697.768	-110.963	0.471	70
3	2004 10 7 21 1	2	116	6697.788	-109.045	0.980	77
4	2004 11 2 22 39	2	141	6697.543	-111.703	0.712	94
5	2004 12 16 18 39	2	159	6701.405	-111.888	0.950	89
6	2005 1 8 4 2	5	**231**	6697.780	-109.918	0.387	232
7	2005 1 12 16 2	4	213	6697.874	-110.801	0.512	185
8	2005 1 23 16 24	4	170	6696.671	-109.852	0.428	201
9	2005 8 5 4 39	2	137	6699.339	-109.093	0.792	63
10	2006 6 6 7 29	2	92	6699.465	-109.487	1.121	89
11	2006 6 14 7 9	4	202	6699.657	-110.388	0.334	183
12	2006 7 12 8 36	3	201	6688.106	-110.060	0.357	164
13	2007 12 25 2 56	3	220	6695.660	-110.570	0.595	124
14	2008 1 23 17 57	6	202	6697.636	-109.736	0.446	248
15	2008 6 18 2 49	3	167	6687.720	-110.544	0.298	142
16	2008 11 15 0 34	5	212	6672.160	-110.818	0.286	235
17	2008 12 14 3 6	5	225	6675.679	-110.898	0.266	237
18	2010 12 6 3 2	7	187	6673.467	-110.191	0.265	331
19	2012 6 3 19 39	7	198	6672.307	-110.376	0.221	316
20	2012 8 18 20 9	**7**	143	6671.595	-110.500	0.170	265
21	2004 4 10 13 54	2	162	6709.243	-110.561	0.642	96
22	2004 5 4 21 24	2	177	6707.056	-110.037	0.485	96
23	2004 8 21 14 44	2	106	6699.916	-111.439	1.004	96
24	2005 6 7 17 41	3	176	6700.378	-111.025	0.378	126

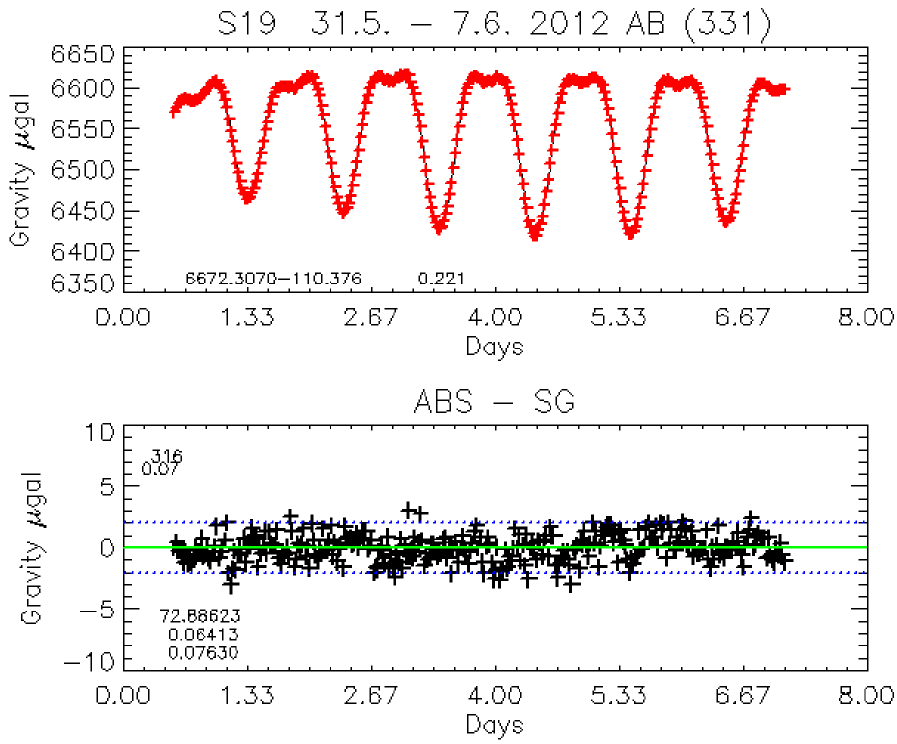

Fig 1: Data set number 19, Top: SG solid black line, AG marked with red cross. Bottom scattering of AG measurements after regression, dotted lines shows limits of 2µgals.

