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On the calibration of superconducting gravimeters with the help of absolute gravity measurements

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Abstract

This paper will focus on the use of absolute gravimeters (AG) to calibrate superconducting gravimeters (SG) operating in parallel at the same site. We will show results for the Strasbourg station in France. Different series of variable length using either the FG5 AG (Micro-g Solutions) or the older JILAG5 are analyzed to calibrate the superconducting gravimeter in operation at this station. We discuss the respective influence on the calibration accuracy in the method by parallel AG/SG measurements of experimental conditions like tidal amplitude, noise level of gravity measurements, duration of a single comparison. It is shown that 0.1% accuracy might be reached in the optimal case.

Introduction

Relative gravity measurements done with precise instruments such as the superconducting gravimeters (SG) can be used to retrieve useful information on a number of geophysical problems like tides, fluid core resonance, ocean and atmospheric loading or the Earth's rotation (see e.g. Hinderer & Legros 1989; Hinderer et al. 1991a). However, the interpretation of the observed phenomena is strongly dependent on a precise (amplitude) calibration of the gravimeters i.e. on the scale factor between the relative gravity change (expressed in microgal) and the feedback voltage (expressed in Volt) applied in order to maintain the superconducting levitating sphere in its equilibrium position. A geophysical interpretation of gravity observations requires in some cases a one per mill calibration accuracy which is in general difficult to achieve.

There are three principal methods which have been used to calibrate relative gravimeters:

- gravitational attraction of masses (see e.g. Achilli et al. 1995);
- inertial acceleration with an oscillating platform (see e.g. Richter et al. 1995);
- parallel registration with an absolute gravimeter (AG) (see e.g. Hinderer et al. 1991b).

We report here only on the last method but it is obvious that further studies of intercomparison between different techniques are needed.

Usually a parallel registration of AG/SG combines the highly sampled raw voltages (typically one value every sec or 2 sec) of the relative meter to individual absolute gravity values (typically one value every 15 sec for a single drop) or to mean values averaging a set of several tens of consecutive drops.

An example of such a comparison in time between SG T005 located in Strasbourg (France) and JILAG5 AG from the Finnish Geodetic Institute is given on Figure 1; every dot represents an absolute gravity determination (drop by drop) and the continuous line the SG feedback voltage converted into microgal with the help of the calibration factor (in microgal/Volt) inferred from the experiment.

Another way to plot the SG/AG values is shown on Figure 2 according to the amplitude of the feedback voltage in Volt; calibrating in amplitude means then finding the slope of the straight line which best fits the cloud of AG dots (notice that the higher concentration of dots near - 2 Volt comes from the well known asymmetrical shape of the tidal gravity fluctuations).

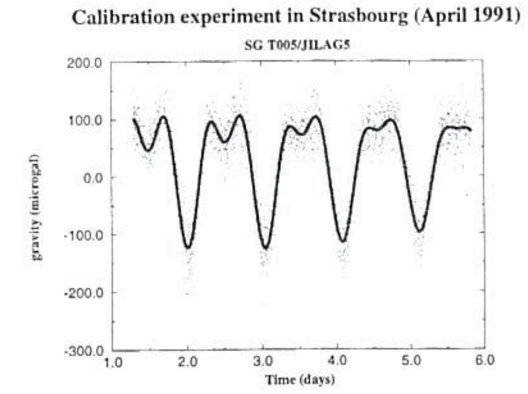

Figure 1: Comparison of AG/SG in Strasbourg in April 1991 as a function of time.

Results

Usually one uses a simple linear model to fit the AG values a_i (in microgal) to the SG voltages r_i (in Volt):

$$a_i = \alpha r_i + \beta \tag{1}$$

where α (in microgal/Volt) is the seeked calibration factor, β a given offset (in microgal) and i = 1, n where n is the total number of combined AG/SG data.

It can be shown that the error estimate σ_α on the calibration factor leads to (Hinderer et al. 1995):

$$\sigma_\alpha^2 = \frac{\sum_i \frac{1}{\sigma_i^2}}{(\sum_i \frac{1}{\sigma_i^2})(\sum_i \frac{r_i^2}{\sigma_i^2}) - (\sum \frac{r_i}{\sigma_i^2})^2} \tag{2}$$

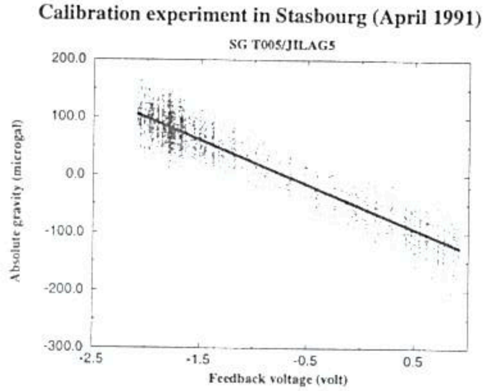

Figure 2: Comparison of AG/SG in Strasbourg in April 1991 as a function of feedback voltage.

where σ_i is the Standard Deviation (SD) of the AG measurements; in the simplified case where the scatter of these measurements is uniform throughout the experiment ($\sigma_i = \sigma$ for all i), the previous expression reduces to:

$$\sigma_\alpha = \frac{\sigma}{\sigma_{r_i}\sqrt{n}} \tag{3}$$

where σ_{r_i} is the SD of the SG voltage distribution (related to the tidal gravity fluctuations).

This formula is interesting because it explicitly indicates some important factors to be taken into account to achieve a precise calibration:
- small errors in the AG measurements (small σ depending on the quality of the AG, the site and the environmental conditions of the experiment;
- strong tidal changes (large σ_{r_i}) to be chosen according to tidal predictions;
- long time span of common observations (large n).

