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A comparative analysis between an absolute gravimeter (FG5-206) and a superconducting gravimeter (GWR C026) in Strasbourg: new results on calibration and long-term gravity changes

M. AMALVICT, J. HINDERER and J. P. BOY

Institut de Physique du Globe, Strasbourg, France

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Abstract. This paper is devoted to a comparative analysis of gravity changes as observed both by an absolute gravimeter (AG-FG5 model 206) and a superconducting gravimeter (SG-GWR model C026) operating in parallel in Strasbourg in 1997-1998. Two main objectives will be sought: on the one hand, we want to establish the calibration capability of AG/SG parallel registrations, especially with respect to stability in time, duration requirement and precision; on the other hand, the absolute gravity values will be superimposed on the superconducting gravimeter observations in order to estimate long-term gravity changes and to attempt to separate true physical effects from the instrumental drift contribution of the cryogenic meter.

1. Introduction

An FG5 AG has been operating in France for over one and a half years. In addition to experiments abroad (Membach in Belgium, Brasimone in Italy), and experiments in different regions of France (SHOM in Brest, CERGA in Grasse, BIPM in Sèvres), the FG5 carries out monthly operations at its home site, namely J9, near Strasbourg. A GWR SG has been operating here for more than ten years (a first instrument was installed and operated from 1987 to 1996, replaced afterwards by a compact model).

The collocation of these two instruments operating regularly in the same place is a very good opportunity to compare the results of both: comparing, on the one hand, the calibration of the SG by the AG; and on the other, once the SG has been calibrated, it is then possible to compare the residuals of both instruments, and even to compare them to the signature which is theoretically predicted from the Earth's polar motion (e.g. Hinderer and Legros, 1989).

Corresponding author: M. Amalvict; EOST 5, Rue Descartes, 67084 Strasbourg - Cedex, France; phone: +33 3 8841 6465; fax: +33 3 8841 6477; e-mail: mamalvict@eost.u-strasbg.fr

Table 1 - Repeated experiments using AG FG5-206 and SG C026 at Strasbourg-J9 Features and Main results.

Date of measurement	nb of drops per set; nb of *s* between drops; nb of *min* between sets	Number of sets Number of drops Duration (h)	mean g 9.80877. . .	setsd (μGal)	mean sd (μGal)	b *μGal/volt*	σ (b) *μGal/volt*
5-8 February 1997	25 / 15 / 15	283 - 7075 - 70.75h	782.0	3.4	22.38		
3-10 March 1997	91 / 10 / 30	314 - 28574 - 157	780.4	2.6	15.47	-79.19	0.12
23-25 April 1997	25 / 15 / 15	200 - 5000 - 50	782.0	2.0	14.29	-79.56	0.26
23-25 May 1997	25 / 15 / 15	176 - 4400 - 44	786.3	4.8	23.85	-80.33	0.39
19-25 June 1997	25 / 15 / 15	352 - 8800 - 88	780.2	2.2	17.40	-79.03	0.24
2-5 July 1997	25 / 15 / 15	272 - 6800 - 68	780.9	2.4	18.57	-79.01	0.25
3-8 October 1997	25 / 15 / 15	495 - 12 375 - 123.75	781.6	2.0	13.91	-78.95	0.18
30 Oct.-3 Nov. 1997	25 / 15 / 15	379 - 9475 - 94.75	784.5	2.2	13.53	-79.16	0.17
11-14 December 1997	25 / 15 / 15	142 - 3550 - 35.5	779.4	2.1	15.29	-79.22	0.27
8-16 January 1998	91 / 10 / 30	274 - 24 934 - 137	780.8	3.2	19.05	-79.68	0.13
10-13 February 1998	91 / 10 / 30	337 - 30 667 - 168.5	781.1	2.6	13.80	-79.24	0.14
11-15 March 1998	91 / 10 / 30	188 - 17 108 - 94	782.6	3.0	15.99	-79.31	0.21
8-12 April 1998	91 / 10 / 30	171 - 15 561 - 85.5	780.9	2.9	16.44	-78.99	0.26
7-18 July 1998	25 / 15 / 15	984 - 24 600 - 246	784.3	2.0	13.56	-79.04	0.12
4-10 August 1998	25 / 15 / 15	564 - 14 100 - 141	784.9	1.9	11.37	-79.03	0.11

