On the use of AG data to calibrate SG instruments in the GGP network. Example of Strasbourg - J9

M. Amalvict, J. Hinderer, P. Gegout, S. Rosat and D. Crossley

EOST - I.P.G. Strasbourg (CNRS – ULP)
5 rue René Descartes 67084 Strasbourg cedex France

mamalvict@eost.u-strasbg.fr

Abstract

This paper is devoted to the presentation of several types of results related to the calibration of the Strasbourg superconducting gravimeter (SG) by the use of parallel recording with the Strasbourg absolute gravimeter (AG). First we compare the scale factors resulting of two calibration algorithms: one involves the individual drops of the AG while the second one involves the AG gravity averaged over a 'set'; we find that the results of two methods are in very good agreement when there is no perturbation (such an earthquake) during the period of measurements. Second we analyse the series of individual scale factors derived from March 1997 to June 2001; the series does not exhibit any clear behaviour (trend, periodicity, ...), in opposition to what is commonly observed with the series of mean values of gravity. Finally, we present what we name a "global calibration" which consists in a single calibration process of the whole series of data get after merging the individual experiments. The feasibility of this process is due to the small drift of the SG. The scale factor for the global calibration is - 79.40 ± 0.03 µGal/volt and is close to the mean value of the 32 individual scale factors, which is - 79.19 ± 0.35 µGal/volt.

1. Introduction

Many presentations and discussions during the third GGP workshop held in Jena in March 2002 have pointed out that the knowledge of the precise calibration factor of SGs plays a more and more crucial role. This is due to the increasing accuracy required in the processing of both absolute and relative gravity data, in order to observe geodynamical phenomena. In this work, we focus on the calibration of the SG#C026 which will be treated as a case-example for any other SG. This is the first part of a wider paper involving calibrations of SGs belonging to the GGP network (Crossley et al., 1999), performed with the FG5#206 (Amalvict et al., 2002a). The compact SG#C026 has been continuously recording, at the Gravity Observatory, J9, located close to Strasbourg, since July 1996 (following SG#T005 which was operating since 1987). Its scale factor is derived from the parallel record of gravity variations by the AG FG5#206 which (as well as the SG), belongs to the French scientific community and is operated by the team of the Gravity Observatory since its purchase in January 1997. When the two instruments are operated at the same time at the Strasbourg-J9 Observatory, they record the gravity variations in two different rooms separated by 10 meters or so.

2. Calibration algorithms

Different calibration methods are used to calibrate SGs, leading to comparable results (Francis et al., 1998). Here, we apply the procedure of superposing the records obtained with two kinds of instruments (SG/AG). The principle is to fit the two data sets using a least square adjustment according to the linear relation:

$$y=bx+a$$

where y stands for the AG data and is expressed in µGal, x for the SG feedback output and is expressed in volt, b is the scale factor expressed in µGal/volt, and a is the offset (value for which the fitting line intercepts the ordinate-axis) is expressed in µGal. As the two meters record the same signal, which means that they are submitted to the same gravity, no correction of (geo)physical phenomenon is applied to either data set.

At Strasbourg, there are two different sampling rates for the SG: 2 seconds and 1 minute. The SG data are first cleaned for spikes, large and identified offsets, gaps, if any. The principle of the FG5 is based on the free fall of an object in the vacuum. According to the operating procedure of the AG, a number of drops (e.g. 25, ..., 150) are grouped in a so-called 'set' and then a statistical value of gravity is computed for the set. We use 10 or 15 seconds between two drops and 15, 30 or 60 minutes between two sets.

We present two ways of calibrating the SG, according to these two entities: the drops and the sets and we shall first ask ourselves how much the value of the calibration factor is depending on the algorithm used for its derivation.

a. Drop by drop algorithm

In this first method, we use the individual *drop* gravity values of the AG (y in µGal) without any processing, which means that no values are *a priori* removed from the data. Nevertheless, a rejection criterion is applied later: a statistics is calculated for every set leading to a given $\boldsymbol{\sigma}$, then a drop gravity value is rejected when the difference between this value and the mean gravity value of the set is greater than $\boldsymbol{n\,\sigma}$ (currently n=3; this is the value used in the examples given in Table 1), where the value of **n** is adjustable, depending on the noise level; a study of the influence of this parameter is in progress. To these data, we superimpose the SG output for gravity values with a 2 second sampling (x in volt); each drop of the AG is then compared to the closest sample of the SG.

