Remarks on superconducting gravimeter calibration by co-located gravity observation

B. Meurers (1), N. Blaumoser (2), Ch. Ullrich (3)

(1) University of Vienna, Department of Meteorology and Geophysics, Vienna, Austria, bruno.meurers@univie.ac.at, +43 1 4277-53724 (2) Central Institute for Meteorology and Geodynamics, Vienna, Austria (3) Federal Office of Surveying, Vienna, Austria

Introduction

After a 12 years' observation in Vienna (VI), the superconducting gravimeter GWR C025 has been transferred in autumn 2007 to the new Conrad observatory (CO) 60 km SW of VI (Fig. 1). It is one of few instruments which were operated at different stations. This aspect motivated a re-analysis of all calibration experiments performed so far in VI and CO, focused on the direct impact of drift effects and noise. Noise limited the calibration accuracy achievable in VI considerably.

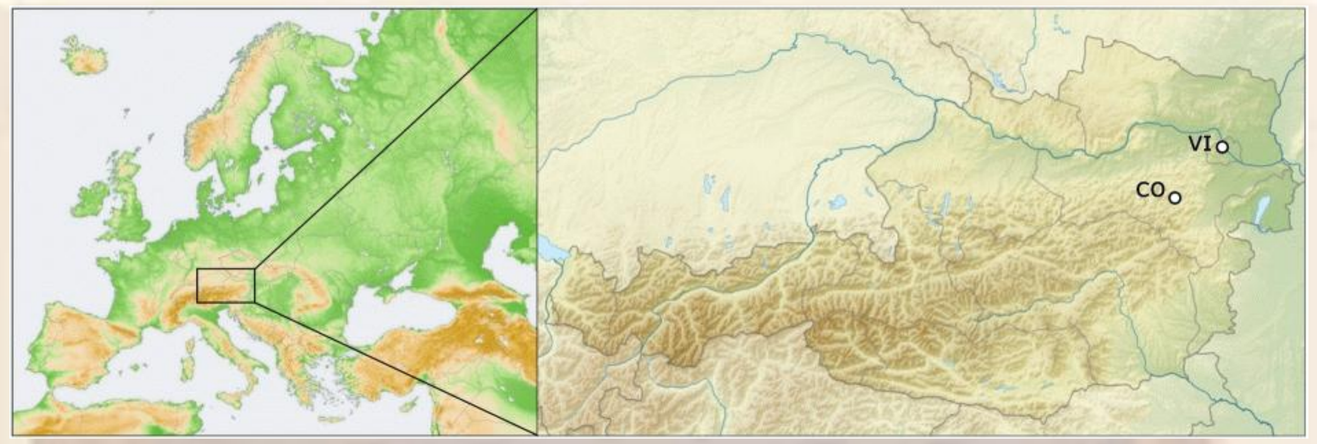

Fig. 1: Location of SG sites in Vienna (VI) and Conrad observatory (CO)

The most common method of Superconducting Gravimeter (SG) calibration is based on co-located gravity observation by using absolute gravimeters (AG) or well calibrated spring gravimeters. The method relies on the basic assumption, that observation errors follow a Gaussian distribution, and that both sensors experience exactly the same gravity variation. Actually, this assumption is never perfectly true, as the signal of both sensors differs due to following reasons:

○ instrumental noise
○ ground noise response
○ spatial separation of both sensors
○ transfer function introducing different time lags
○ pre-processing filter response
○ response on air pressure variations
○ instrumental drift.

Noise

The AG drop-to-drop scatter limits the calibration accuracy. Large ground noise in VI hampered achieving a calibration accuracy better than 2 ‰ for a single experiment. However, getting a reliable calibration factor is crucial for comparing tidal analysis results to models. In case of noise, even if random, the calibration factor does not necessarily converge to the true factor because the number of data pairs is limited (Fig. 2).