2. Calibration

Many studies have investigated the calibration of relative gravimeters using absolute gravity measurements performed at the same location during the same time period (Hinderer et al., 1991; Amalvict et al., 1998; Francis et al., 1998, 1999). The calibration entails the transformation of the output of the SG (expressed as a feedback voltage to maintain the levitating (superconducting) sphere in a fixed position) to a gravity unit. For this purpose, one can compare the continuous recording of the SG with the discrete values of the AG, observed at the same place and time. The calibration factor b and the offset a are determined by a least-square adjustment of the equation $y = bx + a$ where y represents the absolute gravity measurements (mean set values), in microgals and x represents the feedback voltages of the superconducting gravimeter, in volts; b is expressed in μGal/volt; a is expressed in μGal.

2.1. Features of the repeated calibration

We use the FG5#206 at the Strasbourg station (J9) to calibrate SG-C026. The main features of the monthly measurements (date of measurement, number of drops per set; number of seconds between drops; number of minutes between sets, number of sets, number of drops, duration (h)) are shown in Table 1.

There are 14 periods of parallel measurements from March 1997 to August 1998, with a total of 4848 sets corresponding to a total of 205 944 drops.

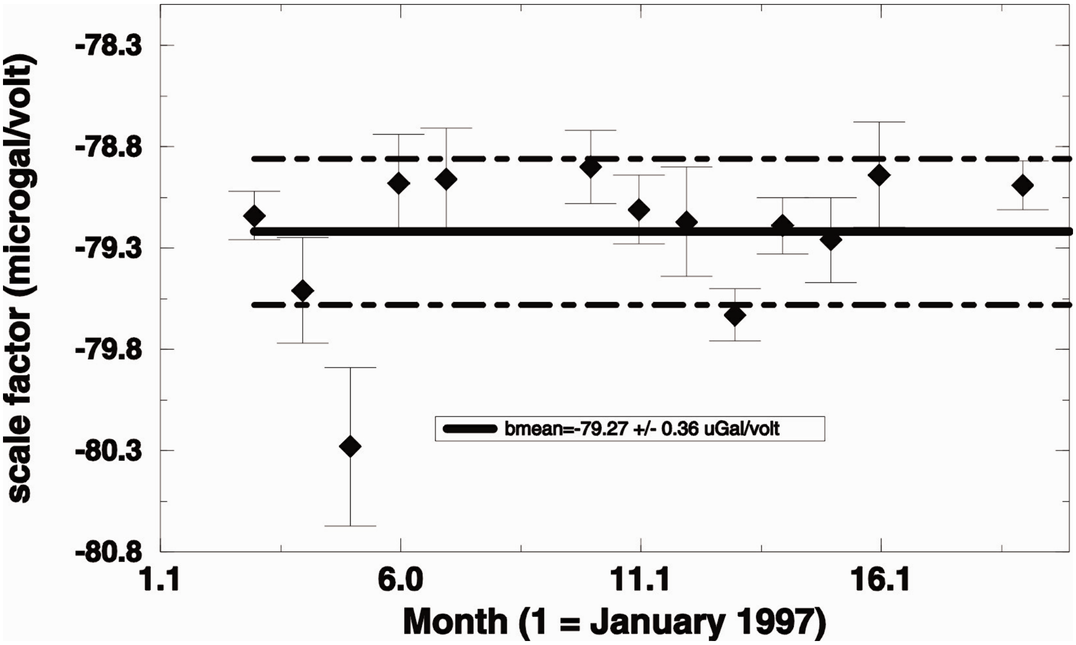

Fig. 1 - Calibration factor at Strasbourg (J9), from March 1997 to August 1998.

