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Observed secular gravity trend at Onsala station with the FG5 gravimeter from Hannover

Abstract: Annual absolute gravity measurements with a FG5 instrument were performed in Onsala Space Observatory by the Institute of Geodesy of the Leibniz Universität Hannover from 2003 to 2011 and have been continued with the upgraded meter FG5X in 2014. Lantmäteriet, Gävle, with their FG5 absolute gravimeter have visited Onsala since 2007. Because small systematic errors may be inherent in each absolute gravimeter, their measuring level and a resulting bias (offset) between the instruments must be controlled over time by means of inter-comparison. From 2007 to 2014, 8 direct comparisons took place well distributed over the time span. A complete re-processing of the absolute gravity observations with the Hannover instrument has been conducted to improve the reduction of unwanted gravity effects. A new tidal model is based on continuous time series recorded with the GWR superconducting gravimeter at Onsala since 2009. The loading effect of the Kattegat is described with a varying sea bottom pressure (water and air mass load) and has been validated with the continuous gravity measurements. For the land uplift, which is a result of the still ongoing glacial isostatic adjustment in Fennoscandia, a secular gravity trend of −0.22 µGal/yr was obtained with a standard deviation of 0.17 µGal/yr. That indicates a slight uplift but is still not significantly different from zero.

Keywords: Absolute gravimetry; Fennoscandian land uplift; gravimeter comparisons; gravity variations; Onsala Space Observatory; superconducting gravimeter

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1 Motivation

Onsala Space Observatory (OSO) is one of the key reference stations for absolute gravimetric measurements in the Fennoscandian land uplift area. The Earth's crust has been rising continuously since the last glacial maximum in response to the decreasing and vanishing ice load in Northern Europe. The uplift is a result of an isostatic adjustment process in the Earth's elastic lithosphere and underlying viscous mantle. The gravimetry group of the Leibniz Universität Hannover (LUH) has been visiting OSO since 2003. The observatory provides not only excellent conditions for testing and comparing absolute gravimeters, but serves also as a geodynamics observatory for monitoring non-tectonic gravity variations and secular tectonic changes on the highest accuracy level. The stationary superconducting gravimeter (SCG) GWR#54 has been available since the new gravimetry laboratory was completed in 2009, see Fig. 1. The absolute gravity determinations of LUH at OSO are also supported by Lantmäteriet (LM, Gävle) with their FG5 instrument. Simultaneous measurements allow to reveal instrumental instabilities in the measuring level of the gravimeters.

For this report, the joint research is driven by the following questions:

1. Is it possible to reliably estimate the gravity effect of the Fennoscandian land uplift at Onsala from the observations with the FG5 gravimeter of LUH, Hannover, since 2003?
2. Will simultaneous measurements (direct comparisons) with FG5-220 (LUH) and FG5-233 (LM) control the stability of the instruments measuring levels and reveal a significant bias (long-term offset) between both meters?
3. Can we already combine the shorter time series from the gravimeter of LM with the results of LUH?
4. What is the improvement for absolute gravimetry in Onsala gained by continuous gravity monitoring with the superconducting gravimeter GWR#54 since 2009?

We will answer these questions in the following four chapters.

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Figure 1: The gravimetry stations at Onsala Space Observatory: (left) the old site (points AS, AN) was occupied by FG5-220 until 2011; (right) the new lab (points AA, AC etc.) has been available since 2009.

2 Land uplift trend from FG5(X)-220

The FG5 series is presently the most common gravimeter model ("state-of-the-art"). Interested readers will get an excellent description with full details in Niebauer et al. (1999) and, for the upgraded version FG5X, in Niebauer et al. (2013). From the user point of view, an introduction to absolute gravimetry with FG5 meters and an overview about non-tectonic gravity variations and their reductions are given in Timmen (2010). The absolute gravimetric survey of the Fennoscandian land uplift by LUH from 2003 to 2008 is summarized in Timmen et al. (2012) and described in full detail by Gitlein (2010). Those publications include also a short summary about other observation techniques to observe this tectonic phenomenon. The gravimetric activities of LUH have been integrated into the Nordic Absolute Gravimetry Plan which is an activity within the Nordic Geodetic Observation System (Poutanen et al. 2005). Absolute gravimetric measurements have been performed with FG5 meters since 1993. Pettersen et al. (2010) compared the results of FG5-220 (LUH) with 3 other FG5 gravimeter employed in Fennoscandia from 2003 to 2006 and compiled the differences and average instrumental biases with respect to the LUH instrument. Mean biases of up to 2 µGal were obtained.