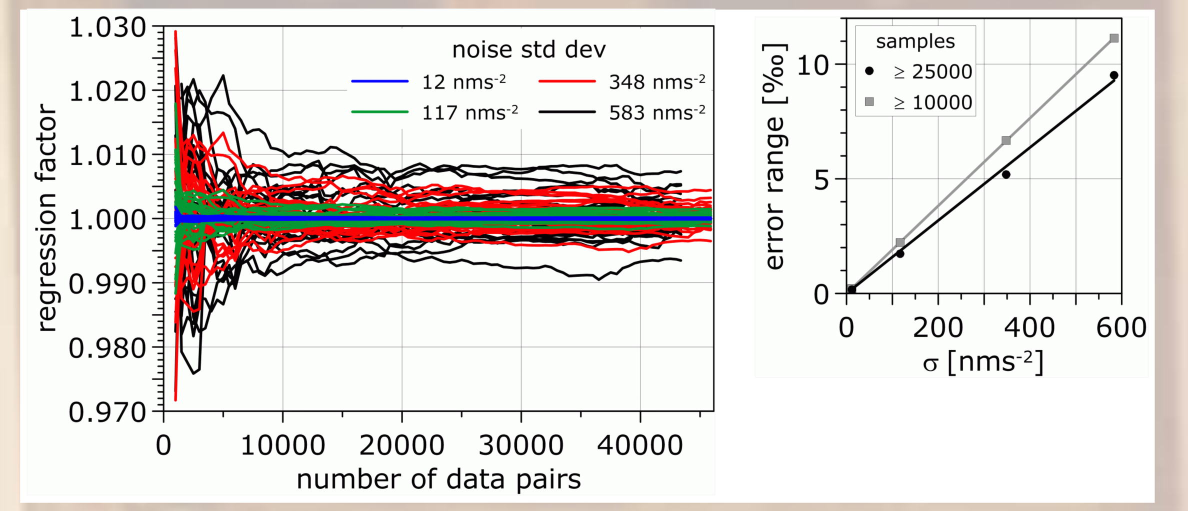

Fig. 2: We use synthetic body tides as reference and compare to an identical time series with Gaussian noise added. The noise standard deviation is defined by multiplying the AG drop set standard deviations taken from a real calibration experiment by the factors 0.1, 1, 3 and 5, resulting to a noise sigma between 10 and 600 nms^{-2}. Left: Regression factor for the synthetic data sets. For each noise standard deviation, 25 data sets have been compiled. Right: Maximum deviation of the resulting regression coefficients from the true value expected for noise-free data in dependence on the noise standard deviation and on the number of data pairs used in the adjustment.

Drift adjustment

SG drift is extremely small and negligible. This does not hold for spring gravimeters and even not for AGs (Figs. 3, 4 and 5). Drift and calibration factor have to be determined in a common adjustment choosing an appropriate drift model.

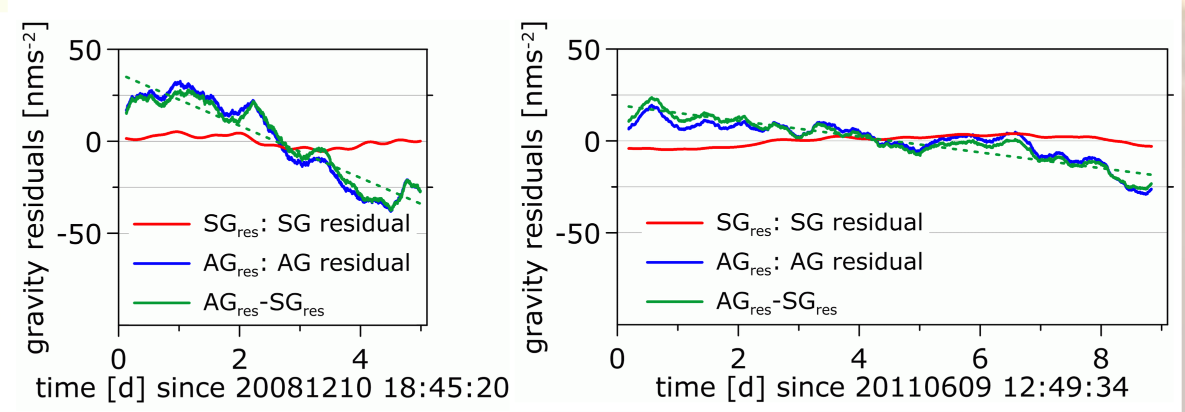

Fig. 3: Gravity residual (running average) of SG (red) and AG (blue) during the calibration experiment at CO in December 2008 (GWR C025/JILAg-6, left panel) and in June 2011 (GWR C025/FG5 242, right panel). The difference (green) is used for drift modeling.