2.2. Results and comments

The respective values of the scale factor *b* for each calibration test are presented in Table 1. The uncertainty is the one provided by the least-squares adjustment and takes into account the AG error measurements (set standard deviation). We notice that the minimum value of *b* (May 1997) is -80.33 µGal/volt and its maximum value (October 1997) is -78.95 µGal/volt. The peak to peak difference is Δb= 1.38 µGal/volt. Finally, averaging these values, we get the mean scale factor which is -79.27 ± 0.36 µGal/volt.

In Fig. 1, we plotted the different values of *b* (with the corresponding error bars). We have also plotted the mean value of *b* and two dashed lines, corresponding to the error bar of this mean value (± 1 standard deviation). The May 1997 point is the only one which is set completely apart from the average value. As can be checked in Table 1, this experiment was particularly noisy, with 23.85 µGal for the mean standard deviation and 4.8 µGal for the set standard deviation. It is therefore satisfactory to notice that after removal of this point all calibration experiments lie within the ± 1 SD error bars of the mean calibration value.

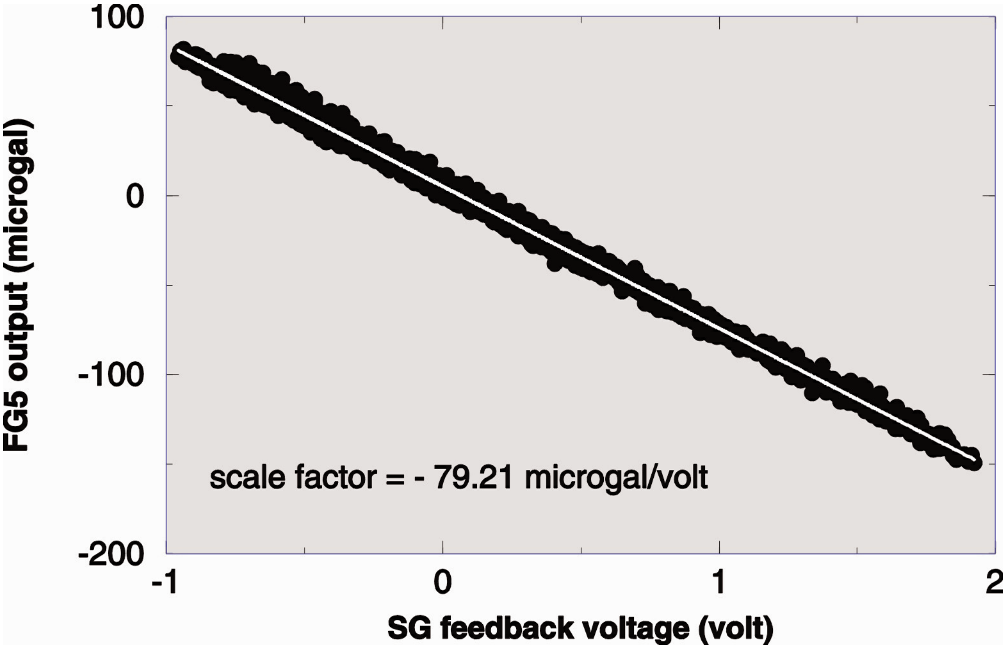

Fig. 2 - Global calibration experiment at Strasbourg (J9) from March 1997 to April 1998.

2.3. Global calibration from March 1997 till April 1998

In Fig. 1, the mean value for the scale factor *b* was obtained by averaging the individual experiments. Then we also decided to process once all the AG/SG data sets. To our knowledge, this is one of the longest comparison periods ever studied; notice, however, that a long continuous record was investigated by Francis, 1997 for the Membach (Belgium) station. We processed 12 series of parallel measurements of the FG5 & the SG C026 all together in order to calibrate the SG. The July and August 1998 values have not been used, because of an offset in the SG recording, when lightning struck in May 1998. This calibration test, extending over a long period of time, requires two conditions to be met: i) no offsets in either AG or SG measurements (condition which is fulfilled in our view for both types of data); ii) no drift (or to put it better a small drift) of the SG with time; this second condition could be checked by a detailed analysis of the two-year set of SG-C026 and an inspection of residuals. Finally 3300 sets (182 244 drops) have so been processed together, leading to the scale factor: *b* =-79.21 μGal/volt with an error *s(b)* = 0.05 (see Fig. 2). This value at 0.13% agrees with the mean value derived above. This demonstrates that the AG/SG method is able to provide calibration factors with an uncertainty close to 0.1% as required for some geodynamic studies (Crossley and Hinderer, 1995).