This report is focusing on the activities of the LUH group at Onsala supported by their Swedish partners. To go beyond the objectives as mentioned in Chapter 1, a combined solution for the gravity trend at Onsala may be striven for by using all available FG5 data from the last decades. Best possible and consistent reductions have to be ensured to remove non-tectonic gravity variations like tides and atmospheric mass movements from the measured signal. Best knowledge of the gravity gradient along the plumb line above each measuring point has to be agreed on to ensure consistency in a common reference height above floor mark. A uniform post-processing of available gravimetric data sets from different sources might be easiest to accomplish with a centralized data archiving and processing team which operates in close cooperation with the participating groups.

To demonstrate the capability of the applied gravimetric techniques for monitoring the land uplift at Onsala, it is useful to know an expectable gravity rate from reliable sources as a reference. An extended review about data, modeling and results of the glacial isostatic adjustment (GIA) in Fennoscandia is given in great detail in Steffen and Wu (2011).We are using in this report the gravity rate −0.42 µGal/yr as reference, which is based on geophysical modeling and was predicted by V. Klemann in Timmen et al. (2012). It agrees well with the gravity-rate map as shown by Steffen and Wu (2011) whose map is based on the apparent uplift map after Ekman (1996). The contour lines of the apparent uplift were derived from geodetic leveling and mareograph records. Steffen and Wu (2011) converted them by adding an eustatic sea-level rise of 1.2 mm/a (Nakiboglu and Lambeck 1991) and by multiplying the geometrical rate with the factor −0.204 µGal/mm (see Ekman and Mäkinen 1996). Another independent source of geometrical variations is BIFROST (Lidberg et al. 2010). Continuous GPS observations over 10 years reveal a clear land uplift at Onsala. The derived absolute height change, with respect to the geocentre, is about 4 mm/yr.

Analyzing gravimetric time series with episodic gravity (or *g*) measurements, the Fennoscandian land uplift is assumed as a linear trend over many decades. Due to a large number of *g*-determinations, seasonal and short periodic variations as well as instrumental errors are averaged out to a certain extent. In Gitlein (2010) and Timmen et al. (2012) the observational trends are compiled for 10 stations in Fennoscandia. They were derived from repeated observations with FG5-220 performed nearly every year from 2003 to 2008. A decrease in gravity due to land uplift became evident at almost all stations. Based on comparisons with rates predicted by geophysical modeling, the absolute gravity measurements delivered reasonable and reliable gravity trends and accuracy estimates. Only for the coastal station Onsala was a large discrepancy found. The observational trend of +0.50 µGal/yr with a standard deviation of 0.52 µGal/yr did not even indicate land uplift.

For this report, the observational trend has been derived from absolute gravity determinations with FG5-220 and FG5X-220, respectively, at points AA (new lab) and AS/AN (old lab) covering the period 2003 to 2014. All determinations in the old lab are referred (centered) to the new site with point AA. The gravity difference between AS and AA at reference height 1.200 m above floor mark is 323.2 µGal and was determined by relative measurements in 2010 (Scintrex CG3M-4492) and absolute observations with FG5-220 in 2010 and in 2011. An uncertainty of about 2 µGal is assumed as an empirical estimate which considers not only the discrepancies between the 3 determinations but also the fact that the gravity difference is not a constant due to slightly different gravity variations at each location, e.g. due to hydrological changes. The gravity difference at height 1.200 m between AS and AN in the old laboratory was derived from the 5 absolute observations with FG5-220 at AN and AS in the years 2004 to 2008 and 3 relative observation (2003, 2005, 2006) with the Scintrex gravimeter. The arithmetic average of the 8 differences is 8.8 µGal with a standard deviation of 0.4 µGal. AS has the highest value of the discussed three points, and AA the lowest.