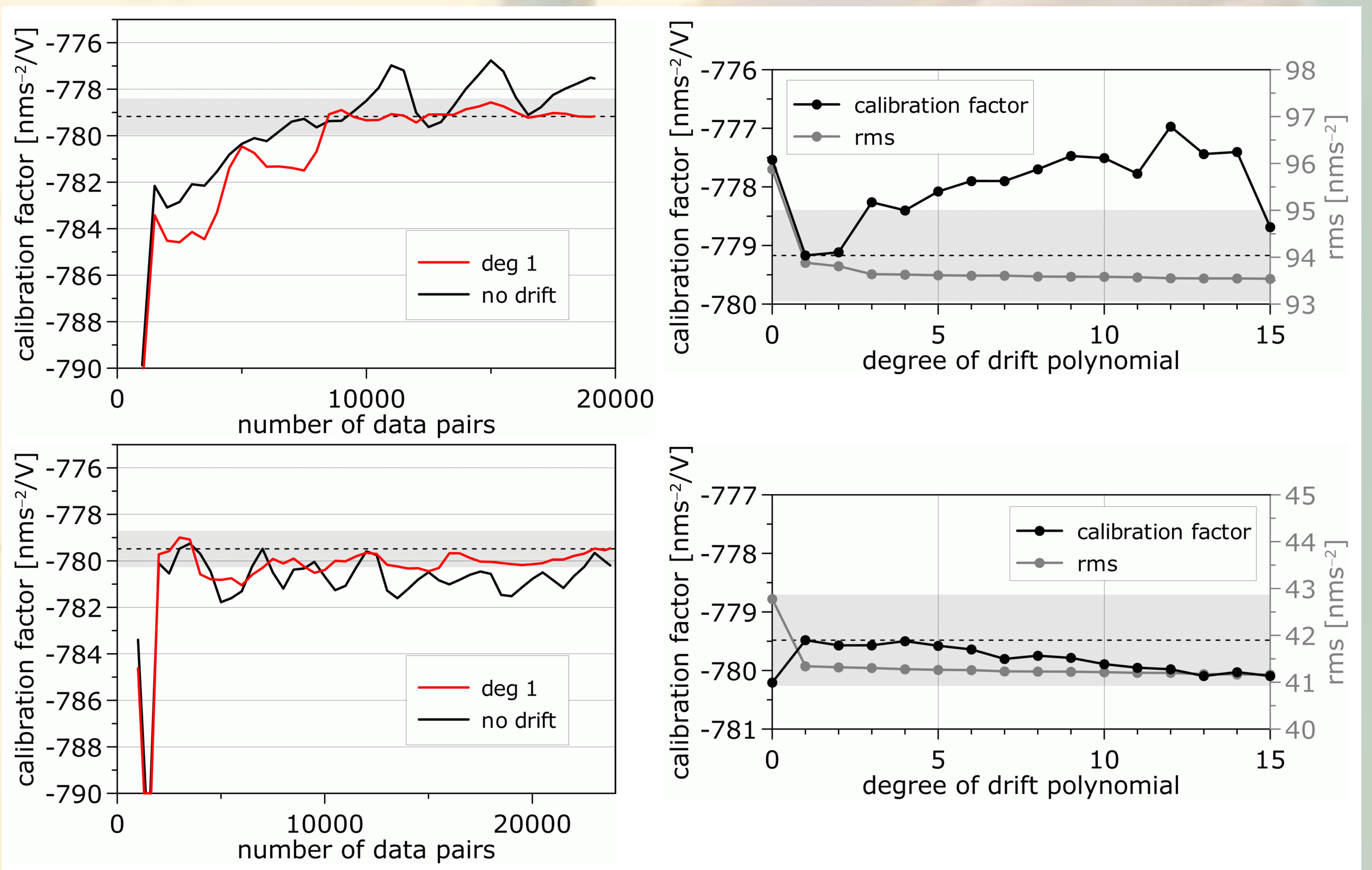

Fig. 4: SG/AG comparison experiment at CO in December 2008 (upper panels) and June 2011 (lower panels). Left: Calibration factor plotted against the number of data pairs used in the linear adjustment taking no (black) or linear (red) drift into account. Right: Calibration factor (black) and RMS of the residual (grey) plotted against the polynomial degree selected for AG drift adjustment. The ±1 ‰ error range is displayed as grey box.