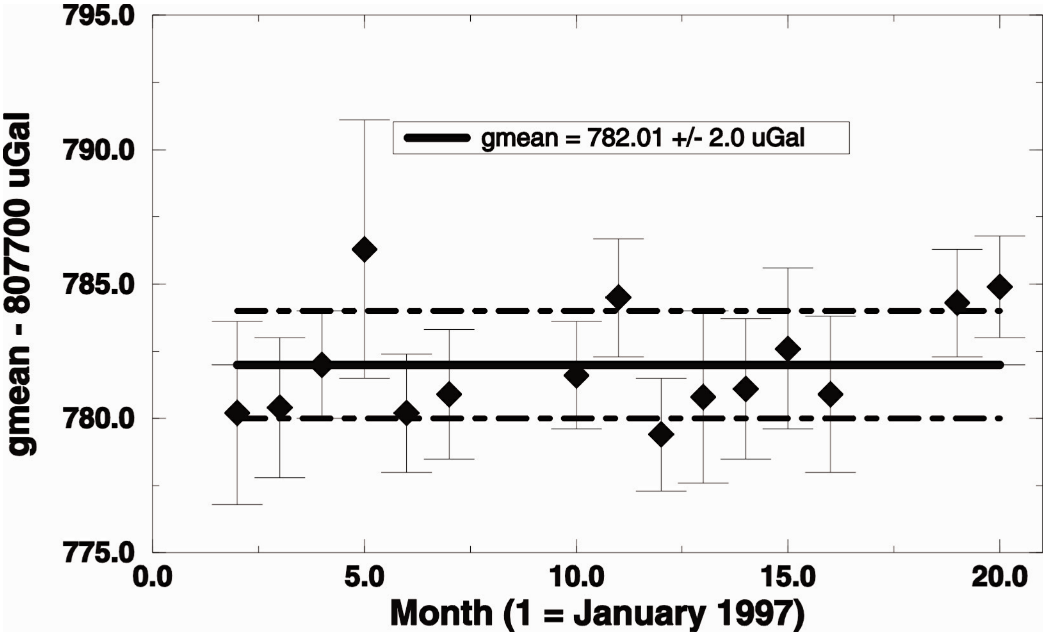

Fig. 3 - Mean value of the gravity at Strasbourg (J9) from February 1997 to August 1998.

3. Long-term variation of the mean value of gravity

3.1. Features of the repeated determination of mean g

Accordingly, we derived the mean *g* value every time the experiment was conducted in parallel. We have thus 15 periods of measurements from February 1997 to August 1998. This amounts to 5274 sets and 216 594 drops. The corrections applied are: solid Earth tides (using the Eterna software, Wenzel, 1994); barometric pressure with a constant -0.3 µGal/mbar admittance value (see Crossley et al., 1995 for a discussion of this factor); ocean loading; polar motion; instrumental effects (speed of light, gradient height, vertical transfer). The *g* value is calculated here at the ground level.

3.2. Results and comments

The respective values of the mean *g* for each experiment are presented in Table 1. We notice that the minimum value of *g* (December 1997) is 98 087 779.4 and its maximum value (May 1997) is 98 087 786.3. The peak to peak difference is Δg= 6.9 µGal. We also give the set standard deviations and the mean standard deviations. Finally, averaging these values, leads to the mean of

