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Calibration of the LaCoste-Romberg 906 by Comparison with the Superconducting Gravimeter C021 in Membach (Belgium)

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Abstract

Three months of simultaneous and collocated observations by a superconducting and a spring gravimeter in Membach are used to calibrate the spring gravity meter. We show that a precision of 0.1% on the amplitude calibration factor can be achieved with two weeks of data. The time variation of this calibration factor over the three months is found to be less than 0.1%. This is the precision required for our specific application of the spring meter, to validate the ocean tides models along the Atlantic coast. The determination of the instrumental phase lag is not satisfactory. A precision of only a few seconds has been achieved. For phase calibration, other methods are more successful.

1. Introduction

In 1996, Francis and Melchior [1996] presented a comparison of gravity attraction and loading effects computed on the basis of ocean tide models derived from the TOPEX/Poseidon altimetric mission. They demonstrated that discrepancies of several microgals exist among the models for the principal tidal lunar wave M_2 at coastal locations in south Western Europe. They recommended that campaigns with spring gravity meters should be performed in Western Europe along a profile where the discrepancies between the computed loading effects from the different models are the highest. Such a profile could then also be used to validate the existing and future ocean tide models. The conclusions presented in this paper inspired a project at by the Royal Observatory of Belgium to make relative gravity measurements on a profile along the Atlantic coast. However, its success, even today, depends on being able to determine the calibration factor of the spring gravity meter to 0.1%.

To determine if this objective was feasible, we operated a spring gravity meter, LaCoste-Romberg 906 (LCR906) equipped with the MVR feedback (Van Ruymbeke, 1991), at the same location as the superconducting gravity meter, C021 (SG-C021), in Membach (Belgium) for 3 months. The amplitude of the SG-C021 is regularly calibrated using the absolute gravimeter FG5-202 with a precision of 0.1% (Francis, 1997). No variations in the calibration factor at the level of 0.1% have been detected except after exceptional modifications in the feedback electronics.

The phase calibration of the SG has been determined by injecting known periodic signals and a step function into the feedback circuit. The precision of the measured instrumental phase lag is 0.01 sec (Van Camp et al., 2000). Phase differences between observed and computed earth tides could help to verify the rheology of the earth (pure elastic or viscoelastic). For that, one should achieve an accuracy much better than ± 0.002° for the phase differences (0.002° at wave M_2 corresponds to 0.3 sec). Wenzel (1994) achieved an accuracy of ± 0.00003° at wave M_2 (± 0.004 sec).

In this experiment, we have benefited from the very stable environmental conditions which exist in the Membach gallery. During the three months of the experiment, the air temperature varied between only 19 and 20 degrees Celsius; the relative humidity between 70 and 80%.

We use two methods to determine the calibration factor of the LCR906: one in the time domain and the other in the frequency domain. In the time domain, we obtain the calibration factor by performing a linear regression between the SG-C021 and LCR906 data. In the frequency domain, we apply the determined calibration factor to the LCR906 data and compare the tidal analyses of the LCR906 and SG-C021. This allows us to determine the reliability of the calibration factor in the different tidal bands (which should not vary) as well as to estimate the phase lag between both instruments.

2. Calibration

2.1. Linear Regression

In Figure 1, we display the uncalibrated LCR906 data and the calibrated SG-C021. The instrumental drift of the LCR906 is modeled by a third degree polynomial. Its coefficients are

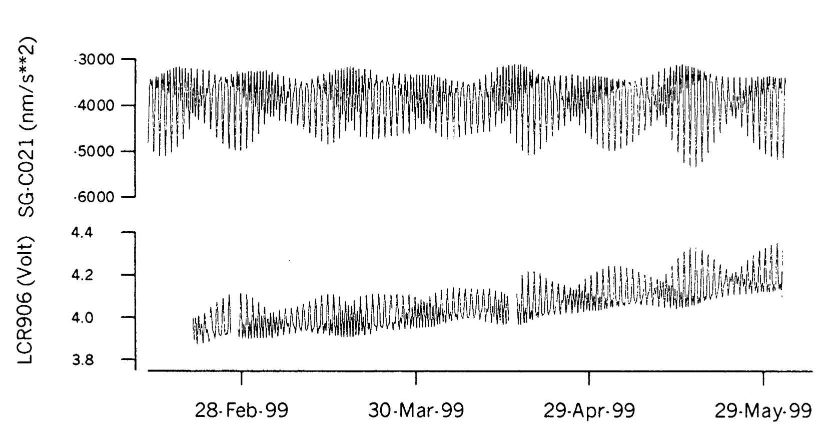

Fig. 1. The top curve in this Figure is the SG-C021 calibrated data. The bottom curve is the LCR906 uncalibrated data for the same period.

estimated at the same time as the calibration factor itself. Using this technique, we obtained -8038.8 ± 0.5 nm/s^2/Volt (± 0.006%) for the amplitude calibration of the LCR906

We were also able to estimate the phase lag between the two instruments. This can be done by fitting an additional term in the linear regression which is proportional to the time derivative of the SG-C021 data. This new term is directly related to the instrumental phase difference between the two instruments. The phase difference determined in this fashion is 7.0 ± 0.5 sec.