In 2012, the Hannover meter was upgraded to FG5X-220. Now it has a different free-fall length (about 30 cm instead of 20 cm) and a different measuring segment along the vertical (from 138 cm to 108 cm above floor level instead of 128 cm to 108 cm). We cannot exclude a small offset of perhaps 2 µGal between the measuring levels of the former FG5-220 and the up-to-date FG5X-220, but up-to-now a zero bias is assumed.

In contrast to the applied standard reduction for Earth tides in the solution presented in Timmen et al. (2012), the continuous GWR#54 time series (2009 to 2014) have been used to derive a new tidal model which includes the annual period Sa and its harmonics Ssa (a half yearly period), Sta (a third year) and Sqa (a quarter year), cf. Scherneck (2015) and Scherneck et al. (2015). The observational amplitude of partial tide Sa is more than twice as big as assumed previously. This tidal model has been applied to all absolute gravity determinations since 2003. The Kattegat sea level measurements at Ringhals, and, since September 2013, at Onsala have been used to model the sea loading effect inherent in the GWR#54 data set. To consider atmospheric effects, the **Atm**ospheric **a**ttraction **c**omputation **s**ervice of BKG (Federal Agency for Cartography and Geodesy, Frankfurt) is used (http://atmacs.bkg.bund.de/index.php). Within an adjustment procedure, the atmospheric admittance on the SCG time series is modeled with two coefficients to distinguish between a global and a regional/local part. Besides the new tidal model, the other mentioned geophysical models, verified by GWR#54 gravity recording, are applied to the absolute gravity measurements performed since 2009. After reducing the derived model effects and the long-term drift from the GWR#54 time series, the final residual series provides a last reduction for absolute gravimetry comprising all not-modeled gravitational effects. The latter reduction considers as well that all geophysical models are to some extend incomplete. E.g., varying attraction effects from local sea level changes of the nearby Kattegat (700 m distance) might not be reduced by the applied tidal model but is considered by the final residual series of the SCG. A reduction for groundwater variations was not possible until 2008. The final residual series of the SCG since 2009 comprehends also the hydrological effect on the AA point in the new lab. Nevertheless, a small reduction error for groundwater remains for the points AS and AN because of their different location with more than 100 m distance to the new laboratory with the SCG site.

The absolute gravimetric results, which were improved with the new reductions, are summarized in Table 1 and are depicted in Fig. 2. For the trend calculation, a least squares adjustment was performed assigning equal weights to the epoch results. The extreme value in 2007 deviates from the other determinations between 2 and 6 µGal. Assuming an accuracy for a single station determination of 2 to 3 µGal, this extreme g-value cannot be identified as an outlier. In addition, we do not have any instrumental explanation. During the 2007 campaign, the station Copenhagen was occupied before and some others in Sweden and Finland afterwards. Reference measurements were performed in Germany before and after the campaign. We found no indicator that the instrumental accuracy or measuring level had changed.

Table 1: Compilation of gravity values as measured with the FG5 gravimeter of LUH at Onsala. The results at AN and AS from the same epoch were combined by centering the AN result on AS and then calculating the artihmetric mean of the AN and AS observations.The new laboratory with AA has been available since 2009 and all AS/AN results were centered on AA. In 2012, FG5-220 was upgraded to FG5X-220. The applied reductions for non-tectonic variations were derived from the recordings with the superconducting gravimeter GWR#54 (since 2009). The reference height above floor level at AA is 1.200 m.