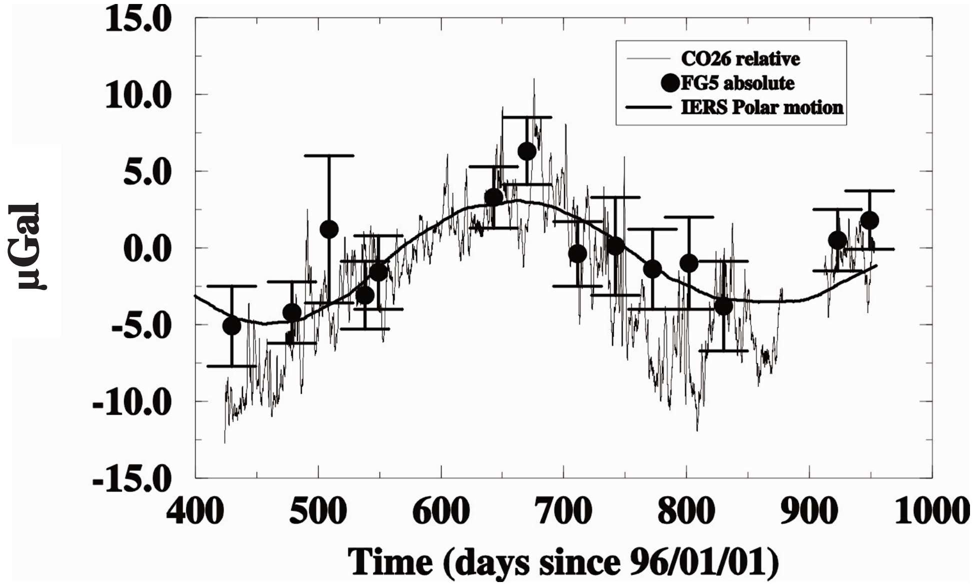

Fig. 4 - Gravity and polar motion at Strasbourg (J9) from March 1997 to April 1998.

the monthly mean values which is 980 877 782.01 ± 2.0 μGal. In Fig. 3, we plotted the different values of *g* (with the corresponding error bars). We also plotted the mean value of *g* and the two dashed lines, corresponding to the error bar of mean *g*. Again the May 1997 value is the only one which is set completely apart from the average value. The scale of the observed variations (± 2 μGal) is comparable to what was found for the scatter of the mean values of the ICAG 94 and ICAG 97 at BIPM (Paris), (see Robertson et al., 1998). We do not notice any apparent annual variation; the minimum value is in December 1997 but it is not obvious to conclude that there is a minimum in winter, more data are needed to verify this point. We notice an "offset" between April and July 1998. It is still not possible to say if it is a real (physical) change in the gravity or if it is due to some instrumental reason (the clock of the AG was changed in the meantime, for example).

4. Comparison between the SG and AG observations

Once the SG is calibrated, it is possible to superimpose the recordings of the two instruments. The series of absolute gravity data consists in several days of continuous measurements performed once every month. The relative gravity series is composed of 1 min samples, in agreement with the GGP (Global Geodynamics Project) standards, Crossley and Hinderer, 1995. The superimposition is quite satisfactory. Rather than presenting this plot, we prefer to show the comparison with polar motion. Fig. 4 shows the calibrated SG, the AG and the polar motion calculated at Strasbourg with the pole coordinates obtained from the IERS (the same geodynamic contributions except polar motion have been subtracted from AG and SG data). Again, the agreement is very good. As shown by previous studies (Richter et al., 1995 , van Dam and Francis, 1998), it is very clear that both types of instruments are capable of exhibiting the gravity signature of the polar motion. And this is encouraging in so far as both instruments appear capable of detecting long-term gravity changes for other applications like tectonics or volcanology.

5. Conclusions

This study involving about one and a half year of parallel registration of SG/AG data at the Strasbourg station leads to two main results. On the one hand, it confirms the capability of reaching calibration accuracies close to the 0.1 % level which is needed for precise gravity investigations in geodynamics. This is true from repeated individual experiments lasting several days or even by combining in one go all these different experiments. On the other hand, the superimposition of mean monthly absolute gravity values on the superconducting gravimeter continuous measurements is very satisfactory and shows that both types of instruments can detect long-term gravity signals like the one caused by changes in the Earth's polar motion.

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