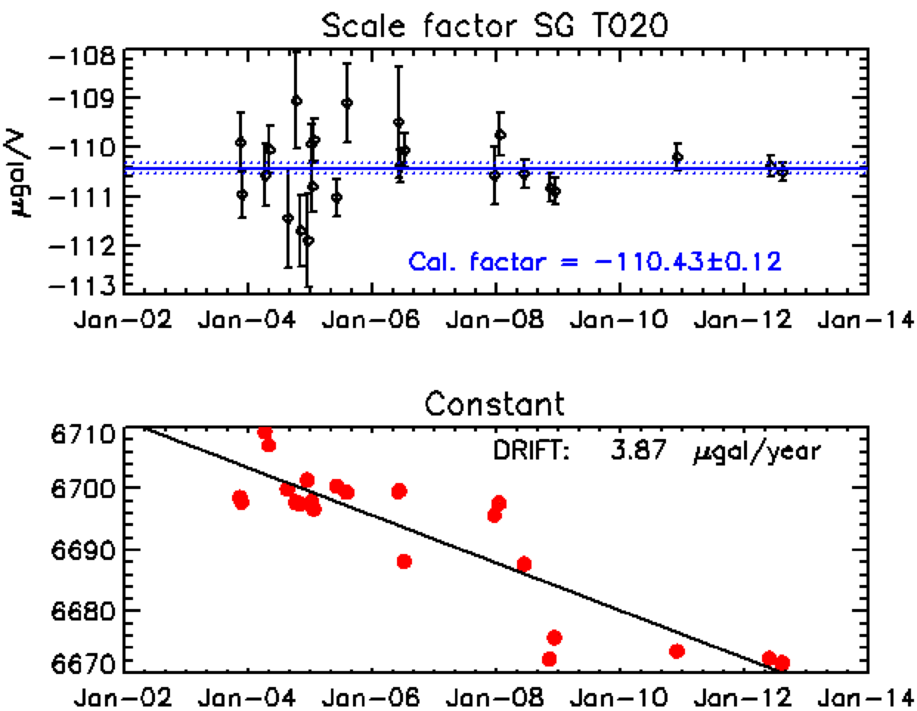

Fig 2. Top: Calculated scale factors and errors for 24 datasets. The new calibration factor is weighted mean of all datasets and shown with blue line. Bottom: Linear drift calculated from constant value of regressions.

Comparisons of long period time series

We have used hourly SG data from November 2003 to September 2012 and 165 datasets of AG (pillar AB 110 and pillar AC 55). A constant value of 981916515 was subtracted from AG observations. Some offsets in SG due to long-term disturbances have been corrected with the help of the AG data. In addition a preliminary drift rate has been estimated from AG. For comparison we have corrected the time series of both instruments in a similar way for three effects: tides, polar motion and influence of the atmosphere. When a discrepancy appears between the SG and the AG time series, it may indicate a problem with one of the instruments. For determining which instrument is producing the more plausible result we can compare their data with models of environmental effects in gravity, not included in the above-mentioned three standard corrections. At Metsähovi, the hydrological variation (local-regional-global) is the largest gravimetric effect. Seasonal variation can be up to 8 µgal peak-to-peak. In addition, loading by the Baltic Sea causes the effects up to 3 µgal. The hydrological signal is seen in both the SG and AG data. More generally, most of the variation in the AG time series is also seen in the SG data and can therefore be attributed to the same environmental effects. Correcting the AG record on the basis of models confirmed by the SG can improve the precision of determination of the gravity trend due to postglacial rebound.

In **Fig. 3** we have presented AG and SG measurements with a trend and without it. Trends were removed with linear regressions. We have used pillar AB for trend determination.

In **Fig. 4** we show the observed gravity with SG, together with gravity effects due to hydrology and the Baltic Sea. We present the gravity effect of the global hydrological model GLDAS including 4 soilmoisture layers and snow. Green's function formalism was applied for the calculations. Gravity effects for local groundwater (GW) (Virtanen 2006), WSFS (Watershed Simulation and Forecast System by Finnish Environmental Institute, Vehviläinen 2002) and the Baltic Sea (HSL) were calculated by regressions (Virtanen 2004). We have used tide gauge record in Helsinki 30 km away. The Metsähovi station is 10 km from the nearest bay of the Baltic Sea and 15 km from the open sea. Then we have applied different corrections for AG data, subtracting these gravity effects. We have used the mean value from these correcting time-series, using the same time intervals as used in datasets of AG. Results are given in **Table 2**.

Table 2. Trend determination with different correction methods for AG

Treatment	Trend (µgal/year)	Error
None	-0.49	0.08
SG	-0.47	0.08
GLDAS	-0.39	0.07
WSFS	-0.47	0.08
HSL	-0.43	0.09
GW	-0.41	0.08

