COMPARISONS BETWEEN ABSOLUTE (AG) AND SUPERCONDUCTING (SG) GRAVIMETERS

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Abstract

The French scientific community has recently (December 1996) acquired an absolute gravimeter (AG) , Micro-g FG5-206. This instrument is based at the Strasbourg gravity station, J9, where superconducting gravimeters (SG), model TT70 replaced in summer 1996 by a compact model C026, are operating since more than 10 years. First we check the instrumental specifications of the FG5 by comparing observations to the specifications given by the manufacturer. Secondly we perform several series of calibrations of the SG by the AG spanned over a time interval of 6 months. We provide results on the stability of the calibration factor in time from different experiments, as well as on the evolution of the factor and its uncertainty according to the duration of each experiment. We conclude that an accuracy of several parts per mill can be achieved in standard conditions.

I - Instrumental specifications

The Micro-g FG5 absolute gravimeter is a free-fall type of gravimeter. According to the manufacturer, its main specifications are as follows (see Niebauer et al., 1995):

- **accuracy** : ± 2 μGal*
- **precision**: ± 1 μGal
- **measurement time**: less than 2 hours for 1 μGal precision in a quiet site.

Set standard deviation

A possible way to approach the accuracy of the AG measurements is to use the Set Standard Deviation (SSD) which expresses the dispersion of the set mean values with respect to the session mean (mean of the set means). In fact, strictly speaking, one cannot constrain the accuracy from a single instrument alone as stated by Okubo et al. (1997); for instance, the SSD could be small but the mean gravity wrong due to a laser frequency shift for example.

At the moment, the FG5 has been operating in three sites: Strasbourg-J9, a site in the Vosges Mountains, named Welschbruch, and Membach (Belgium), the site of the C021

* 1 μGal = 1 x 10^{-8} m s^{-2}

superconducting gravimeter. The results are given in Table 1. The station J9 is known to be a medium quality site, with respect to microseismic noise (Freybourger et al., 1997) mainly because it is located on the sediments of the Rhine Graben. This medium quality is what we observe. Nevertheless, the value of the Set Standard Deviation is close to the one given by the manufacturer and much better than the best SSD obtained by the Jilag5 operating at this site. The Welschbruch is a station which is used for magnetic measurements, but no gravity measurements have been performed before this year. It is not yet a very well equipped station for gravimetry (we are testing it): there is no pillar or thermal stability. Nevertheless we can see that the results are very good; without any peculiar care neither in the measurements nor in their treatment, the SSD is smaller than the manufacturer's specification. Membach is known to be a very good site, located in a mine, very stable in temperature and very quiet. The set standard deviation is much smaller than the one given by the manufacturer, and very close to the value (1.35) of the FG5 from the ROB which was operating at the same time in the same site. More complete results about this experiment of two FG5s measuring in parallel can be found in Hinderer et al. (1997). There is a recent study in Japan (Okubo et al., 1997) which could also verify that the precision of the FG5 measurements is between 1 and 2 μGal.

	Manufacturer	J9 - Strasbourg (F)	Welschbruch (Vosges, F)	Membach (B)
Set Standard Deviation FG5 - 206	2.0	2.29	1.69	1.4
other AGs		3.6 Jilag 5		1.35 FG5 - 202

Table 1 - Set Standard Deviation of the AGs in different sites (in μGals).

Single set standard deviation

The precision of the AG measurements can be inferred from the Single Set Standard Deviation (SSSD) which expresses the dispersion of the drop by drop values in a set which is usually of short duration (~15 min).

The specified value seems easy to reach (cf. Table 2). Usually the SSSD is obtained from the Mean Standard Deviation (MSD), which expresses the single drop scatter, divided by the square root of the numbers of drops per set. The single set standard deviation we give for the FG5-206 was obtained in the Vosges site, Welschbruch, which seems to indicate a very low seismic noise as compared to the value obtained in Membach.

	Manufacturer	FG5 - 206 (Vosges)	FG5 - 202 (Membach)
Single Set Standard Deviation (μGal)	1.0	0.9	1.2

Table 2 - Single Set Standard Deviation of FG5s (in μGal).