The residuals of the linear regression are shown in Figure 2A. The root mean square of the residuals is 10 nm/s^2. This Figure demonstrates the close agreement between both instruments (if the LCR906 is corrected for its drift). The Power Spectral Density (PSD) of the residuals, Figure 2B, indicates that there is more power at low frequencies than at high. At the diurnal and semi-diurnal frequencies, the PSD is almost flat, which is what would be expected if the estimate of the calibration factor is correct.

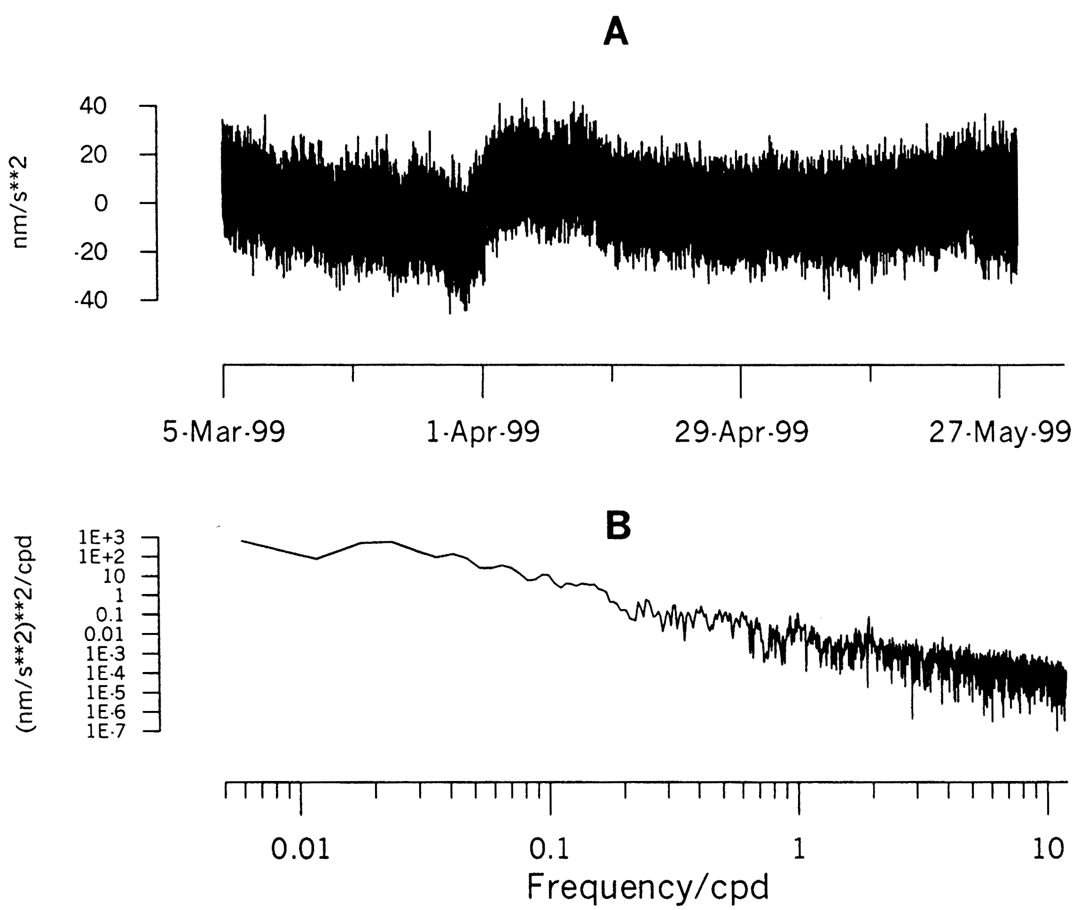

Fig. 2. A. Residuals of the linear regression between the LCR906 and SG-C021 data with a RMS of 10 nm/s**2. B. Power Spectral Density of the residuals.

Despite the temperature stability of the Membach gallery, temperature variations still exist. We did not find any significant correlation between the ambient air temperature or air relative humidity and the residuals. Note that in a closed room the air pressure and relative humidity are highly anti-correlated.

For this experiment, we have used three months of data. Three months for a calibration is often impossible for instruments that are constantly used in the field. Hence, we repeated the calibration experiment using only 15 days of data. The results are displayed in Figure 3. Each point represents a calibration determined with 15 days of data. Except for the single point at the beginning of the time series, the values of the estimated calibration factors are all within ±0.1% of the calibration factor calculated using three months of data. This means that one can expect to get a precision of 0.1% on the calibration factor using only 15 days of collocated observations with a SG making this procedure more attractive for users with very busy campaign schedules.