Date (mean)	g-value (AA) [µGal]	Measuring site
14.06.2003	981715896.2	AS
28.10.2004	981715897.7	AS/AN
12.10.2005	981715897.5	AS/AN
09.10.2006	981715899.9	AS/AN
09.05.2007	981715901.7	AS/AN
21.08.2008	981715897.6	AS/AN
05.11.2009	981715897.0	AA
18.04.2010	981715896.7	AS
21.04.2010	981715896.9	AA
14.06.2011	981715895.0	AA
19.06.2011	981715896.1	AS
29.05.2014	981715896.4	AA

Compared to the trend result in Timmen et al. (2012) with +0.50 (±0.52) µGal/yr for the period 2003 to 2008, the new solution with –0.22 (±0.17) µGal/yr is more reasonable. Within the measurement uncertainty (empirical standard deviation), the obtained observational trend is now in better accordance with the GIA rebound model provided by V. Klemann in Timmen et al. (2012) who predicted a rate of –0.42 µGal/yr.

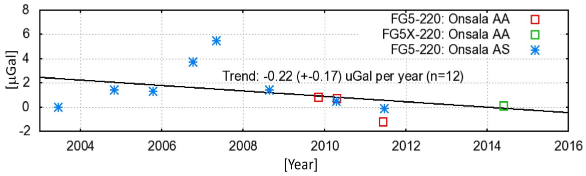

Figure 2: Gravity variations at Onsala as obtained with the gravimeter FG5(X)-220 of LUH (since 2003) in combination with the superconducting gravimeter GWR#54 (since 2009).

3 Inter-comparisons between the FG5 gravimeters of LM and LUH and their measuring levels

For geodynamic investigations in tectonically active areas, the long-term measuring stability of an absolute gravimeter is a major concern. In addition, the attempt to combine results from two absolute gravimeters requires that no systematic difference due to the gravimeters themselves should exist, or that the instrumental offset should be well known. Within this context the instrumental offset should be understood as a mean measuring offset (or bias) valid for a long time period, e.g. some years or even the gravimeters' lifetime. One possibility for detecting such an offset is to compare observation series of two instruments performed simultaneously at a reference station. Thus, both gravimeters experience identical gravity variations. The so-called "gravitational noise", which is due to incomplete modeling and reduction of real gravity effects, is canceled out in the difference. Only instrumental errors remain in the difference and a bias might become evident.

Fig. 3 shows the two absolute gravimeters FG5-233 (LM) and FG5X-220 (LUH) during the parallel measurements in Onsala at the points AA and AC in the new gravimetry lab. This direct comparison was conducted by setting up each instrument 4 times: at the first setup point each meter measures one day, and then it is dismantled and installed again at the same point but in a 180° different orientation for a new measuring period; the same procedure follows in the third and fourth day on the second point. Thus, both instruments have measured on the two points simultaneously. The 180° turn is performed to control any disturbances connected to the Coriolis force due to Earth rotation as well as any setup depending instrumental effects like inhomogeneous floor quality below the tripod feet.

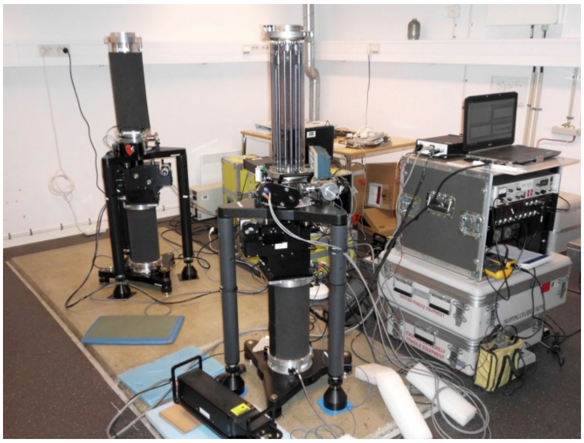

Figure 3: OSO absolute gravity site with the absolute gravimeter FG5X-220 (point AA, room center) of LUH and FG5-233 (AC) of LM.OSO absolute gravity site with the absolute gravimeter FG5X-220 (point AA, room center) of LUH and FG5-233 (AC) of LM.