Figure 3 shows how the calibration uncertainty diminishes with increasing time according to statistics based on eqn. (3). The top part corresponds to a particular tidal variation during the experiment, the middle part is the calibration error and the bottom part the normalised error (where the decrease in $\sqrt{n}$ is omitted).

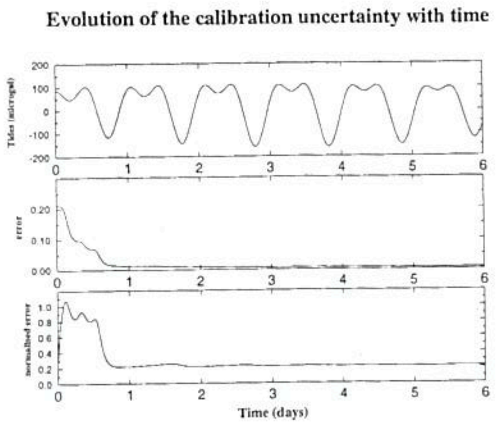

Figure 3: Calibration uncertainty as a function of time (statistical prediction).

It is obvious that the duration of the parallel registration needs to exceed a given time (at least one full tidal cycle) to allow the uncertainty to begin to decrease. But after a given threshold in duration, very little gain in accuracy is to be expected except the classical decrease in $\sqrt{n}$ from the assumed random error distribution in the AG values. On one hand it is quite easy to choose an optimal period of measurements to gain high tidal amplitudes and to measure for a duration long enough. On the other hand the standard deviation of the AG measurements is limited by the site quality (e.g. microseismic noise, temperature and tilt stability) and by the intrinsic quality of the absolute gravimeter.
Figure 4 from Amalvict et al. (1997) illustrates the importance of the length relative to a real experiment performed in March 1997 between the SG C026 and the AG FG5-206 (see Niebauer et al. 1995).
The relative uncertainty decreases from 4.5 per mill in one day to about 1.5 per mill after 6.5 days of parallel registration.

We have also reported in Table I the uncertainty in the calibration factor provided by different experiments performed in Strasbourg at different time epochs and between different absolute and relative gravimeters. It appears clearly that a one day common registration is not sufficient to obtain a scale factor with a sufficient precision. On the contrary a week long experiment

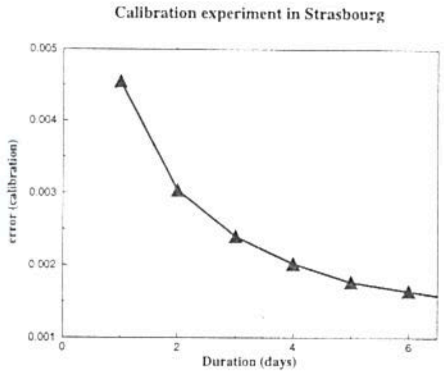

Figure 4: Calibration uncertainty as a function of time (March 1997 in Strasbourg).

leads to a precision close to 1 per mill; such a factor was also found in a similar study in Belgium (Francis 1996). It can be noticed that the uncertainty is slightly smaller using a FG5 rather than a JILAG5 with the same experimental length.

Instruments	Date	Duration	Calibration uncertainty
JILAG5/T005	May 1989	1 day	1 %
JILAG5/C026	February 1997	75 hours	0.39 %
FG5/C026	February 1997	75 hours	0.33 %
FG5/C026	Mars 1997	6.5 days	0.15 %

Table I. Accuracy of calibration factor according to different experiments in Strasbourg

Conclusion

In this paper, we have shown the potentiality of using a continuous set of absolute gravity measurements to calibrate in amplitude superconducting gravimeters. We considered the particular case of experiments performed at the Strasbourg station since 1989 between differents types of AG and SG. The importance of the quality of the AG determinations as well as the duration of the common registrations is pointed out. In particular, several days are needed to achieve a reasonable uncertainty lower than 1 per cent but the ultimate 1 per mill precision required for some geophysical interpretations seems to be only reachable in optimal experimental conditions.

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Comparison between the Tide and Gravity Signal output of the GWR superconducting gravimeter C021

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Abstract

GWR-cryogenic gravimeters are provided with different outputs. Usually data acquisition systems are connected on "*Tide*" or "*High Resolution Gravity Signal*" outputs. These are provided with a 1 minute lowpass filter. We present here a data acquisition system that is connected on the "*Gravity Signal*" output ("*G.S.*") provided with a 1s lowpass filter.

This system consists in a DCF-controlled card provided with a 18 bits analog/digital converter. It allows to determine the differential phase shift between filters of the "*Tide*" and "*G.S.*" outputs. Gravity residuals from "*Tide*" and "*G.S.*" are subtracted and we find remaining spikes and steps smaller than 20 nm/s^2. This stresses the problem of data processing as data from each system are processed by 2 different persons. Forgetting spikes and steps, subtracted residuals are smaller than 1 nm/s^2 peak-to-peak.

On 17 February 1996, an important earthquake gave an opportunity to test the "*G.S.*" data acquisition system. We present here a comparison with other instruments at other sites: superconducting gravimeters C020, C025 and La Coste-Romberg gravimeter ET-19.

1. The data acquisition systems

On GWR-C021 gravimeter, changes in gravitational forces are available from 4 different outputs[1]:

1. the "*Gravity Signal*" output, lowpass filtered ($T_{cutoff} \approx 1$ s);

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[1] This will be no more the case for gravimeters provided with the new GWR gravity card (GGP Newsletter #5, 1997)