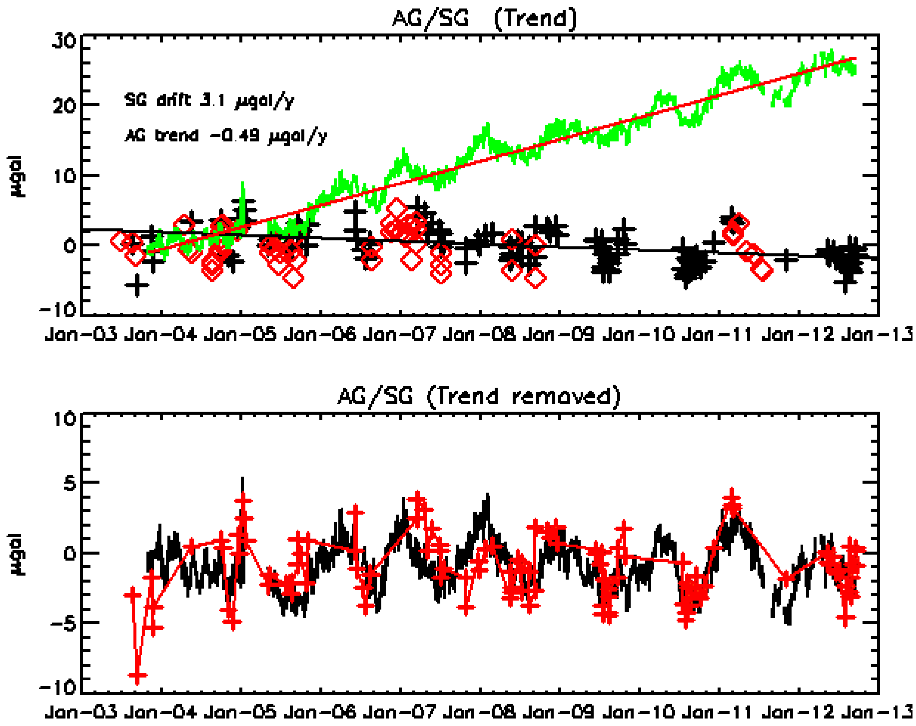

Fig 3. Top: Green curve shows SG gravity. The fitted drift is shown with red line, AG measurements are with black cross (AB) and with red diamond (AC). Bottom linear drift/trend removed: Black curve shows SG data and AG is marked with red cross and solid line.

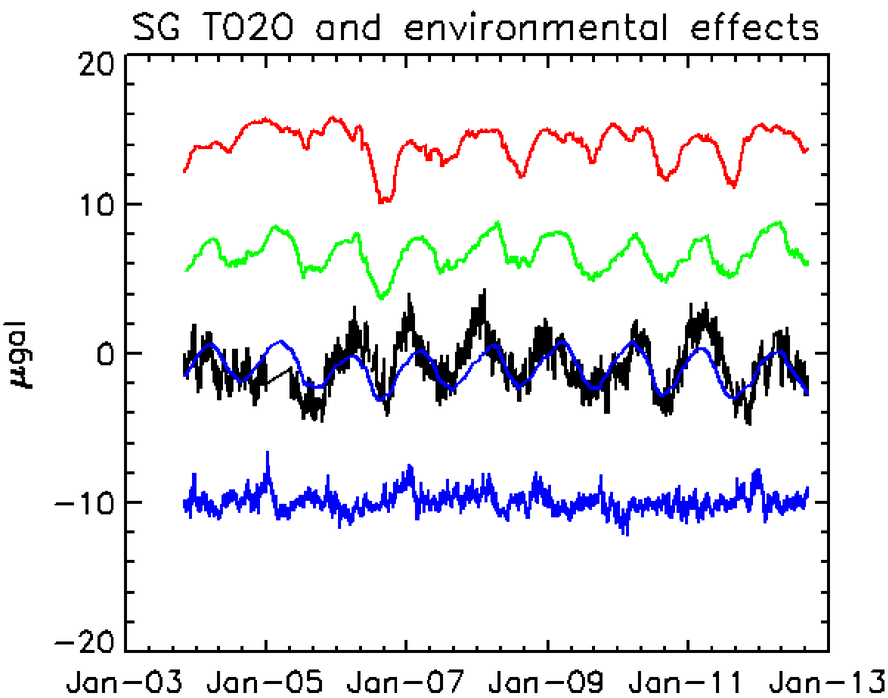

Fig 4. From top: Gravity effects of local groundwater (red), WSFS (green), GLDAS blue, for comparisons SG (black) and HSL (blue).

Conclusions

A new calibration factor has been determined for SG T020 with AG FG5-221 (**110.43±0.12 µGal/V**). This results is 0.3% smaller as the factor used at present. The results agree with earlier studies (Baker and Bos 2001, 2003), The observed instrumental drift of SG seems to be 3.6 µgal/y (3.1+0.5). Postglacial rebound is at Metsähovi about 2 mm/yr and the expected gravity change due to it about 0.7 µGals/y. Earlier studies have given as the trend about 0.5µgals/y at Metsähovi (Bilker-Koivula 2008). In this study, AG corrected using SG gives compatible results. It seems that hydrological corrections have small effect on the trend determinations, due to long timeseries (9 years with FG5). Two instruments are necessary to ensure that the AG measurements are referencing the mean station gravity and not short-term gravity perturbations due to, for example hydrology and meteorology. Hydrological variations from local to global are the largest unmodeled effect on AG measurements. SG can provide correction parameters due to environmental effects for AG and AG can give drift control for SG. SGs and AGs are thus very complementary instruments (Crossley et al 2009). They serve to check each other by independent measurements. We have in this study used rather simple methods, more advances methods have also been presented (Wziontek et al 2006).

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