To meet the accuracy requirements for long-term research over many decades and for comparability with other instruments, the observation level of an absolute gravimeter has to be verified by comparisons with many qualified absolute gravimeters. Rigorous control of the absolute accuracy with respect to a "true" gravity value at the moment of an absolute gravity measurement is not possible. The real *g*-value is not known with superior accuracy, and a "standard" absolute gravimeter, which is superior to the state-of-the-art FG5 meters, does not exist. Therefore, the empirical accuracy estimate has to be understood as describing the agreement of the instrument's measuring level and its time stability with regard to the international absolute gravity datum definition. Here, the international datum is defined by the physical standards (time and length) and, in addition, as the average result obtained from qualified absolute gravimeters participating in the international comparison campaigns; see Jiang et al. (2012).

Since the 1980s, International Comparisons of Absolute Gravimeters (ICAG) are performed at the Bureau International des Poids et Mésures (BIPM) in Sèvres and since 2003, with a 4-year time interval, also at the European Centre of Geodynamics and Seismology (ECGS) in Walferdange, Luxembourg. Such extensive campaigns with a large number of absolute gravimeters may reveal biases not only between single instruments but also between different instrumental developments and technological realizations.

Table 2 presents the results for FG5-233 and FG5-220 from the international comparisons in Walferdange (ECGS) in 2003, 2007, 2011 and 2013 (ECAG2003, Francis and van Dam 2006 with its Table 16 and 15; ECAG2007, Francis et al. 2010 with its Table 3; ECAG2011, Francis et al. 2013 with its Table 5 in appendix; ICAG2013, publ. in progress (preliminary results)), and the BIPM comparison in 2009 (ICAG2009, Jiang et al. 2012 with its Table 15). Two regional comparisons were organizes by the Federal Agency for Cartography and Geodesy, Frankfurt (BKG), at the German reference station Wettzell in 2010 and 2013 (RICAG_WET2010, RICAG_WET2013, both unpublished). One local comparisons between the FG5s from LM and LUH was carried out in Mårtsbo in 2007 and a second one in Onsala in 2014 (both unpublished).

Focussing on the results from the international comparisons ICAG and ECAG, both instruments show a positive bias since 2007, in the average about 2 µGal. We may conclude that the instruments are well embedded within the international datum level (within 2 to 3 µgal), and that the measurement stability (long-term repeatability) is also within a few µGal. Larger differences, again positive, are obtained in the RICAG comparisons in which the reference values are defined by the absolute gravimeters of BKG. The discrepancies between the two FG5s from all comparisons (last column of Table 1) vary between +2.1 and −2.9 µGal (rms 1.7 µGal) with an average of −0.1 µgal. Interpreting the latter value as the long-term bias between the meters, it can be concluded that there is no bias for the period 2007 to 2014. Nevertheless, studying the 8 comparisons with regard to their chronological sequence, temporal valid biases are indicated. E.g., the differences in 2010 and 2011 were about −2 to −3 µGal, and in 2013 and 2014 they are close to zero. As mentioned in Chapter 2, we cannot exclude a small offset of perhaps 2 µGal between the measuring levels of the former FG5-220 and the FG5X-220 which upgrade was done in 2012. However, a slightly higher measuring level of the FG5X-220 is not proven and therefore not applied.

4 Combining *g*-results of FG5-233 and FG5(X)-220

As a first attempt to combine results of two absolute gravimeters, Fig. 4 depicts the FG5 results of LUH together with 3 determinations of LM. Just preliminary *g*-results are available for FG5-233 from the observations in the new laboratory. The whole FG5-233 data sets at Onsala (old/new lab) since 2007 are presently under re-processing. Comparing Fig. 2 and Fig. 4, it becomes obvious that we did not achieve any real improvement. The trend result is dominated by the FG5(X)-220 measurements which cover a time span of 11 years since 2003. Using the 3 FG5-233 results only, a trend of −2.0 (±0.6) µGal/yr is obtained for the period 2011 to 2014. This is far-off from the expectable land uplift rate of some −0.4 µGal/yr. More measurements and a longer time period of the measuring series are needed. The Onsala location seems not only to be a problematic site for the Hannover instrument (2003 – 2008: +0.50 (±0.52) µGal/yr) but also for the meter of LM. We recommend here that the *g*-results of a single gravimeter should already show a reliable trend before the results of the different absolute gravimeters can be combined for an improved trend solution.