Measurement time

This is the duration of measurements which is necessary to get a value of the mean gravity g, at a given precision. It will be, of course, depending on the quality of the site and on the weather conditions.

If we assume 200 drops per hour, and a 2-hour experiment and consider the Mean Standard Deviation obtained in the different sites, we can estimate the precision as: $\frac{MSD}{\sqrt{400}}=\frac{MSD}{20}$, assuming an ideal white noise distribution of the measurement errors. The precision obtained in the three sites, under the assumptions of this fictitious experiment, is given in Table 3 where the MSD values are typical for the considered stations.

Theoretically, we can conclude that two hour duration of measurements seems to be enough for getting a value of the mean gravity with a precision of 1μGal, and even better. Once more, the Welschbruch station appears to be a very promising site. The value of g at 1μGal precision could be reached in fifteen minutes.

	Manufacturer	J9 - Strasbourg	Welschbruch	Membach
MSD		17	7	9
precision	1.0	0.85	0.35	0.45

Table 3 - Mean Standard Deviation of the FG5 (in μGal).

Actually, in real experiments, one has to measure for much longer time, to stabilize the mean gravity measurement according to the dispersion of individual set mean values which is generally observed.

II - Calibration results

The first superconducting gravimeter (SG TT70) at the Strasbourg site J9 has been calibrated almost every year since 1989 with the Jilag 5 absolute gravimeter of the Finnish Geodetic Institute (Hinderer et al., 1991, 1995). In July 1996, it was replaced by a compact SG (SG C026) which has been calibrated for the first time in February 1997, in parallel by the Jilag 5 Finnish instrument, in order to insure the continuity of experiment, and by the new FG5 AG.

The calibration is performed by least squares fitting at every time t_i the values of the AG y_i (in μGals) to the feedback voltage of the SG, x_i (in volts):

$$y_i = bx_i + a$$

This provides the calibration factor b in μGal/volt, and the offset a in μGal (cf. Figure 4).

	Jilag 5/SG CO-26	FG5-206/SG CO-26
b : calibration factor (in (μGal/volt)	- 78.92 ± 0.31	- 79.03 ± 0.26

Table 4 - Calibration factor at Strasbourg - J9

The values of the calibration factor obtained with two AGs operating at the same site are in good agreement. The uncertainties are 1 σ error bars from the least squares adjustment. We used the mean gravity values for each set (25 drops every 15 seconds; 1 set every 15 minutes) in the inter-comparison.

More details can be found in Hinderer et al. (1997). We discuss below other aspects of the calibration problem.

Monthly calibration

We have repeated the calibration experiment, at J9, every month, and obtained a series of 6 values from February to July 1997. The values of the calibration factors are shown in Figure 1, the y-axis of which has a very dilated scale. The value of May is quite different from the other estimates but the quality of the experiment was bad because of noisy measurements (single drop scatter of 25 μGals). The uncertainty on the value is clearly under-estimated as can be seen from its error bar. The March experiment was long (6.5 days) while the duration of the other ones is between 2 and 5 days. The error bar for March is hence much smaller.

We conclude that 4 values are perfectly coherent, when taking into account the error bars. A fifth one (April) is easily included when taking 2 sigma uncertainty instead of 1 sigma.