b. Step by step algorithm

In this second method, we use the *set* gravity values of the AG (y in µGal) resulting of the statistical processing of the drop gravity values; a rejection criterion of outlier sets (**1σ**) is applied in this first process of the AG data, prior to the calibration. Then, from the SG output for gravity values with a 1 minute sampling (x in volt), the calibration software derives the value of the output at the time corresponding to the time of the set. Finally we superimpose the two series of data.

c. Comparison of the results

We present in Table 1 the calibration factors obtained when using the two codes for an arbitrary selection at different periods of time. We see that under 'normal' conditions, the values of the scale factors are close, as well as the corresponding standard deviation. Nevertheless, in the case of June 2001, the greater discrepancy between the results is due to the fact that an earthquake of magnitude larger than 8, occurred in Peru during the parallel measurements. In the set by set method, outlier sets are removed during the processing of AG data, which is not the case for the drop by drop method. It is clear that a drop rejection should be done in such a noisy situation; the study exhibiting the influence of the level of the criterion rejection is in progress. The last column of Table 1 is the ratio $(b_d- b_s)/b_s$; it is, as expected, very small except in the case of the Peru earthquake in June 2001.

	set by set scale factor b_s µGal/volt	σ (b)		drop by drop scale factor b_d µGal/volt	σ (b)		$(b_d- b_s)/b_s$ 10^{-4}	
July 1998	-79.04	0.12		-79.05	0.12		1.3	
January 2000	-78.96	0.31		-78.94	0.38		-2.5	
April 2001	-78.96	0.28		-78.90	0.39		-7.6	
May 2001	-79.25	0.09		-79.21	0.13		-5.1	
June 2001	-78.98	0.08		-79.37	0.26		49.4	Peru earthquake

Table 1. Scale factors according to different experiments and methods.

3. Four-year series of individual calibrations

In a second stage, we present the results of the different calibrations experiments performed individually. For this purpose, we analysed the data according to the set-by-set method.

a. Main features

As we already mentionned, it is very important to be sure of the accuracy of the scale factor, in order to carefully analyse the information provided by the long records of the SGs. At the Strasbourg Observatory, we are in a good situation for having several determinations of the calibration factor per year. Thus, we have derived 32 individual calibration factors from March 1997 to June 2001. The extreme values are - 80.33 (May 1997) and – 78.44 (December 2000), leading to a peak to peak discrepancy of 1.89 µGal/volt or 1.2 % maximum difference. The mean value of the 32 experiments is b = - 79.19 ± 0.35 µGal/volt. This value is in agreement with the ones previously derived (Amalvict et al;, 1998, 2001a). Taking into account the error bars on this mean value, only three determinations of the scale factor are outliers, namely May 1997, September 1999 and December 1999. Further on, no obvious trend is observed in these data.

b. Periodogram

In view of the previous paragraph, the calibration factor can be regarded as quite stable in time; nevertheless, looking for a potential periodicity of the scale factor, we present a periodogram of the data. The largest peak, still only weakly significant at a probability of 0.5, is at roughly four cycles per year, which means a period of about three months; such a possible periodicity would still have to be (geo)physically explained. A similar study on the mean gravity value at J9 during the same 5-year time span leads to a much more clear annual variation (Amalvict et al., 2002b).