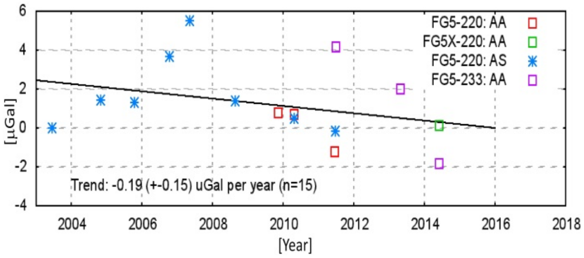

Figure 4: Gravity variations at Onsala as obtained with the FG5 gravimeters of LM and LUH, after applying reductions from SCG GWR#54 (available since 2009).

5 Gain by the OSO superconducting gravimeter GWR#54

Superconducting gravimeters are the most precise instruments in gravimetry. Such an instrument delivers high frequent gravity measurements continuously over periods up to some decades. SCGs are affected by an instrumental

Table 2: Compilation of gravity differences between FG5-233 (LM) and FG5(X)-220 (LUH) within international, regional and local comparisons. Comparison reference values (CRVs) are defined by all participating qualified gravimeters (ICAG, ECAG) or by the reference gravimeters of BKG (RICAG). Statistical values (short-term reproducibility of a single instrument) are partly not available. Since 2012 the FG5X-220 (upgrade of FG5-220) has been available.

Comparisons	Epoch	No. of absolute gravimeters	Δg [µGal] (FG5(X)-220 – CRV)	Δg [µGal] (FG5-233 – CRV)	Δg [µGal] (FG5(X)-220 – FG5-233)
ECAG2003, ECGS	Nov. 2003	13	−1.9 ±1.4	FG5 not available	
Mårtsbo	May 2007	2			+**2.1**
ECAG2007, ECGS	Nov. 2007	19	+2.4	+1.0	+**1.4**
ICAG2009, BIPM	Oct. 2009	21	+1.7 ± 0.9	+1.0 ± 0.3	+**0.7**
RICAG_WET2010	Nov. 2010	5	+3.3	+5.8	−**2.5**
ECAG2011, ECGS	Nov. 2011	21	+1.8 ± 0.3	+4.7 ± 0.9	−**2.9**
RICAG_WET2013	Jan. 2013	5	+6.3	+6.9	−**0.6**
ICAG2013, ECGS	Nov. 2013	25	+2.3 ± 0.8	+2.1 ± 1.3	+**0.2**
Onsala	May 2014	2			+**0.7**
					rms = 1.7
					mean = −0.1

drift (variations in the measuring level) of some or even many µGal per year. Therefore, absolute gravimetric measurements are needed to overcome this drawback. SCGs are manufactured by GWR Instruments, Inc., San Diego. Overviews and information in great detail are given, e.g., by Goodkind (1999) and Hinderer et al. (2009).

From the SCG observations since 2009 with GWR#54 (Fig. 5), a new tidal model has been derived which is applied to all FG5(X)-220 results since 2003. The new tidal model comprises additional tide effects from the Kattegat. A significant improvement has been achieved with respect to the annual tidal wave Sa and its harmonics. As a first big hit of the re-processing, Fig. 6 depicts the FG5(X)-220 results with and without the SCG tidal results. Quite often, the new model changed the absolute result by 1 µGal. E.g., the 2 determinations from 2008 and 2010 disagreed by 2 µGal in the "no SCG tides" version, and now they agree excellently. The gravity trend changed from +0.06 to −0.06 µGal/yr when applying the new SCG tidal model. Additional reductions for absolute *g*-determinations are provided for epochs since 2009. The full benefit for absolute gravimetry with FG5(X)-220 is already shown in Fig. 2.