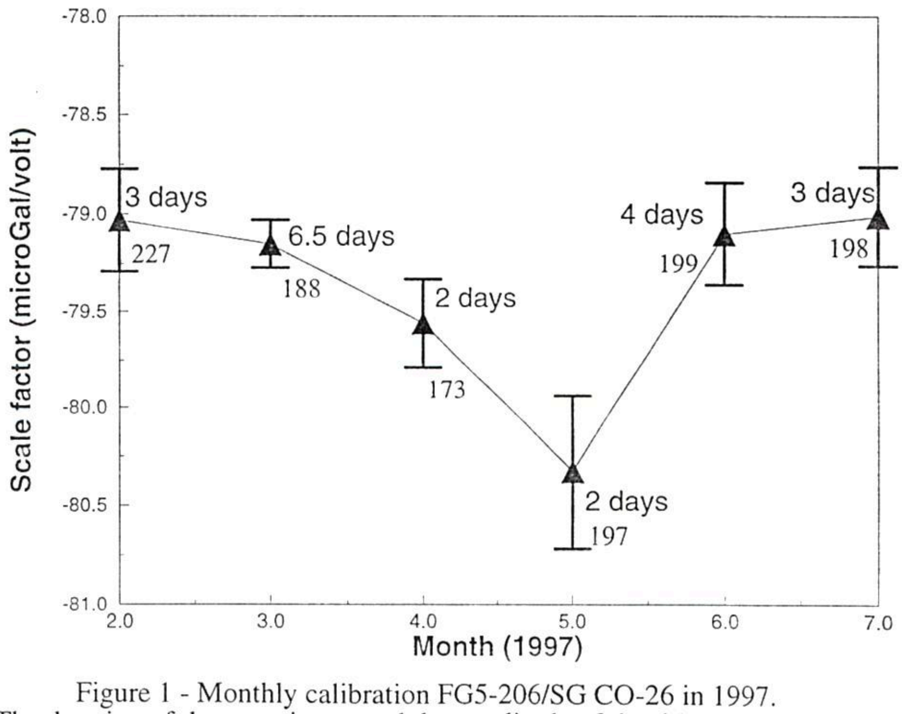

Figure 1 - Monthly calibration FG5-206/SG CO-26 in 1997.
The duration of the experiment and the amplitude of the tide are indicated.

Daily calibration

As the March experiment was long, we use it to study how the calibration evolves with increasing time (cf. Figure 2). First of all, we notice that the calibration factor is increasing with time, whereas the offset is decreasing; this is a verification that these two parameters are not independent. If there is an aperiodic instrumental process (e.g. drift, tilt, superspring), the model we are using is inappropriate and this could explain the features depicted in Figure 2. The calibration factor is varying from -80.0 to -79.1 μGal/volt.

According to the error bar on the final value, we can say that we need four days of measurement to reach this value. It is also the time needed to achieve a 0.2% uncertainty. In a recent study, Francis (1997) found a similar result. Moreover the offset is varying from 426.8 to 426.4 which is small.

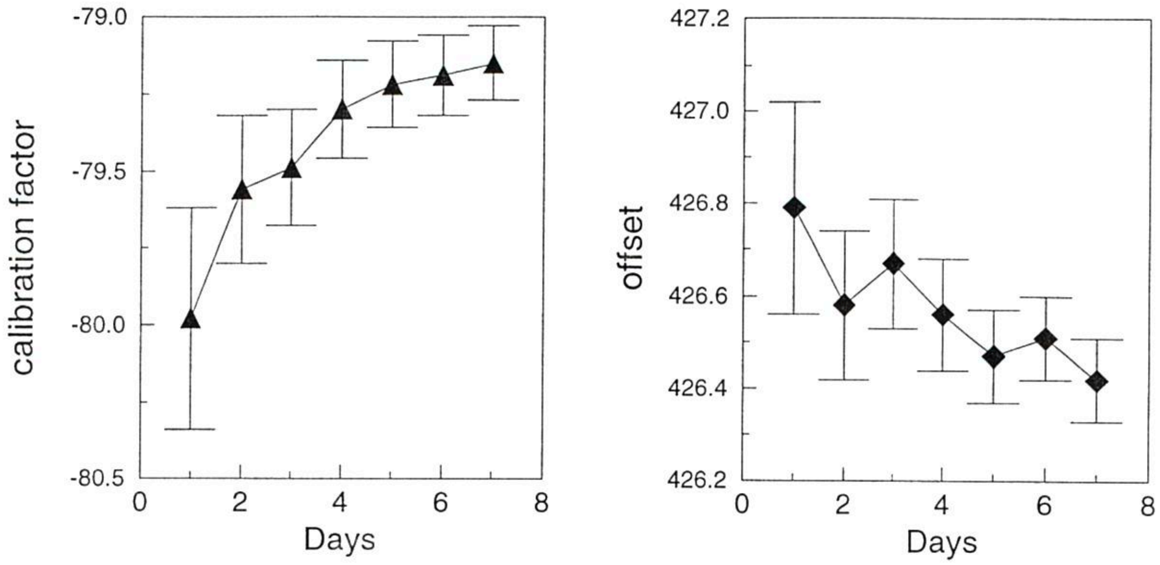

Figure 2 - Evolution with increasing time of the calibration factor (in µGal/volt) and of the offset (in µGal).