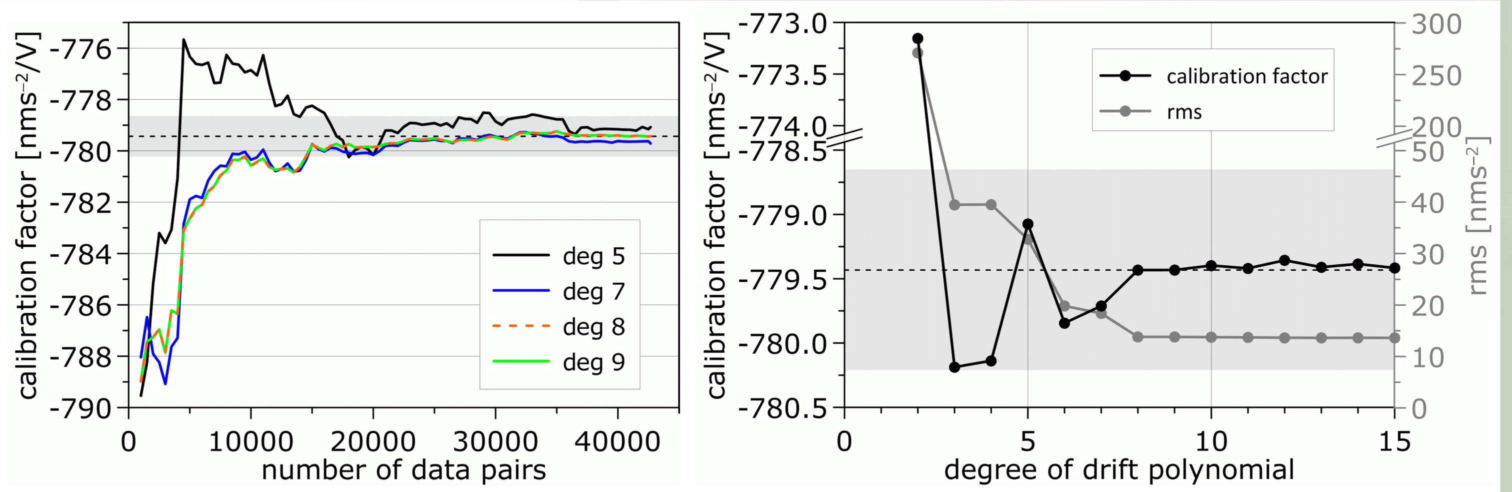

Fig. 5: SG/CG5 comparison experiment at CO (July 13, 2010 to September 22, 2010). Left: Calibration factor plotted against the number of data pairs used in the adjustment for different drift polynomials. As best choice, a drift polynomial of degree 8 has been selected (dashed red line). Right: Calibration factor (black) and RMS of the residual (grey) plotted against the polynomial degree selected for AG drift adjustment. The ±1 ‰ error range is displayed as grey box.