Merging the FG5 results with the SCG models and the final residual series of the SCG (see Chapter 2), the observational land uplift trend changed from +0.06 (±0.31) to −0.22 (±0.17) µGal/yr. The standard deviation still expresses that the obtained uplift rate is not significant. However, the improvement due to the implementation of the results from GWR#54 is more than anyone of the FG5 experts at LUH has expected.

Figure 5: Superconducting gravimeter GWR#54 at Onsala Space Observatory.

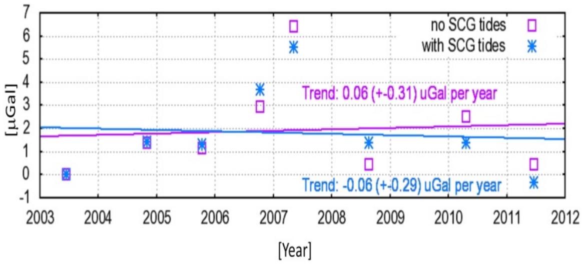

Figure 6: Gravity results before applying tides from GWR#54 (just synthetic tides) and the improved results with observational tides.

6 Summary and conclusions

In accordance with the sequence of the motivation questions in Chapter 1, we may conclude:

1. The absolute gravimetric time series of the FG5(X)-220 covers the period 2003 to 2014 and consists of 12 single station determinations. For the post glacial land uplift, a secular gravity trend of −0.22 (±0.17) µGal/yr was obtained which is statistically in accordance with the predicted rate −0.42 µGal/yr. With respect to the observational trend in Timmen et al. (2012) with +0.50 (±0.52) µGal/yr for 2003 to 2008, the new solution is more reasonable and a real improvement but is still not showing a significant land uplift trend.
2. From 8 direct comparisons between the FG5 meters of LUH and LM over 7 years since 2007, a mean discrepancy of −0.1 µGal with an rms difference of 1.7 µGal has been obtained. Thus, no measurement bias (long-term offset) between the two FG5s should be applied. Although, temporally valid biases are indicated. On the level of about 2 to 3 µGal for instrumental stability (repeatability) and accuracy (international datum definition), it is still a challenge to apply absolute gravimetry in geo-sciences.
3. The attempt to combine *g*-determinations of the LM and LUH instruments was not satisfying. The observational uplift trend changed from −0.22 (±0.17) µGal/yr (with FG5(X)-220 only, 12 g-values since 2003) to −0.19 (±0.15) µGal/yr (additional 3 *g*-values of FG5-233 since 2011). The 3 determinations of FG5-233 by itself do not show the land uplift trend. More measurements covering a longer time period are needed. Before combining results from different absolute gravimeters to obtain an improved solution, we recommend to investigate at first whether each gravimeter provides a reliable trend by itself. Thus, all data of FG5-233 are currently being reprocessed and should be ready in the spring of 2015.
4. The combination of FG5(X)-220 absolute gravimetric results with geophysical models, which are validated by SCG recordings, and with observed residual gravity variations from the SCG at Onsala has been proven to be real progress. The observational land uplift trend changed from +0.06 (±0.31) to −0.22 (±0.17) µGal/yr due to the merging of both techniques. The full potential of the SCG data on the absolute measurements at OSO is clearest from its installation in 2009 and onwards. However, the *g*-determinations before 2009 benefitted from the new tidal model based on the GWR#54 data.

Because of its unique location close to the Kattegat and Atlantic Ocean, the OSO station experiences larger non-tectonic gravity variations than many other inland sites and is therefore an excellent demonstration site for merging SCG and FG5 results. Combining the advantages of both types of gravimetric techniques, the integral effect of all gravity variations from hours to decades will be recorded within the measurement uncertainties. Absolute gravimetry is needed for defining the absolute level of *g*, and for determining the instrumental drift of the SCG. Superconducting gravimetry provides a continuous measuring series with high sampling rate which can be used to apply reductions to the episodic absolute *g*-determinations for temporal gravity variations for periods below one year. These observational time series can then be used to verify or elaborate geophysical models of scientific interest.

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