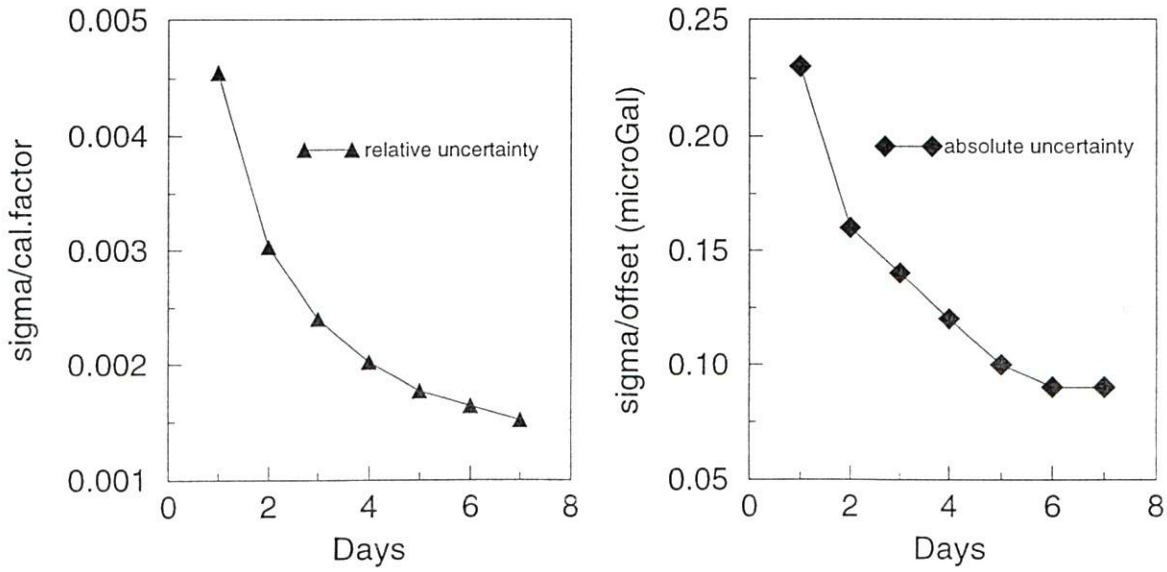

Figure 3 - Evolution of the uncertainty on the calibration factor and on the offset, with increasing time - march 1997

As can be seen on Figure 3, we have also studied the uncertainty on these two quantities. We show the relative uncertainty of the calibration factor b and the absolute uncertainty of the offset a. The two quantities are decreasing with time, which was expected since they are related to the number of measurements. From Figure 2, we see that the calibration factor indicates a 0.6% variation between 2 and 6.5 days. If one dismisses the May value, the variation seen in Figure 1 is almost similar and could reflect the effect of the duration of experiments.

We notice that the uncertainty for b is close to reach 0.1%. This is the value which is now needed in geophysics to study global geodynamics problems like Earth tides, ocean and atmospheric loading (e.g. Hinderer, 1996).

Conclusions

The main results of this study are the following:

Specifications: There is a good agreement between the observed values and the instrumental specifications given by the manufacturer. We have emphasised the importance of the site, whereas differences between two FG5s operating side by side are small.

Monthly calibration: Except for a bad experimental value (April), we find a good agreement of the values of the calibration factor over a 6-month time span, and also of the corresponding offset.

Daily calibration: To reach a 0.2% uncertainty in the calibration factor, at least 4 days of continuous AG measurements are needed in a medium quality site like J9.

Future: The repeated series of measurement will be very useful to check the stability (or the unstability) of the value of the mean gravity at J9 and Welschbruch. This is a very important result for the knowledge of the dynamics of the Rhine graben: is the graben going down or are the Vosges mountains going up?

Instrumental limitations: More work has to be done in order to check definitely if the uncertainty of 0.1% for the calibration factor, which is the value expected in present geophysical and geodynamical problems can be reached by parallel AG/SG comparisons.

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