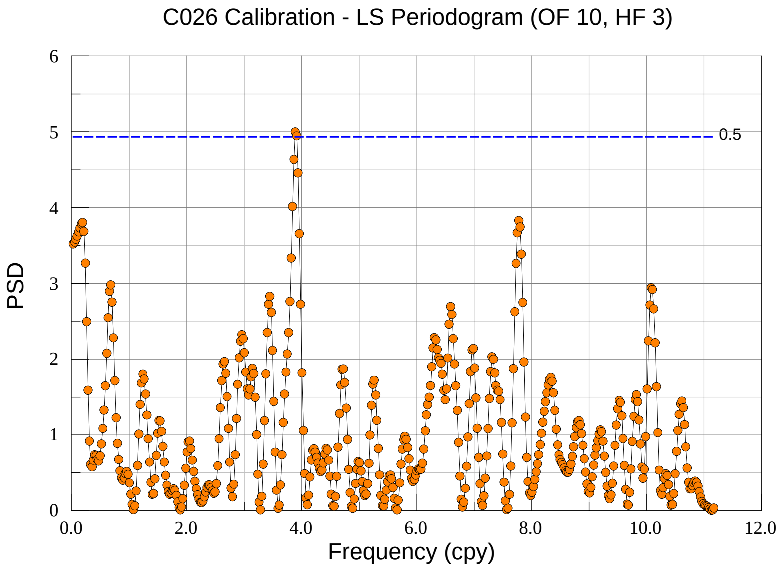

Figure 1. Periodogram of the scale factor individual determinations.

c. Discussion

Thus, we have not observed any clear variation in time of the scale factor of the SG (no trend, no periodicity). Of course, we feel quite happy with this since it would be quite difficult to explain any change in the value of the scale factor. Such a stability is observed elsewhere (Falk et al., 2001, Ogasawara, 2001); nevertheless some other series can present a trend which is certainly an artefact due to the small number of measurements (Amalvict et al., 2001b). One could think of some variations in the electronics due to temperature variations for instance. In that respect, it is worth noting that, in our data set, the extreme values of the calibration factor correspond to the extreme values of the individual determination of mean g. This could indicate poor AG measurements due to unexplained instrumental problems.

4. Global calibration

Assuming that i) the drift of the SG is small (the 'instrumental' drift is about +3.96 µGal/year) and ii) it can be well corrected for spikes, offsets, gaps, the data have been processed all together as a single experiment, in order to obtain only one calibration factor for the whole series. The software for the set by set method has been used.

a. Main features

For the absolute gravimeter data, we have concatenated the 32 individual series, which corresponds to 9 937 sets (after having previously removed noisy sets in a pre-processing) and about 450 000 drops. The SG data consist of roughly 2 300 000 values at 1 minute sampling; the offsets, due to storm, lightning, helium refilling, earthquakes, ... have been corrected for, which is the most delicate operation to be performed since it requires often subjective decisions concerning the significance and correction of offsets that appear in the data (see the discussion in Hinderer et al, this issue).
Some comments should be made concerning the determination of the SG drift. Analysing the time series of the mean values of the gravity at J9 from March 1997 to June 2001, we observe a linear trend of +1.2 µGal/year (Amalvict et al., 2002b). Our assumption is then that the total (i.e. observed) SG drift is the sum of the (purely) instrumental SG drift and of

the “geophysical” trend deduced from AG observations. The SG data being then as “clean” as possible, we process as usually to derive the calibration factor.

b. Results

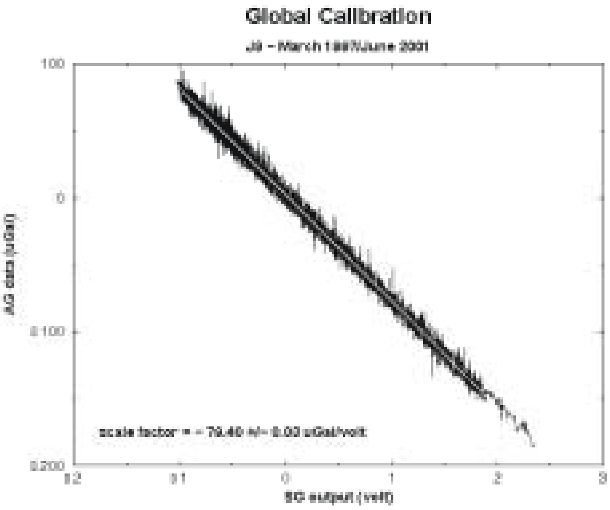

Figure 2. AG versus SG data in the global calibration experiment from March 1997 to June 2001.

We obtain a calibration factor equal to - 79.40 ± 0.03 µGal/volt, which can be compared to the mean value of the 32 individual calibrations which was -79.19 ± 0.35 µGal/volt. The (formal) standard deviation is much smaller for the global calibration, due to the huge number of processed data. We can also note that a similar derivation has been previously done for a shorter period of time (March 1997 – April 1998) leading to a value of – 79.21 ± 0.05 µGal/volt (Amalvict et al, 1999).