Results

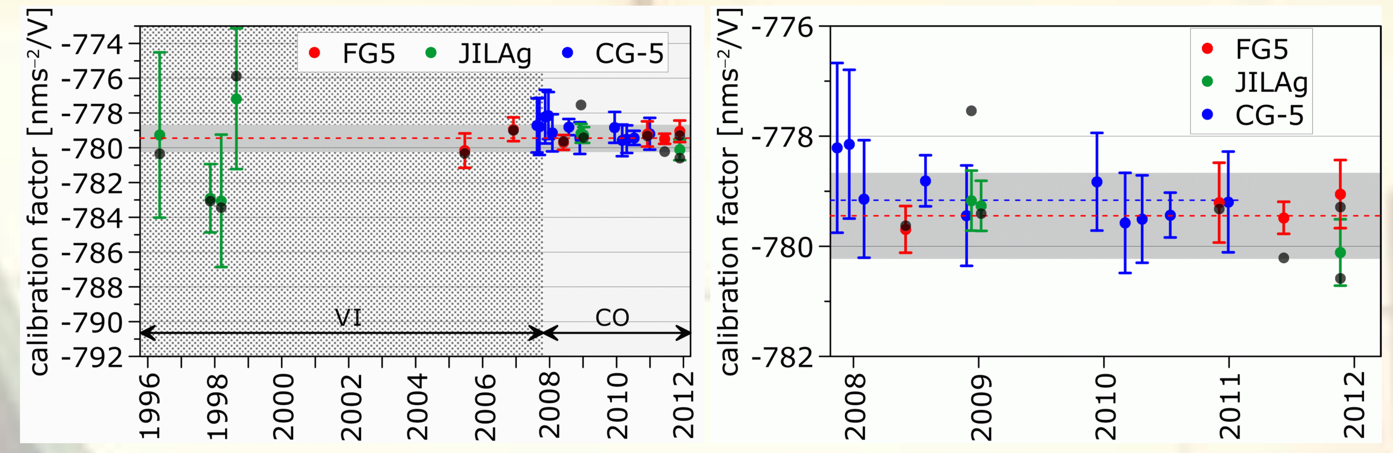

Fig. 6: Calibration factors determined by adjusting co-located gravity observations of FG5 (red dots), JILAg-6 (green dots) and CG5 (blue dots). Drift has been adjusted by low degree polynomials. Grey dots indicate the results obtained for the zero drift assumption. Left: all calibration experiments performed in VI and CO. Right: experiments performed at CO only.

	Method	Single drop					
	Outlier detection	3 σ criterion			modified Z-score method		
		$\bar{a}_0$ [nms^{-2}/V]	*error* [nms^{-2}/V] [‰]	*RMS* [nms^{-2}/V] [‰]	$\bar{a}_0$ [nms^{-2}/V]	*error* [nms^{-2}/V] [‰]	*RMS* [nms^{-2}/V] [‰]
VI + CO	FG5 + JILAg since 2005 with AG drift adjustment	-779.4537	0.1692 0.22	0.5121 0.66	**-779.4458**	0.1667 0.21	0.4220 0.54
VI + CO	FG5 + JILAg since 2005 no AG drift adjustment	-779.6221	0.1692 0.22	0.8726 1.12	-779.6055	0.1667 0.21	0.8637 1.11

Tab. 1: Weighted average of the calibration factor $\bar{a}_0$ obtained by AG experiments in VI and at CO between 2005 and 2012.

	DDW/H [2]	DDW/NHi [2]	MAT01/NH [3]	WEN [4]	ave (CO,VI)	Dev DDW/H	Dev DDW/NHi	Dev MAT01/NH
δ(O_1)	1.1528	1.1543	1.1540	1.1534	1.1534	0.0006	-0.0009	-0.0006
δ(K_1)	1.1324	1.1345	1.1349	1.1353	1.1351	0.0027	0.0006	0.0002
δ(M_2)	1.1605	1.1620	1.1616	1.1621	1.1621	0.0016	0.0001	0.0005

Tab. 2: Comparison of the corrected amplitude factor (average using 7 ocean models, [1]) with the DDW and MAT body tide models and the West European Network (WEN). Deviations are calculated as observed minus model amplitude factors.

Conclusion

○ The calibration experiments show, that even the AG drift should be considered. Though the systematic effect is small, the RMS error of the averaged calibration factor is essentially reduced (Tab. 1).

○ Calibration results are biased not only by drift effects, but also by random noise (Fig. 1) Therefore the calibration experiment has to be repeated very often.

○ Accurately calibrated spring gravimeters can contribute to the SG calibration factor determination provided the drift is carefully modeled. The dependence of the RMS error of the adjustment on the polynomial degree of the drift function may serve as selection criterion for an appropriate drift model.

○ The calibration factor of GWR C025 remained unchanged during the transfer from VI to CO.

○ The amplitude factors O_1, K_1 and M_2 obtained in VI and CO after correcting for ocean loading effects [1] differ by less than ±0.1 ‰ and fit closely to non-hydrostatic body tide models ([2], [3]) and to the results of the West European network [4] (Tab. 2).

References:

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