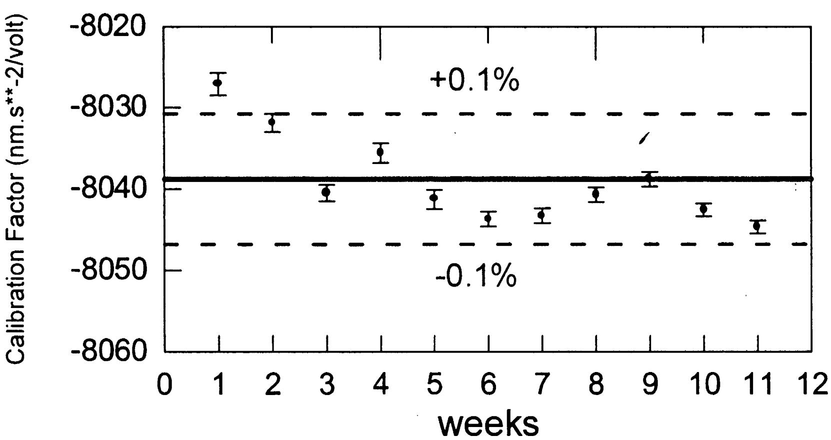

Fig. 3. Each dot represents the LCR906 calibration factor calculated using 2 weeks of data. The data sets overlap by one week. The dotted lines are the values of the calibration factor at ±0.1% of the calibration factor calculated using three months of data (solid line).

We also tried to determine the minimum time necessary to calibrate the phase. Using one month of data, we obtained values for the instrumental phase of between 3 and 12 sec. We thus conclude that the best way to estimate the instrumental phase is by injecting a known signal into the feedback system. This technique is faster and significantly more precise.

2.2 Earth Tides Analyses

The LCR906 data are calibrated using the factor estimated from the linear regression. An earth tidal analysis using the ETERNA package (Wenzel, 1996) has been performed on both LCR906 and SG-C021 time series covering the same period. In Table 1, we provide the results of the calculations of the sums of the amplitudes for all the waves for both instruments. The ratio between the two sums is 0.9994. We thus conclude that the transfer of the amplitude calibration factor from the SG-C021 to the LCR906 has been achieved with a precision of about 0.05%. On the other hand, we found that the mean instrumental phase difference is 7.6 seconds by averaging over all the tidal waves and 4.8 seconds using a weighted average with a weight for each wave being proportional to the amplitude of that wave. The first result is similar to the result obtained using the linear regression technique discussed earlier. We estimate the phase lag between the SC-C021 and LCR906 at 7 ± 3 sec.

Table 1. Amplitude and phase of the tidal waves resulting from the analysis of 85.5 days of simultaneously recorded SG-C021 and LCR906 observations in Membach.

Wave	SG-C021		LCR906		Amplitude	Phase
	Amplitude nm/s**2	Phase second	Amplitude nm/s**2	Phase second	Ratio LCR906/ C021	Difference LCR906- C021
Q_1	67.05	-63.4	66.917	-63.7	0.9981	-0.3
O_1	350.19	16.4	349.77	20.5	0.9988	4.1
M_1	27.65	37.8	27.89	-7.1	1.0086	-44.9
K_1	487.88	49.5	488.15	51.7	1.0006	2.2
J_1	27.75	64.0	27.42	107.3	0.9879	43.3
OO_1	15.13	21.7	15.16	-15.5	1.0019	-37.2
$2N_2$	10.74	413.0	10.84	456.0	1.0090	43.0
N_2	68.03	360.9	68.00	360.2	0.9989	-0.6
M_2	359.33	294.8	359.06	306.9	0.9992	12.1
L_2	10.43	147.2	10.30	199.3	0.9882	52.1
S_2	167.86	81.2	167.66	83.7	0.9988	2.5
Sum	1592.03		1591.10		0.9994	
Mean						7.6
Weighted mean						4.8

Finally, for completeness, we give the values of atmospheric pressure admittance −3.37 ± 0.02 $nm/s^2/hPa$ and −3.06 ± 0.06 $nm/s^2/hPa$ for the SG-C021 and LCR906, respectively. There is a 10% difference indicating that the vacuum of the LCR906 is no longer adequate. However, this discrepancy in the atmospheric pressure admittance does not affect the result of the calibration. The precision on the calibration factor depends partly on the range of the gravity signal variations which are mainly due to the tides and for a smaller amount due to the atmospheric pressure effect.

3. Conclusions

The LCR906 gravity meter has been calibrated by direct comparison with SG-C021 data to a precision of 0.1%. This precision has been achieved using 3 months of collocated observations in stable environmental conditions.

We find temporal variations in the sensitivity of the LCR906 of up to 0.2 % over a time period of 15 days. So, a precision on the calibration factor of 0.1% can be achieved using only 2 weeks of data. The determined value of the calibration factor is 0.78% higher than that given by the manufacturer.

The instrumental phase lag was also estimated to a precision of only a few seconds with our three month data span. Other methods for determining the phase calibration (see Wenzel, 1994) are still more efficient.

We obtained our objective in calibrating the LCR906 with a precision of 0.1%. Nevertheless, for the sake of completeness, we still need to investigate how well the calibration method presented in this paper compares with other widely used methods, e.g. calibration line, inertial platform, external masses or tilt.

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