5. Conclusions

We have presented different results referring to the calibration of SG#C026 using AG FG5#206 at Strasbourg-J9: i) the linear adjustment by two methods using all individual drops or separate sets leads to no significant difference in the calibration factors; ii) 32 individual calibration factors have been obtained between March 1997 and June 2001, the average of which is b = - 79.19 ± 0.35 µGal/volt. The value is stable and is not related to the seasonal fluctuation observed on the gravity itself; iii) the instrumental drift of the SG (observed drift - AG trend) is very small, which allows to perform a calibration on the whole period involving parallel measurements. The calibration factor of this ‘global’ calibration is b = - 79.40 ± 0.03 µGal/volt, value in agreement with the mean of the individual calibrations. The actual precision on the calibration factor lies somewhere between the two values (0.35 and 0.03), the first one does not take into account the number of measurements and the second one does not take into account the ‘fact that the determination of the factor is not continuous. The corresponding relative errors are respectively 4 ‰ and 0.4 ‰.
The stability of the scale factor of SG#CO26 over more than four years, whatever the period of time, is of great importance in view of geodynamical applications of SG records. It seems

that the relative error is approaching the limit value of 1 ‰ which is necessary for geodynamical goals.

6. References

Amalvict M., Hinderer J., Francis O., & Mäkinen J., 1998, Comparison between absolute (AG) and superconducting (SG) gravimeters, in Forsberg R., Feissel M. and Dietrich R. (eds) 'Geodesy on the Move'. Gravity, Geoid, Geodynamics and Antarctica, IAG Symposia **119**, 24-29.

Amalvict M., Hinderer and Boy J.P., 1999, A comparative analysis between an absolute gravimeter (FG5-206) and a superconducting gravimeter (GWR C026) in Strasbourg: news results on calibration and long term gravity changes; Bolletino di Geofisica, 40, n°2-3.

Amalvict M., Hinderer J., Boy J.P. and Gegout P., 2001a, A 3 year comparison between a superconducting gravimeter (GWRC026) and an absolute gravimeter (FG5#206) in Strasbourg (France) , Journal of Geodetic Society of Japan, **47**, 334-340.

Amalvict M., McQueen H. & Govind R. 2001b, Absolute Gravity Measurements and Calibration of SG CT #31 at Canberra, 1999-2000, Journal of Geodetic Society of Japan, **47**, 410-416.

Amalvict et al., 2002a, On the use of AG data to calibrate SG instruments in the GGP network, in preparation.

Amalvict et al.,2002b, Long term stability of the gravity at Strasbourg J9, in preparation.

Crossley D., Hinderer J., Casula G., Francis O., Hsu H.-T., Imanishi Y., Jentzsch G., Kääriänen J., Merriam J., Meurers B., Neumeyer J., Richter B., Shibuya K., Sato T. and van Dam T., 1999, Network of superconducting gravimeter benefits a number of disciplines, Eos, 80, N°11, 121,125-126.

Falk R., Harnish M., Harnish G., Nowak I., Richter B. and Wolf P., 2001, Calibration of the superconducting gravimeters SG103, C023, CD029 and CD030, Journal of Geodetic Society of Japan, **47**, 22-27.

Francis O., Nibauer T.M., Sasagawa G., Klopping F. and Gschwind J., 1998, Calibration of a superconducting gravimeter by comparison with an absolute gravimeter FG5 in Boulder, Geophysical Research Letters, **25**, n°7, 1075-1078.

Hinderer J., Rosat S., Crossley D., Amalvict M., Boy J.-P. and Gegout P., 2002, Influence of different processing methods on the retrieval of gravity signals from GGP data, B.I.M., this issue.

Ogasawara S., Higashi T., Fukuda Y. and Takemeto S., 2001, Calibration of a superconducting gravimeter with an absolute gravimeter FG5 in Kyoto, Journal of Geodetic Society of Japan, **47**, 404-409.

Acknowledgments – This is EOST contribution N° 2002-13-UMR7516.